Agronomy Research

Established in 2003 by the Faculty of Agronomy, Estonian Agricultural University

Aims and Scope:

Agronomy Research is a peer-reviewed international Journal intended for publication of broad-spectrum original articles, reviews and short communications on actual problems of modern biosystems engineering incl. crop and animal science, genetics, economics, farm- and production engineering, environmental aspects, agro-ecology, renewable energy and bioenergy etc. in the temperate regions of the world.

Copyright:

Agronomy Research online:

Agronomy Research is available online at: http://agronomy.emu.ee/

Acknowledgement to Referees:

The Editors of *Agronomy Research* would like to thank the many scientists who gave so generously of their time and expertise to referee papers submitted to the Journal.

Abstracted and indexed:

SCOPUS, CABI Full Paper and Thompson Scientific database: (Zoological Records, Biological Abstracts and Biosis Previews, AGRIS, ISPI, CAB Abstracts, AGRICOLA (NAL; USA), VINITI, INIST-PASCAL.)

Subscription information:

Estonian Grassland Society
St. Teaduse 4, 75501 Saku, ESTONIA
E-mail: heli.meripold@eria.ee

Journal Policies:

Estonian University of Life Sciences, Estonian Research Institute of Agriculture, Latvia University of Agriculture, Aleksandras Stulginskis University, Lithuanian Institute of Agriculture and Lithuanian Institute of Horticulture and Editors of *Agronomy Research* assume no responsibility for views, statements and opinions expressed by contributors. Any reference to a pesticide, fertiliser, cultivar or other commercial or proprietary product does not constitute a recommendation or an endorsement of its use by the author(s), their institution or any person connected with preparation, publication or distribution of this Journal.

ISSN 1406-894X

CONTENTS

VI PRODUCTION ENGINEERING

Agronomy Research **13**(3), 629–638, 2015

FEM based numerical simulation for heat treatment of the agricultural tools

R. Chotěborský[1] and M. Linda[2,*]

[1]Czech University of Life Sciences in Prague, Faculty of Engineering, Department of Material Science and Manufacturing Technology, Kamýcka 129, CZ-16521 Praha – Suchdol, Czech Republic
[2]Czech University of Life Sciences in Prague, Faculty of Engineering, Department of Electrical Engineering and Automation, Kamýcka 129, CZ-16521 Praha – Suchdol, Czech Republic; [*]Correspondence: linda@tf.czu.cz

Abstract. Quenching as a heat treatment method is commonly used to control the mechanical properties of steels. This article deals with the modelling and simulation of quenching of steel chisel using a multi–phase model. The process of the heat treatment is non stationary phase due to temperature variation with time. In this study, the problem of heat transfer in three dimensional phase was transformed into a two dimensional axisymmetric case. ElmerFem solver was used for the heat transfer through different cooling media such as water, oil and salt bath. The results from heat solver were used for austenite transformation modelling by applying Johnson–Mehl–Avrami–Kolmogorov equation in TTT diagram. The Scheill's decomposition was used for anisothermal transformation of austenite. The hardness prediction was done according to simple mixture rule where total hardness of the steel was calculated based on volume of the phases and their Vickers hardness.

Key words: numerical simulation, FEM, heat treatment, ElmerFEM.

INTRODUCTION

Quenching is used as a heat treatment method for controlling the mechanical properties of steel such as tensile strength, toughness and hardness. The quenching process promotes the formation of different microstructures namely ferrite, pearlite, bainite and martensite that depend on the cooling rate as well as the chemical composition of the steel. The quenching application of the material is subjected to heat treatment above the austenitization temperature (approximately 900 °C) which involves continuous and rapid cooling in a quenching media such as water, air and oil. During quench hardening process, heat flux is rapidly transfered to the coolant which varies in time hence the HTC (heat transfer coefficient) cannot be calculated or measured by standard techniques. In such cases, the effective procedure is the formulation of the boundary inverse heat conduction (Telejko, 2004; Buczek & Telejko, 2013).

Constitutive modelling of the quenching process can be performed within the scope of standard generalized materials under the assumption that the thermodynamic state of the material can be completely defined by a finite number of state variables (Archambault & Azim, 1995; Fall et al., 2011; Hasan et al., 2010). Phase transformation from austenite to martensite is non diffusive process meaning that the amount of volume fraction is only a function of temperature which can be described by the Koistinen–Marburger law (Eq. 1). On the other hand, microstructures such as ferrite, pearlite and bainite formations are diffusion controlled transformation which are time dependent. The diffusive transformation kinetics are described by Johnson–Mehl–Avrami–Koglomorov (JMAK) equation (Eq. 2). The evolution of these phases transformation can be predicted through an approximate solution using data from Time–Temperature–Transformation diagrams (TTT).

$$V_M = 1 - e^{-\alpha \times (M_s - T)} \quad (1)$$

$$V_{P,B} = 1 - e^{-k \times t^n} \quad (2)$$

where: α and M_s are both constants determined by material type, k is the overall rate constant that generally depends on temperature, n is the Avrami's exponent (Kolmorgorov, 1937; Avrami, 1939a; Avrami, 1939b; Johnson & Mehl, 1939; Avrami, 1940a; Avrami, 1940b; Marder & Goldstein, 1984; Kirkaldy, 2007; Sinha et al., 2007).

This article describes the modelling and simulation of quenching of steel chisel using a multiphase constitutive model proposed by (Çetinel et al., 2000; Ferguson et al., 2005; Carlone et al., 2010).

MATERIALS AND METHODS

The process of heat transfer during quenching of a steel chisel (Fig. 1) is nonstationary due to the variation of temperature with time. In this work the problem of heat transfer in a three dimensional phase was examined.

Figure 1. Real chisel computerization.

The nonstationary problem of heat transfer within a component in the quenching process is described mathematically by simple differentiation with respect to the volume. Based on that the heat transfer equation (Eq. 3) was derived as follows:

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right) + Q = \rho \times c \times \frac{\partial T}{\partial t} \quad (3)$$

where: k – thermal conductivity; Q – is the inner heat–generation rate per unit volume; T – temperatuure; q – heat transfer coefficiente; ρ – densitye; c – heat capacitye; t – time.

The Neumann boundary conditions were used for the simulation of the heat cycles in quenching media like air, water and oil whiles the heat flux was determined experimentally in cylinder shape samples by inverse methods (Telejko, 2004).

The equilibrium transformation temperatures during cooling were also determined experimentally by thermal analysis. The ferrite transformation started below the A_{c3} temperature whiles the pearlite transformation occurred at the A_{c1} temperature when a volume fraction of pro–eutectoid ferrite reached an equilibrium volume fraction. The bainite and martensite transformations occurred below bainite and martensite temperatures respectively. Table 1 gives the transformation temperatures of different steel samples.

Table 1. Transformation temperatures of different steel samples

Temperature phase change	$A_{c3}=T_F$ (°C)	$A_{c1}=T_P$ (°C)	T_B (°C)	T_M (°C)
High boron steel – B1	810	741	606	382
High boron steel – B2	830	743	593	411
Boron27	840	675	525	335

Table 2. Chemical composition of different steel samples

Chemical composition	C	Si	Ni	Cr	Mn	Mo	Cu
High boron steel – B1	0.6	0.3	0.05	0.4	0	0.01	0
High boron steel – B2	0.3	0.3	1	1.5	0	0.05	0
Boron27	0.2	0.2	0.1	0.3	1.3	0	0

The ElmerFEM solver (CSC – IT Center for Science (CSC), 2013) was used for calculation of thermal field of the steel samples. The simulation results were obtained as matrix of nodes and temperatures. Two kinds of mathematical models were used for deducing microstructure field from temperature field based on TTT (Time, Temperature, Transformation) curve which is used for kinetic transformation of austenite at constant temperature. In addition, CCT (Continuous Cooling Transformation) curve was used for kinetic transformation of austenite in water and oil quenching media (Smoljan, 2006; Malinowski et al., 2012).

The diffusional transformation reaction was based on equation (Eq. 2). The constants for these equations were determined from a nonlinear optimization of the experimental data. Table 2 shows the values used for the three transformation products resulting from a diffusion–controlled reaction of ferrite, pearlite and bainite. The temperature dependencies of constants were fitted by Gaussian function and these dependencies were used as input algorithm (Marder & Goldstein, 1984; Çetinel et al., 2000; Ferguson et al., 2005). The C–curves of a calculated IT diagram for boron steel using equation (Eq. 2) for each product structure and the data points indicate the determined experimental values for the starting and final transformations during isothermal heat treatments.

The actual temperature variation is continuous cooling rather than isothermal variation. But austenite transformation under M_s temperature can develop a partial transformation of bainite. By applying Scheil superposition principle (Scheil, 1935), the actual continuous cooling transformation can be calculated by isothermal transformation model. Here the time period was discretized based on the assumption that within each time step is Δt at constant temperature involving isothermal transformation. For the corresponding constant T_i, were parameters b_i, n_i and τ_i (transformation starting time, i.e. incubation period). By dividing the time step Δt by incubation period τ_i, increment of inoculation rate ΔE_i was the volume transformation during the former time step V_i. By substituting it into equation (Eq. 4) then the time period was obtained for the volume transformation reaching V_i under T_{i+1} isothermal transformation condition that is virtual time t_{i+1} as described below.

$$t_{i+1} = \left[\frac{-ln(1 - V_i)}{k_{i+1}}\right]^{\frac{1}{n_{i+1}}} \tag{4}$$

The microstructures were calculated from arrays {T (t)} and {V (t)} during the simulation period. Equations (Eq. 5 to Eq. 9) described below were included in the computer algorithm.

$$Vf_{max} = \left(\frac{0.8 - C}{0.8}\right)^{-1} + \left(\frac{0.8 - C}{0.8}\right)^{-1} \tag{5}$$

$$Vf = \sum_{i=1}^{n} -Kf \times Nf \times t^{Nf-1} \times e^{-Kf \times t^{Nf}} \times (1 - Vf_{max}) \tag{6}$$

$$Vp = \sum_{i=1}^{n} -Kp \times Np \times t^{Np-1} \times e^{-Kp \times t^{Np}} \times (1 - Vf) \tag{7}$$

$$Vb = \sum_{i=1}^{n} -Kb \times Nb \times t^{Nb-1} \times e^{-Kb \times t^{Nb}} \times (1 - Vf - Vp) \tag{8}$$

$$Vm = 1 - e^{-\beta \times (Tm_{start} - T)} \times (1 - Vf - Vp - Vb) \tag{9}$$

where: *Vf* is the volume of ferite phase, *Vp* is the volume of pearlite phase, *Vb* is the volume of bainite phase, *Vm* is the volume of martensite phase, *Kf* (*Kp* and *Kb*) are the overall rate constant of feritic, pearlitic and bainitic transformation that generally depends on temperature, *Nf* (*Np* and *Nb*) are the Avrami's exponent for feritic, pearlitic and bainitic transformation that depends on temperature, *t* is the time, *T* is the temperature, T_{mstart} is the temperature martensite start transformation and β is the coefficient of martensite transformation volume that depends on temperature.

The structure composition of steel cooling depends on the actual hardness defined as:

$$HV = V_P \times HV_P + V_B \times HV_B + V_M \times HV_M \quad (10)$$

Amount of phases proportion is an equal unity defined by (Li et al., 2001; Liu et al., 2003; Pietrzyk & Kuziak, 2011; Xie et al., 2013) as:

$$HV_M = 127 + 949 \times C + 27 \times Si + 8 \times Ni + 16 \times Cr + 21 \times lnV_r \quad (11)$$

$$\begin{aligned} HV_B = -323 + 185 \times C + 330 \times Si + 153 \times Mn + 65 \times Ni + 144 \\ \times Cr + 191 \times Mo \\ + (89 + 53 \times C - 55 \times Si - 22 \times Mn - 10 \times Ni - 20 \\ \times Cr - 33 \times Mo) \times lnV_r \end{aligned} \quad (12)$$

$$\begin{aligned} HV_{F,P} = 42 + 233 \times C + 53 \times Si + 30 \times Mn + 12.6 \times Ni + 7 \times Cr \\ + 19 \times Mo \\ + (10 - 19 \times Si + 4 \times Ni + 8 \times Cr + 130 \times V) \times lnV_r \end{aligned} \quad (13)$$

where: *C*, *Si*, *Mn* and others represent different kinds of chemical elements respectively (wt.%); V_r represents cooling speed at 700 °C (°C h^{-1}).

From Eq. 10, it is not difficult to predict fraction of phases if the hardness of cooling microstructure and the hardness of microstructure constituents' are separately known (Eq. 11 to 13). Results of austenite decomposition depend on the chemical composition and steel history. The characteristic cooling time relevant for structure transformation for most steel is the time $t_{8\text{-}5}$. The characteristic cooling time was determined through series of algorithm where an average value of heat gradient between500 °C and 800 °C was found as illustrated in (Fig. 2).

The calculation of hardness was done by retrieving the temperature of nodes file. The analysis was performed for N nodes corresponding to the mesh of model. The temperature parameters of the nodes of the model were introduced (inlet) into the calculation of the volumetric representation of ferrite, pearlite, bainite and martensite.

In each step the temperature difference between the node in time was compared with the possible formation (or can be written as nuclei) parameters relevant phase (temperature and time dependence of TT diagram, for the structure formation) Fig. 2. The volume phase of the lower temperature node of ferrite formation (Ac3) was described by Eq. 6 whiles if that of pearlite formation (Ac1) with higher temperature node but higher than bainite formation was given by Eq. 7. On the other hand, the volume phase of bainite formation with temperature node higher than martensite was defined by Eq. 8 and that of volume phase of martensite formation with lower temperature node was given by Eq. 9. Equation (Eq. 10) was used to calculate the total hardness of individual phases. Data were saved to a new file that has the same format as the source file which can be opened in the program Paraview. This cycle was repeated for each temperature nodes file to the last file with nodes.

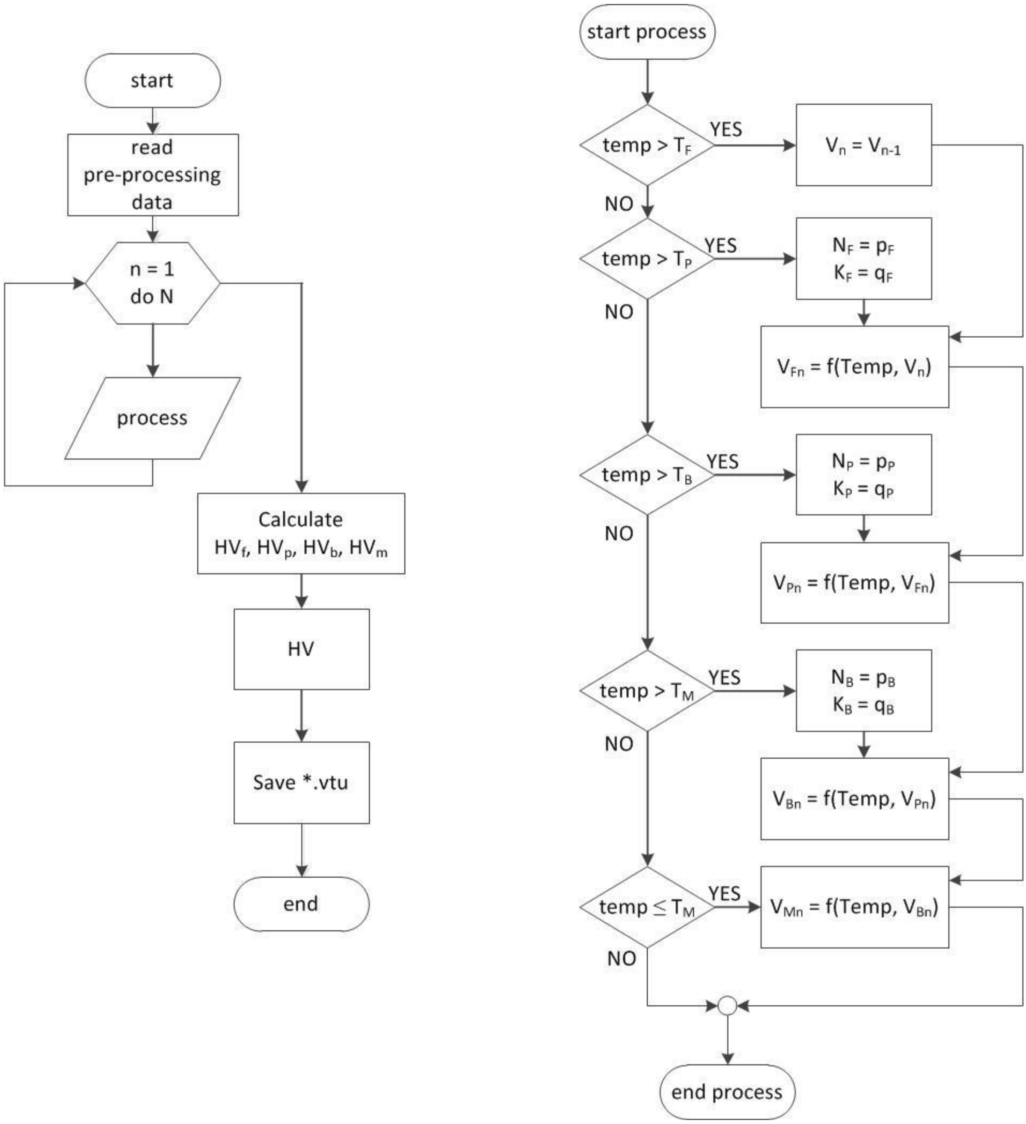


Figure 2. Schematic of computer algorithm.

RESULTS AND DISCUSSION

A mathematical model for the prediction of temperature of nonstationary heat transfer in relation to time of a quenched steel chisel was used. The initial properties of the steel and the boundary conditions were used in the model to verify the results using ElmerFem software. The temperature distribution and curves are illustrated in Figs 3 and 4 respectively.

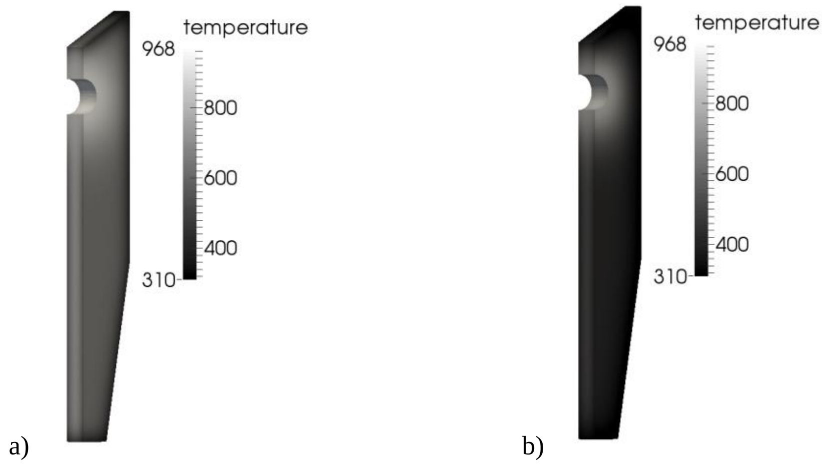


Figure 3. Temperature distribution of a quenched chisel at 5 (a) and 15 (b) sec cooling in water.

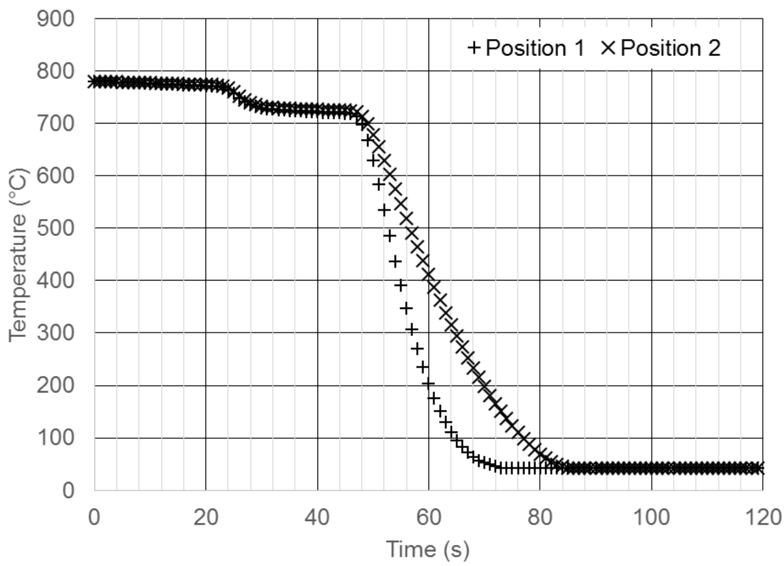


Figure 4. Cooling curve of modeled chisel in two positions (near to hole – position 1 and far from hole – position 2).

Distribution of microstructure fields of the quenched chisel is presented in Fig. 5 whiles the hardness fields of the quenched chisel is shown in Fig. 6. The results showed a good distribution of softer microstructure around a hole in chisel, where their sharp notches were often placed by cracked initiation (Liu et al., 2003; Liu et al., 2004; Guo et al., 2009; Chen et al., 2012). The problem with low fracture toughness of the martensite structure was solved using lower heat flux around hole as well as technological solution using ceramics holders in hole and around hole.

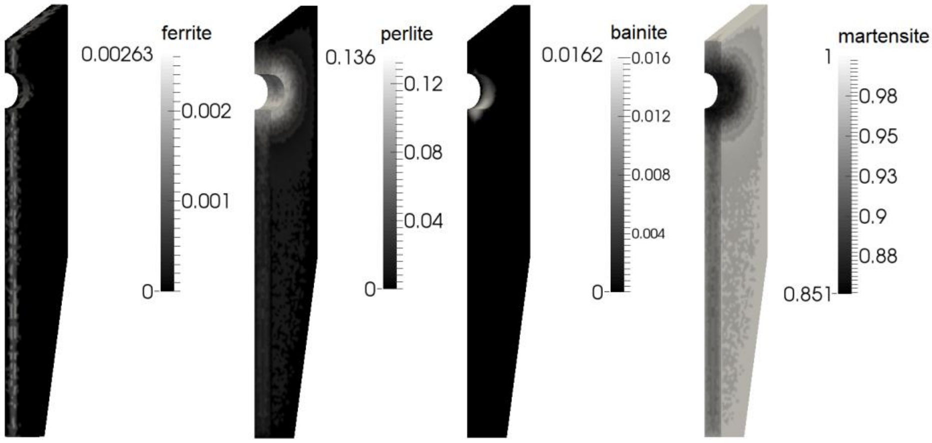


Figure 5. Distribution of microstructure fields of the quenched chisel – high boron steel B1.

Using models of steel B2 and Boron 27 produced two microstructure mixtures namely martensitic and ferritic. These mixtures are non homogenous because ferrite is usually acicular on the boundary of austenite (Liu et al., 2004). They are also more brittle than other mixtures of microstructure in the steel and they have a high degree of damage of the intercrytalline fracture (Jam et al., 2014). Therefore the martensitic structure get better wear resistant properties than softer microstructures (Chotěborský, 2013; Chotěborský & Hrabě, 2013). Samples of chisel were not analyzed on microstructure. In this article are discussed only circle sample (3 pieces of each steel) tested steels after heat treatment cycle of similar properties like modeled microstructure.

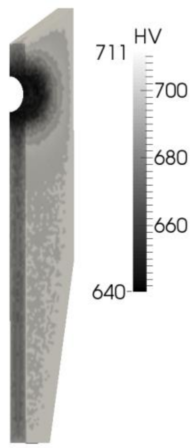


Figure 6. Hardness field of high boron steel B1 after quenching in water.

But microstructure volume of tested steel was different after heat treatment in comparison with modeled samples. Errors were observed from the modeling of the specific heat coefficient, heat flux, computed transformation diagrams. Equations (Eqs 10 to 13) increased the difference between modeling and experimental results. Also real chemical composition, grain size, number of crystal lattice and thermal history directly influenced the results of experimental steel as well as the difference between modeling and experimental results. These analyses showed errors around 15% volume of microstructure phases similar to published results (Liu et al., 2003; Huiping et al., 2007; Lee et al., 2010; Lee et al., 2013).

CONCLUSIONS

A simply method for axisymmetric modeling of heat FEM in agriculture tools is possible.

JMAK equation can be used for prediction of microstructure.

A relatively good relationship between modeled and measured microstructures was observed compared to modeled and measured volume of microstructural phases.

Experimental and modeled results showed errors around 15% of predicted hardness. Hardness is one of the interested mechanical properties but the presented errors were very high. These models setup can be useful for different technological procedures with heat cycle during processing and for prediction of microstructure.

REFERENCES

Archambault, P. & Azim, A. 1995. Inverse resolution of the heat-transfer equation: application to steel and aluminum alloy quenching. *Journal of Materials Engineering and Performance* **4**(6), 730–736.

Avrami, M. 1939a. J. Chem. Phys. 7 (pp. 1103–1109).

Avrami, M. 1939b. Kinetics of phase change. I: General theory. *The Journal of Chemical Physics*, *7*(12), 1103–1112.

Avrami, M. 1940a. J. Chem. Phys. 8 (pp. 212–224).

Avrami, M. 1940b. Kinetics of phase change. II Transformation-time relations for random distribution of nuclei. *The Journal of Chemical Physics*, *8*(2), 212–224.

Buczek, A. & Telejko, T. 2013. Investigation of heat transfer coefficient during quenching in various cooling agents. *International Journal of Heat and Fluid Flow* **44**, 358–364.

Carlone, P., Palazzo, G.S. & Pasquino, R. 2010. Finite element analysis of the steel quenching process: Temperature field and solid–solid phase change. *Computers & Mathematics with Applications* **59**(1), 585–594.

Çetinel, H., Toparlı, M. & Özsoyeller, L. 2000. A finite element based prediction of the microstructural evolution of steels subjected to the Tempcore process. *Mechanics of Materials* **32**(6), 339–347.

CSC - IT Center for Science (CSC). (2013). Elmer finite element software. Retrieved from http://www.csc.fi/english/pages/elmer

Fall, A., Regnier, M.C., Manga, P.-S., Ramassamy, C., Tonnon, E., Romberger, C. & Xiao Yuefa, J. 2011. Tools for continuous improvement of the plate quenching process. *Revue de Métallurgie* **108**(5), 313–321.

Ferguson, B.L., Li, Z. & Freborg, A.M. 2005. Modeling heat treatment of steel parts. *Computational Materials Science* **34**(3), 274–281.

Guo, Z., Saunders, N., Miodownik, P. & Schille, J.P. 2009. Modelling phase transformations and material properties critical to the prediction of distortion during the heat treatment of steels. *International Journal of Microstructure and Materials Properties* **4**(2), 187.

Hasan, H.S., Peet, M.J., Jalil, J.M. & Bhadeshia, H.K.D.H. 2010. Heat transfer coefficients during quenching of steels. *Heat and Mass Transfer* **47**(3), 315–321.

Huiping, L., Guoqun, Z., Shanting, N. & Chuanzhen, H. 2007. FEM simulation of quenching process and experimental verification of simulation results. *Materials Science and Engineering: A*, **452-453**, 705–714.

Chen, J., Mo, W., Wang, P. & Lu, S. 2012. Effects of tempering temperature on the impact toughness of steel 42CrMo. *Jinshu Xuebao/Acta Metallurgica Sinica* **48**(10), 1186–1193.

Chotěborský, R. 2013. Effect of heat treatment on the microstructure, hardness and abrasive wear resistance of high chromium hardfacing. *Research in Agricultural Engineering* **59**(1), 23–28.

Chotěborský, R. & Hrabě, P. 2013. Effect of destabilization treatment on microstructure, hardness and abrasive wear of high chromium hardfacing. *Research in Agricultural Engineering* **59**(4), 128–135.

Jam, J.E., Abolghasemzadeh, M., Salavati, H. & Alizadeh, Y. 2014. The Effect of Notch Tip Position on the Charpy Impact Energy for Bainitic and Martensitic Functionally Graded Steels. *Strength of Materials* **46**(5), 700–716.

Johnson, A.W. & Mehl, E.R. (1939). Trans. AIME 135 (pp. 416–458).

Kirkaldy, J.S. 2007. Flux-independent theory of nonlinear diffusion for Vegard's law solutions. *Materials Science and Engineering: A*, **444**(1-2), 104–111.

Kolmorgorov, A.N. 1937. Izv. Akad. Nauk. SSSR. Ser. Matem (pp. 355–359).

Lee, S.-J., Matlock, D.K. & Van Tyne, C.J. 2013. Comparison of two finite element simulation codes used to model the carburizing of steel. *Computational Materials Science* **68**, 47–54.

Lee, S.-J., Pavlina, E.J. & Van Tyne, C.J. 2010. Kinetics modeling of austenite decomposition for an end-quenched 1045 steel. *Materials Science and Engineering: A*, **527**(13–14),

Li, X., Miodownik, A.P. & Saunders, N. 2001. Simultaneous calculation of mechanical properties and phase equilibria. *Journal of Phase Equilibria* **22**(3), 247–253.

Liu, C.C., Xu, X.J. & Liu, Z. 2003. A FEM modeling of quenching and tempering and its application in industrial engineering. *Finite Elements in Analysis and Design* **39**(11), 1053–1070.

Liu, D., Xu, H., Yang, K., Bai, B. & Fang, H. 2004. Effect of bainite/martensite mixed microstructure on the strength and toughness of low carbon alloy steels. *Jinshu Xuebao/Acta Metallurgica Sinica* **40**(8), 882–886.

Malinowski, Z., Telejko, T. & Hadała, B. 2012. Influence of Heat Transfer Boundary Conditions on the Temperature Field of the Continuous Casting Ingot. *Archives of Metallurgy and Materials* **57**(1).

Marder, A.R. & Goldstein, J. 1984. Phase Transformations in Ferrous Alloys: Proceedings of an International Conference, 411.

Pietrzyk, M. & Kuziak, R. 2011. Computer aided interpretation of results of the Jominy test. *Archives of Civil and Mechanical Engineering* **11**(3), 707–722.

Scheil, E. 1935. Archiv f. Eisenhűttenw. 8, pp. 565–567.

Sinha, V.K., Prasad, R.S., Mandal, A. & Maity, J. 2007. A Mathematical Model to Predict Microstructure of Heat-Treated Steel. *Journal of Materials Engineering and Performance* **16**(4), 461–469.

Smoljan, B. 2006. Prediction of mechanical properties and microstructure distribution of quenched and tempered steel shaft. *Journal of Materials Processing Technology* **175**(1–3), 393–397.

Telejko, T. 2004. Analysis of an inverse method of simultaneous determination of thermal conductivity and heat of phase transformation in steels. *Journal of Materials Processing Technology* **155–56**, 1317–1323.

Xie, J. Bin, Wu, C.C., Fan, J., Fu, M. & Hu, D.F. 2013. Numerical Simulation on the Temperature Field of Steel 1045 Quenched by Different Hardening Media. *Applied Mechanics and Materials* **444–445**, 1222–1228.

Agronomy Research **13**(3), 639–653, 2015

Effect of chemical modification of wood flour on the mechanical properties of wood-plastic composites

H. Kallakas*, M.A. Shamim, T. Olutubo, T. Poltimäe, T.M. Süld, A. Krumme and J. Kers

Department of Polymer Materials, Tallinn University of Technology, Ehitajate tee 5, EE19086 Tallinn, Estonia; *Correspondence: heikko.kallakas@ttu.ee

Abstract. The poor compatibility between the highly hydrophilic wood fibres and the hydrophobic polymers is associated with a loss of mechanical properties. Therefore, to improve the interfacial adhesion between the polymer matrix and wood flour (WF), a chemical modification of WF is an appropriate solution. This study analyzes the influence of different chemical modifications of WF on the mechanical properties of wood-plastic composites (WPCs). WPC test samples were prepared from birch (*Betula*) WF with a mesh size of 0.63 mm as the filler material and polypropylene (PP) as the matrix material. WF was chemically modified by six different methods to increase its adhesion to, and compatibility with, the polymer matrix. The six chemical methods used were: alkaline (NaOH) modification, polyvinyl alcohol (PVA) modification, silane treatment with 3-aminopropyltriethoxysilane (APTES), acetylation with acetic anhydride, cyanoethylation, and wood fibre esterification. The composites were produced using a twin-screw extruder and the test samples were prepared by injection moulding. The composites' mechanical properties (three-point bending test), Charpy impact strength and thermal properties were tested. In addition, SEM micrographs of WPC surfaces were generated. WF as a filler material enhanced the flexural properties, while impact strength decreased, making the material more rigid and brittle. The test results revealed that the chemical modifications of WF improved the mechanical properties and crystallinity of WPC materials, while the melting temperature decreased. However, the influence of the chemical modification on the mechanical and thermal properties of WPC varied by method.

Key words: wood-plastic composite, wood flour, chemical modification, mechanical properties, thermal properties.

INTRODUCTION

In recent years, wood-based renewable composites have garnered much attention, both scientific and commercial, due to their light weight, eco-friendliness and low cost, as well as worldwide environmental awareness. Natural fibres are considered potential alternatives to glass or carbon fibres in fibre-reinforced thermoplastic composites because of their nature-friendliness, recyclability, biodegradability and low cost compared to mineral fillers (Ashori, 2008; Lu et al., 2008). According to previous research, natural fibres are less abrasive than inorganic mineral fillers and therefore cause little damage to moulding and mixing equipment (Acha et al., 2006).

However, the usability of natural fibres in composite materials is still limited due to their hydrophilic nature, which leads to poor compatibility with the hydrophobic polymer matrix. This may also result in composites with poor mechanical properties and decreased durability. Here, chemical modification of wood is used to alter its structure, enhancing interfacial adhesion between the polymer matrix and wood fibres and thus improving the physical and mechanical properties of the composite material (Gwon et al., 2010b; Těšinová, 2011). The chemical modification of wood flour (WF) has been studied by many authors. It has been reported that chemical modification can clean the wood fibre surface, stop the moisture absorption process, and increase the surface roughness. Different chemical modification techniques have been used, such as alkaline treatment, benzoylation, silylation, peroxide, acetylation, esterification, maleated coupling, etc. (Kalia et al., 2011). With alkaline treatment, the amount of crystalline cellulose is increased, impurities and swelling of the wood fibres are reduced, resulting in a smaller number of hydroxyl groups. The swelling of the wood fibres depends on the alkali concentration (Kim et al., 2011). Silanes efficiently connect with the superficial hydroxyl groups of the wood fibres and induce hydrolysis, condensation, and bond formation, producing chains between the polymer matrix and wood fibres. It is reported that silane modification enhances the properties of composite materials (Farsi, 2010; Kim et al., 2011).

Acetylation of wood has been widely used for modifying wood with acetic anhydride, which results in the esterification of accessible hydroxyl groups in the cell wall with acetyl groups. Previous research has shown that acetylated wood fibre based WPC materials exhibit enhanced mechanical properties, decreased moisture content and an improved resistance to brown-rot decay compared with unmodified WPC materials (Khalil et al., 2002; Segerholm et al., 2005). Generally, these chemical modification methods all improve the overall properties of WPC materials compared with unmodified composites. Based on previous studies it is also believed that the interfacial adhesion between the polymer matrix and the chemically modified WF is significantly increased (Gwon et al., 2010a).

The aim of this study was to investigate the influence of the chemical modification of WF on the interfacial strength of WPC. Therefore, WF was modified with six different chemical agents. Chemically modified WF was compounded with polypropylene (PP) resin and WPC test specimens were prepared by injection moulding. The mechanical behaviour of these composites was evaluated after the flexural and impact test.

MATERIALS AND METHODS

Materials

In this study, PP was used as a matrix material for WPCs. The PP obtained from the company Borealis Polymers OY is a heterophasic copolymer (block copolymer) with a density of 0.905 g cm^{-3} and a melt flow index (MFI) of 3.5 g 10 min^{-1}. The wood filler from hardwood (birch (*Betula*)) chips was supplied by the firm UPM Kymmene Otepää AS and then refined to a mesh size of 0.63 mm using the disintegrator device DS-A. For a chemical modification of the WF, a reagent grade sodium hydroxide (NaOH), 98%; polyvinyl alcohol (PVA); 3-aminopropyltriethoxysilane (APTES), 98%; acrylonitrile, 99%; dimethylformamide (DMF), 99%; and acetone, 99.5%, were purchased from Sigma Aldrich Chemical Co. For acetylation, acetic anhydride (AA), 98.5%, acquired from Merck Millipore chemicals, vinyl acetate (VA), 99%, from Fluka Chemical Corp, toluene from LACH-NER, s.r.o. and ethanol were used.

Alkaline modification of WF

Different concentrations of NaOH were selected based on previous studies (Doczekalska & Zborowska, 2010; Doczekalska et al., 2014) to investigate the effect of removing impurities and increasing crystalline cellulose content on the mechanical properties of WPCs. The chosen concentrations of NaOH for WF treatment were 5 wt% and 17.5 wt% (based on the mass of the WF). WF was treated in the chosen solutions of NaOH at room temperature (25 °C) for 90 min. The NaOH solution was prepared in the laboratory by dissolving NaOH granules in water and the solution was then poured onto the WF. After activating, the WF was rinsed with distilled water to neutralize the excess NaOH and then oven-dried at 60 °C for 24 h.

Polyvinyl alcohol modification of WF

PVA has excellent adhesive properties and therefore could be used for cross-linking wood fibres to polymer matrix. In this experimental method, an aqueous solution was prepared with 5 wt% of PVA (based on the mass of the WF) to compare it with other modifications. WF was treated with the PVA solution at room temperature (25 °C). The PVA solution was prepared in the laboratory by dissolving PVA powder in distilled water and then poured onto the WF. After treatment the WF was oven-dried at 60 °C for 24 h.

Silane modification of WF

For silane modification, the WF was treated at room temperature (25 °C) with an aqueous APTES solution. The concentration of APTES chosen for comparison with other modification methods was 5 wt%. On the basis of previous research in WF modification (Gwon et al., 2010a), 5 wt% of APTES (based on the mass of the WF) was added, prior to treatment, for the purpose of hydrolysis in a solution of ethanol/distilled water at a ratio of 9:1 (where ethanol is highly volatile and the objective was to obtain fast-drying WF) and at a pH value of 5. The stirring time was 10 min. A silane solution was then poured onto the WF and treated for 2 h; after the treatment the WF was oven-dried at 60 °C for 24 h.

Acetylation of WF

The acetylation of WF was carried out by two different methods to compare acetylation by boiling and acetylation using a co-solvent and a catalyst to increase the reaction rate. The effect of the two different acetylation methods and using the catalyst on the mechanical and physical properties of WPCs were investigated. The first method, based on a previous study (Ibach & Clemons, 2006), was straightforward and consisted in boiling the WF in AA. The WF was boiled in AA in a 1 l round-bottom flask with a stirrer for 4 h. The modified WF was then washed with distilled water and oven-dried at 60 °C for 24 h.

In the second method (Cetin et al., 2011), the WF was transferred to a round-bottom flask with a condenser containing a DMF solution with AA. The reaction was carried out using potassium carbonate (K_2CO_3) as a catalyst for 1.45 mmol g^{-1}dry wood. The amount of AA used in the solution was 70 mmol g^{-1} dry wood. The reaction was performed at 100 °C for 4 h. After the reaction, the modified WF was Soxhlet extracted by means of distilled water for 6 h and then by means of toluene/acetone/ethanol solution (at a ratio of 4:1:1 vol/vol) for 6 h to remove unreacted chemicals and by-products. After extraction the WF was oven-dried at 60 °C for 24 h.

Esterification of WF

WF esterification was carried out at the conditions established in a previous study (Wei et al., 2013). WF was weighed into a 3-neck round-bottom flask fitted with a condenser, an overhead stirrer and a thermometer. WF was reacted with VA at an amount of 12.5 mmol g^{-1} dry wood, 15 g of K_2CO_3 and 600 ml of DMF. Heat was then applied using sand as the heating medium because of the high temperature; the reaction mixture was stirred continuously at 120 °C for 6 h. After this, the reaction mixture was filtered to remove any excess reagents and the WF was then washed with distilled water and rinsed with acetone. After washing, the WF was oven-dried at 60 °C for 24 h.

Cyanoethylation

WF was cyanoethylated according to a method found in previous research (Ghali et al., 2011). Prior to cyanoethylation, the WF was treated with a NaOH solution (5 wt% based on the mass of the WF) for 2 min at room temperature to about 90% wet pickup. After the alkaline treatment, the WF was put into a round-bottom flask containing acrylonitrile/toluene solution (at a ratio of 50:50). The reaction was performed at 60 °C for 60 min. When the reaction was finished, the WF was thoroughly washed with 5% acetic acid solution and then with distilled water. After washing, the WF was oven-dried at 60 °C for 24 h.

Composite processing

After modification, the WF was weighed and the composite mixtures for all the samples were calculated at a ratio of 65% polymer and 35% WF. The mixture of the composites is shown in Table 1. The composites were compounded in a twin-screw extruder Brabender Plasti-Conder PLE 651 at 195 °C at a screw speed of 40 rpm. The compounded materials were then ground to produce granules. Test samples were prepared by injection moulding (Battenfeld BA 230 E) using the previously made granules according to standard ISO 178:2010. The conditions for injection moulding were as follows: temperature 170–185 °C from feed zone to die zone; injection pressure 7 MPa; screw speed 40 rpm; cooling time 15 s. The molten mixture was injected into two-bar shape moulds to produce flexural and impact test samples. The dimensions of the test samples were 63 x 10 x 4 mm.

Table 1. Make-up of the composites

Sample	PP (wt%)	WF (wt%)	Modification	Modification (wt%)
1	100	0	–	–
2	65	35	–	–
3	65	35	NaOH	5
4	65	35	NaOH	17.5
5	65	35	PVA	5
6	65	35	APTES	5
7	65	35	AA	5
8	65	35	AA and DMF	5
9	65	35	VA and DMF	5
10	65	35	Acrylonitrile	5

Mechanical properties

The flexural properties were determined with the three-point loading system Instron 5866 according to ISO 178:2010. The testing was carried out at room temperature 20 °C, at a crosshead speed of 20 mm min^{-1} and a test span of 60 mm. Five samples were used for each composite. For each composite, its flexural strength and modulus of elasticity (MOE) were calculated. In addition, Charpy impact strength was determined for single-notched samples according to ISO 179-1. Notched impact strength was tested with a Zwick 5102 pendulum impact tester at room temperature 20 °C and nominal pendulum energy of 4 J. The energy absorbed by breaking the test sample was measured and Charpy impact strength was calculated.

Differential scanning calorimetry

WPC samples were tested by differential scanning calorimetry (DSC) to measure the thermal transition of the composites. DSC was performed by means of the Mettler Toledo FP900 Thermosystem with FP90 Central Processor (control and evaluation unit) and FP85 Measuring Cell fitted with cooler system using a nitrogen atmosphere at a flow rate of 20 mL min^{-1}. WPC samples were weighed at about 10 mg, placed in a small aluminium crucible and subjected to a temperature program. The heating and cooling conditions for WPC samples were 30 to 250 °C and 250 to 30 °C with heating and cooling rates of 10 °C min^{-1}, respectively. For each WPC sample its melting temperature (T_m), melting enthalpy (ΔH_m), crystallization temperature (T_c), crystallization enthalpy (ΔH_c) and crystallinity (X_c) were determined.

Scanning electron microscopy

The unmodified and modified composite surfaces and cross-sections were evaluated microscopically by means of the field emission scanning electron microscope (FE-SEM) ZEISS Ultra-55 with GEMINI In-lens SE detector. The acceleration voltage used was 20 kV. Samples were prepared by cutting and mounting a microtomed cross-section. After that, the samples were coated with gold.

RESULTS AND DISCUSSION

Flexural properties

The flexural strength of WPCs with different wood modifications is presented in Fig. 1. The results show that the addition of WF to the PP matrix increased the flexural strength; this effect is enhanced by different chemical modifications of the WF, which make the material more rigid and brittle. However, some chemical modifications demonstrated a decrease in the flexural strength compared to unmodified WF composites. 5% NaOH, PVA and AA modified PP/WF composites showed the lowest values of flexural strength (33.1 MPa, 33.3 MPa, and 33.4 MPa, respectively), which indicates poor interfacial adhesion between the PP matrix and WF. Adding 35% WF to the PP matrix increased the flexural strength of the composites by about 10% with unmodified WF. A similar increase in flexural strength with 30–40% unmodified WF has also been noted in previous studies (Stark & Rowlands, 2003; Karmakar et al., 2007; Ndiaye et al., 2012). However, these previous studies also show that when adding a maleic anhydride grafted polypropylene (MAPP) coupling agent to the composite mixture the increase in flexural strength is significantly higher. The best flexural strength values were obtained by the WF esterification method (38.5 MPa), which increased flexural strength by about 7% compared to unmodified WF (36.2 MPa). The conclusion here is that interfacial adhesion between PP and WF improved with the esterification of WF.

As seen from Fig. 1, an increase in the NaOH concentration from 5% to 17.5% results in a 12% higher flexural strength (from 33.1 MPa to 36.9 MPa, respectively). Alkaline treatment increases the fibre surface roughness and possible reaction sites on the fibre surface, which helps to improve the mechanical properties of WPC through mechanical interlocking and chemical bonding (Gwon et al., 2010a). The mechanical properties of WPC materials are influenced by removing impurities from WF. Based on the results presented in Fig. 1, it can be concluded that at an increased alkaline content the mechanical properties of WPC are also enhanced. However, previous research has shown that at an alkaline content increased to more than 10 wt%, the flexural strength starts to decrease slightly as a result of corrosive interactions between wood fibres in the composites caused by excessive alkali that weakens the WF surface (John et al., 2008; Gwon et al., 2010a). Therefore it is important to choose an optimum amount of NaOH to achieve strong mechanical properties of WPCs.

Two different methods of WF acetylation were also tested and the mechanical properties were compared. The flexural strength results in Fig. 1 show that just boiling the WF in AA even decreases the flexural strength of WPC compared to unmodified WF-based composites. However, another method using the solution of AA and DMF with a catalyst (K_2CO_3) gave better results, increasing the flexural strength slightly, by 2%, compared with unmodified WF (from 36.2 MPa to 37.1 MPa, respectively) and by 11% compared with acetylation by boiling in AA (from 33.4 MPa to 37.1 MPa, respectively). Therefore, acetylation with the AA and DMF solution with a catalyst (K_2CO_3) was found more effective with regard to enhancing the mechanical properties of WPCs. An enhanced acetylation of wood in the presence of a catalyst and an improvement in the mechanical properties of WPCs has also been shown in previous studies (Cetin, et al., 2011; Özmen et al., 2013). Acetylation replaces the OH groups of wood cell wall polymers with acetyl groups, so that they become hydrophobic and thus compatible with thermoplastics.

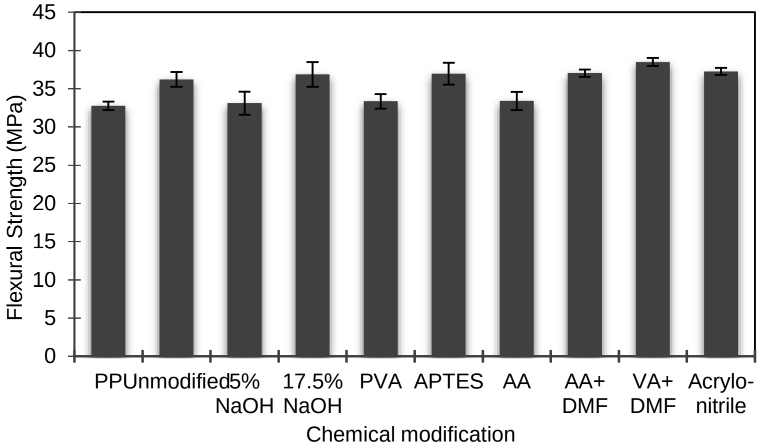


Figure 1. Flexural strength of chemically modified and unmodified WF/PP composites.

With acrylonitrile and APTES modification of WF, the flexural strength was also higher than with unmodified WF composites. With cyanoethylation, the wood OH groups are modified with acrylonitrile and wood is made hydrophobic and compatible with polymers. With acrylonitrile, the composites' flexural strength (37.3 MPa) was increased by 3%, and with APTES (37.0 MPa), it was 2% higher than with unmodified WF composites. However, previous research (Kim et al., 2011) has shown a significantly higher improvement in flexural properties with APTES modified PP/WF composites (about 80% compared to unmodified composites) when the WF is modified with NaOH prior to silane modification. The increase in flexural properties with APTES modification is explained by a stronger interface between WF and PP compared to unmodified composites. This enhances flexural stress distribution in the composites. Silane-reactive chemical groups provide covalent bonding with the OH groups of wood fibres and another chemical group connects with the polymer by creating interfacial adhesion between the polymer and WF.

The flexural MOE values of different composites are shown in Fig. 2. The results demonstrate that significantly higher values of flexural MOE were achieved by four different chemical modifications: 5% NaOH, PVA, APTES and AA. APTES gave the highest flexural MOE value (2.6 GPa) and compared to unmodified WF composites, the value increased from 1.00 GPa to 2.56 GPa, respectively, making the composite stiffer. On the other hand, WF esterification gave the lowest values of flexural MOE (0.91 GPa).

Therefore, it can be concluded from the flexural properties that most of the chemical modification methods tested in this study improved the flexural strength values, which indicates that interfacial adhesion between WF and PP was increased. The increase in bonding between WF and PP may be due to the fact that chemical modification reduces the number of hydroxyl groups in WF and modification with NaOH leads to the removal of extractives and hemicellulose from the WF.

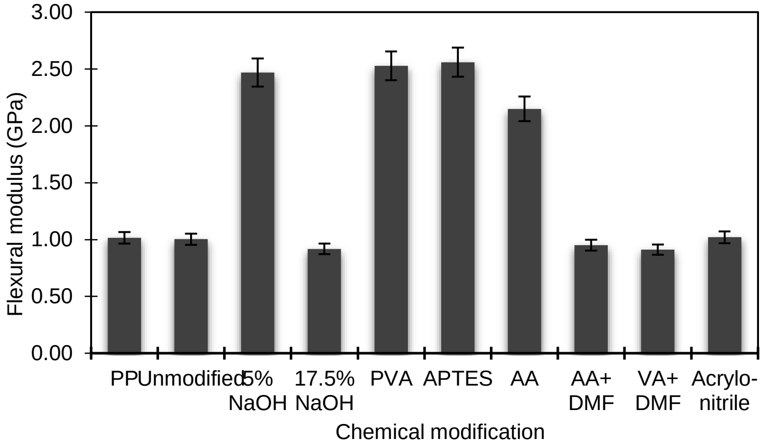


Figure 2. Flexural modulus of chemically modified and unmodified WF/PP composites.

Impact strength

The Charpy impact strength of single-notched specimens of unmodified and modified WPC samples is shown in Fig. 3. The single-notched impact test was chosen because the pendulum impact tester did not provide sufficient energy to break un-notched PP samples due to the high elasticity of the PP matrix. This is the reason why many other researches have also previously used the single-notched impact test for WPC impact testing. With all the composites, the addition of WF to the PP matrix lowered the impact properties significantly (about threefold) compared to pure PP; this is also in accordance with previous research (Bledzki & Frauk, 2004; Bledzki et al., 2009). When incorporating WF in the PP matrix, impact strength is decreased due to the stress concentration regions in WPC that require less energy to break the composite, making the material more brittle. The results show that only the PVA and acrylonitrile modifications of WF had a slightly higher impact strength (4.72 kJ m^{-2} and 4.56 kJ m^{-2}, respectively) compared with unmodified WF composites (4.44 kJ m^{-2}). All the other modified composites exhibited a lower impact strength compared with the unmodified ones. The lowest impact strength was demonstrated by APTES modified WF composites (3.56 kJ m^{-2}) – 25% lower than that of unmodified WPC samples. APTES silanol groups can create strong bonds with the hydroxyl groups of WF and thus improve interfacial adhesion between WF and the polymer matrix.

The chemical modification of WF improves the interaction between WF and the polymer matrix, resulting in strong bonding, and therefore the breaking of the composites needs relatively low impact energy. Composites with weaker interfacial bonding have higher impact strength because micro-cracks can occur in the impact test, propagating along the fibre/matrix interface and causing debonding, which leads to a higher energy-absorption capacity of the WPC (Ray et al., 2001; Nourbakhsh & Ashori, 2010). Therefore, an impact test shows the effect of chemical modification on the interfacial bond in the composites, which also affects the mechanical properties of WPC materials.

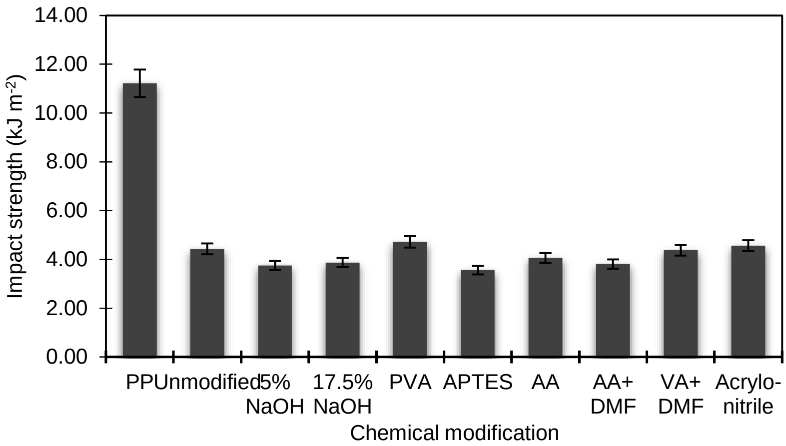


Figure 3. Impact strength of chemically modified and unmodified WF/PP composites.

Differential scanning calorimetry

All the WPC samples (unmodified and modified) were measured with the DSC system and the data of the composites is shown in Table 2. Thermal analysis demonstrates that the addition of WF to the polymer matrix decreased the T_m by 1.3–4.3 °C. The addition of 35% unmodified WF to the polymer matrix decreased the T_m by 1.7 °C, while the largest decrease, by 4.3 °C, was provided by NaOH (17.5 wt%) modified WF composites. ΔH_m values decreased significantly when WF was added to the polymer matrix. It was interesting that PVA modified WF composites gave only 14.1 J g^{-1} of ΔH_m compared to pure PP (54.6 J g^{-1} of ΔH_m) and therefore a lot less energy is required to melt the composite. With WPC samples, the highest ΔH_m was obtained with APTES – it was just 17% lower than pure PP. Therefore, the APTES modification of WF requires a lot more energy than other modifications to melt the composite. The same trend was also noted in a previous study (Kim et al., 2011).

The T_c of the WPCs with PVA and NaOH (5 wt%) modified PP/WF composites was higher than with other modifications and unmodified composites, indicating a better nucleation ability of PVA and NaOH (5 wt%) modified WPCs. Accordingly, these act as nucleating agents, increasing the rate of crystallization of polymers and thereby also the crystallization temperature (Ayrilmis et al., 2014). Other WF modifications show lower T_c values (0.6–5.8 °C), which indicates a weakened nucleation ability with these modified WF composites, resulting in a better interfacial adhesion between PP and WF. Wood consists of cellulose with a crystalline structure, and hemicellulose and lignin with an amorphous structure, thus reducing the crystallinity of composites. Therefore, the improved interfacial adhesion in these composites is explained by the hindered movement of PP chains, decreasing the crystallization rate of PP in the WPCs (Ndiaye & Tidjani, 2012).

All WPC samples except AA+DMF modified WF composites show a decrease in the ΔH_c results compared to pure PP. Most of the WF modifications decreased the ΔH_c compared to unmodified composites. However, APTES, AA and AA+DMF modified composites increased the ΔH_c by 7%, 1%, and 36% respectively, compared to unmodified WPCs. Previous research (Ayrilmis et al., 2014) has shown that the modification of WF can increase the ΔH_c by inducing a formation of crystals in heterogeneous nucleation spots. This increases the crystallization rate in the WPCs.

The crystallinity X_c of all the composites was reduced with the addition of WF to the polymer matrix. The lowest X_c was obtained with the PVA modified composite of only 6.2% crystallinity. Most of the modified composites increased the X_c compared to unmodified composites. The highest X_c was achieved with APTES (X_c = 21.3%) and 17.5% NaOH (X_c = 20.2%) modified composites – just 19% and 26% lower than pure PP, respectively. The decreased crystallinity of WPCs shows that the formation of polymer crystals is hindered by WF in the composites. However, the higher crystallinity of APTES modified composites may be explained by the better interfacial adhesion between WF and the PP matrix. Previously it has been reported that APTES modification provides the highest increase in X_c (Kim et al., 2011).

Table 2. DSC results of the unmodified and modified WPC samples

Sample	PP/WF (wt%)	Modification	Modification (wt%)	T_m^a (°C)	ΔH_m^b (J g^{-1})	T_c^c (°C)	ΔH_c^d (J g^{-1})	X_c^e (%)
1	100/0	–	–	173.0	54.6	107.5	1,950	25.4
2	65/35	–	–	171.3	32.6	107.6	1,760	15.3
3	65/35	NaOH	5	171.7	36.0	109.2	1,420	18.9
4	65/35	NaOH	17.5	168.7	40.5	102.4	1,380	20.2
5	65/35	PVA	5	169.5	14.1	116.3	868	6.2
6	65/35	APTES	5	171.5	46.7	103.3	1,880	21.3
7	65/35	AA	5	171.3	40.4	107.5	1,780	19.2
8	65/35	AA and DMF	5	172.1	22.6	106.9	2,400	10.5
9	65/35	VA and DMF	5	170.1	38.2	101.7	1,620	19.0
10	65/35	Acrylonitrile	5	169.6	34.5	103.8	1,520	15.4

[a]Melting temperature; [b]melting enthalpy; [c]crystallization temperature; [d]crystallization enthalpy; [e]crystallinity

Scanning electron microscopy

SEM pictures of the surfaces and cross-sections of modified and unmodified WPC samples are shown in Fig. 3. With a chemical modification of WF there is a better dispersion of wood and adhesion with the polymer matrix. With unmodified composite samples (Fig. 4a and 4b) cavities and voids are present in the composite surfaces. Also PVA modified composite surfaces (Fig. 4g and 4h) reveal voids and separate wood particles, representing a non-compatibilized system. Therefore, these composites have poor interfacial adhesion between WF and the PP matrix. With modified composites, micrographs show fewer cavities and voids and more homogenous surfaces, which also indicate an improved interfacial adhesion between WF and the PP matrix. Smooth and uniform surfaces with a good dispersion of WF in the PP matrix can be seen in Fig. 4m, 4n, 4q and 4r, which shows a strong compatibility between WF and the PP matrix with AA+DMF and Acrylonitrile modifications. With other chemical modifications, minor cavities and voids are present on the surfaces of WPCs, reducing the interfacial bonding of PP and WF. These SEM observations clearly explain the enhanced mechanical properties of modified WPCs, so that the stronger interaction between WF and PP also improves the mechanical properties of WPCs.

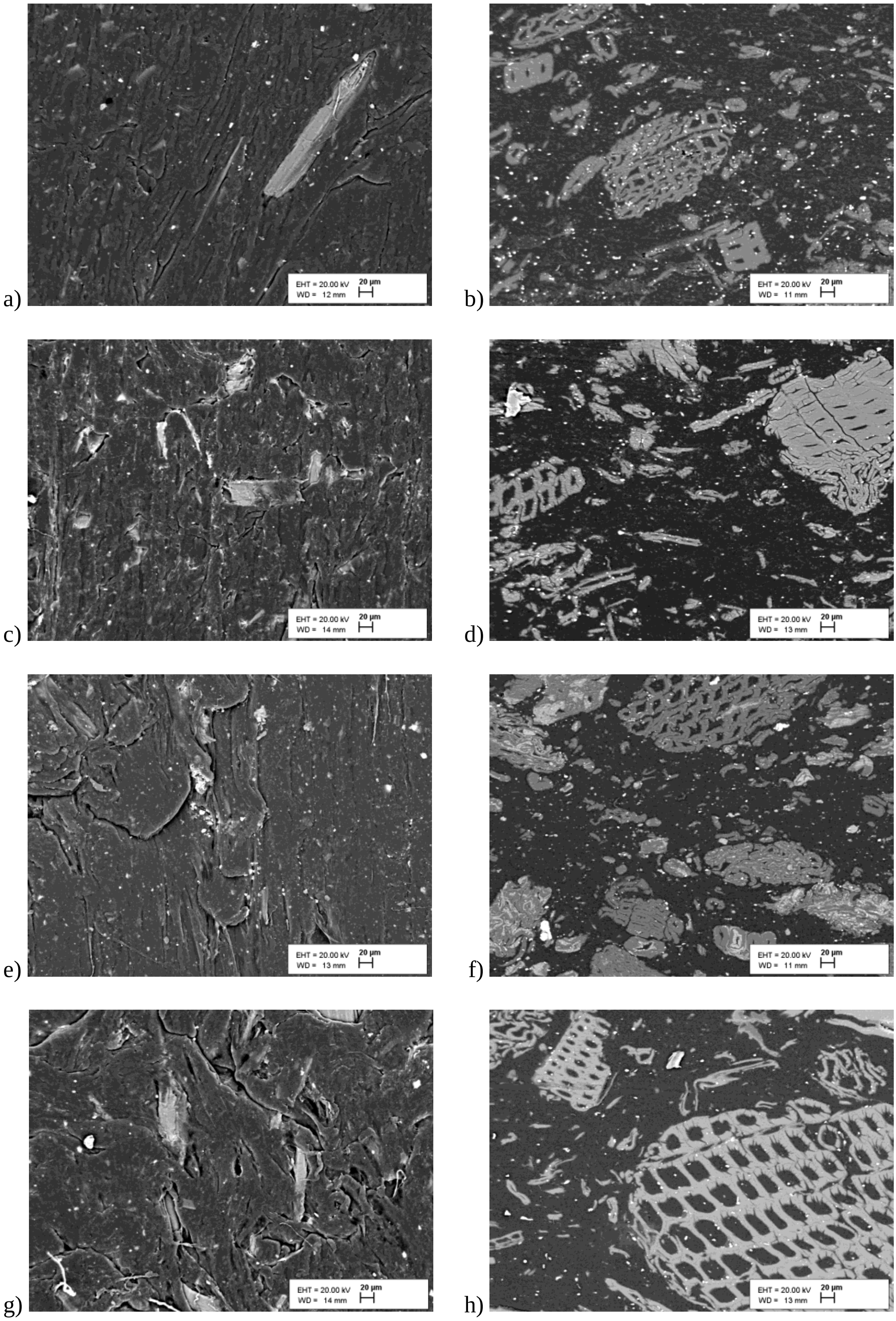
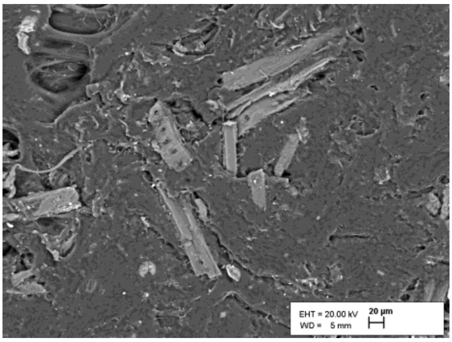
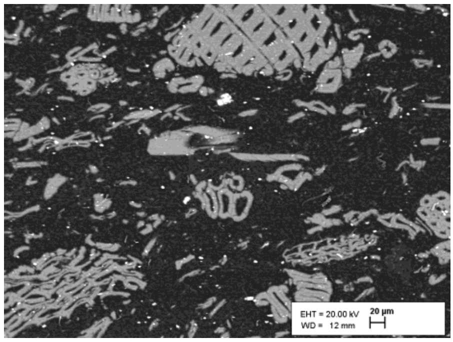

a)
EHT = 20.00 kV WD = 12 mm 20 µm
b)
EHT = 20.00 kV WD = 11 mm 20 µm
c)
EHT = 20.00 kV WD = 14 mm 20 µm
d)
EHT = 20.00 kV WD = 13 mm 20 µm
e)
EHT = 20.00 kV WD = 13 mm 20 µm
f)
EHT = 20.00 kV WD = 11 mm 20 µm
g)
EHT = 20.00 kV WD = 14 mm 20 µm
h)
EHT = 20.00 kV WD = 13 mm 20 µm

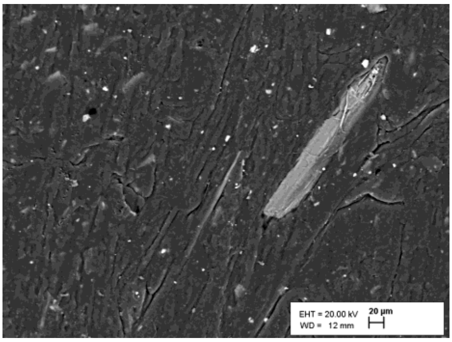
Fig.4 (continued)



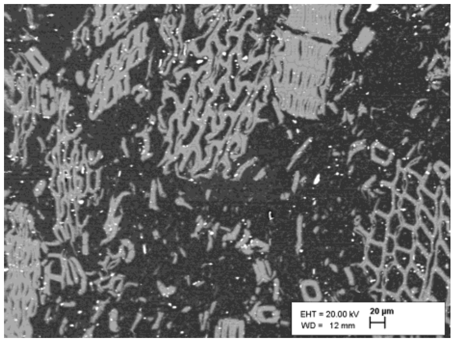
i)



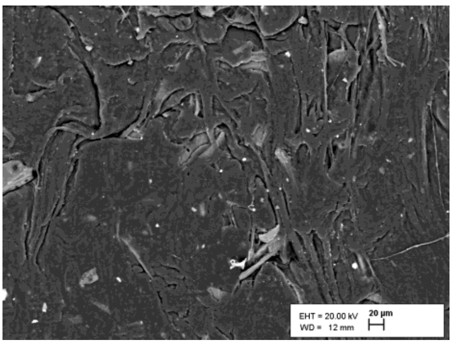
j)



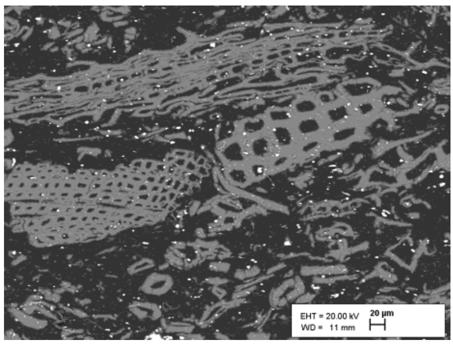
k)



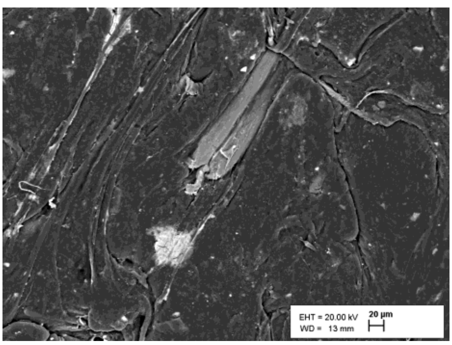
l)



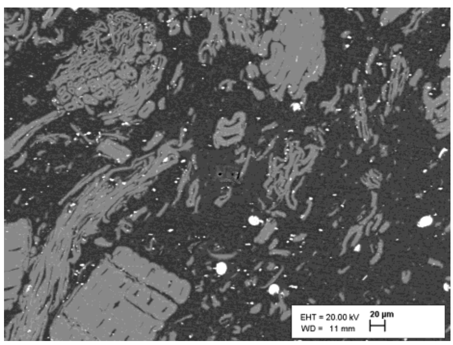
m)



n)

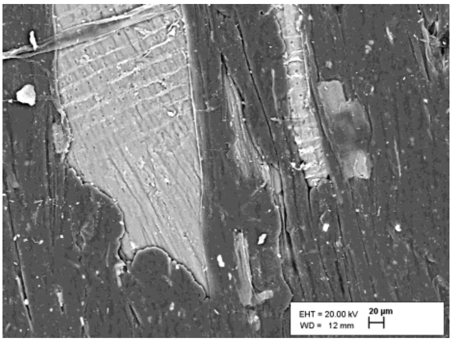


o)



p)

Fig.4 (continued)

q) 

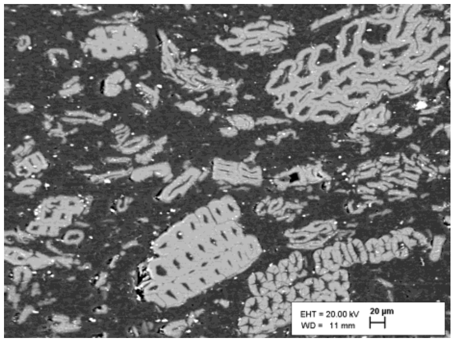
r) 

Figure 4. SEM micrographs of the surfaces and cross-sections of unmodified and modified composites: a) unmodified WPC surface; b) unmodified WPC cross-section; c) 5% NaOH modified WPC surface; d) 5% NaOH modified WPC cross-section; e) 17.5% NaOH modified WPC surface; f) 17.5% NaOH modified WPC cross-section; g) PVA modified WPC surface; h) PVA modified WPC cross-section; i) APTES modified WPC surface; j) APTES modified WPC cross-section; k) AA modified WPC surface; l) AA modified WPC cross-section; m) AA+DMF modified WPC surface; n) AA+DM modified WPC cross-section; o) VA+DMF modified WPC surface; p) VA+DMF modified WPC cross-section; q) Acrylonitrile modified WPC surface; r) Acrylonitrile modified WPC cross-section.

CONCLUSIONS

This study focused on the influence of WF modification on the mechanical properties of WPC. The chemical modification of WF with seven different chemicals was evaluated. It was found that chemical modification enhances the flexural properties of WPC materials due to an improved compatibility between WF and the polymer matrix. WF esterification showed the best flexural properties, indicating strong interfacial adhesion between WF and the PP matrix. The results of an impact strength test showed that the chemical modification of WF lowers the impact strength needed for breaking the WPC material. This is due to the fact that the debonding effect of the WF/PP matrix absorbs more impact energy with modified composites than with unmodified ones. The largest decrease in impact energy was observed with APTES modified composites. It can be concluded that the chemical modification of WF results in improved mechanical properties of WPCs. The results varied slightly by method but it is possible to choose an optimal modification method for the best mechanical performance of the composites.

In the DSC analysis, T_m, ΔH_m and X_c decreased with chemically modified composites. Most of the composites with chemical modifications showed higher values of X_c compared to unmodified composites, suggesting better interfacial adhesion between WF and PP. SEM micrographs showed that the surfaces of the modified composites had fewer voids and cavities, resulting in a more homogeneous material with improved mechanical properties.

REFERENCES

Acha, B.A., Reboredo, M.M., Marcovich, N.E. 2006. Effect of coupling agents on the thermal and mechanical properties of polypropylene–jute fabric composites. *Polym. Int*., **55**, 1104–1113.

Ashori, A. 2008. Wood–plastic composites as promising green-composites for automotive industries! *Bioresource Technol*. **99**, 4661–4667.

Ayrilmis, N., Dundar, T., Kaymakci, A., Ozdemir, F., Kwon, H.J. 2014. Mechanical and thermal properties of wood-plastic composites reinforced with hexagonal boron nitride. *Polym. Compos.* **35**, 194–200.

Bledzki, A.K., Frauk, O. 2004. Creep and impact properties of wood fibre–polypropylene composites: influence of temperature and moisture content. *Compos. Sci. Technol*., **64**, 693–700.

Bledzki, A.K., Jaszkiewicz, A., Scherzer, D. 2009. Mechanical properties of PLA composites with man-made cellulose and abaca fibres. *Compos. Part A: App. Sci. Man*., **40**, 404–412.

Cetin, S.N., Özmen, N., Birinci, E. 2011. Acetylation of wood with various catalysts. *J. Wood. Chem. Technol.* **31**, 142–153.

Doczekalska, B., Bartkowiak, M., Zakrzewski, R. 2014. Esterification of willow wood with cyclic acid anhydrides. *Wood Res.* **59**, 85–96.

Doczekalska, B., Zborowska, M. 2010. Wood chemical composition of selected fast growing species treated with NaOH Part I: structural substances. *Wood Res.* **55**, 41–48.

Farsi, M. 2010. Wood–plastic composites: influence of wood flour chemical modification on the mechanical performance. *J. Reinf. Plast.* **29**, 3587–3592.

Ghali, L., Msahli, S., Zidi, M., Sakli, F. 2011. Effects of fiber weight ratio, structure and fiber modification onto flexural properties of luffa-polyester composites. *Advan. Mat. Phys. Chem*. **1**, 78–85.

Gwon, J.G., Lee, S.Y., Chun, S.J., Doh, G.H., Kim, J.H. 2010a. Effect of chemical treatments of wood fibers on the physical strength of polypropylene based composites. *Korean. J. Chem. Eng*. **27**, 651–657.

Gwon, J.G., Lee, S.Y., Chun, S.J., Doh, G.H., Kim, J.H. 2010b. Effects of chemical treatments of hybrid fillers on the physical and thermal properties of wood plastic composites. *Compos. Part A: App. Sci. Man*. **41**, 1491–1497.

Ibach, E.R., Clemons, M.C. 2006. Effect of acetylated wood flour or coupling agent on moisture, uv, and biological resistance of extruded woodfiber-plastic composites. *For. Prod. Soc.* 139–147.

John, M.J., Francis, B., Varughese, K.T., Thomas, S. 2008. Effect of chemical modification on properties of hybrid fiber biocomposites. *Compos. Part A: App. Sci. Man.* **39**, 352–363.

Kalia, S., Dufresne, A., Cherian, B.M., Kaith, B.S., Averous, L., Njugana, J., Nassiopoulus, E. 2011. Cellulose-Based Bio- and Nanocomposites: A Review. *Int. J. Polym. Sci*. **2011**, 35p.

Karmakar, A., Chauhan, S.S., Modak, M.J., Chanda, M. 2007. Mechanical properties of wood–fiber reinforced polypropylene composites: Effect of a novel compatibilizer with isocyanate functional group. *Compos. Part A: App. Sci. Man*. **38**, 227–233.

Khalil, H.P.S.A., Rozeman, H.D., Ismail, H., Ahmad, R., Ahmad, M.N. 2002. Polypropylene (PP)-Acacia Mangiumcomposites: The effect of acetylation on mechanical and water absorption properties. *Polym. Plasts. Technol. Eng*. **41**, 453–468.

Kim, T.W., Lee, S.Y., Chun, S.J., Doh, G.H., Paik, K.H. 2011. Effect of silane coupling on the fundamental properties of wood flour reinforced polypropylene composites. *J. Compos. Mat*. **45**, 1595–1605.

Lu, X., Zhang, Y., Liang, Y., Yang, J., Zhang, S., Suzuki, E. 2008. Kinetic studies of hemicellulose hydrolysis of corn stover at atmospheric pressure. *Korean. J. Chem. Eng*. **25**, 302–307.

Ndiaye, D., Diop, B., Thiandoume, C., Fall, A.P., Farota, K.A., Tidjani, A. 2012. Morphology and Thermo Mechanical Properties of Wood/Polypropylene Composites. *Polyp.* 415–428.
Ndiaye, D., Tidjani, A. 2012. Effects of coupling agents on thermal behavior and mechanical properties of wood flour/polypropylene composites. *J. Compos. Mat.* **46**, 3067–3075.
Nourbakhsh, A., Ashori, A. 2010. Wood plastic composites from agro-waste materials: Analysis of mechanical properties. *Biores. Tech.* **101**, 2525–2528.
Ray, D., Sarkar, B.K., Rana, A.K., Rose, N.R. 2001. The mechanical properties of vinylester resin matrix composites reinforced with alkali-treated jute fibres. *Compos. Part A: App. Sci. Man.*, **32**, 119–127.
Segerholm, K., Walinder, M., Larsson, B.P., Walkenström, P., Westin, M. 2005. Wood plastic composites made from acetylated wood: Effects on water vapour sorption behaviour and durability In: *Proceedings of the 9th European Panel Products Symposium*. Llandudno, Wales. UK. pp. 233–242.
Stark, M.N., Rowlands, E.R. 2003. Effects of wood fiber characteristics on mechanical properties of wood/polypropylene composites. *Wood. Fiber. Sci*., **35**, 167–174.
Těšinová, P. 2011. *Advances in Composite Materials – Analysis of Natural and Man–Made Material.* InTech, 584 p.
Wei, L., McDonald, G.A., Freitag, C., Morrell, J.J. 2013 Effects of wood fiber esterification on properties, weatherability and biodurability of wood plastic composites. *Polym. Deg. Stab.*, **98**, 1348–1361.
Özmen, N., Cetin, S.N., Mengeloglu, F., Birinci, E., Karakus, K. 2013. Effect of wood acetylation with vinyl acetate and acetic anhydride on the properties of wood-plastic composites. *BioRes.* **8**, 753–767.

Agronomy Research **13**(3), 654–661, 2015

Influence of dusty micro-particles contamination on adhesive bond strength

A. Krofová* and M. Müller

Department of Material Science and Manufacturing Technology, Faculty of Engineering, Czech University of Life Science, Kamýcká 129, CZ-16521 Prague, Czech Republic; *Correspondence: krofovaa@tf.czu.cz

Abstract. A necessity for a bond creation is one of common attributes of production companies. An adhesive bonding technology is a method of a connecting. This method is suitable for workings with a single and serial production. Many research projects dealt with a preparation of adhesive bonds, degradation aspects etc. An area, which has not been properly investigated at present, is an influence of a contamination of the adhesive bonds by dusty micro-particles, e. g. from a ventilation of assembly shops, production hall etc. The research was focused on the evaluation of the influence of dusty micro-particles contamination of the two-component epoxy adhesive at the hardening process. The dusty micro-particles were gained from the filtering equipment used in a production hall. Sizes of gained dusty particles were analysed on sieves of dimensions 315 μm, 250 μm, 160 μm, 90 μm. Subsequently, these particles were added in various ratios into the mixture of the adhesive during its preparation. The adhesive bonds containing the dusty particles of the sizes 250 μm, 160 μm and 90 μm showed the fall of the adhesive bond strength. The adhesive bonds containing the dusty particles of the size 315 μm showed the mild increase of the adhesive bond strength. The failure area did not change owing to the contamination of the adhesive bond with the dusty particles.

Key words: adhesive bond, elongation, failure area, dusty micro – particles.

INTRODUCTION

A necessity for a bond creation is one of common attributes of production companies. An adhesive bonding technology is a method of a connecting. This method is suitable for workings with a single and serial production. Many research projects dealt with a preparation of adhesive bonds, degradation aspects etc. An area, which has not been properly investigated at present, is an influence of a contamination of the adhesive bonds by dusty micro-particles, e.g. from a ventilation of assembly shops, production hall etc. The adhesive bonds enable to substitute welding seams and mechanical connecting elements, help to decrease the material fatigue and failure around the heat-influenced area.

Undesirable changes of the adhesive properties occur not only when using products but they can already occur at own process of the working of adhesives and at their storing (Müller & Valášek, 2014).

The adhesive bonding is a modern method of connecting different materials. This method is still seldom spread in spite of its advantages just because of its low durability at exposing to unfavourable influences. An assumption for securing the service life of the adhesive bond is keeping basic processes at its creation. The essential factor is a cleanness of a working environment under given conditions under which the bond is created and also a character of degradation processes influencing strength of whole construction. This undesirable but inevitable factor has to be analysed.

The dust which can be found all in the air is a significant source of a rise of the dangerous working environment. It is a restriction which cannot be avoided in a common practice.

Many studies researching the air quality in various environments were performed in past (di Giorgio et al., 1996; Jones, 1999). Spaces in which people are moving when doing various working activities were also investigated (Bluyssen, 1996; Karwowska, 2003; Kic & Chládek, 2010; Kic & Růžek, 2014), farms and agricultural plants for poultry-farming too (Karwowska, 2005; Kic et al., 2007; Kic et al., 2012; Nimmermark et al., 2009). The dust is a general term for solid particles of a mean smaller than 0.075 mm. It consists of cells of a human skin, a small amount of a vegetable pollen, human and animal hair, textile fibres, paper fibres and many other materials which can be found depending on the particular environment (Nõu & Viljasoo, 2011). We can suppose on a basis of general pieces of knowledge that the pollution of adhesives will cause a fall of a resultant adhesive strength of the adhesive bond. Zhang el al. state in their work that the adhesive is more resistant to water and its strength is increasing when adding starch particles into the adhesive (Zhang et al., 2015).

By adding fractions into the macro–molecular materials (which are also polymers) it comes to changes of a chemical chain on which the properties of the polymers depend (Ducháček, 2006). Generally it can be said that the change of the molecular mass of the macro–molecular materials influences their mechanical properties in both ways-in positive as well as in negative one (Ducháček, 2006; Valášek, 2014).

However, the cohesion mechanism of the adhesive bond depends on an adhesion, a cohesion and a wettability of the adhesive bonded surface. During the hardening e.g. of two-component epoxy adhesives the epoxy resins react with hardeners and they create macro-molecules. The polymerisation process influences the resultant strength of the adhesive bond. It can be supposed that it comes to lowering of the resultant adhesive bond strength at the adhesive bond contamination during the hardening process (the polymerisation).

The aim of this work was to perform laboratory experiments focused on the strength of the adhesive bond polluted with the dust gained from the filtering equipment used in production halls using the information gained from available references and by means of recommended introduced standard processes. Results should serve for the evaluation of the influence of two-component epoxy adhesives contamination with dusty micro-particles on the adhesive bond and because of the fact that the bond cleanness is the main factor causing the failure of adhesive bonded constructions it is necessary to comprehend and explain their degradation processes. Pieces of knowledge will be subsequently used at the evaluation of properties of the adhesive bonds at their creation depending on the environment contamination.

MATERIAL AND METHODS

The research was focused on the evaluation of the influence of dusty micro-particles contamination of the two-component epoxy adhesive Glue Epox Rapid F (marked as a matrix in the text) at the hardening process. The dusty micro-particles were gained from the filtering equipment used in a production hall.

In the production hall there were e.g. these technologies: blasting cabin, a working place of connecting and dividing of materials. A source of higher dusty particles in the filtering equipment was obviously the blasting equipment.

Two-component epoxy adhesive Glue Epox Rapid F was prepared by mixing a part A (a low-molecular epoxy resin) and a part B (a polyamide hardener). A ratio for mixing the parts A : B was 100 : 45 of mass parts. A processing time of the adhesive bonded mixture at the temperature 22 ± 2 °C is max. 10 minutes. An exceeding of the processing time influences the adhesive bond strength in the negative way (it decreases) (Müller & Valášek, 2013).

Sizes of gained dusty particles were analysed on sieves of dimensions 315 μm, 250 μm, 160 μm, 90 μm (Fig. 1). The dusty micro-particles were of an irregular shape. The size of used dusty particles was given by a sieve analysis (that means by size of used sieves). The particles below 90 μm were not used. A reason was an impossibility to set the size.

Subsequently, these particles were added in various ratio into the mixture of the adhesive during its preparation.

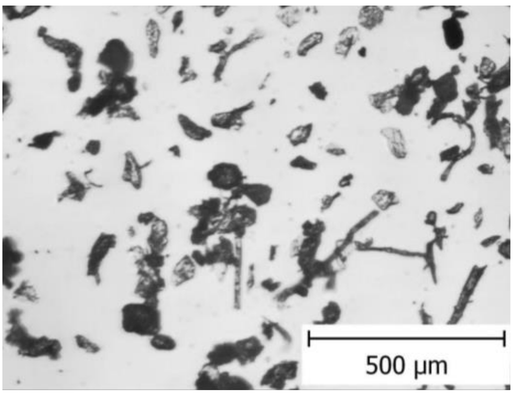


Figure 1. Dusty particles of size 90 μm.

The mass ratios of test specimens are following 100,000 mg of a matrix: 250 mg, 500 mg, 750 mg and 1,000 mg of dusty particles. The influence of the dusty particles contamination was investigated at the adhesive bonds according to the standard CSN EN 1465 (2009).

The basis of adhesive bonds laboratory testing was the determination of the tensile lap-shear strength of rigid-to-rigid bonded assemblies according to the standard CSN EN 1465 (2009) (Equivalent is BS 1465). The tests were performed using the steel S235J0 specimens of dimensions 100 x 25 x 1.5 mm.

The surface preparation is important and should guarantee good strength on the boundary of adherents. Steel adherents were firstly mechanically surface treated with blasting by a synthetic corundum (Al_2O_3) with a size of a fraction F80. Using the profilograph Surftest 301 following values were determined: Ra 1.83 ± 0.25 μm, Rz 10.42 ± 0.88 μm. Then the surface was cleaned and degreased using acetone P6401 and prepared to the application.

The adhesive bonds were created until 5 ± 2 minutes after adding the dusty particles into the matrix.

An even thickness of the adhesive layer was reached by a constant pressure 0.5 MPa. The lapping was according to the standard 12.50 ± 0.25 mm. The adhesive bonds were hardened for 48 hours at the laboratory temperature (22 ± 2 °C). The adhesive layer thickness in the adhesive bonds was 0.15 ± 0.15 mm. The real thickness of the adhesive layer was set on the basis of the picture analysis in the cut of the adhesive bonds by means of the microscope.

The tensile strength and the elongation tests were performed using the universal tensile strength testing machine LABTest 5.50ST (a sensing unit AST type KAF 50 kN, an evaluating software Test & Motion). A speed of the deformation corresponded to 6 mm min^{-1}.

The failure type according to CSN ISO 10365 (1995) was determined at the adhesives bonds.

RESULTS

The adhesive bond strength (without the contamination with the dusty particles) was 12.02 ± 0.76 MPa. It showed a fall at the adhesive bonds contaminated with the dusty particles of the sizes 250 μm, 160 μm and 90 μm. The fall was in the interval 0.79 to 18.85% (all concentrations). The adhesive bond strength increased at the adhesive bonds contaminated with the dusty particles of the size 315 μm. The strength increase was in the interval 4 to 5%. A graphic presentation of the results of the adhesive bond strength prepared by 3D graph with method of the smallest squares can be seen from Fig. 2.

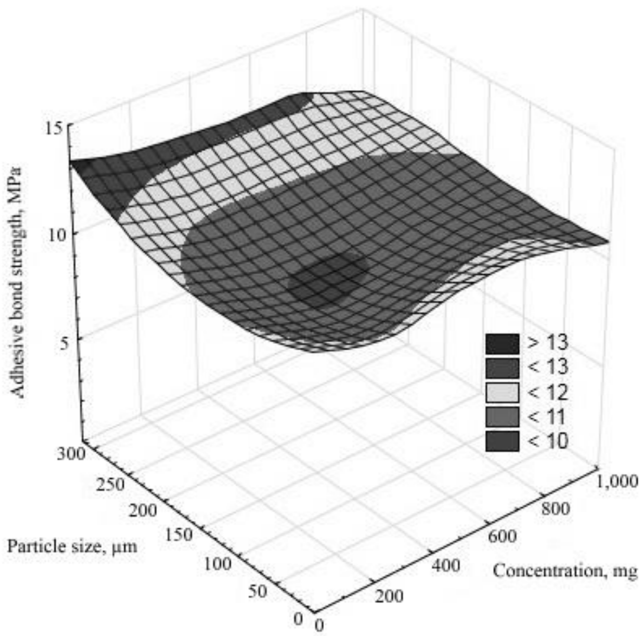


Figure 2. Influence of concentration and size of dusty particles on adhesive bond strength.

The elongation of the adhesive bond (without the contamination with dusty particles) was 1.27 ± 0.10%. It showed a fall at the adhesive bonds contaminated with the dusty particles of the sizes 160 μm and 90 μm. The elongation fall was in the interval 0.69 to 20.08% (all concentrations). The elongation of the adhesive bond increased at the adhesive bonds contaminated with dusty particles of the sizes 315 μm and 250 μm. It can be supposed that it was not the impurity but the filler at this size.

The elongation increase was in the interval 9.84 to 75.50%.

A graphic presentation of the results of the elongation of the adhesive bond prepared by 3D graph with method of the smallest squares can be seen from Fig. 3.

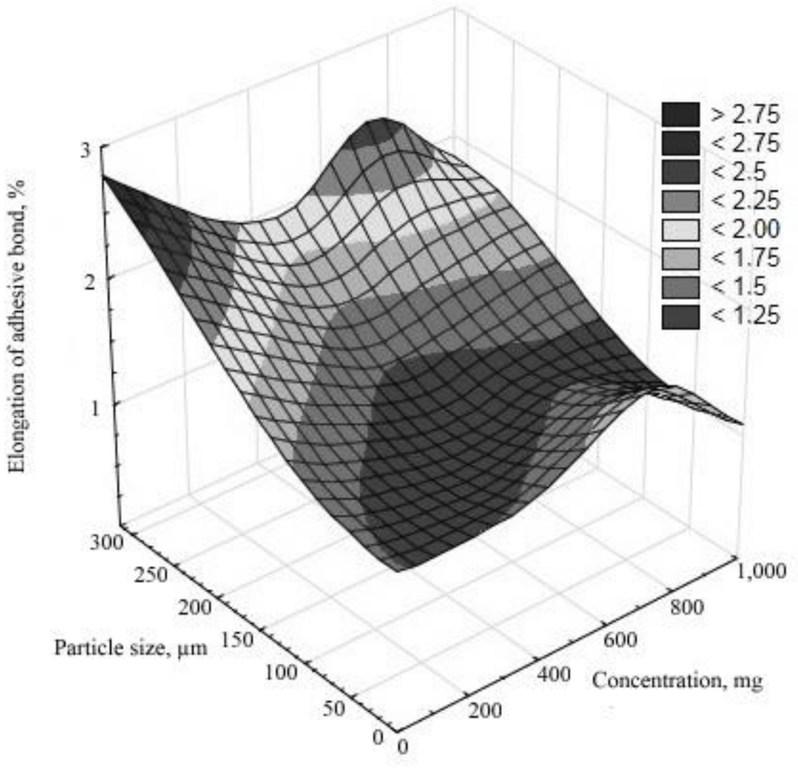


Figure 3. Influence of concentration and size of dusty particles on elongation of adhesive bond.

F-test is used for testing a significance of a difference of two dispersion variances. A value of the criteria *p* was gained by a calculation in the programme Statistica.

F-test was used for the statistical comparison. The zero hypothesis H_0 presents the state when there is no statistically significant difference ($p > 0.05$) among tested sets of data from their mean values point of view.

The results of F-test are from the point of view of the influence of dusty particles concentration on the adhesive bond strength following: the hypothesis H_0 was confirmed at the dusty particles of the size 250 μm ($p = 0.3730$), so there is no difference among particular tested concentrations in the significance level 0.05. The hypothesis H_0 was not confirmed at other sizes of the dusty particles: 315 μm ($p = 0.0262$), 160 μm ($p = 0.0016$)

and 90 μm (p = 0.0046), so there is a difference among particular tested concentrations of dusty particles in the significance level 0.05.

The results of F-test are from the point of view the influence of the size of the dusty particles on the adhesive bond strength following: The hypothesis H_0 was confirmed at the concentration of the dusty particles 1,000 mg (p = 0.1991), so there is no difference among particular tested sizes of the particles in the significance level 0.05. The hypothesis H_0 was not confirmed at other concentrations of the dusty particles: 750 mg (p = 0.0061), 500 mg (p = 0.0003) and 250 mg (p = 0.0012), so there is a difference among particular tested sizes of the dusty particles.

The results of F-test are from the point of view of the concentration of the dusty particles on the elongation of the adhesive bonds following: the hypothesis H_0 was confirmed at the sizes of the dusty particles 250 μm (p = 0.0505) and 160 μm (p = 0.0656), so there is no difference among particular tested concentrations in the significance level 0.05. The hypothesis H_0 was not confirmed at other sizes of the dusty particles 315 μm (p = 0.0263) and 90 μm (p = 0.00009), so there is a difference among particular tested concentrations of the dusty particles in the significance level 0.05.

The results of F-test are from the point of view of the influence of the size of the dusty particles on the elongation of the adhesive bonds following: the hypothesis H_0 was not confirmed at all concentrations of the dusty particles: 1,000 mg (p = 0.0044), 750 mg (p = 0.0014), 500 mg (p = 0.0009) and 250 mg (p = 0.0056), so there is the difference among particular tested sizes of the dusty particles in the significance level 0.05.

A composite comes into being at the contamination of the adhesive bond with the dusty particles. The resultant strength of the adhesive bond usually decreases at the composite materials filled with various particles. More significant changes of the strength occur by acting the created adhesive bond by degradation processes. Also a storing and a transport have similar influence on the creation of the adhesive bond (Müller el. al., 2009 & 2013; Balkova et. al., 2002; Doyle & Pethrick, 2009, Liljedahl et. al., 2007). The fall of the adhesive bond strength ranged in the interval 2 to 18% at the tested adhesive (Müller, 2013).

Exposing of the adhesive bonds to impurities, water, extreme temperatures or chemical stuffs can influence the process of the adhesive bond failure (Nolting et al., 2008). The fall of the adhesive bond strength is also connected with it. The change of the strength of the adhesive bonds caused by the adhesive bond production was smaller than 19%.

Sargent (2005), Doyle & Pethrick (2009) and claim that the changes in the environment can act both the way by which the physical properties of the adhesive change in time, and the strength of the boundary of the adhesive – adherent.

Undesirable changes of mechanical properties usually occur at the contamination by the particles at the adhesive bond creation (Brown, 1999; Ducháček 2006; Mleziva, 2008; Valášek 2014).

The adhesive bonds without the dash of the dusty impurities are of adhesive-cohesive failure area (Fig. 4). The failure area of the adhesive bonds contaminated with the dusty particles did not change (Fig. 5).

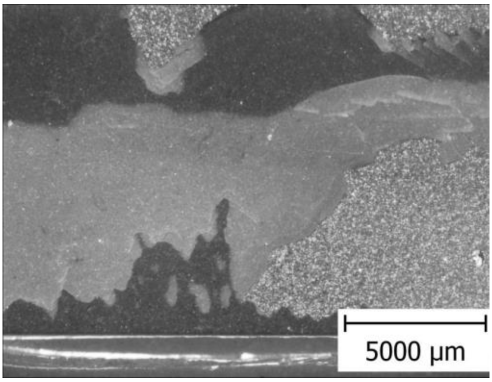


Figure 4. Adhesive-cohesive failure area – adhesive without dusty particles.

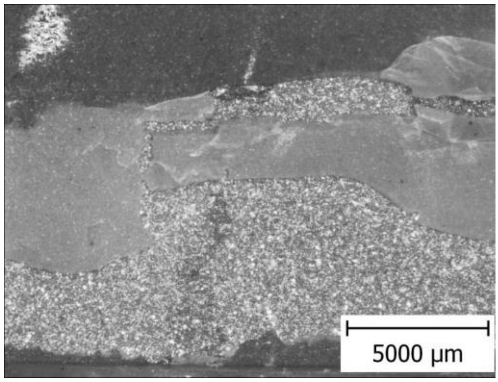


Figure 5. Adhesive-cohesive failure area – adhesive contaminated with dusty particles of size 315 μm and concentration 1,000 mg.

CONCLUSION

Following conclusions can be deduced from the research focused on the influence of the contamination with the dusty micro-particles on the adhesive bond strength:

- The adhesive bonds containing the dusty particles of the sizes 250 μm, 160 μm and 90 μm showed the fall of the adhesive bond strength. The strength fall of the adhesive bond did not exceed 18%. The adhesive bonds containing the dusty particles of the size 315 μm showed the mild increase of the adhesive bond strength.
- The dusty particles above 160 μm caused the increase of the elongation of the adhesive bonds.
- The failure area did not change owing to the contamination of the adhesive bond with the dusty particles.

ACKNOWLEDGEMENT. Supported by Internal grant agency of Faculty of Engineering, Czech University of Life Sciences in Prague no: 2015:31140/1312/3106.

REFERENCES

CSN EN 1465. 2009. Adhesives. Determination of tensile lap-shear strength of bonded assemblies. Czech Office for Standards, Metrology and Testing, Prague, Czech Republic. (in Czech)

CSN ISO 10365. 1995. Adhesives. Designation of main failure patterns. Czech Office for Standards, Metrology and Testing, Prague, Czech Republic. (in Czech)

Balkova, R., Holcnerova, S. & Cech, V. 2002. Testing of adhesives for bonding of polymer composites. *International Journal of Adhesion & Adhesives* **22**(4), 291–295.

Bluyssen, P.M. 1996. European indoor air quality audit project in 56 office buildings. *Indoor Air*. **6**(4), 221–238.

Brown, R. 1999. *Handbook of Polymer Testing: Physical Methods.* (M. Dekker, Ed.). p. 845. New York: CRC Press.

Di Giorgio, C., Krempff, A., Guiraud, H., Binder, P., Tiret, C., & Dumenil, G. 1996. Atmospheric pollution by airborne microorganisms in the city of Marseilles. *Atmospheric Environment* **30**(1), 155–160.

Doyle, G. & Pethrick, R.A. 2009. Environmental effects on the ageing of epoxy adhesive joints. *International Journal of Adhesion & Adhesives* **29**(1), 77–90.

Ducháček, V. 2006. *Polymers: production, properties, processing, use.* 2nd ed., p. 278. Prague: ICT Prague Press.(in Czech)

Jones, A.P. 1999. Indoor air quality and health. *Atmospheric Environment* **33**(28), 4535–4564.

Karwowska, E. 2003. Microbiological air contamination in some educational settings. *Polish Journal of Environmental Studies* **12**(2), 181–185.

Karwowska, E. 2005. Microbiological air contamination in farming environment. *Polish Journal of Environmental Studies* **14**(4), 445–449.

Kic, P., Hubený, M., Ledvinka, Z., Tumová, E., Giner, C.C., & Torres, C. M. 2007. Control of indoor environment in housing of laying hens. *Conference Proceedings – 3rd International Conference, TAE 2007: Trends in Agricultural Engineering 2007.* 212–214.

Kic, P., & Chládek, L. 2010. Microclimate in tutorial and research brewery during winter season. *Conference Proceeding – 4th International Conference, TAE 2010: Trends in Agricultural Engineering 2010*. 311–315.

Kic, P., & Růžek, L. 2014. The microbiological environment in specific rooms of a university campus. *Agronomy Research* **12**(3), 837–842.

Kic, P., Růžek, L., Ledvinka, Z., Zita, L., & Gardianoba, I. 2012. Pollution of indoor environment in poultry housing. *Engineering for Rural Development* **11**, 480–483.

Liljedahl, C.D.M., Crocombe, A.D., Wahab, M.A. & Ashcroft, I.A. 2007. Modelling the environmental degradation of adhesively bonded aluminium and composite joints using a CZM approach. *International Journal of Adhesion & Adhesives* **27**(6), 505–518.

Mleziva, J. 2008. *Polymers – Production, Structure, Properties and Applications* (1st ed.). Prague: Czech Technical University Publishing House. (in Czech)

Müller, M. 2013. Research of liquid contaminants influence on adhesive bond strength applied in agricultural machine construction. *Agronomy Research* **11**(1), 147–154.

Müller, M., Chotěborský, R. & Hrabě, P. 2009. Degradation processes influencing bonded joints. *Research in Agricultural Engineering* **55**(1), 29–34.

Müller, M. & Valášek, P. 2013 Assessment of bonding quality for several commercially available adhesives. *Agronomy Research* **11**(1), 155–162.

Müller, M. & Valášek, P. 2014. The logistics aspects influencing the resultant strength of adhesives at practical application. *Agronomy Research* **12**(1), 285–290.

Nimmermark, S., Lund, V., Gustafsson, G., & Eduard, W. 2009. Ammonia, dust and bacteria in welfare-oriented systems for laying hens. *Annals of Agricultural and Environmental Medicine* **16**(1), 103–113.

Nolting, A.E., Underhill, P.R. & DuQuesnay, D.L. 2008. Variable amplitude fatigue of bonded aluminum joints. *International Journal of Fatigue* **30**(1), 178–187.

Nõu, T., & Viljasoo, V. 2011. The effect of heating systems on dust, an indoor climate factor. *Agronomy Research* **9**(1), 165–174.

Valášek, P. 2014. *Polymeric Materials*. p. 67. Czech University of Life Sciences Prague. ISBN 978-80-213-2489-3. (in Czech)

Sargent, J.P. 2005. Durability studies for aerospace applications using peel and wedge tests. *International Journal of Adhesion & Adhesives* **25**(3), 247–256.

Zhang, Y., Ding, L., Gu, J., Tan, H., & Zhu, L. 2015. Preparation and properties of a starch-based wood adhesive with high bonding strength and water resistance. *Carbohydrate Polymers* **115**, 32–37.

Agronomy Research **13**(3), 662–670, 2015

Sandwich wall constructions made of perforated metallic materials

M. Lisicins[1,*], V. Mironovs[1], I. Boiko[2] and V. Lapkovskis[1]

[1]Riga Technical university, Faculty of Civil Engineering, Institute of Building Production, Azenes street 16/20–331, LV-1048 Riga, Latvia
[2]Riga Technical University, Faculty of Transport and Mechanical Engineering, Institute of Mechanical Engineering, Ezermalas street 6k, LV-1006 Riga, Latvia
[*]Correspondence: mihails.lisicins@rtu.lv

Abstract. The formation of cellular core for sandwich wall constructions made of perforated steel band is presented in the paper. The information about the main mechanical properties of perforated tapes and plates is provided. Basic technological methods for obtaining cellular structures from perforated metallic tape achieved from waste material by stamping are suggested. The main attention is focused on the analysis of the compressive strength of key elements of obtained cellular structures. Examples of the use of cellular structures made of perforated metallic materials in sandwich wall constructions are given. The main benefits of perforated metallic materials usage in sandwich wall's construction are outlined.

Key words: metallic sheets and profiles, perforation, cellular core, sandwich wall.

INTRODUCTION

Perforated metallic materials have a big potential to be used in different building constructions. Stiffness, strength and elastic/plastic properties of perforated metallic materials open up good opportunities for their wide range of use in the building industry.

For example, they could be used as spacers for wall and floor constructions, reinforcement materials (Kalva, 2011), fixtures and connectors for nodes of wooden constructions, etc. (Ozola, 2011). Because of high strength, light weight, good painting abilities and easy installation, perforated materials are becoming widely used in the design of decorative building facades and frame structures of light party walls (Mironovs & Lisicins, 2015). The application of perforated metallic materials for electromagnetic shielding (Mironovs et al, 2014) and acoustic barrier constructions is also known (O' Donell & Associates, Inc. 1993).

The aim of the current investigation is to propose sandwich wall structures based on different type of cellular cores made from perforated metallic materials.

Currently sandwich cores are composed mainly of light, thin profiled aluminium sheets without perforation. Such structures are very light and durable enough for their application in aircraft or in light door constructions (Solina, 2012). However, that type of constructions suffers from an inability to withstand a lot of pressure or impact. It is possible to increase structural strength and stiffness by using a denser metal (eg. steel) or increasing thickness of the sheet, which also significantly increases the overal mass of construction. Using perforated metallic sheets it is possible to reduce the initial weight maintaining sufficient overall structural strength ans stiffness.

MATERIALS AND METHODS

The properties of perforated metallic materials as end products directly depend on the mechanical and technological properties, intended perforation types, shapes, sizes, steps and other characteristics of used material. The technology of perforation also affects mechanical properties of the perforated end product. In order to select the required perforation technology and related equipment we should know the mechanical properties of the used material – density, tensile strength, hardness, etc.

The main materials for producing perforated construction elements are the steel, aluminium and copper. Sheet materials from aluminium and copper could be used in construction due to their high corrosion resistance and architectural impression, but steel – due to its relatively high strength. Besides, aluminium alloys are lightweight and have sufficiently high strength, they have good machinability during perforating and durability. Copper is widely used for roof covering. The oxide layer provides high corrosion resistance and, consequently, durability. Copper sheets have good machinability during perforating as well as good weldability. Nevertheless steel perforated materials have better perspectives for use as a material for cellular building structures and constructions due to their lower cost and higher strength.

The weight of perforated aluminium products will be lower, but at the same time, the final products from perforated aluminium will have worse tensile strength properties compared to other materials, referred to in Table 1. Harder workable materials due to their mechanical properties are steel and different copper alloys. However, the strength of constructions is much better.

Table 1. Mechanical properties of metallic materials used in the production of perforated tapes and plates

Materials	$\rho,\ \frac{kg}{m^3}$	σ_t, MPa	HB, (MPa)	Marks of material
Steel	7,700–7,900	320–930	1,310–2,550	C50E, C22E, C8E, S235JRG2
Aluminium alloys	2,700	60–310	520–847	AMg2H2, AD31T1
Copper alloys	8,920–8,980	220–640	1,186–2,430	M1–M3

Mechanical properties of different types of metallic materials (tapes, plates) changes during punching (Figs 1, 2). Relationships shown, characterise the yield strength ratio and effective elastic properties depending on the percentage of perforation (O'Donell & Associates, Inc. 1993). The above mentioned relationships achieved for a perforated plate with round holes in a standard staggered 60° pattern are shown in Fig. 3. It is evident that the perforation reduces the yield strength ratio and effective elastic properties. The modulus of elasticity and Poisson's ratio of metallic material shows ultra-rapid changes.

Main methods for manufacturing of different types of cellular building constructions from perforated metallic materials are stretching, corrugation, plate shearing, cut-sheet and stretching, perforated tape twisting, method of interlacement, profiling and welding (Bogojavenskij et al., 1978; Wadley et al., 2003). The right choice of method is directly affected by the properties of raw and perforated materials. For example, the method of stretching requires a slightly high strength of glued locations of connected plates (enough to allow the stretching of the structure) which in the case of a thin cell wall is usually provided with modern adhesive polymers. The value of force necessary for stretching the cells steadily approaches the strength of adhesion between the plates, when the ratio of the cell wall's thickness against the cell size increases. In this case, for the production of a honeycomb structure with a higher relative density, another method of manufacturing (corrugation) or method of joining the elements (welding, soldering) is necessary.

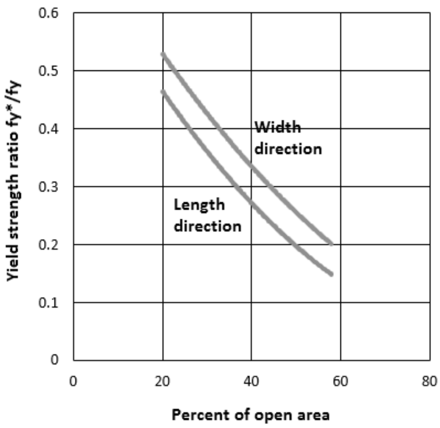


Figure 1. Yield strength ratio depending on percent of perforation (f_y* – yield strength of perforated plate; f_y – yield strength of unperforated plate).

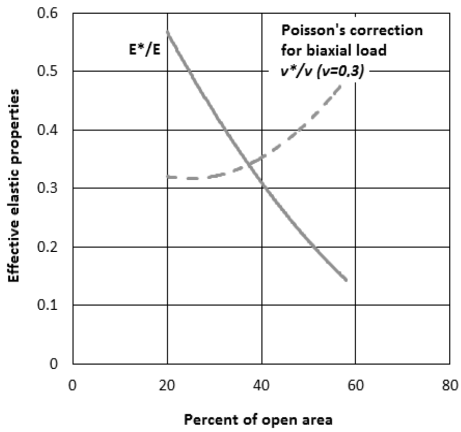


Figure 2. Effective elastic properties depending on the percentage of perforation (E* – elastic modulus of perforated plate; E –elastic modulus of unperforated plate; v* –Poisson's ratio of perforated plate; v –Poisson's ratio of unperforated plate).

The usage of perforated metallic materials opens up new possibilities for the production of fundamentally new cellular materials and constructions. There are a variety of cellular structures with different types of structure and mechanical properties that can be produced using different profiling and bonding methods. The usage of such structures in sandwich panel core raises particular interest.

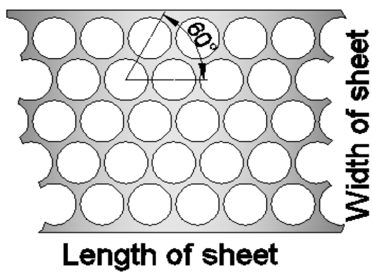
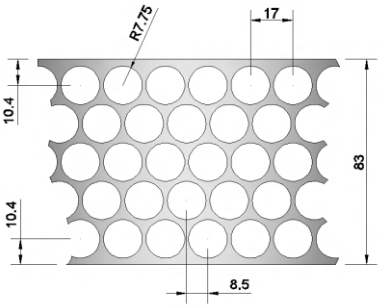


Figure 3. Perforated plate with round holes arranged in 60° angle.

Formation of cellular core using perforated steel tape

In the experimental investigation we used samples of perforated steel tapes, obtained as waste in the production of driving chain (Products, 2013). This structure was made from bands of LPM–1 – trade mark of JSC ’DITTON Driving Chain Factory’, Latvia (Table 2).

Table 2. Mechanical and geometrical characteristics of perforated steel band produced by punching

Type of band & geometrical characteristics	Material	Permeable area, %	Thickness, mm	Tensile strength, N mm^{-2}
	Steel S235JRG2	66.97	1.50	320.70

Samples of cellular structures were made from perforated steel tape using profiling and welding. Profiling was made in crosswise direction (Fig. 4) Previously profiled tapes were joined. As a result, cavities were generated between the tapes (Fig. 5). Subsequently cavities may be filled, for example, by insulating filler.

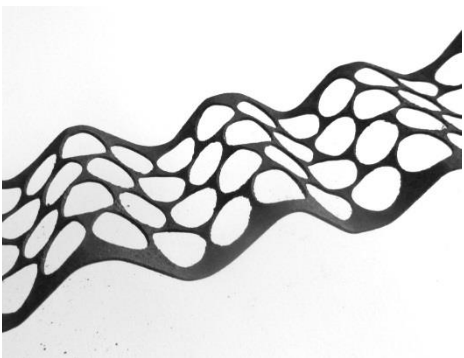


Figure 4. The crosswise profiling of perforated steel tape (width 100 mm, thickness 1.2 mm).

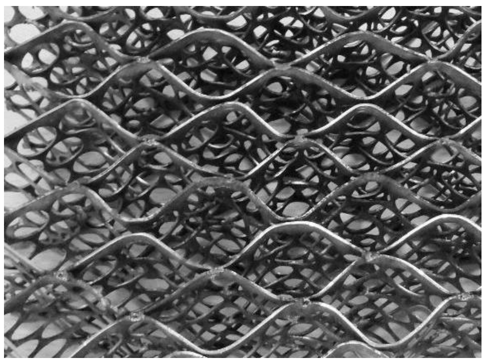


Figure 5. Cellular structure from S235JRG2 perforated tapes produced by RSW.

It was experimentally determinated that profiling of tape of C50E steel is hard to implement and possible only with high curvature. For example, there was cracking observed with a bend radius of less than 30 mm for several types of tape.

The profiling by bending in the case of C8E steel was much easier. This material is soft and ductile. There were different profiles experimentally obtained by bending in the profiling machine – with a radial curvature of 90° and a greater angle curvature.

LPM–1 sample of tape can be bent even slightly less than 180° due to its thin dimension.

Previously profiled tapes were joined by resistance spot welding (RSW) using experimental AC RSW equipment 'Impulse KM' earlier elaborated in Riga Technical University. The outer diameter of the spot weld is in the range of 4–5 mm. Preliminary experiments were revealed that resistance welding is an appropriate technology for the generation of cellular structures (Calva & Eagar, 1990; Mironovs et al., 2012). RSW welding parameters are given in Table 3.

Table 3. RSW welding parameters for steel S235JRG2 welding

Welding parameters	Welding current range, kA	Electrode force, kN	Weld time, sec (50 Hz cycles)
Conditions	8–9	3.5–4.0	0.18–0.20

Assessment of deformation of cellular core

One of the aims of modeling cellular sandwich wall core structure with complex shapes and structures of the material is the determination of their deformation properties. Experimental tests performed on the compression setting Zwick Z100.

Evaluation of mechanical properties was carried out using an elaborated model of the basic element (Fig. 6) of the structure shown in Fig. 7.

Figure 6. The model of cellular structure basic element.

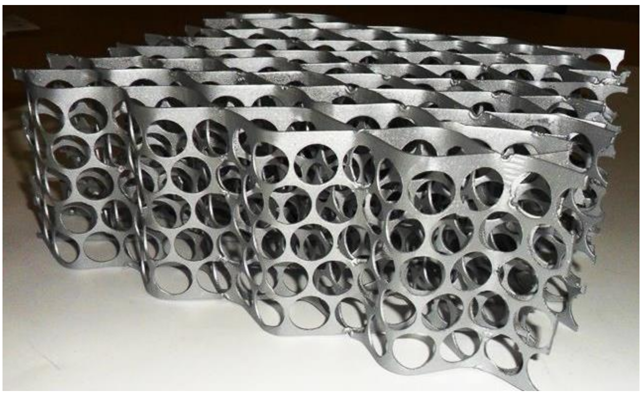


Figure 7. Cellular structure made of perforated bands.

RESULTS AND DISCUSSION

The compression load-bearing capacity of cellular structure basic element ranged from 2,644 N to 2,815 N. The maximum deformation by the y-axis is 1.0–1.4 mm. The average load capacity (2,744 N) results in average deformation 1.17 mm.

It is possible to predict structural behavior also using FEM calculation. The maximum deformation using FEM calculation model for viewed structure was 1.15 mm, which is at 1.17% lower than experimental results. The difference between results obtained by computer simulation and experimental work is in the range of 5%. Thus, computer simulation is a feasible way to predict the deformation of geometrically complex cellular structures, using perforated bands (Mironovs et al., 2013).

The compressive strength test results for the metallic core elements of the cell structure are shown in Table 4, where: H – height of cellular structure; $A_{s,eff}$ – effective cross-sectional area; $F_{c,max}$ – maximal load carrying capacity; $\Delta l_{c,Fmax}$ – maximal deformation; ε_{Fmax} – maximal strain, σ_c – compressive stress.

Table 4. Compressive strength test results for the metallic core elements of the cell structure

No.	H, mm	$A_{s,eff}$	$F_{c,max}$, N	$\Delta l_{c,Fmax}$, mm	ε_{Fmax}, %	σ_c, N mm^{-1}
1.	83	14.40	2,773.20	1.0	1.20	192.58
2.	83	14.40	2,643.93	1.5	1.81	183.61
3.	83	14.40	2,814.98	1.0	1.20	195.48
Average results:		14.40	2,744.04	1.17	1.40	190.56

It is also worth noting that all the welds passed the above-mentioned load, and hence the strength of the pins provided no less strength than that of the construction. The local loss of load carrying capacity was observed in the walls between perforation (Fig. 8).

One of the application possibilities of cellular core made of perforated metallic materials is sandwich wall panels.

The facing skins of a sandwich panel can be compared to the flanges of an I-beam, as they carry the bending stresses to which the beam is subjected. One facing skin is in compression, the other – in tension. The core resists the shear loads, increases the stiffness of the structure by holding the facing skins apart, and improving on the I-beam, it gives continuous support to the flanges or facing skins to produce a uniformly stiffened panel. The core-to-skin adhesive rigidly joins the sandwich components and allows them to act as one unit with a high torsional and bending rigidity. The separation of the skins by the core increases the moment of inertia of the panel with little increase in weight – in such a way an efficient construction with good bending and buckling strength is obtained.

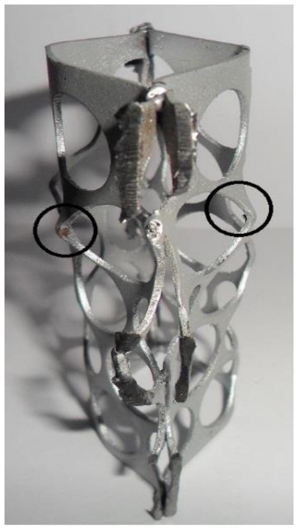
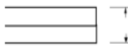
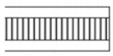
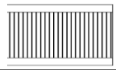


Figure 8. View of deformed basic element of cellular structure and the load bearing capacity local failure places.

By splitting a solid laminate down the middle and separating the two halves with a core material, the result is a sandwich panel. The new panel weighs a little more than the laminate, but its flexural stiffness and strength are much greater (Table 5). By doubling the thickness of the core material, the difference is even more striking (Petras et al., 1998).

Table 5. The efficiency of thickness of sandwich panel core

			
Relative bending stiffness	1	7.09	37.09
Relative bending strength	1	3.59	9.29
Relative weight	1	1.03	1.06

By use of perforated metallic tapes or plates the weight of the sandwich panel can be reduced even more. In that case, the load carrying capacity of the panels will be reduced. However, in most cases it is enough to provide functioning of the construction under load (especially in the case of facade panels). The use of perforated sheets also provides additional opportunities for the installation of fastenings of the panels depending on the constructive solution. There are the opportunities to join the elements of the core of the sandwich panel by wire, sleeves, nuts, etc. Using perforated steel waste materials, the compressive strength of the cell structure is sufficient (Table 4) to ensure safe work of panels even in floor constructions, but lower costs significantly increase the economic efficiency.

Sandwich panels shown in Fig. 9 and Fig. 10 are diverse in terms of the types of profile and their distribution. Profiles can be based on the perforated tape with different widths and thicknesses. The percentage of open area (perforation) also may vary. The profiling of tape may vary depending on the engineering solution of the construction and expected load. Profiles of the core can be arranged upright (Fig. 9) or flatwise (Fig. 10) relative to the cladding. All these parameters are chosen according to the mechanical properties of the profiles (and their material) and expected service circumstances of the end product (panel). For example, profiles arranged upright have a greater load carrying capacity, but those placed flatwise – better connection options with cladding sheets, as well as mechanical energy absorption capability. Core sheets are commonly completed with profiling in the transversal direction. The method of stretching, corrugation or slotting (especially in the case of the perforated metallic waste materials) can be efficiently used for production of the core.

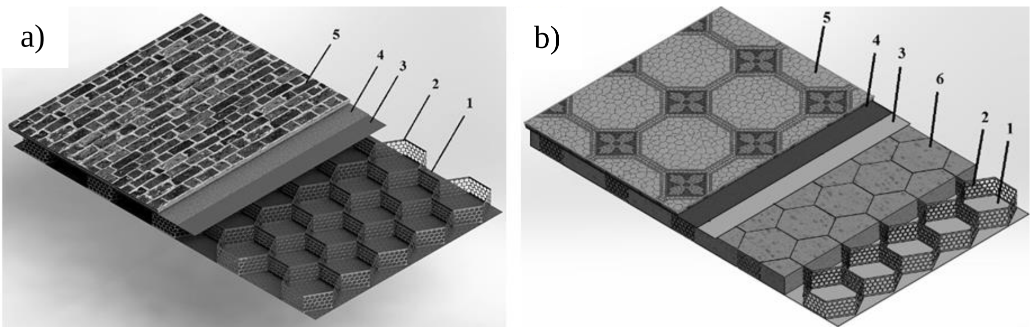


Figure 9. Example of sandwich wall panel based on perforated and profiled metal tape placed upright without an insulation layer (a) and with an insulation layer (b): 1 – lower metallic sheet; 2 – perforated and profiled metal tape; 3 – upper metallic sheet; 4 – layer of glue, 5 – facing (finishing) material; 6 – insulation material.

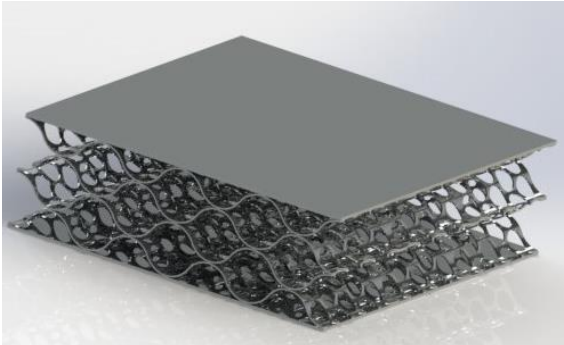


Figure 10. Example of a multilayer sandwich wall panel for absorption of mechanical energy based on perforated and profiled metal tape placed flatwise.

Cavities between the plates of the panel may be empty or filled by thermal or acoustic insulating materials. The upper cladding sheet of the panel can consist of only one layer, for example, in the case of interior facing panels, or multilayer, where the lower layer smoothly splits the load, but the upper layer is decorative and connected to the upper layer with a layer of glue (Fig. 11) or a damping layer is applied on top – in the case of floor panels.

Artificial or natural stone materials – granite, marble, limestone, sandstone, etc., may create the upper decorative layer.

Panels based on a metallic cellular structure can be used as load carrying or non-load carrying constructions. They can be used not only for sandwich walls, but also floor, stairs and door constructions, scaffolding and gantry constructions, pre-manufactured and pre-fabricated garages, car shelters, bus stops, shower and toilet modules.

The main benefits of perforated metallic materials usage in sandwich panel's constructions are:

- weight reduction (compared with non-perforated metallic materials);
- noise reduction or vice versa – the acoustic effects;
- ventilation possibilities;
- durability, vandal proof;
- fire resistance.

CONCLUSIONS

Perforated metallic materials (tapes, plates, strips) have a big potential to be used in construction. It was shown that by profiling and welding it is possible to produce different cellular structures that match with filler material and decoration.

The computer simulation is a feasible way to predict the deformation of geometrically complex cellular structures, using perforated bands as well as for form optimization in regard to the effective use of the material. Experiments (computer and mechanical testing) prove, that a cellular structure from perforated steel S235JRG2 strip have a high compressive strength, when the average carrying capacity is 2,744 N.

One of the possible applications of perforated metallic materials in building construction, is sandwich panels. Such sandwich panels could be used as supporting or decorative structures. According to the core material and core location in the panel, the sandwich panels could be with high stiffness as well as with good absorption ability of mechanical energy. Filling of the cellular structure with insulating filler allows heat-insulating and sound-insulating properties of the sandwich panels to be improved.

REFERENCES

Bogojavenskij, K., Neubauer, A., Ris, V. 1978. *Technology of producing of lightweight profiles.* VEB DeutscherVerlag fur Grundstoffindustrie, Leipzig, Germany. 565 pp. (in German).

Calva, C.M., Eagar, T.W. 1990. Enhancement on the Weldability in Resistance Spot Welding. In: *AWS Detroit Section Sheet Metal Welding Conference IV*, USA, Southfield. pp. 1–33.

Daugavpils Driving Chain plant: Products (2013) [online] [accessed on 13.01.2014]. Available: http://www.dpr.lv/index.php?lang=en&id=produkt.

Kalva, L. 2011. *Metallic perforated materials in concrete works.* Riga Technical University, Riga, Latvia. 87 pp. (in Latvian).

Mironovs, V., Lisicins, M. 2015. *Perforated metallic materials and their application possibilities.* Riga Technical University, Riga, Latvia. pp. 170.

Mironovs, V., Lisicins, M., Boiko, I., Zemchenkovs, V. 2012. Manufacturing of Cellular Structures of the Perforated Steel Tape. *Proceedings of the 8th International Conference of DAAAM Baltic Industrial Engineering.* Tallinn University of Technology, Tallinn, Estonia. 688–693.

Mironovs, V., Lisicins, M., Boiko, I., Zemchenkovs, V. 2013. Manufacturing of the cellular structures from the perforated metallic materials. *Agronomy Research* **11**(1), 139–146.

Mironovs, V., Lisicins, M., Boiko, I., Koppel, T., Zemchenkovs, V., Lapkovskis, V., Shishkin, A. 2014. Cellular structures from perforated metallic tape and its application for electromagnetic shielding solutions. *Agronomy Research* **12**(1), 279–284.

O' Donell & Associates, Inc.1993. Strength of Perforated Metal. In*: Designers, Specifiers and Buyers Handbook for Perforated Metals.* A publication of the Industrial Perforators Association. 124 pp.

Ozola, L. 2011. Connections with perforated metallic plates. In: *Estimation and design of timber constructions II: Application of Eurocode 1 and Eurocode 5 in construction design.* Latvia University of Agriculture, Jelgava, Latvia. pp. 89–91. (in Latvian).

Petras, A., Sutcliffe, M P.F. 1998. *Design of sandwich structures.* Engineering Department of Cambridge University, United Kingdom. 99 pp.

Solina, A. 2012. *Honeycomb sandwich panel development and experimental validation.* Riga Technical University, Riga, Latvia. 101 pp. (in Latvian).

Wadley, H.N.G, Fleck, N.A., Evans, A.G. 2003. Fabrication and structural performance of periodic cellular metal sandwich structures. *Composites Science and Technology* **63**. 2331–2343.

Improving the accuracy of manufacturing of hydraulic power cylinders using vibration-proof cutting tool

V. Maksarov

National Mineral Resource University, department of mechanical engineering, Vasilevsky island, 21 Line, House 2, 199106 St. Petersburg, Russia; e-mail: maks78.54@mail.ru

Abstract. The article introduces new results on designing multilayer cutting tool holder. Experimental study of metal turning process workpieces shows efficient dynamic damping of oscillations. The coefficient of oscillations absorption and damping is increased due to large dissipative force of the material holder oriented in different deformation directions of holder material.

Key words: flat rolled stock, heterogeneity of structures, oriented deformation, adjustable anisotropy, multi-layered damping tool holder.

INTRODUCTION

Dynamic stability of the manufacturing system, reduction of vibration level generated in the process of cutting are prerequisites for stable chip formation. Meeting these requirements is crucially important for the automation of the process (Weitz, 2002). It is known that the vibration generated in the process of metal cutting leads to essential obstruction for automated manufacturing. Premature failure of tools, accidents of machines and facilities are some of potential consequences. Increased stability of the manufacturing system stability due to reduced level of self-oscillations is important issue for metal cutting industry. Main challenges are met when dealing with final machining of parts by automatic NC machines (Anastasiadis & Silnikov, 2002; Maksarov & Olt, 2008; Maksarov & Olt, 2010).

A number of fundamental research papers are devoted to studying of self-oscillations at metals cutting. The chip forming process at turning operation and the importance of manufacturing system stability at mechanical processing have been explained. Analyses of the methods and techniques that ensure stability of manufacturing systems confirm that these methods allow increasing stability of a manufacturing system in a varying degree and techniques. Several of those methods are applied successfully in practice at mechanical processing. Nevertheless, at present there is no universal method that allows effective suppression of vibration generated at turning.

In terms of dynamic stability the subsystem of the cutting tool is mainly affected by vibrations at final turning. Free damped oscillations, forced oscillation, parameter-induced oscillations and self-oscillations occur as a result of the impacts within the manufacturing system. Frequency equal to forcing frequency or frequency of the complicated periodical processes stipulated by nonlinear properties of the system are to be expected. Intensity of forced oscillations is especially high in resonant modes, which are inadmissible in cutting machines when performing final machining.

MATERIALS AND METHODS

At turning, in conditions of constrained cutting, the resultant cutting force P is composed of three mutually-perpendicular force components (Fig. 1). P_z is cutting force or tangential force tangent to the rake face and matching direction of the main motion; P_x is axial or feed force acting in parallel to the workpiece axis in direction opposite to feed motion; P_y is radial force directed perpendicular to the axis of the processed workpiece.

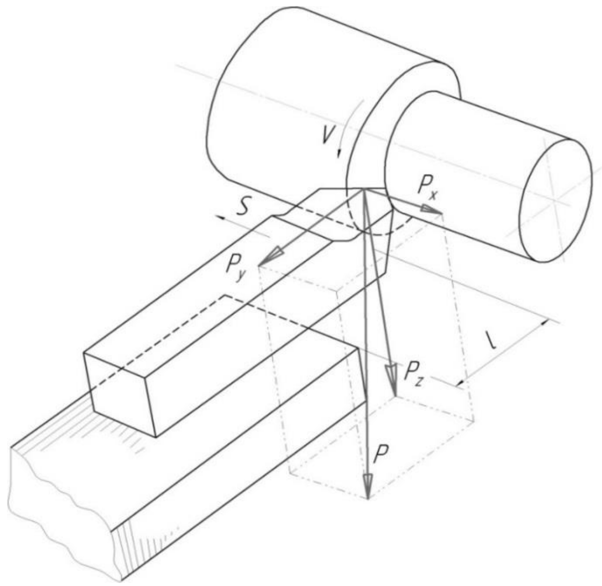


Figure 1. Diagram of cutting forces at turning, where: *s* is feed direction and *v* is cutting speed.

Development of a damping tool equipped with a multilayer holder with anisotropic properties is one of the most effective methods to ensure stability of the tool subsystem at final turning of cylindrical parts. Turning process with a tool equipped according to the suggested method show reduced level of self-oscillations occurring in cutting process due to designed disorientation in texture of anisotropic plates of a prefabricated multilayer holder. This allows effective dissipation of oscillatory wave energy at interfacial boundary between the holder plates. This method allows essential improvement in endurance of the tools cutting edge and extension of processing capabilities in regard to selection of effective cutting modes. Additionally ensuring compliance with demands of dimensional and geometric accuracy specification of processed surfaces.

The method suggests the using intrinsic anisotropy of holder plates by the method of pressure shaping. Plastic deformation of steels by hot rolling leads to change in direction of the structural constituents and inclusions along its direction thus forming mechanical deformation texture besides crystallographic texture. It is suggested to manufacture a cutting tool holder out of a pack of plates preassembled by planes parallel to the holder support surface; at that the plates are cut out of flat rolled stock with longitudinal, transversal and vertical orientation in plane regarding direction. After which they are assembled into a pack with the texture gain-boundary angle between the plates. Oscillations occurring in process of mechanical processing of the holder rod at low deformations are described by Hooke's law. Friction resistance at fixed connections between the plates and internal friction in the holder material must be considered. Inelastic effects of internal friction stipulated by available texture of the material and related to dislocations migration lead to irreversible hysteresis losses inside the metal at mechanical oscillations (Barmin, 1972; Ashkenazi, 1980; Borodkin, 1981; Anastasiadis & Silnikov, 2002). The holder plates should be oriented so that at transition from one plate to another one deformation is changed per $90 \pm 10°$ as related to action to the holder of the main tangential component of cutting force. Under action of cutting force in the upper layers of the holder mainly maximum tensile stresses σ_t occur while in the lower support layers compression stresses σ_c appear.

The Fig. 2 shows structure of a straight-turning tool holder with plates having oriented structure. The plate 1 is cut so that its surface has longitudinal orientation in regard to the direction of rolling. At that cross-section plane of the plate 1 is oriented transversally in regard to the direction of rolling. Plane of the plate 2 is oriented across the direction of rolling while its cross-section plane is oriented along the direction of rolling. Plane of the plate 3 is oriented vertically in regard to the direction of rolling and its cross-section is oriented in longitudinal direction. Accordingly all plates have different texture of deformation in their plane and cross-section, different physical and mechanical properties, including damping properties, as related to action of forces (cutting force components) (Weitz, 2002; Maksarov & Olt, 2010) loading the holder.

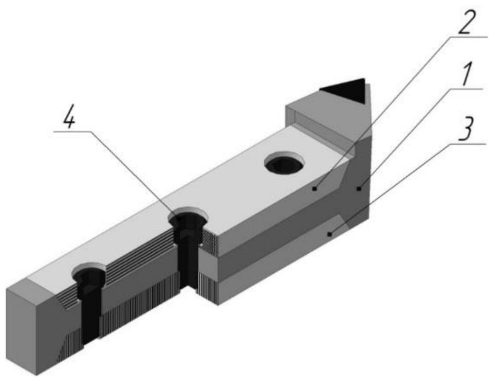


Figure 2. Structure of the straight-turning tool holder with plates having oriented structure.

At oscillations occurring in process of mechanical processing behaviour of the multilayer holder cross-section at low deformations is described by means of Hooke's law considering friction resistance at fixed connections between the plates and internal friction in the holder material (Vishnyakov, 1979; Vishnyakov, 1989).

In result of imperfect elasticity of metals the lines of stress deformation curve do not match at loading and unloading and form a hysteresis loop (Fig. 3). Its square area characterizes energy dissipated in one loading cycle. Internal friction is related to static hysteresis when shape and square area of its loop are not stipulated by temporary relaxation processes and therefore they do not depend on oscillation frequency, oscillation amplitude and material of the holder (Maksarov & Olt, 2008; Maksarov & Olt, 2010).

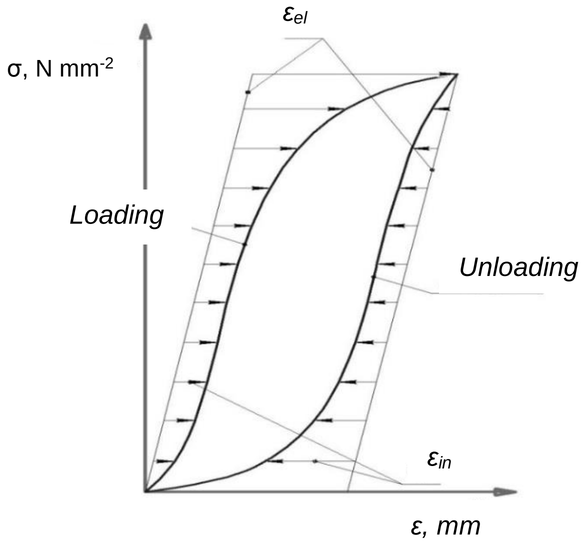


Figure 3. Hysteresis loop of stress σ deformation ε curve: ε_{el} is elastic deformation; ε_{in} is inelastic deformation.

While transiting the boundary between the plates the oscillatory wave changes its direction, and in result dissipation of vibration energy takes place. Dissipation of energy is insignificant at low value of the plate texture disorientation.

As is known, metals with a lattice of a space-centred cube have essential anisotropy of their properties (Vishnyakov, 1979; Vishnyakov, 1989; Glebov, 1990). Well-pronounced ductile-to-fragile transition is often observed in them, and this transition is defined by availability of fragile inclusions, temperature, conditions of load application and other factors. Annealing and recrystallization of flat rolled stock lead to redistribution of inclusions and change in texture. This change in texture leads to decrease in strength and viscosity in normal direction to a sheet.

RESULTS AND DISCUSSION

Table 1 is showing testing results of mechanical properties. Samples of flat rolled stock of steel ВСт3 brand with thickness from 30 up to 40 mm (Glebov & Duchovni, 1990). The testing results provide evidence of significant anisotropy of mechanical properties, especially plasticity, Poisson’s ratio and impact toughness.

Table 1. Mechanical properties of a steel sheet

Direction of rolling	Yield limit σ_y, MPa	Ultimate strength σ_u, MPa	Plasticity σ, %	Posson's ratio Ψ, %	Impact toughness RCU, J cm^{-2}
Lengthwise	237	402	35.9	63.3	42
Transverse	235	402	29.4	55.3	29
Crossed	322	402	7.0	11.8	16

Anisotropy of mechanical properties in materials may be high and it depends on stress-deformation profile at testing. Fig. 4 shows changes in conventional yield limit for low-carbon steel with 3% of Si depending on angle toward rolling direction where anisotropy reaches 30%.

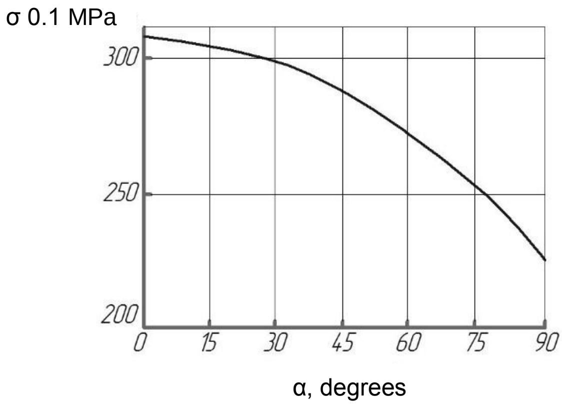


Figure 4. Change in conventional yield limit depending on angle towards the rolling direction.

Dependency of Young's modulus for chromium-molybdenum steel in the rolling plane on rolling direction upon hot deformation is specified in Fig. 5 (Miklyaev & Friedman, 1986). The figure demonstrates that difference in Young's modulus is 15% upon rolling and 10% upon annealing, which is related to deformation structure.

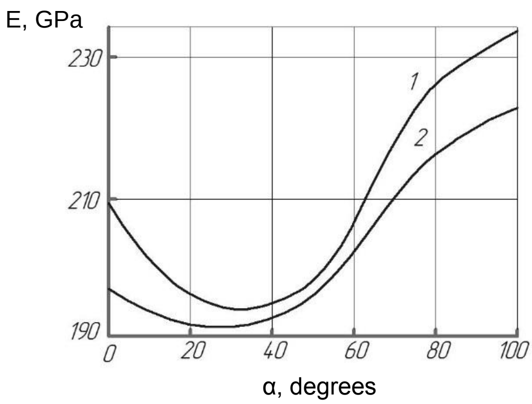


Figure 5. Change in Young's module depending on angle towards the rolling direction: 1 – upon rolling; 2 – upon annealing.

At static loading of the samples, at stages of elastic and elastoplastic strain, anisotropy of the characteristics is insignificant; it increases sharply at the yield pint and more towards bigger plastic deformation. In many practical cases mechanical texture causes anisotropy of the properties. Two mechanisms of considerable impact are possible:

- influence of crystallographic texture relative to anisotropy of elastic modulus and respective deformations;
- influence of non-metal inclusions relative to progressive increase of the surface area in process of alloy deformation and destruction considering that critical length of cracks, for example, for steel with yield strength of 1,700 MPa is 0.2–0.5 mm.

The Fig. 6 shows cracks with non-metal inclusions represented as elongated lines with sulphide and oxide inclusions. These inclusions have direct impact on the anisotropy of the impact toughness.

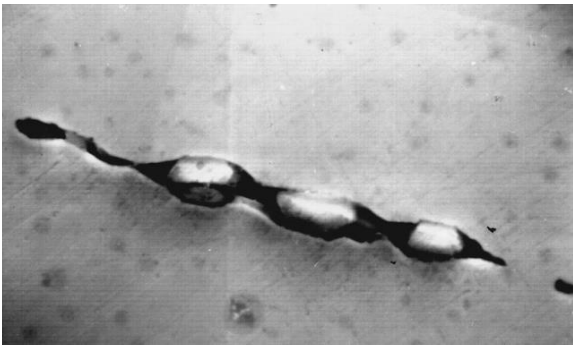


Figure 6. Non-metal inclusions: a, b – 100 times increase; c – 200 times increase.

In order to determine direction of texture in the holder plates and to assess anisotropy values, tests were performed to define mechanical properties of the material used for manufacturing of the designed multilayer holder.

The tests were carried out on a universal testing machine TIRAtest 2820. That is a measuring system capable of measuringforce and changes in linear dimensions of the metal samples for tension, compression and bending at static load modes.

The testing was performed on specimens made of hot rolled steel 45 (as per GOST 1577-93).

The samples were cut out of the surveyed flat rolled stock in three perpendicular directions (Fig. 7): lengthwise rolling (samples B), perpendicular rolling (samples C) and cross direction rolling (samples A).

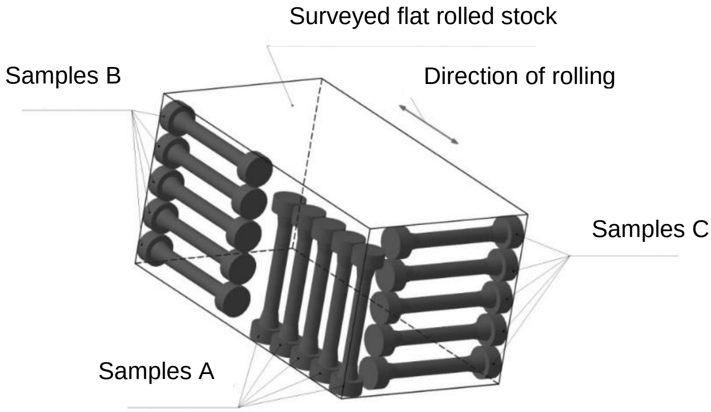


Figure 7. Points of the samples cutting out of the surveyed flat rolled stock.

The samples were made according to requirements of the standard GOST 1497-84, type V, number 7, with initial diameter of a sample of d_0 = 5 mm and initial design length of l_0 =5 d0 = 25 mm. Turning of the samples was carried out according to the drawing (Fig. 8) with allowance of 0.5 mm at the surface with initial diameter of a sample of d_0 = 5 mm for heat treatment. Heat treatment was performed in the following sequence: tempering – heating up to temperature of 850° C, cooling medium – oil; temper drawing – heating up to temperature of 200° C, cooling medium – air. Hardness test for each sample was made by TP 5014 hardness tester. Then final turning of the initial diameter was made up to the size of $d_0 = 5_{-0.012}$ mm.

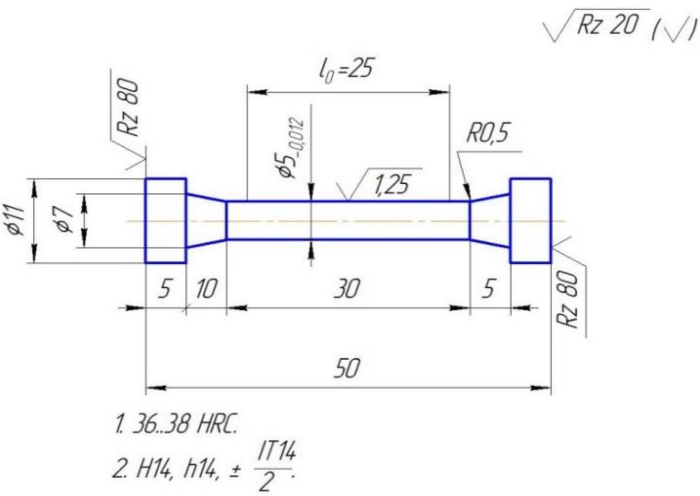


Figure 8. Drawing of a sample.

The Table 2 presents testing results for the samples of flat rolled stock received by elongation method.

Table 2. Average values of mechanical properties for the samples out of flat rolled stock

Rolling direction of a sample	Sample hardness, HRC	Ultimate strength $\sigma_{0.2}$, MPa	Tensile strength, σ_t, MPa	Plasticity σ_{av}, %	Poisson's ratio Ψ_{av}, %
A	37	1,281	1,350	0.71	6.29
B	37.2	1,219	1,334	5.03	28.38
C	36.8	1,212	1,365	2.36	18.8

CONCLUSIONS

For commercial steels anisotropy of their mechanical properties is stipulated mainly by structural heterogeneity. In addition there are influences from the quantity and morphology of non-metal inclusions.Parameters of microstructure have less significant effects.

It is shown that increaseing structural heterogeneity of a material its dampening quality also increases and this fact may be used to reduce self-oscillations. This principle is used for for increasing the performance quality of the manufacturing subsystem: cutting tool in process of high-speed turningoperation.

REFERENCES

Anastasiadis, P. & Silnikov, M.C. 2002. *Heterogeneity and performance of steel*. Polygon, St. Petersburg, 624 pp. (in Russian).

Ashkenazi, E.K. 1980. *The anisotropy of structural materials*. A Handbook, Engineering, Leningrad, 148 pp. (in Russian).

Barmin, B.N. 1972. *Vibration and cutting modes*. Mashinostroenie, Moscow, 72 pp. (in Russian).

Borodkina, M.M., Spector, E.N 1981. *Radiographic texture analysis of metals and alloys.* Metallurgy, Moscow, 272 pp. (in Russian).

Glebov, A.G. & Duchovni, A.C. 1990. The influence of nonmetallic inclusions on the fracture resistance of the steel plate high strength rolled. Strength and fracture of steels at low temperatures. Metallurgy, Moscow, 86–94. (in Russian).

Maksarov, V. & Olt, J. 2010. Increase process efficiency thin blade handle when turning due to the anisotropic properties of cutting tools. *Metalworking* **1**, 16–23. (in Russian).

Maksarov, V. & Olt, J. 2008. Cutting theory and cutting tool. Tartu, Estonian University of Life Sciences, pp. 132. (in Estonian).

Miklyaev, P.T. & Fridman, J.B. 1986. *Anisotropy of mechanical properties of metals.* Metallurgy, Moscow, 226 p. (in Russian).

Solotorevsky, C.S. 1983. *Mechanical properties of metals*. Metallurgy, Moscow, 352 pp. (in Russian).

Vishnyakov, J.D. 1979. *The theory of the formation of textures in metals and alloys*. Nauka, Moscow, 329 pp. (in Russian).
Vishnyakov, J.D. 1989. *Control of residual stresses in metals and alloys*. Metallurgy, Moscow, 254 pp. (in Russian).
Weitz, V.L., Maksarov, V.V. 2002. Simulation of chip formation during blade machining. *STEEN* **4**, 13–15 (in Russian).

Agronomy Research **13**(3), 680–689, 2015

Mechanical behaviour of polymeric composite with fibres of false banana (Ensete ventricosum)

Č. Mizera[1,*], D. Herák[2], M. Müller[3] and P. Hrabě[4]

[1,2]Czech University of Life Science Prague, Faculty of Engineering, Department of Mechanical Engineering, Kamýcká 129, CZ-16521 Praha 6 Suchdol, Czech Republic
[3,4]Czech University of Life Science Prague, Faculty of Engineering, Department of Material Science and Manufacturing Technology, Kamýcká 129, CZ-16521 Praha 6 Suchdol, Czech Republic
[*]Correspondence: mizera@tf.czu.cz

Abstract. This study was focused on the analysis of the deformation characteristics of the polymer composite with continuous phase in the form of two-part epoxies and discontinuous phase (reinforcing particles) in the form of fibres of false banana (Ensete ventricosum). The aim of the experiment was to describe the mechanical behaviour of polymeric composite reinforced by fibres of false banana under tensile loading and to determine the modulus of elasticity and deformation energy. The fibres of Ensete ventricosum, originally from Ethiopian region Hawasa, were used in this experiment. Reinforcing fibres were prepared in sizes of lengths 1–2, 2–3, 3–5, 5–6, 7–8, 9–10, 15, 20, 25, 30, and 35 mm with randomly fibres arrangement in matrix. The fibres with length of 1–2, 2–3, 3–5, 5–6, 7–8 and 9–10 mm were used in short fibres composites and fibres with length of 10, 15, 20, 25, 30 and 35 mm in long fibres composites. The composite material was created with 2 wt.% of the filler. The modulus of elasticity of the short-fibre composite material was increased of 28 ± 12% by adding Enset fibres as the filler. The modulus of elasticity of the long-fibre composite material was increased of 46 ± 14%. The influence of the fibre length on the value of the volume deformation energy was not proved.

Key words: agriculture, deformation energy, tensile strength.

INTRODUCTION

Currently worldwide environmental and economic interests stimulate research in designing new materials whose substantial portion is based on natural renewable resources in order to avoid further pressure on the environment (Alves et al., 2010). A constantly increasing trend of using organic fibre as a reinforcement in composite materials based on epoxy resin has been seen in recent years. The organic fibre can be a suitable substitute of synthetic fibres because they are available in a fibre form at low costs (Aseer et al., 2013). They reach relatively high specific strength and a rigidity owing to their low density. Replacing of the synthetic fibres by the organic ones has a lot of advantages which can be rationalized also by means of an ecological equlibrium. Plastic composite materials reinforced with natural fibres become more significant in constructional applications. E.g organic fibre from a coir, kenaf, oil palm and a jute have suitable mechanical properties which are used in various industrial applications (Hpsa et al., 2001; Lu et al., 2003; Sharifah & Martin, 2004; Harun et al., 2008; Mominul Haque et al., 2009). However, they also have some disadvantages owing to their low plasticity (Keller, 2003). This can be removed by connecting the natural fibre with the natural or the synthetic polymer when a light composite material with required mechanical properties is gained. One of the suitable plants with great potential for the production of natural fibres is Ensete (Ensete ventricosum) also known as false banana (Tsehaye & Kebebew, 2006). The Ensete doesn't produce edible fruits and it is not categorized as usual banana plants (genera Musa). It is a perennial herbaceous plant that grows in Ethiopia and it is primarily intended for human consumption and animal feeding (Vincent et al., 2013; Herak et al., 2014). Over centuries the Ensete fibres have been extracted from the leaves of this plant as major material for the weaving, ropes and cord production, as well as for baskets production (Diriba et al., 2013; Yirmaga 2013). Composite material reinforced with Ensete fibres could be used for the production of parts for automotive industry. The aim of this experiment is to describe mechanical properties of the composite material reinforced with the fibres of the plant false banana Ensete ventricosum and determine a volume deformation energy.

MATERIALS AND METHODS

Preparation of test samples

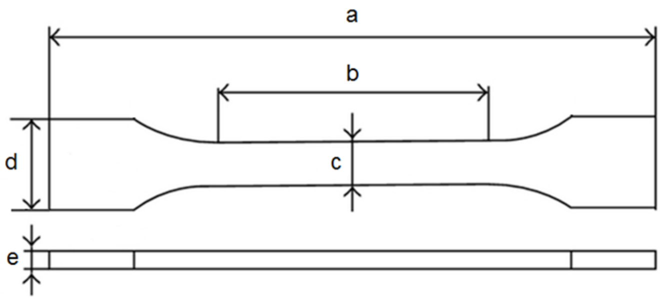
The fibres from the plant Ensete ventricosum originated from Etiopia (region Hawasa) were used for a production of test samples of the composite material. A humidity of the fibres 8.7 ± 0.74% (d.b.) was set by a standard method in a drying equipment according to (ASAE S410.1 DEC97, 1998). Samples of 100 g mass from a batch of Ensete fibres were randomly selected for the moisture content determination. The mass of each samples was determined using an electronic balance (Kern 440–35, Kern & Sohn GmbH, Balingen, Germany). The true fibre density 710 ± 45 kg m^{-3} was determined gravimetrically (Blahovec, 2008) This means that the mass of individual samples from a batch of fibres, randomly selected and measured using an electronic balance (Kern 440–35, Kern & Sohn GmbH, Balingen, Germany), was divided by the volume of sample. The volume of the individual sample was determined by weighing the sample in toluene and applying the principle of buoyancy (Kim et al., 2012). The results obtained were expressed as mean of three replicates.

A maximum tensile stress 537 ± 77 MPa according to (ASTM D3379-75) was set at the sample of the fibres. Further, the fibre mean 0.1887 ± 0.0464 mm was set by means of a picture analysis by an optical microscope (Zeiss Jenavert, Carl Zeiss, Jena, Germany). Gained results were expressed as an average value of twenty replicates.

Ensete fibres were used as the filler from which fractions of a length of the fibres for short-fibre composites: 1–2 mm, 2–3 mm, 3–5 mm, 5–6 mm, 7–8 mm and 9–10 mm were created. The length of the fibres for long-fibre composites were chosen following: 10 mm, 15 mm, 20 mm, 25 mm, 30 mm and 35 mm.

The epoxy resin GlueEpox Rapid was used as a matrix. It is a two-component resin prepared from a bisphenol A and epichlorhydrin. This epoxy resin is suitable as a casting material. It serves as the matrix at the production of composites (Müller, 2014; Valášek, 2014). The composite material was created by mixing of the matrix and the filler in a ratio 50:1 (2%). This material was used for the preparation of test specimens (Fig. 1) according to the standard (ČSN EN ISO 3167, 2004). The composite systems containing

100 g of the resin GlueEpox Rapid and 2 g of the reinforcement in the form of the fibres Ensete were tested within the research. Moulds for casting of the test specimens were produced from a material Lukapren N. Dimensions of the test specimen are present in Fig. 1.



Dimension (mm)

a	b	c	d	e
150	80	10	25	4

Figure 1. Test sample – Tensile strength (ČSN EN ISO 3167, 2004).

Laboratory tests

To determine the relationship between tension force and deformation, a device (Labortech, MPTest 5.050, Czech Republic) was used to record the course of deformation function. The tensile test was performed according to (ČSN EN ISO 527-2, 2012). A deformation speed at the tensile test was 6 mm.min^{-1}. Set values of tensile forces were transformed by means of an equation 1 to the tensile stress and deformations were transformed by means of an equation 2 to the relative deformation.

$$\sigma = \frac{F}{S} \tag{1}$$

where: σ – tensile stress in sample, MPa; F – tensile force, N; S – appropriate cross section area of sample, mm^2,

$$\varepsilon = \frac{x}{L_0} \tag{2}$$

where: ε – strain, -; x – elongation of sample, mm; L_0 – gauge length, mm.

The elongation of the sample was determined from crosshead displacement. Modulus of elasticity was determined as a slope of line which was specified by fitting stress strain curve. The slope of fitted line was calculated by Marquardt Levenberg algorithm (Lourakis, 2005; Marquardt, 1963) using computer program Mathcad 14 (MathCAD 14, PTC Software, Needham, MA, USA), (Pritchard, 1998).

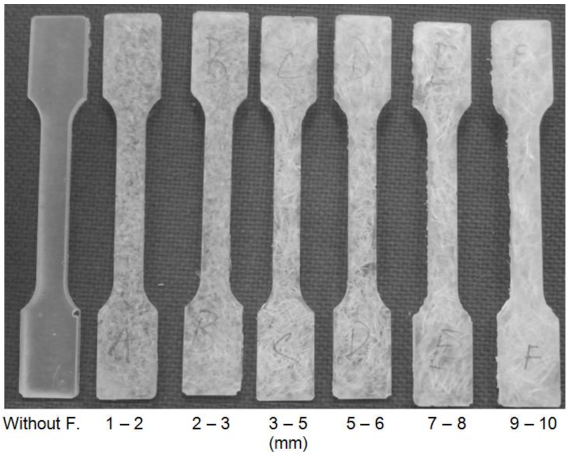
The volume deformation energy was set as an area below a curve 'stress – strain' from zero to a maximum value of the deformation according to an equation 3.

$$\lambda = \sum_{n=0}^{n=i-1}\left[\left(\frac{\sigma_{n+1}+\sigma_n}{2}\right)\cdot\left(\varepsilon_{n+1}-\varepsilon_n\right)\right] \quad (3)$$

where: α – volume energy, J m^{-3}; i – indicates the additional amount of strain in which the stress was determined (step of measurement – 0.001 mm), -; σ_n – tension stress at appropriate strain, MPa; σ_{n+1} – tension stress at the sequential strain, MPa; ε_n – strain, -; ε_{n+1} – sequential strain, -.

RESULTS AND DISCUSSION

The specimen of the composite material was analysed by means of the optical microscope. A disposition of the fibres in the composite material and their size is visible in Fig. 2.



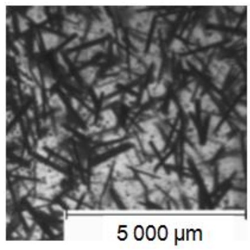


Figure 2. Specimens of composite material with Ensete fibres and disposition of fibres in matrix.

Modulus of elasticity of the short-fibre composite material with Ensete fibres is presented in Fig. 3. The modulus of elasticity increased by adding various lengths of the fibres comparing with the specimen of the epoxy resin without the fibres where the modulus of elasticity 2.173 ± 0.132 GPa was reached. The highest modulus of elasticity 3.217 ± 0.326 GPa was reached at the short-fibre composites at the specimen with the length of the fibres 10 mm. The polymeric materials are generally of relatively low values of the modulus of elasticity. The elasticity modulus is increased when crosslinking of the structure by means of e.g. natural Ensete fibres. The modulus of elasticity is increased also by adding of the natural fibres from a flax and jute into the epoxy matrix of the composite material (Ku et al., 2011; Arrakhiz et al., 2013). This quality was also certified at the fibres of the false banana Ensete ventricosum (Fig. 3).

At first, a two-choice F – test was used for a statistical comparison of particular measured values for an analysis of an agreement of variance. After verifying the agreement of variance. T-test of a significance of differences of two chosen means was subsequently used. Resultant parameters of T-test are stated in Table 1. Particular measured values for different lengths of the fibres were compared with the set of data of the epoxy resin without the fibres. It is visible from the Fig. 3 that the modulus of elasticity was increased at all short-fibre composite materials reinforced with Enset fibres which is evident also from the coefficients of T-test stated in Table 1. Measured deformation energy at the short-fibre composites is presented in Fig. 4. Similar trend is also at polymeric particle composites when small concentration of particles with sizes in the order of units and tens of micrometers leads only to mild improving of cohesive properties, that means the strength (Valášek et al., 2014). The statistical evaluation of the volume deformation energy is presented in Table 1.

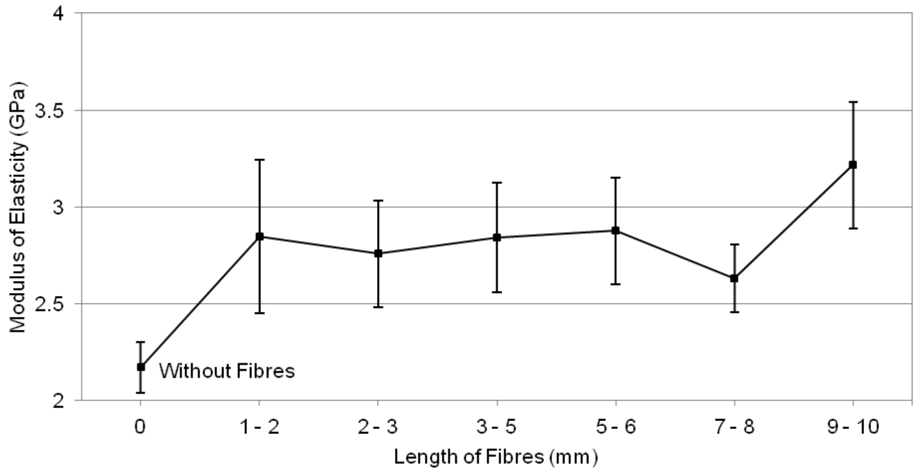


Figure 3. Dependence of modulus of elasticity on length of used fibres in short-fibre composite material.

Table 1. T-test Modul of elasticity and Volume Energy for short-fibre composites. Statistical comparison with pure specimen of epoxy resin without fibres

T-test	Modul of Elasticity			Volume Energy		
Length of F. (mm)	T_{stat} (-)	t_{crit} (-)	P_{value} (-)	T_{stat} (-)	t_{crit} (-)	P_{value} (-)
1–2	2.929	2.306	0.019	5.507	2.306	0.001
2–3	3.446	2.364	0.011	1.374	2.364	0.211
3–5	3.859	2.364	0.006	2.393	2.306	0.044
5–6	4.284	2.306	0.003	1.377	2.364	0.202
7–8	3.988	2.306	0.004	2.249	2.364	0.059
9–10	5.433	2.306	0.001	1.949	2.306	0.087

T-test H_0: $\mu_1 = \mu_2$ (p>0,05)

It is obvious from the Table 1 that the statistically significant change of the volume deformation energy did not occur by adding of Ensete fibres in stated ratio. Thus, the influence of the length of Ensete fibres in the composite material on the value of the volume deformation energy was not proved.

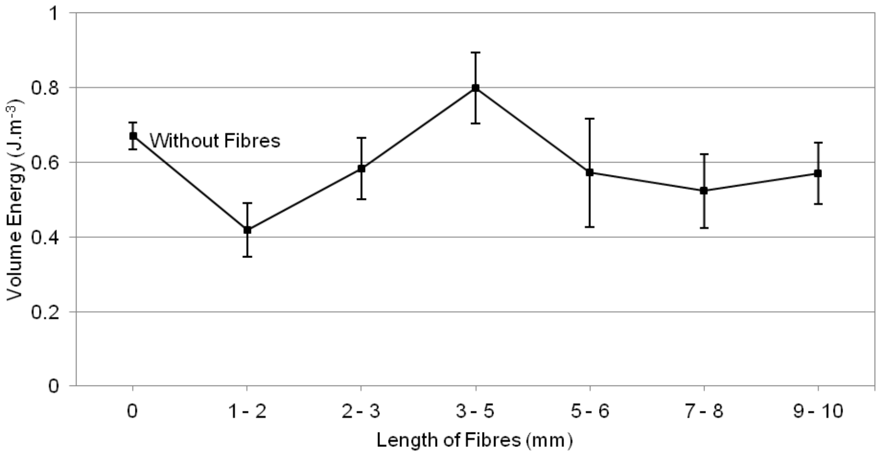


Figure 4. Dependence of volume deformation energy on length of used fibres in short-fibre composite material.

Modulus of elasticity at the long-fibre composites is presented in Fig. 5. The highest modulus of elasticity 3.341 ± 0.452 GPa was reached at the composite with the length of the fibre 35 mm. Particular specimens of composites were compared with the epoxy resin without the fibres where the modulus of elasticity was set as 2.268 ± 0.128 GPa. The two-choice F – test for the analysis of the agreement of variance was again used at first for the statistical comparison of particular measured values. After verifying the agreement of variance, T-test of the significance of differences of two chosen means was subsequently used. Resultant parameters of T-test for long-fibre composites are stated in Table 2. The modus of elasticity at the long-fibre composite materials was increased by adding of reinforcing fibres which is shown by the coefficients of T-test presented in Table 2.

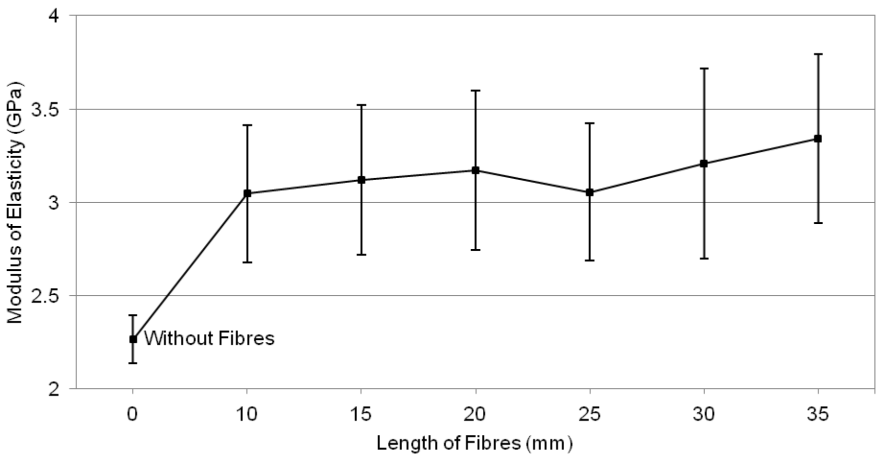


Figure 5. Dependence of modulus of elasticity on length of used fibres in long-fibre composite material.

Table 2. T–test Tensile Strength and Volume Energy for long-fibre composites. Statistical comparison with pure specimen of epoxy resin without fibres

T-test	Modul of Elasticity			Volume Energy		
Length of F. (mm)	T_{stat} (-)	t_{crit} (-)	P_{value} (-)	T_{stat} (-)	t_{crit} (-)	P_{value} (-)
10	3.989	2.306	0.004	0.193	2.364	0.852
15	4.056	2.306	0.004	0.090	2.306	0.931
20	3.962	2.364	0.005	0.157	2.364	0.160
25	4.052	2.306	0.004	0.372	2.262	0.718
30	3.574	2.306	0.007	0.464	2.306	0.655
35	4.482	2.364	0.002	0.275	2.228	0.789

T-test H_0: $\mu_1 = \mu_2$ ($p > 0,05$)

Measured volume deformation energy at the long-fibre composites is presented in Fig. 6. The statistical evaluation of the deformation energy at the long-fibre composites is stated in Table 2. The statistically significant change of the deformation energy did not occur at the long-fibre composites by adding of Ensete fibres in stated ratio which is certified also by the coefficients of T-test stated in Table 2.

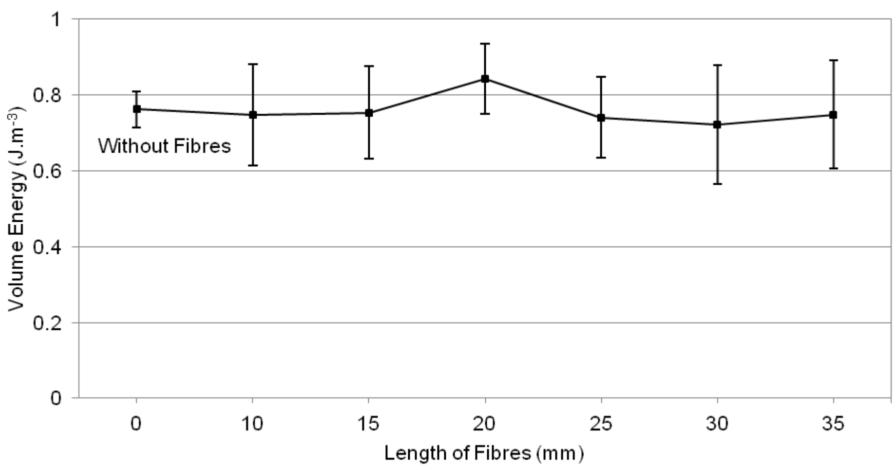


Figure 6. Dependence of volume deformation energy on length of used fibres in long-fibre composite material.

Ensete fibres are of suitable mechanical properties and that is why they can have a great potential for utilization in the composite materials. Adding of various types of fillers into the composite materials can modify their mechanical properties. (Valášek et al., 2014). One of possible treatments for improving of the mechanical properties of the composite materials reinforced with natural fibres is a chemical treatment of the fibres. A hydrogen bond in a structure of a net of the fibres is removed by using sodium hydroxide (NaOH) and a surface energy and a roughness of the fibre surface are increased (Lee et al., 2009).

The application of tested composite system is in the area of cementing and hollow reinforcements in constructions of bonds. The reason is a rise of the construction rigidity. Further, for eliminating of a penetration of degradation mediums (fertilizers) and humidity at agricultural machines. Used typ of matrix is of increased resistance to the influence of liquid contaminants (Müller, 2013).

CONCLUSIONS

The aim of this study was to set the mechanical properties of the composite materials prepared from the fibres of the plant false banana Ensete Ventricosum. It was ascertained following:

- Untreated Ensete fibres added as the filler into the composite materials increase the modulus of elasticity. The matrix reached the modulus of elasticity 2.173 ± 0.132 GPa. The modulus of elasticity was increased at the composite materials with the length of the fibres in the interval 1–2 to 7–8 mm comparing to the matrix without the fibres of 28 ± 12%. The modulus of elasticity was increased at the composite materials with the length of the fibres in the interval 9–10 to 35 mm of 45 ± 14%. The marginal values of the modulus occur at the material (composite) without fibres and of the composite with the length of the fibres 8–9 mm.
- The influence of the length of the fibres on the change of the deformation energy was not proved. The matrix reached the volume deformation energy 0.721 ± 0.054 J m^{-3}. The average value of the deformation energy was reached 0.582 ± 0.098 J m^{-3} at the composite materials with the length of the fibres in the interval 1–2 to 7–8 mm. The average value of the deformation energy was reached 0.759 ± 0.125 J m^{-3} at the composite materials with the length of the fibres in the interval 9–10 to 35 mm.

ACKNOWLEDGEMENT. This paper has been made with the assistance of the grant IGA TF CZU No. 2015:31130/1312/3104.

REFERENCES

Alves, C., Ferrao, P.M.C., Silva, A.J., Reis, L.G., Freitas, M. & Rodrigues, L.B. 2010. Ecodesign of automotive components making use of natural jute fiber composites. *Journal of Cleaner Production* **18**, 313–327.

Arrakhiz, F.Z., Achaby, M.E., Malha, M., Bensalah, M.O., Fassi–Fehri, O., Bouhfid, R., Benmoussa, K. & Qaiss, A. 2013. Mechanical and thermal properties of natural fibers reinforced polymer composites: Doum/low density polyethylene. *Materials and Design* **43**, 205–205.

ASAE S410.1 DEC97. 1998. Moisture measurement of peanut. In: ASAE standards, 45th edition. 560–561.

Aseer, J.R., Sankaranarayanasamy, K., Jayabalan, P., Natarajan, R., Dasan, K.P. 2013. Morphological, Physical and Thermal Properties of Chemically Treated Banana Fiber. *Journal of Natural Fibers* **10**, 365–380.

Blahovec, J. 2008. Agromaterials – study Guide. *Czech University of Life Sciences Prague*, Prague.

ČSN EN ISO 3167. 2004. Plastics –Multipurpose test specimens. In: Czech Standard Institution.
ČSN EN ISO 527-2. 2012. Plastics – Determination of tensile properties. In: Czech Standard Institution.
Diriba, H.D., Mazancová, J., Rušarová, K. & Havrland, B. 2013. Possibilities and Acceptance of Alternative Energies from Farm Solid Waste Material (Kocho): Case Study from Kembata Tenbaro Zone. *EthiopiaTropentag 2013 International Research on Food Security, Natural Resource Management and Rural Development Agricultural development within the rural-urban continuum*, Gottingen.
Harun, J., Abdan, K. & Zaman, K. 2008. Rheological behaviour of injection moulded oil palm empty fruit bunch fiber-polypropylene composites: effects of electron beam processing versus maleated polypropylene. *Molecular Crystals and Liquid Crystals Science* **484**, 134–142.
Herák, D., Blahovec, J. & Kabutey, A. 2014. Analysis of the axial pressing of bulk Jatropha curcas L. seeds using reciprocal slope transformation. *Biosystems Engineering* **121**, 67–76.
Hpsa, K., Ismail, H., Rozman, H.D. & Ahmed, M.N. 2001. The effect of acetylation on interfacial shear strength between plant fibers and various matrices. *European Polymer Journal* **37**, 1037–1045.
Keller, A. 2003. Compounding and mechanical properties of biodegradable hemp fiber composites. Compos Sci Technol 2003;63:1307–16.
Kim, J.H., Lee, H.J., Lee, H.S., Lim, E.J., Imm, J.Y., Suh, H.J. 2012. Physical and sensory characteristics of fibre – enriched sponge cakes made with Opuntia humifusa. *Food Science and Technology* **47**, 478–484.
Ku, H., Wang, Pattarachaiyakoop, N. & Trada, M. 2011. A review on the tensile properties of natural fiber reinforced polymer composites. *Composites: Part B* **42**, 856–873.
Lee, B.H., Kim, H.J. & Yu, W.R. 2009. Fabrication of long and discontinuous natural fibre
reinforced polypropylene biocomposites and their mechanical properties. *Fibers and Polymers* **10**, 83–90.
Lourakis, M.I., 2005. Brief Description of the Levenberg-Marquardt Algorithm Implemened by levmar. *Matrix* **3**, 2.
Lu, X., Qiu Zhang, M., Zhi Rong, M., Shi, G. & Cheng Yang, G. 2003 Melt processable composites of sisal. *Composites Science and Technology* **63**,177–186.
Marquardt, D.W. 1963. An Algorithm for Least-Squares Estimation of Nonlinear Parameters. *Journal of the Society for Industrial and Applied Mathematics* **11**, 431–441.
Mominul Haque, M., Hasan, M., Saiful Islam, M. & Ershad Ali, M. 2009. Physical– mechanical properties of chemically treated palm and coir fiber reinforced polypropylene. *Bioresource Technology* **100**, 4903–4906.
Müller, M. 2013. Research of liquid contaminants influence on adhesive bond strength applied in agricultural machine construction. *Agronomy Research* **11**, 147–154.
Müller, M. 2014. Setting of Causes of Adhesive Bonds Destruction by Means of Optical Analysis. *Manufacturing Technology* **14**, 371–375.
Pritchard, P.J. 1998. Mathcad: A tool for engineering problem solving. *McGraw-Hill Science Engineering*, New York.
Sharifah, H.A. & Martin, P.A. 2004. The effect of alkalization and fiber alignment on the mechanical and thermal properties of kenaf and hemp bast fiber composites: Part 1 – polyester resin matrix. *Composites Science and Technology* **64**, 1219–30.
Tsehaye, Y. & Kebebew, F. 2006. Diversity and cultural use of Enset (Enset ventricosum (Welw.) Cheesman) in Bonga in situ Conservation Site, Ethiopia. *Ethnobotany Research and Applications* **4**, 147–57.
Valášek, P. 2014. Mechanical Properties of Epoxy Resins Filled with Waste Rubber Powder. *Manufacturing Technology* **14**, 632–637.

Valášek, P., Müller, M. & Ružbarský, J. 2014. Using recycled rubber particles as filler of polymers. *Applied Mechanics and Materials* **616**, 260–267.
Vincent, H., Wiersama, J., Kell, S., Fielder, H., Dobbie, S., Castaneda-Alvarez, N.P., Guarino, L., Eastwood, R., Leon, B. & Maxted, N. 2013. A prioritized crop wild relative inventory to help underpin global food security. *Biological Conservation* **167**, 265–275.
Yirmaga, M.T. 2013. Improving the Indigenous Processing of Kocho, an Ethiopian Traditional Fermented Food. *Journal of Nurition and Food Science* **3**, 1–6.

Agronomy Research **13**(3), 690–699, 2015

Laboratory research of granulated heat insulation material from coniferous forestry residue

I. Muizniece*, L. Vilcane and D. Blumberga

Riga Technical University, Institute of Energy Systems and Environment, Azenes Street 21-1, LV-1048 Riga, Latvia; *Correspondence: indra.muizniece@rtu.lv

Abstract. The purpose of this research paper is to determine the heat conductivity of a granular heat insulation material made of coniferous greenery (fine twigs and needles), and the suitability of the material for application as heat insulation. In order to achieve the objective, a three-factor experiment plan was developed, and 11 samples produced. The thermal conductivity coefficient, moisture content, and density of the samples was determined. A full analysis of the experiment plan was compiled on the basis of the obtained results. The analysis results suggest that size composition, density, and tree species affect the thermal conductivity of the material. It was discovered that smaller spruce greenery insulation material pellets have a smaller thermal conductivity coefficient, which indicates a better capacity for retaining heat.

Key words: needles, coniferous, heat insulation, forestry residue.

INTRODUCTION

Bioeconomy has turned a new page in the development of using and evaluating biomass. It is important to find the right applications with the greatest added value (European Commission strategy, 2012). One of the fields where this can be done is increasing the energy efficiency of buildings. The question of the thermal insulation of buildings and development of innovative heat insulation materials as well as their introduction into everyday use is becoming more and more topical. It is essential for sustainably-minded people to have natural materials in their home, and for these materials to have minimal influence on climate change and cause the least possible harm to the environment and human health throughout their life cycle.

The environmental impact of a product during its full life cycle, including the production stage, can be reduced by using cleaner production strategies (Blumberga, 2010). A cleaner production strategy includes using resources sustainably, and striving towards non-waste production. This can be achieved if by-products or residues are integrated into the production processes where new products are made from by-products or residues. Using by-products or residues would reduce the consumption of new raw materials. This principle can be used for biomass resources. Therefore, raw materials and energy sources, their total volumes and impact on the environment are taken into account in the process of inventing new products so that after the industrial product is developed, its impact and unnecessary resource consumption are kept to a minimum (Haggar, 2007).

In Latvia, forests take up more than 51% of the total land area. Forest massifs are dominated by coniferous trees (54% of the total forest area) (NFI data, 2012). Forests, and coniferous trees in particular, are the largest natural resource in Latvia. As such, the resource is widely used in different industries and exported abroad (CSB Database, 2013). Despite the importance of this resource and the large cutting volumes, forest residues are still not properly used; neither are small branches. At the moment, the only industrial use of coniferous needles in Latvia is the production of coniferous extract. The maximal amount of needles utilized for extract production is 800 t per year (Pollution permit, 2010). Consequently, thousands of tons of coniferous greenery (fine softwood branches with needles) are left to decompose at the clearings. Taking into account the work volumes of the forestry section in the Baltic States, it would be technically possible to obtain about 700 thousand tons of coniferous greenery (needles and small branches) (Muizniece & Blumberga, 2015). Therefore, it is worth finding an economically and environmentally sound solution for the sustainable use of this biomass resource.

Consequentially, authors of this paper propose an innovative idea for the production of an ecological heat insulation material using the needles and small branches of coniferous trees (greenery). The proposed idea combines both the rational use of coniferous logging residue, and the production of an ecological heat insulation material, which is friendly to the environment and human health throughout its life cycle, while respecting the principles of cleaner production.

So far, there are no scientific publications with information on an insulation material that is produced from needles or coniferous greenery. There is no information on the physical or mechanical properties of such a material. In previous studies (Muizniece et al., 2015) the thermal conductivity coefficient of this heat insulation material in the form of plates made of coniferous greenery has been determined to be λ = 0.056 W (m K)$^{-1}$, and the thermal conductivity coefficient of freely poured pine needles was identified to be λ = 0.037 W (m K)$^{-1}$. These values are similar to natural heat insulation materials already widely used in the market. For example, wood fibre panels (λ = 0.045 W (m K)$^{-1}$), cork panels (λ = 0.043 W (m K)$^{-1}$), hemp fibre panels (λ = 0.041 W (m K)$^{-1}$), coconut fibres (λ = 0.045 W (m K)$^{-1}$) (Ingrao et. al., 2014), flax fibres (λ = 0.045 W (m K)$^{-1}$) (Kymalainen & Syoberg, 2008) and cotton stalk fibres (λ = 0.059 W (m K)$^{-1}$) (Zhou et. al., 2010). Previous studies have revealed that freely poured pine and spruce needles have different thermal conductivity coefficients. This is explained by the difference in the dimensions of air gaps between the needles (Muizniece et al., 2015). There are no studies on the influence of the species of coniferous trees used for the production of the material on the thermal conductivity of the material in case it is produced from milled greenery. Such a study could determine whether the species of coniferous trees or their proportions in the greenery should be considered in producing heat insulation materials. However, there are several issues that should be studied. The most important of them is poor adhesion (without additional binding substances) of the heat insulation material in the form of plates, which limits its transportation, usage and dimensions. The decomposition and formation of fine dust fractures was observed in the case of freely poured coniferous needles. The fine fracture is denser and, therefore, has a lower capacity for retaining heat. As a solution for preventing this problem, it has been proposed to produce poured granular heat insulation materials from coniferous tree greenery. A three-factor experiment plan was developed, and the experiments were performed in order to determine the efficiency of such a material, as well as its properties and the factors influencing it.

MATERIALS AND METHODS

Experiments were planned carefully before the production and testing of the granular coniferous greenery heat insulation material – this allowed to determine the proportion and extent of the influence posed by selected factors in a more efficient manner, providing the best results. The thermal conductivity coefficient, the main indicator describing the efficiency of heat insulation materials, was selected for expressing the results of this experiment.

The thermal conductivity coefficient of a heat insulation material can be influenced by material bulk density, porosity, density, moisture content and other properties of the material (Popovs, 1990). Only three factors associated with the production of the granular coniferous needle heat insulation material that can directly or indirectly influence the thermal conductivity of the material were selected for the experiment. These factors are: granule size (granulometry), tree species (spruce or pine) used, and whether or not the material is washed and re-dried before the measurements.

Particles of milled greenery are not so fine that it would be possible to create very small granules. This must be taken into account when producing a granular heat insulation material from milled coniferous needle greenery. Also, smaller-sized granules would crumble faster. Therefore, the minimal value for this factor was set at 3–8 mm (fine granules) and maximal value at 16 mm (large granules).

Previous experiments showed (Muizniece, 2014) that granules produced from milled conifer greenery and potato starch do not disintegrate after being soaked and kept in water for a few hours. After re-drying, their mass decreases but volume and shape stay the same. This indicates that water washes out fine particles, while the material becomes lighter and more porous. Porosity is a very important factor that influences thermal conductivity. Light and porous materials retain heat better. Therefore, the third factor examined is whether the granules are washed and re-dried or not washed. First, the thermal conductivity coefficients were determined for coniferous pellets that had not been washed. The pellet samples were rinsed as follows: samples were soaked in clean water for 2 hours and occasionally lightly stirred, water was decanted and the samples were dried again. The processed samples underwent repeated heat flow measurements, and their thermal conductivity coefficients were determined.

Table 1. The experimental plan with factor values of the granular coniferous greenery heat insulation material

Factors	Sample No.							
	1	2	3	4	5	6	7	8	9,10,11
Size composition, mm	<8	>16	<8	<8	>16	<8	>16	>16	8–16
Species (pine or spruce)	pine	spruce	pine	spruce	spruce	spruce	pine	pine	mix 1/1
Washed or unwashed	unwashed	washed	washed	washed	unwashed	unwashed	washed	unwashed	mix 1/1

During the experiment, the maximal and minimal values of factors were varied in a number of ways, thus testing all possible combinations for a certain number of factors, see Table 1.

In total, 11 samples were made (Fig. 1), from which three were made with the average factor values. First, fresh (water content at least 50%) coniferous greenery mass was milled with a milling machine (PM120 Vibrotehnik), then sieved with a sieve (mesh size 10 mm), then processed repeatedly with a fine sieve (mesh size 3 mm). The ground greenery mass was then manually mixed with a binder made from water and potato starch (1:10). The prepared mass was forced through an appropriate mesh (depending on the required granule size), then processed in the analytical screeners (Retsch analysensieb AS400) for 3–6 min, where the mass was rolled into spherical or elliptical granules. Granules were dried in a thin layer in a drawer-type drying stove (BMT ECOCELL) at 105°C for about 24 h. Once the pellets were dried, heat flow measurements were performed with the heat flow sensor Hukesflux DT01 in order to determine the thermal conductivity coefficient. Heat flow measurements were performed according to the standard method ISO 9869 Thermal insulation – Building elements – In-situ measurements of thermal resistance and thermal transmittance (ISO standard, 2014).

Figure 1. Samples of coniferous greenery granules (sample No. 1 on the left and sample No. 8 on the right).

Heat flow measurements were performed with a heat flow meter consisting of four thermocouples and two heat flow sensors. Parallel to measuring the samples, one pair of thermocouples and a heat flow sensor were attached to a reference surface with a known thermal conductivity coefficient for measurement reliability and accuracy control. In this experiment, the reference surface was extruded polystyrene with the theoretical conductivity coefficient value of $\lambda_{teor.}$ = 0.035 W (m K)$^{-1}$. The sample – freely poured coniferous granules – was placed in a vertical position between two 3 mm thick corrugated cardboard sheets with $\lambda_{teor.}$ = 0.18 W (m K)$^{-1}$. The experimental stand was placed in a closed chamber to avoid the influence of ambient conditions (wind and sun). Heat flow measurements were carried out at the average warm temperature (hereinafter warm environment) of +26 °C and at the average cold temperature (hereinafter cold environment) of -4 °C, the temperature range being 30 °C. Each of the samples was measured 3 times to verify the accuracy of results and obtain the average value of the thermal conductivity coefficient. Since freely poured coniferous granules were placed between sheets of corrugated cardboard, it was necessary to deduct its impact on the results.

In order to determine whether the obtained thermal conductivity results were reliable, measurement error was calculated for each result using the data processing program Statgraphics. The coefficient was τ_{95} = 1.412 with the confidence probability of 95% in case of 3 measurements. If the proportion of the sum of differences between each measurement and the arithmetical mean compared to the standard deviation is smaller than τ_{95}, all measurements can be considered reliable. Regression analysis was performed to determine the correlation between the thermal conductivity coefficient and the selected experimental factors, i.e., density and moisture content.

Even though the granules were dried, they absorbed some moisture from air before and during the measurements. So the thermal conductivity was determined for an air-dry material. Therefore, moisture content, as it was at the time of the measurements, was determined (according to the standard method LVS EN 14774-2:2010) for all samples to identify the moisture content to which the certain thermal conductivity coefficients corresponded. Material density can also have an influence on thermal conductivity, so the average density of each freely poured coniferous needle granule sample was determined (according to the standard method LVS EN 15103:2010).

Insulation material samples were made out of coniferous (spruce and pine) forest residue granules. Small branches with needles were harvested in the 2014/2015 winter (felled forests). The median time period from the collection of coniferous forest residues to the production of insulation material samples was 1 month. The average moisture content for the raw material was 50%. The necessary materials for sample making were collected only from forest residues, not from growing trees (this will be also tried if industrial production is proved to be viable). Thus, the cleaner production principle was observed – the residues of another process were used as a raw material.

RESULTS AND DISCUSSION

The mean thermal conductivity coefficients of the granules, sample moisture content and density are summarized in Table 2. As you can see from the obtained results, the thermal conductivity of the samples is in the range of 0.0452 W $(m\ K)^{-1}$ to 0.0916 W $(m\ K)^{-1}$. Fine (<8 mm) washed and repeatedly dried spruce needle granules have the lowest thermal conductivity. The highest thermal conductivity was observed in case of large (>16 mm) unwashed pine needle granules. Granule size has a significant influence on the thermal conductivity of bulk heat insulation materials because the volume of the air gaps between the granules depends on granule size. The larger the air gaps, the higher the thermal conductivity coefficient of the material. Consequentially, smaller-sized granules retain heat better.

The calculation of measurement error at a given confidence probability of 95% (coefficient τ_{95}= 1.412) showed that all the measurement results are reliable.

Table 2. Raw data and obtained thermal conductivity coefficients for coniferous forest residue granules

Sample No.	Thermal conductivity coefficient, W (m K)$^{-1}$	Moisture content, wt%, d	Density, kg m^{-3}	Size composition, mm	Species	Washed or unwashed
1	0.0674	5.24	205	<8	pine	unwashed
2	0.0767	4.63	175	>16	spruce	washed
3	0.0578	7.22	188	<8	pine	washed
4	0.0452	3.53	170	<8	spruce	washed
5	0.0821	5.89	192	>16	spruce	unwashed
6	0.0630	2.92	185	<8	spruce	unwashed
7	0.0637	5.27	208	>16	pine	washed
8	0.0916	9.68	225	>16	pine	unwashed
9	0.0654	6.64	203	8–16	0.5 spruce / 0.5 pine	0.5 washed / 0.5 unwashed
10	0.0666	6.64	205	8–16	0.5 spruce / 0.5 pine	0.5 washed / 0.5 unwashed
11	0.0687	6.64	205	8–16	0.5 spruce / 0.5 pine	0.5 washed / 0.5 unwashed

Regression analysis proved that a material's density has a significant influence on thermal conductivity. This was also observed in the experiment with insulation granules made of needles. As you can see in Fig. 2, less dense freely poured needle granules have a better (lover) thermal conductivity coefficient.

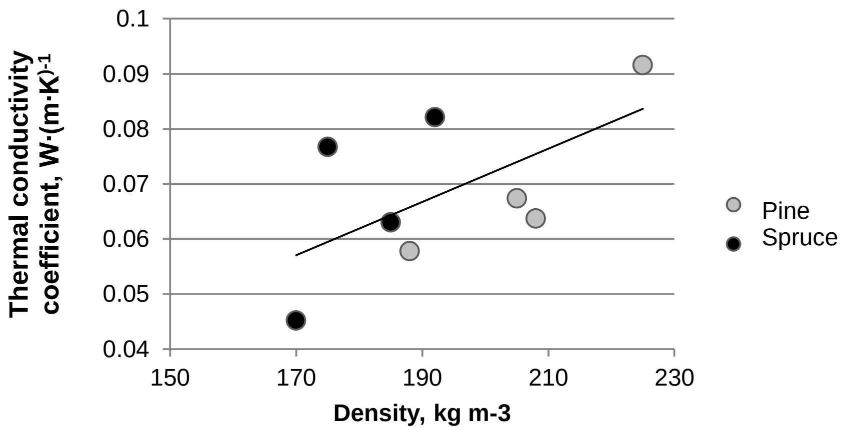


Figure 2. Correlation between thermal conductivity and the density of the material samples No.1–8.

This is demonstrated by the correlation coefficient, in this case 0.602, which indicates a strong causal link between the thermal conductivity coefficient and density. The fewer air gaps there remain between coniferous granules in the material, the better it retains warmth.

As it was mentioned before, the density of the sample material can influence the accuracy of determining the thermal conductivity coefficient. This was also observed in the performed experiment (Fig. 3) in case of the correlation coefficient 0.630, which indicates to a correlation between these two values.

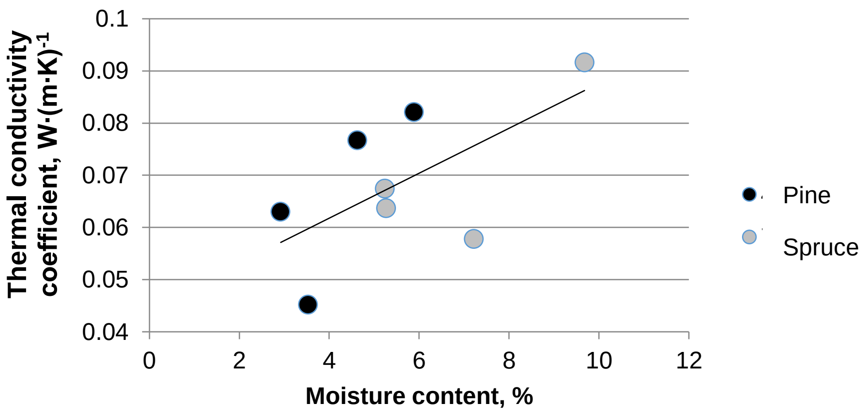


Figure 3. The dependence of thermal conductivity on the moisture content of material samples No. 1–8.

A strong correlation between the thermal conductivity coefficient and sample moisture content was observed during this experiment. In practice, the impact of the moisture content cannot be this high because the samples had low moisture content values (3–10%).

A regression analysis for the thermal conductivity coefficient and pellet size reveals a close relationship between the coefficient of thermal conductivity and bulk density of coniferous granules. A strong correlation was observed in this case, the correlation coefficient being 0.737.

The obtained results prove that the second experimental factor – species of coniferous tree – also affects thermal conductivity. Granules produced only from spruce greenery had better thermal conductivity coefficients than other materials of the same size, notwithstanding whether the granules were washed or not washed. However, regression analysis showed that this effect is very weak, as evidenced by the correlation coefficient of -0.123.

The results showed that rewashed granules had better thermal conductivity coefficients (0.554) in all cases, suggesting a moderate impact. Washing the granules had an impact on the thermal conductivity coefficient because the granule mass, and, therefore, the bulk density of granules, decreased. Mass, density and thermal conductivity changes due to sample washing are summarised in Table 3.

Washing leads to a significant decrease in granular mass – an average of 15.5% – which, in turn, decreases the density of bulk granules about 7.6–8.9% (8.2% on average). The reduction of the thermal conductivity coefficient is different for each sample, and it is not proportional to the decrease in mass and density. The highest thermal conductivity coefficient reduction was observed for large pine pellets, which had the highest coefficient of thermal conductivity.

Table 3. Mass, density and thermal conductivity changes (%) in granules as a result of washing

Sample	Difference in density, %	Mass difference, %	Difference in thermal conductivity, %
Fine pine granules (3)	8.3	-18.4	-14.2
Large pine granules (7)	7.6	-15.3	-30.5
Large spruce granules (2)	8.9	-11.5	-6.6
Fine spruce granules (4)	8.1	-16.8	-28.3
Average:	8.2	-15.5	-19.9

A full analysis of the experimental design was carried out to express pre-established correlations in the form of a single linear regression equation. Not all three factors studied in this experiment are expressed in numerical values. Therefore, in the second step (species) and the third step (washed and re-dried or un-washed granules) of calculations, the factors were given the maximal value of 1 and minimal value of 0 (spruce – 1, pine – 0, washed – 1, unwashed – 0). For the first factor, the minimal numerical value is 8 and the maximal is 16. The full regression equation after its simplification with the natural values of thermal conductivity coefficient λ (W (m K)$^{-1}$) can be expressed as follows:

$$\lambda = 0.06844 + 0.00252(g - 12) - 0.01518(sn - 0.5) + 0.00384(g - 12)(ep - 0.5)(sn - 0.5) \quad (1)$$

where: g is size composition (mm); sn is washed or unwashed material; ep is species (spruce or pine).

The experiment and analysis of the obtained data show that the thermal conductivity coefficient of granules produced from coniferous tree greenery is significantly influenced by the size of the granules (size composition), and whether the granules are washed or unwashed. The second factor (species of trees) also influences the thermal conductivity coefficient. Material made from fine (< 8mm) washed spruce greenery had the best thermal conductivity coefficient (λ_4 = 0.0452 W (m K)$^{-1}$). We can conclude that in order to make good heat insulation material from needles, its size composition must be up to 8 mm and it is preferable to use spruce greenery. The material must also be washed and re-dried.

Several significant problems were discovered during the experiment. The most significant of them is forming chunks of fine granules; the essence of the problem is in the separation of fine particles rather than the disintegration of the granules themselves. It is possible that the granules would decompose completely with time. To avoid this problem, it is necessary to use stronger adhesive materials. In order to maintain the safety of the material to the environment, the new adhesive should be of natural origin and safe to the environment and human health throughout the product life cycle. The combustibility of the material is the second biggest problem. This can be solved by adding antipyrine. Additional studies are required in order to find solutions to address the brittleness of the granular coniferous greenery heat insulation material.

Scientific literature offers information about the physical properties of the different types of granular insulation materials, although information is not as extensive as in the case of board-type insulation materials. The production of granular insulation materials from vegetable raw materials is relatively rare but there is information on granular insulation materials produced from waste, most often glass. If it would be possible to avoid the crumbling of the natural granular insulation material, and if it would retain its physical properties, such granular insulation materials would already exist. The properties of some of them have been compared with the results of this study (see Fig. 4). As it can be seen, there are granulated insulating materials that have a much lower thermal conductivity coefficient, such as silicon-aerogel granulate and foam glass granules. However, the coniferous granular insulation material tested in this study has a lower thermal conductivity than the most widely known granular insulation material: expanded clay granules. Further research is needed to study the properties of this granular material.

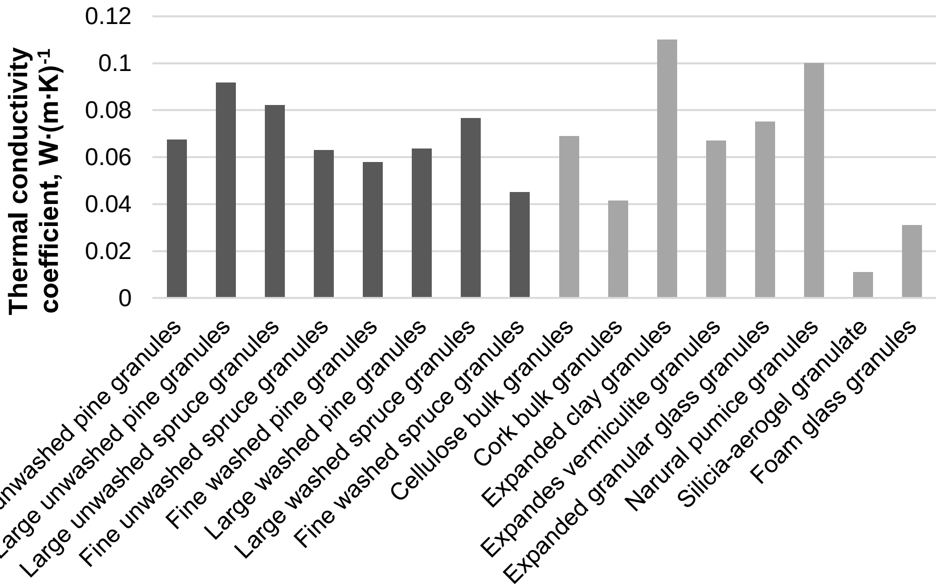


Figure 4. Comparison of the thermal conductivity coefficients of coniferous needle granules and other natural granulated heat insulation materials (Ayadi et al., 2009; Reim et al., 2004; Ingrao et al., 2014).

CONCLUSIONS

Thermal conductivity coefficients of granular coniferous greenery insulation materials and the factors influencing this indicator were studied by implementing a three-factor experimental plan.

The experiment showed that the thermal conductivity of freely poured heat insulation materials depends on the size of granules and whether or not the raw material is washed and re-dried (therefore reducing its density).

The thermal conductivity coefficient of the material made from fine (< 8 mm) washed spruce greenery granules (λ_4 = 0.0452 W (m K)$^{-1}$) is equivalent to existing and already widely used natural heat insulation materials. If solutions are found to prevent the disintegration of the granules and to reduce their combustibility while maintaining environmental safety throughout the life cycle in future studies, the physical properties of the material would be more advantageous in comparison to the heat insulation materials already on the market.

ACKNOWLEDGEMENTS. The research has been supported by the National Research Program 'Energy efficient and low-carbon solutions for a secure, sustainable and climate variability reducing energy supply (LATENERGI)'.

REFERENCES

Ayadi A., Stiti, N., Boumchedda, K., Rennai, H., Lerari, Y. 2009. Elaboration and characterization of porous granules based on waste glass. *Powder Technology* **2**, 423–426.

Blumberga, D. 2010. *Vides tehnoloģijas*. Rīga, 212 pp. (in Latvian).

Central Statistical Bureau Database. http://data.csb.gov.lv/pxweb/lv/atirdz/atirdz__ikgad__atirdz_nace/?tablelist=true&rxid=cdcb978c-22b0-416a-aacc-aa650d3e2ce0. Accessed 13.01.2014. (in Latvian).

European Commission strategy. 13.02.2012. *Innovating for Sustainable Growth: A Bioeconomy for Europe.*

Haggar, E.S. 2007. *Sustainable Industrial Design and Waste Management.* Academic Press, 420 p.

Kymalainen, H.R. & Sjoberg, A.M. 2008. Flax and hemp fibres as raw materials for thermal insulations. *Building and Environment* **48**, 1261–1269.

Latvia National forest inventory data. https://sites.google.com/site/lvlulucf/activity/nir-1990–2011/Meza%20apsaimniekosana%20%28FMRL%2020120730%29.ods?attredirects=0&d=1. Accessed 12.01.2014. (in Latvian).

Muizniece, I. 2014. Skuju koku mežizstrādes atlikumu izmantošana ekoloģiska materiāla izveidei. Project report. Rīga, 35 pp. (in Latvian)

Muizniece, I. & Blumberga, D. 2015. Analysis of Coniferous Wood Waste in Baltic States. *Energy Procedia* (in press).

Muizniece, I., Blumberga, D. & Ansone, A. 2015. The use of coniferous greenery for heat insulation material production. *Energy Procedia* (in press).

Muizniece, I., Lauka, D. & Blumberga, D. 2015. Thermal Conductivity of Freely Patterned Pine and Spruce Needles. *Energy Procedia* (in press).

Ingrao, C, Giudice, A.L., Tricase, C., Rana, R., Mbohwa, C., Siracusa, V. 2014. Recycled-PET fibre based panels for building thermal insulation: Environmental impact and improvement potential assessment for a greener production. *Science of the Total Environment* **493**, 914–929.

ISO 9869 standart. 2014. Thermal insulation – Building elements –In-situ measurements of thermal resistance and thermal transmittance

Pollution permit. http://www.vpvb.gov.lv/lv/piesarnojums/a-b-atlaujas/?ur=vecventa&id_ur=&search_ur_submit=Mekl%C4%93t+p%C4%93c+uz%C5%86%C4%93muma. Accessed 12.01.2014. (in Latvian).

Popovs, L. 1990. *Būvmateriāli un būvizstrādājumi*. Zvaigzne. Rīga, 250 pp. (in Latvian).

Reim, M., Reichenauer, G., Körner, W., Manara, J., Arduini-Schuster, M., Korder, S., Beck, A., Fricke, J. 2004. Silica-aerogel granulate – Structural, optical and thermal properties. *Journal of Non-Crystalline Solids* **350**, 358–363.

Zhou, X., Zheng, f, Hua-guan, Li, Cheng-long, Lu. 2010. An environment-friendly thermal insulation material from cotton stalk fibers. *Energy and Buildings* **42**, 1070–1074.

Agronomy Research **13**(3), 700–708, 2015

Hybrid composite materials on basis of reactoplastic matrix reinforced with textile fibres from process of tyres recyclation

M. Müller

Department of Material Science and Manufacturing Technology, Faculty of Engineering, Czech University of Life Science, Kamýcká 129, 165 21 Prague, Czech Republik; e-mail: muller@tf.czu.cz

Abstract. The paper deals with a testing of composite materials reinforced with fabric, which were obtained after a recycling process of used tyres and a matrix is on a base of reactoplastics. The aim of the research was to set a possible utilization of unsorted textile waste from the process of the tyres recycling in the area of the polymeric composite systems. The subject of performed experiments was the hybrid polymeric composite, whose continuous phase was in a form of a two-component epoxy adhesive and a discontinuous phase (reinforcing particles) in a form of Polyamide PA (fibres) and rubber particles (granules of different sizes). An influence of a tensile stress, an elongation and an impact strength on the newly suggested hybrid composite materials were experimentally tested.

Key words: hybrid polymeric composite, mechanical properties, morphology of fibres, tyre recycling.

INTRODUCTION

Used tyres, or tyres, whose parameters do not meet the requirements specified by the relevant rules of the road safety are recovered or disposed in accordance with the law. A principle of the ecological liquidation of tyres is a separation of various types of materials from which the tyres consist of. The output products of the recyclation are the recycled rubber and other parts of the tyres that mean textile fibres and steel wires. Nowadays the number of worn tyres reaches 10 millions each year in all the world (Fang et al., 2000; Valášek et al., 2013). Technologies dealing with the recyclation of products from the ecological liquidation of tyres have been constantly developing.

We can obtain a valuable raw material - crushed rubber from used tyres. It is widely used as an ingredient in asphalt, concrete filler, layer base of roads, rail crossings, coatings, paints, running tracks, playgrounds etc. Separate steel parts are also used in engineering and metallurgical industries. The last component of used tyres is the fabric. Fibres from the process of the tyres recyclation are of polyamide how it is visible from the results of the thermal analysis (Parres et al., 2009).

A shattering of tyres for a purpose of gaining a granulate is one of effective possibilities of their recyclation. This material is possible to use as a filler for a production of other rubber products and composite materials. An utilization of the textile waste is problematic because of a contamination with the rubber granulate. Various exploiters of this waste reach considerable differences in a composition of the textile waste / rubber granulate (Parres et al., 2009; Knapčíková et al., 2014). It depends on a production technology and on a degree of purification in cyclone. A reason for that is a fact that this waste does not belong among primarily gained secondary raw-material.

The epoxy resins are typical reactoplastics. They dispose of three-dimensional structure. They show higher rigidity, strength and heat stability. The epoxy resins are brittle and prone to the initiation of cracks (Valášek, 2014; Valášek et al., 2014). The epoxy resin properties can be changed by adding appropriate types of fillers. Shi Ai Xu et al. (Shi Ai Xu et al., 2013) present an example of the modification of the epoxy resins by means of a liquid rubber (CTBN liquid rubber). They reached an improvement of failure properties of the epoxy resins.

Reactoplastics are used for the material recycling of various types of the waste (Valášek & Müller, 2014).

The aim of performed experiment was to describe the change of mechanical qualities of the epoxy resin filled with the recycled rubber and textile fibres from process of tyres recyclation with changeable amount of the filler.

A basic assumption for an optimum choice of materials is the knowledge of the applied material behaviour. The aim of the research was to set a possible utilization of unsorted textile waste from the process of the tyres recycling in the area of the polymeric composite systems. The research was realized according to the requirements of two significant firms dealing with the tyres recyclation in the Czech Republic.

MATERIALS AND METHODS

The subject of performed experiments was the hybrid polymeric composite, whose continuous phase was in a form of a two-component epoxy adhesive (RAPID F) and a discontinuous phase (reinforcing particles) in a form of Polyamide PA (fibres) and rubber particles (granules of different sizes).

Epoxy resins are suitable for filling with organic as well as inorganic particles (Valášek & Müller, 2014). The adhesive RAPID F is a low-molecular epoxy resin prepared from bisphenol A and epichlorhydrin. It is distinguished for high liquidity and increased speed of a hardening. The processing time is till 10 minutes at the temperature 23 ± 5 °C. The hardening is reached at least in 24 hours. The resin secondarily hardens during several days. The hardening of the resin is an exothermic reaction. The hardening process was watched by means of a thermocamera. The resin temperature before mixing was ca 22 °C. The temperature increased to 28 till 30 °C after mixing of the resin and the hardener. After adding the filler into the matrix the temperature ranged in the interval 29 to 34 °C. The matrix was chosen according to the requirement of the firm using this type of the resin in the production. The fibres were not treated before mixing with the resin. This requirement came out from an expected practical application. It was required only the storing temperature ranging in the interval 15 to 27 °C.

An influence of a tensile stress, an elongation and an impact strength on the newly suggested hybrid composite materials were experimentally tested.

The concentration of the components was expressed in volume percentage.

Two products of significant firms dealing with the tyres recyclation process were used for the research (Fig. 1). The fillers in the Fig. 1 were prepared by two different producers and each of the fillers contains different ratio of the rubber and the textile fibres. A different representation of the rubber fraction portion followed from the analysis of these two products. The evaluation was performed by means of a sieve analysis.

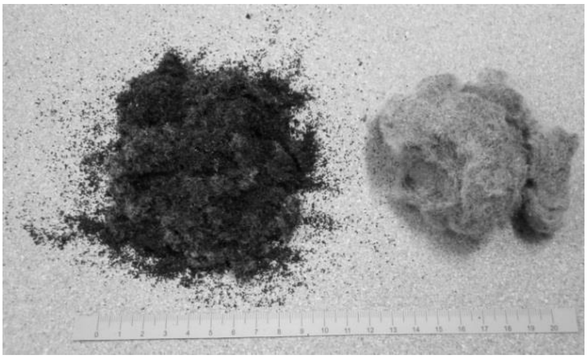


Figure 1. Filler (left: filler for composites A, B, C; right: filler for composites D, E, F).

Following composite systems were tested in the research (Table 1)

Table 1. Tested variants of composite systems

Composite type	Mass of filler (a rubber, a fibre) (g)	Characteristic – volume ratio (fibre/rubber/matrix) (%)
Composite A	2	0.18/1.85/97.98
Composite B	5	0.44/4.64/94.95
Composite C	10	0.88/9.22/89.90
Composite D	2	1.61/0.72/97.67
Composite E	5	4.03/1.79/94.18
Composite F	10	8.06/3.58/88.36

A mean of recycled fibre and rubber particles was evaluated on a basis of a picture analysis. The evaluation was performed in a microscope Jenavert PA HD with a camera ARTCAM 300 MI. A width of the fibre was 16.32 ± 4.21 μm. The length of the fibre was 2667.47 ± 2079.47 μm. Also Parres et al. (2009) state a huge variability of the length of recycled fibres. The average size of rubber particles was 410.38 ± 146.30 μm.

The hybrid composite systems were tested from two points of view. The first one was the material testing. The reason is an application in a form of a production of self-contained products. The second point of view – in the interaction with the adherent that means the adhesive bond. The reason is a hypothetical utilization as the filled adhesive.

By mixing of the specified matrix – filler phases ratio the composite was made, which was used for the preparation of test specimens according to the specified standards. The composite mixture was left for the total hardening for 330 hours. The secondary hardening of the composite mixture was ensured.

Fifteen test specimens were always prepared for testing. The test specimen was not tested in the case that a defect was ascertained by a visual check. Own testing was performed at 10 pieces of test specimens. The surface roughness was measured on the profilograph Surftest 301 (a value of cut off was 0.8 mm). The surface roughness of the matrix was Ra 0.29 ± 0.05 μm, Rz 1.80 ± 0.42 μm in the bottom part of the specimen and Ra 0.48 ± 0.14 μm, Rz 2.85 ± 0.66 μm in the upper part of the specimen. The surface roughness of the composites A to F was 0.37 ± 0.10 μm, Rz 2.17 ± 0.37 μm in the bottom part of the specimen and Ra 1.20 ± 0.41 μm, Rz 5.90 ± 2.09 μm in the upper part of the specimen.

The theoretical density of the composite systems was calculated on the basis of the physical relationships, the real density was stated on the basis of the ratio of weight and volume of the composites (Berthelot, 1998). An important first-class quality of the composite system – porosity (P) was calculated according to the equation (1):

$$P = \frac{\rho_{The} - \rho_{\mathrm{Re}a}}{\rho_{The}} \qquad (1)$$

where: P – porosity (%); ρ_{The} – theoretical composite density (g cm^{-3}); ρ_{Rea} – real composite density (g cm^{-3}).

The porosity of the composites A to F was 5.6 to 8.1%. The porosity was caused by a presence of air bubbles in the matrix and by the distribution of the filler in the matrix.

Tensile test: The test specimens for the tensile properties determination according to the standard CSN EN ISO 527-1 (Plastics – Determination of tensile properties – Part 1: General principles) were prepared according to the standard CSN EN ISO 3167 (Plastics – Multipurpose test specimens). By the destructive testing the tensile strength and the elongation were determined.

The moulds for casting of the test specimens were made from the material Lukapren N using prepared models. The shape and sizes of moulds meet the corresponding standards (Fig. 2).

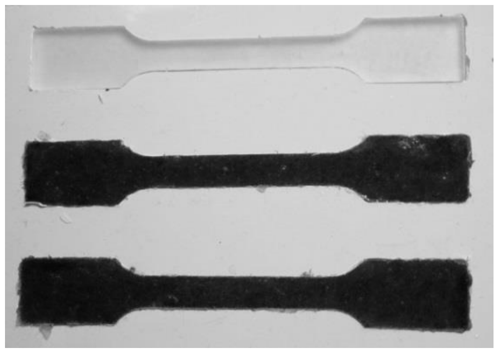


Figure 2. Mould and casts of test specimens for tensile test.

Adhesive bonds: The basis of adhesive bonds laboratory testing was the determination of the tensile lap-shear strength of rigid-to-rigid bonded assemblies according to the standard CSN EN 1465 (Equivalent is BS 1465).

Specimens of all the tested materials were obtained identically – cutting from the semi-products in the hydraulic guillotine sheet metal machine. Laboratory tests of the adhesive bonds were performed using the standard test specimens made according to the standard CSN EN 1465 (dimensions 100 ± 0.25 x 25 ± 0.25 x 1.6 ± 0.1 mm and lapped length of 12.5 ± 0.25 mm) from the constructional plain carbon steel S235J0.

The surfaces of 1.5 mm thick steel sheets were at first blasted using the synthetic corundum of a fraction F80 under the angle of 90°. Using the profilograph Surftest 301 the following values were determined: Ra 1.28 ± 0.12 μm, Rz 6.2 ± 0.86 μm.

Then the surface was cleaned and degreased using acetone and prepared to the application. The surface preparation is important and should guarantee good strength on the boundary adherent/adhesive/adherent (Novák, 2011; Hricová, 2014; Legutko et al., 2014). An even thickness of the adhesive layer was reached by a constant pressure 0.5 MPa. The lapping was according to the standard 12.5 ± 0.25 mm.

The tensile strength and the elongation test (the adhesive bond, the cast of the test specimens) were performed using the universal tensile strength testing machine LABTest 5.50ST (a sensing unit AST type KAF 50 kN, an evaluating software Test&Motion). A speed of the deformation corresponded to 6 mm min^{-1}.

Impact strength: The impact strength was set in an apparatus Dynstat determined for the testing of plastics. The test specimen preparation and impact tests were performed according to the standard CSN 64 0611 (Determination of the impact resistance of rigid plastics by means of Dynstat apparatus). By the destructive testing the impact strength was determined.

RESULTS AND DISCUSSION

Tensile strength of composites showed lower values compared with the matrix (the epoxy adhesive) – see Fig. 3. The composite systems A, B and C showed higher tensile strength than the composite system D, E and F because composites A, B, C consist of smaller percentage of the fibres. It is obvious from the results that the textile fibre acts the tensile strength in a negative way.

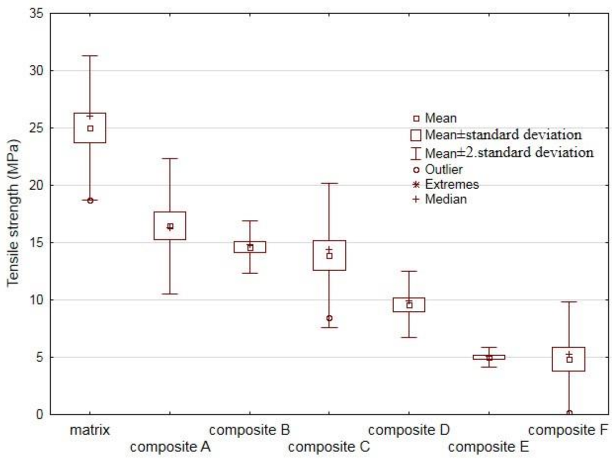


Figure 3. Tensile test – CSN EN ISO 527-1 – tensile strength of matrix and composite systems.

Fig. 4 shows the results of the tests focused on the evaluation of the elongation of the matrix and composite systems. It is obvious from the results that higher ratio of the filler decreases the elongation values.

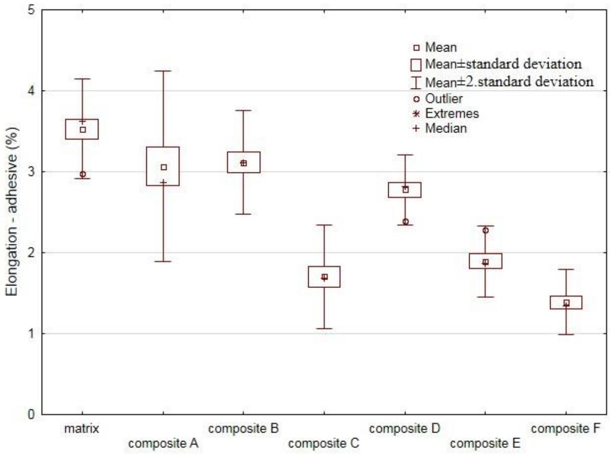


Figure 4. Tensile test - CSN EN ISO 527-1 – elongation of matrix and composite systems.

The tested sets were mutually compared using F-test from the point of view of the influence of various filler concentrations of cast test specimens on the tensile strength and the elongation.

The zero hypothesis H_0 presents the state when there is no statistically significant difference ($p > 0.05$) among tested sets of data from their mean values point of view.

The tensile strength ($p = 0.0000$) and the elongation ($p = 0.0000$) did not certify the hypothesis H_0, so there is the difference among particular tested filler concentrations in relation to the adhesive bond strength and to the elongation in the reliability level 0.05.

It is obvious from the strength results of the adhesive bonds that the composite systems A, B and D reach higher values of the adhesive bond tensile lap-shear ength (Fig. 5) than the matrix. The strength results of the interaction with the adhesive bonded material (the adherent) show different behaviour compared with the results of the tensile test.

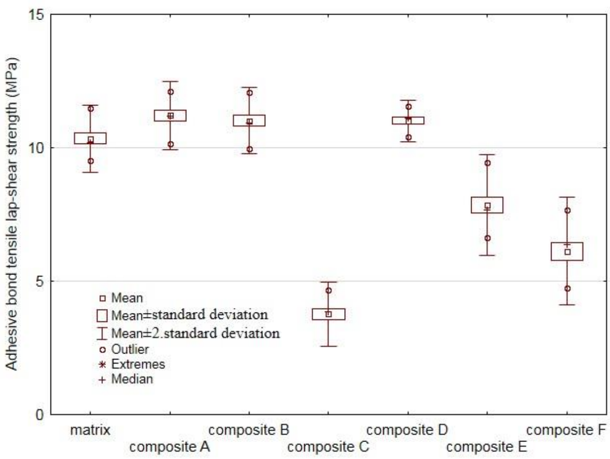


Figure 5. Adhesive bond tensile lap-shear strength – CSN EN 1465.

The composite systems A, B, D and E proved higher values of the adhesive bond elongation (Fig. 6). Higher concentration of the filler in the area of the adhesive bonds acts the resultant tested mechanical properties of the adhesive bond in the negative way (Fig. 6).

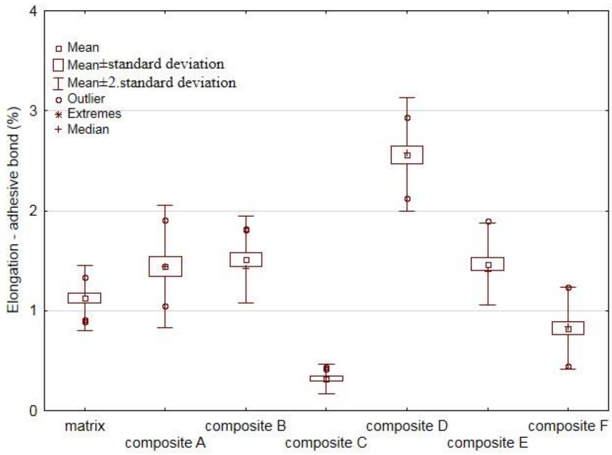


Figure 6. Elongation of adhesive bond – CSN EN 1465.

The tested sets were mutually compared using F-test from the point of view of the influence of various filler concentrations on the tensile lap-shear strength and the elongation of the adhesive bonds.

The zero hypothesis H_0 presents the state when there is no statistically significant difference ($p > 0.05$) among tested sets of data from their mean values point of view. The adhesive bond tensile lap-shear strength ($p = 0.0000$) and the elongation of the adhesive bond ($p = 0.0000$) did not certify the hypothesis H_0, so there is the difference among particular tested filler concentrations in relation to the adhesive bond tensile lap-shear strength and the elongation in the reliability level 0.05.

Fig. 7 shows the results of the impact strength. The positive influence of the filler on the impact strength of the composite system is visible from the results. Higher values of the impact strength are reached at the composites D, E and namely F. These composites contain higher volume ratio of the textile fibres.

The tested sets were mutually compared using F-test from the influence of various filler concentrations on the impact strength point of view.

The zero hypothesis H_0 presents the state when there is no statistically significant difference ($p > 0.05$) among tested sets of data from their mean values point of view. The impact strength ($p = 0.0000$) did not certify the hypothesis H_0, so there is the difference among particular tested filler concentrations in relation to the impact strength in the reliability level 0.05.

Results of Dadfar and Ghadami showed that it came to improving the fracture toughness owing to increasing content of the rubber modifier (Dadfar & Ghadami, 2013). It is possible to agree with the results. The filler in the form of the rubber granules and the textile waste has a similar function.

On the basis of laboratory results it is possible to agree to the statement of Jiao Weizhou et al. that epoxy adhesives are of low impact strength and that they are brittle (Jiao Weizhou et al., 2009).

The presumption was certified that the presence of rubber particles lower the tensile strength. The mechanical properties showed throughout negative trend (Ferreira et al., 2013; Kejval & Müller, 2013; Valášek, 2014; Valášek & Müller, 2014). These conclusions were confirmed by the results of the research. Adhesive bonds with maximum 15 vol.% of the filler do not show the statistically significant fall of the tensile lap-shear strength. The experiment results proved the increase of the adhesive bond strength.

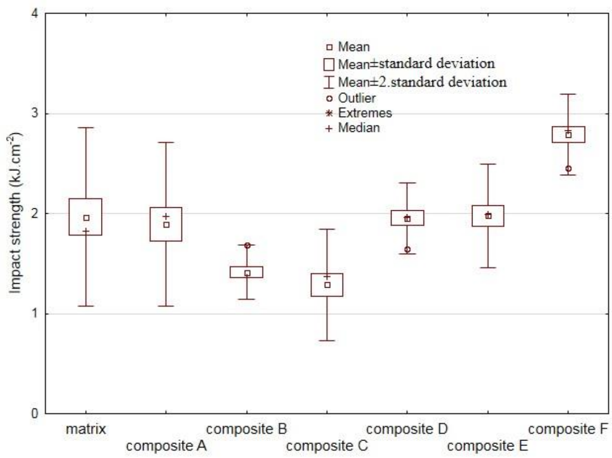


Figure 7. Impact strength – CSN 64 0611.

CONCLUSIONS

The knowledge of applied materials behaviour is the basic presumption of the optimum material choice.

The research results proved the possibility to use the waste textile fibres and the rubber granules in the composite systems on the basis of the reactoplastics.

Following statements can be said in the end:

- The tensile strength was decreasing. The fall of the tensile strength was 80.1% at the application of the filler. The composite systems A, B and C (they contain higher percentage of the rubber) showed the strength fall of 34 till 44%. The composite systems D, E and F showed the fall of 61 till 80%.
- The elongation of the composite systems was of no explicit trend.
- The tensile lap-shear strength showed the increase (the composites A, B and D).
- The impact strength showed increased values at the composite systems which contained higher ratio of the textile fibres.

The composite material can be used at a renovation of machine parts, for a production of new products e.g. a roofing material.

ACKNOWLEDGEMENT. Supported by Internal grant agency of Faculty of Engineering, Czech University of Life Sciences in Prague.

REFERENCES

Dadfar, M.R., Ghadami, F. 2013. Effect of rubber modification on fracture toughness properties of glass reinforced hot cured epoxy. *Materials and Design* **47**, 16–20.

Berthelot, J.M. 1999. *Composite materials – Mechanical engineering series*. Springer: New York, 635 pp.

Fang, Y., Zhan, M., Wang, Y. 2000. The status of recycling of waste rubber. Materials and Design. **22**(2), 123–127.

Ferreira, C.T., Perez, C.A.B., Hirayama, D., Saron, C. 2013. Recycling of polyamide (PA) from scrap tires as composites and blends. *Journal of Environmental Chemical Engineering* **1**, 762–767.

Hricova, J. 2014. Environmentally conscious manufacturing: the effect of metalworking fluid in high speed machining. *Key engineering materials* **581**, 89-94.

Kejval, J. & Müller, M. 2013. Mechanical properties of multi-component polymeric composite with particles of Al2O3/SiC. *Scientia Agriculturae Bohemica* **44**(4), 237–242.

Knapčíková, L., Monka, P., Hloch, S. 2014. Composite Materials Reinforced with Fabric from Used Tyres. Journal of Manufacturing and Industrial Engineering **12**(3-4), 20–24.

Legutko, S., Krolczyk, G., Krolczyk, G. 2014. Quality evaluation of surface layer in highly accurate manufacturing. *Manufacturing technology* **14**, 50–56.

Novák, M. (2011). Surface duality hardened steels after grinding. *Manufacturing technology* **11**, 55–59.

Parres, F., Crespo-Amorós, J.E, Nadal-Gisbert, A. 2009. Mechanical properties analysis of plaster reinforced with fiber and microfiber obtained from shredded Aires. *Construction and Building Materials* **23**, 3182–3188.

Shi Ai Xu, Gong Tao Wang, J., Yiu Wing Mai J. 2013. Effect of hybridization of liquid rubber and nanosilica particles on the morphology, mechanical properties, and fracture toughness of epoxy composites. *Material Science* **48**, 3546–3556.

Valášek, P. 2014. Mechanical Properties of Epoxy Resins Filled with Waste Rubber Powder. *Manufacturing technology* **14**, 632–637.

Valášek, P. & Müller, M. 2014. EPDM rubber material utilization in epoxy composite systems. *Agronomy Research* **12**(1), 291–298.

Valášek, P., Müller, M., Ružbarský, J. 2014. Using recycled rubber particles as filler of polymers. *Applied Mechanics and Materials* **616**, 260–267.

Valášek, P., Žarnovský, J., Müller, M. 2013. Thermoset Composite on Basis of Recycled Rubber. *Advanced Materials Research* **80**1, 1022–6688.

Weizhou Jiao, Youzhli Liu, Guisheng Qi. 2009. Studies on mechanical properties of epoxy composites filled with the grafted particles PGMA/Al2O3. *Composites Science and Technology* **69**, 391–395.

Agronomy Research **13**(3), 709–722, 2015

The theoretical analysis and optimization of the cutting knife-grille pair parameters in the screws

V.V. Pelenko, E.I. Verboloz* and A.V. Baranenko

St. Petersburg National Research University of Information Technologies, Mechanics and Optics, Institute of Refrigeration and Biotechnology, Department of Food Engineering and Automation, 9 Lomonosov St., 191002 St. Petersburg, ITMO University Russia; *Correspondence: elenaverboloz@mail.ru

Abstract. We show how energy-force knife-grille pair parameters depend on their tightening torque which also indicate the node which is the most dynamically and thermally tensed. The research demonstrates that the temperature, at the junction of the knife-grille, varies in the 10°C, and therefore this is a significant factor in the rate increasing of the grids and knives deterioration. From the condition of the screw grille and the knife blade compatibility deformations, we are shown the analytical dependence between the structural and technological characteristics, which allows us to minimize the depreciation value of the grille and the knife, as well as to reduce the energy intensity of the grinding process.

Key words: lattice, the cutter knife, friction, bending, wear, temperature, pressure, distortion, efficiency, performance, etc.

INTRODUCTION

The mathematical model of the screw (Aret et al. 2012; Pelenko et al., 2014c; 2014d) and the results of experiments of the dependence of the energy-force knife-grille pair parameters on their tightening torque indicate that the specified node is the most dynamically and thermally tensed.

The experience in the industrial exploitation of the screws confirms this fact, as the frequent resharpening of the cutting knives and changing the sets of the screws are the common weak point of grinding-cutting equipment (Gorbatov et al., 1977; Chizhikova, 1978; Andrianov, 1982; Pelenko et al., 2006; Pelenko et al., 2008a; 2008b; 2008c; Voronenko et al., 2009).

The research demonstrates that the temperature, at the junction of the knife-grille, varies in the 10 °C, and therefore this is a significant factor in the rate increasing of the grids and knives deterioration. Moreover, uncontrolled increase in torque and a knife blade lattice nut shell lead to the increasing of the blade node parts mutual friction moment and therefore it increases the power consumption by 20–25%. (Pelenko et al., 2014a; 2014b).

Advanced analysis of the essence of physical processes which occur in the operation of the screw type meat grinders shows that the exerted pressure of the raw meat on the bars and a knife reaches $(3 \div 7) \cdot 10^5$ Pa and over. Therefore, based on the terms of the way it is constructed and due to the under the influence of the pressure, the grille is bent outwardly with the screw body and the knife being flexed bulge inward. Thus, the knife, on the peripheral annular surface, while rotating, creates a significant stress concentration at the junction of the knife-grille, which leads to accelerated deterioration of both the knife and the grille as well as a rapid and premature blunting of the knife.

The foregoing leads to the necessity of the correct mathematical description of the interaction process between the knife and the knife grille of the screw, in order to optimize structural and technological parameters of the cutting node.

MATERIALS AND METHODS

For the implementation of the formulated problem, the authors have reviewed the literature materials describing this problem, but no specific analytical solutions on how to fix these circumstances were found. Thus, our problem was solved using the theory of elasticity and strength of materials by making differential equations for the deflection of the knife and the lattice of their analytical solutions by taking into account the temperature of the bending moment, using the compatibility conditions of deformation and lattice cutter knife.

RESULTS

From the perspective view of the theory of elasticity, the knife screw grille is a thin circular perforated annular plate. In the most general case of the consideration, more than two dozen options of the fixing with clamping nut of the knife grille in the screw body should be subjected by the analysis (Vlasov, 1958; Smolentsev, 1963; Timoshenko & Voynovskiy-Krieger, 1963; Tymoshenko, 1965; Weinberg, D.V. & Weinberg, E.D., 1970; Savruk, 1980; Dozhzhel, 1982; Birge & Mavlyutov, 1986; Savruk & Timoshuk, 1987).

Fig. 1 shows 20 fixing options (hinged annular support, the ring rigid closure) and the loading round plate (uniform loading over the entire area, the annular uniform load without bending moment and with him). In addition, the plate can be approximately considered as a continuous disc, a disc with a central hole or as a perforated disc with a central hole.

Of the considered variants of the schemes of the grille fixing we put attention on the most advantageous, from a practical point of view, the case (Fig. 1., Scheme 14), when fixing the annular plate is carried on the inner edge of the ring by the tight clamp, and external influence is uniformly distributed as the load 'q' over the area of the perforated plate and thermal bending moment 'M_T'.

This choice is based on the analysis of the process of the mutual deformation of the grille and the knife during the screw operation. Indeed, in this case, the deformation of the plate is carried out with the bulge going inside the body of the screw, as well as the knife, so it is possible to ensure (with the given temperature of the grille deformation) the equal displacement values of the annular peripheral sections of the grille and the knife blade. It provides a uniform force of the knife and the grille interaction in the place of the junction, the exclusion of the stress concentration and the reducing of the deterioration rate of the grille and the blade, as well as the blunting knife. Besides, there is the decreasing of the energy losses to friction and the thermal load at the junction.

For the realization of the reasonable effective concept of the conditions of the knife and grille interaction we need to solve two problems.

Task 1: We need to define the deformation parameters of the selected option for the grille (Fig. 1, Scheme 14).

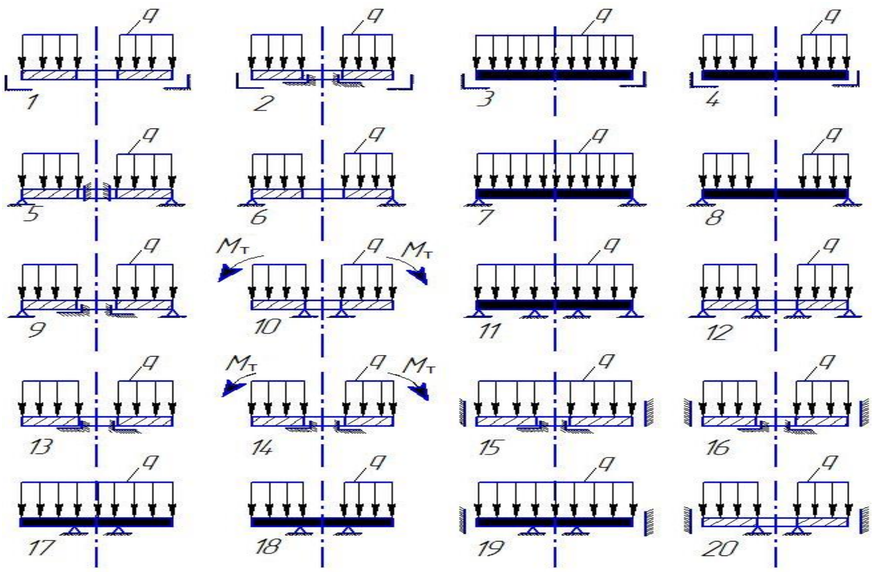


Figure 1. Loading scheme and fix lattice.

Solutions to the problem defined above are known, but the theory of the plates and shells was highly developed and is currently applicable (Vlasov, 1958; Smolentsev, 1963; Timoshenko & Voynovskiy-Krieger, 1963; Tymoshenko, 1965; Weinberg, D.V. & Weinberg, E.D. 1970; Savruk, 1980; Dozhzhel, 1982; Birger & Mavlyutov, 1986; Savruk & Timoshuk, 1987) and it has been widely used in practice, especially in high-tech industries, such as hydro, turbine construction, shipbuilding, aviation, astronautics. However, specific solutions to these problems are similar to those stated above, with mentioned fixing conditions, had not been found.

For the development of the desired mathematical model of the screw grille bending, we consider the calculation scheme that is shown in Fig. 2.

The proposed scheme shows a circular ring perforated plate (Fig. 2, pos. A-d) with a rigid closure on the inner edge of the ring (Fig. 2, pos. a, c, d) in the conditions of the transverse load q which is uniformly distributed over the grid area (Fig. 2, pos. a-D). And the bending moment M_t (Fig. 2, pos. a-d) which is caused by thermal deformation, linearly distributed over the plate thickness h (Fig. 2, pos. d) due to the frictional heating in the knife-grille junction.

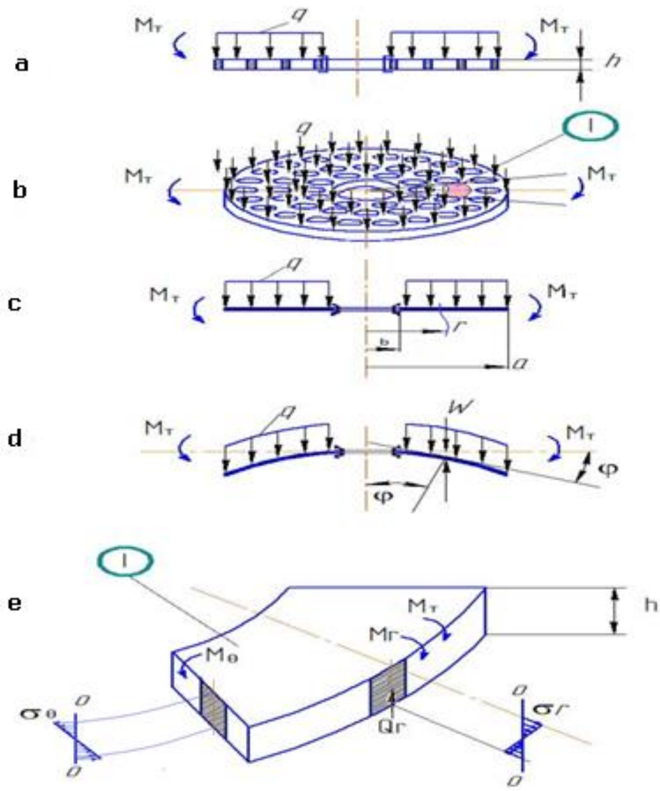


Figure 2. Scheme of loading and deformation of the lattice.

As it is known (Timoshenko & Voynovskiy-Krieger, 1963), the equilibrium equation for the plate element (Fig. 2, Pos. D) can be written as following:

$$\frac{d^2\varphi}{dr^2} + \frac{1}{r}\frac{d\varphi}{dr} - \frac{\varphi}{r^2} = -\frac{Q}{D} \tag{1}$$

or, considering the dependence of *φ=φ(w):*

$$\varphi = -\frac{dW}{dr}, \tag{2}$$

in another form:

$$\frac{d^3W}{dr^3} + \frac{1}{r}\frac{d^2W}{dr^2} - \frac{1}{r^2}\frac{dW}{dr} = \frac{Q}{D}, \tag{3}$$

where: r – the distance from the point under consideration to the center of the plate, m; φ – the rotation angle of the normal to the section under consideration with the coordinate 'r'; Q – cutting force per length unit of the cylindrical section of the radius 'r', N m; D – cylindrical rigidity of the perforated plate, N m.

Equations (1) and (3) may be prescribed in a more compact and easy to integrate form:

$$\frac{d}{dr}\left[\frac{1}{r}\frac{d}{d^2}(ry)\right] = -\frac{Q}{D}, \tag{4}$$

or

$$\frac{d}{dr}\left[\frac{1}{r}\frac{d}{dr}\left(r\frac{dW}{dr}\right)\right] = \frac{Q}{D}, \tag{5}$$

From the equilibrium equation above, we can obtain the dependence of $Q = Q(q)$ for a plate with an external load 'q" which is distributed over the area. It should be mentioned that in the plate has a radius center hole 'b':

$$Q \cdot 2\pi r = \int_b^r q 2\pi r dr\,. \tag{6}$$

Under outward transverse load which is evenly distributed over the area of the plate $q = const$, from the equilibrium equation (6) we obtain:

$$Q = \frac{q}{2}(r - b)\,. \tag{7}$$

Now the equation of the deflection of the plate (5) takes the form:

$$\frac{d}{dr}\left[\frac{1}{r}\frac{d}{dr}\left(r\frac{dW}{dr}\right)\right] = \frac{q}{2D}(r - b)\,. \tag{8}$$

Integrating this equation for three times, we get:

$$W = \frac{qr^4}{64D} - \frac{qbr^3}{18D} + \frac{c_1 r^2}{4} + c_2 \ln r + c_3\,. \tag{9}$$

The integration constants c_1, c_2, c_3 found from the fixing plate condition.

1. At the inner annular edge of the round plate $(r = b)$ there is no movement $W = 0$; as well as the angle of the rotation of the section $\varphi = -\frac{dW}{dr} = 0$, so we can write for the displacement:

$$W|_{r=b} = -\frac{23qb^4}{576D} + \frac{c_1 b^2}{2} + c_2 \ln b + c_3 = 0\,. \tag{10}$$

Given that

$$\frac{dW}{dr} = \frac{qr^3}{16D} - \frac{qbr^2}{6D} + \frac{c_1 r}{2} + \frac{c_2}{r}, \tag{11}$$

for the rotation angle in the cross section $r = b$, we obtain:

$$\varphi|_{r=b} = -\frac{dW}{dr}|_{r=b} = \frac{-5qb^3}{48D} + \frac{c_1 b}{2} + \frac{c_2}{b} = 0. \quad (12)$$

2. On the outside, the plate annular round edge ($r=a$), that is free from the connections, only temperature bending moment M_T is applying, so we can write:

$$M_r|_{r=a} = M_T \quad (13)$$

where M_r – a radial bending moment intensity per length unit of the circular cylindrical section of the the annular plate, $H\ m\ m^{-1}$.

As it is known [13 ÷ 9] the radial bending moment is written in the form:

$$M_r = -D\left(\frac{d^2W}{dr^2} + \frac{\nu}{r}\frac{dW}{dr}\right), \quad (14)$$

where ν – the Poisson's ratio for the material of the plate.

For the curvature of the plate according to (11) the following relation:

$$\frac{d^2W}{dr^2} = \frac{3qr^2}{16D} - \frac{qbr}{3D} + \frac{c_1}{2} - \frac{c_2}{r^2}. \quad (15)$$

Substituting (11) and (15) into the equation (14) yields:

$$M_r = -\frac{qr^2}{16}(3+\nu) + \frac{qbr}{6}(2+\nu) - c_1(1+\nu)\frac{D}{2} + c_2(1-\nu)\frac{D}{r^2}. \quad (16)$$

In view of (13) we can write:

$$M_T = -\frac{qa^2}{16}(3+\nu) + \frac{qba}{6}(2+\nu) - c_1\frac{D}{2}(1+\nu) + c_2\frac{D}{a^2}(1-\nu), \quad (17)$$

Solving the system of three equations (10) and (12), (17) with three unknowns, we find the integration constants c_1, c_2, c_3.

$$c_1 = \frac{5qb^4(1-\nu) + 8qba^3(2+\nu) - 3qa^4(3+\nu) - 48M_T a^2}{24D[a^2(1+\nu) + b^2(1-\nu)]} = c_1(b, M_T) \quad (18)$$

$$c_2 = \frac{5qb^4(1+\nu) - 8qb^3a^3(2+\nu) + 3qb^2a^4(3+\nu) + 48M_T a^2 b^2}{48D[a^2(1+\nu) + b^2(1-\nu)]} = c_2(b, M_T) \quad (19)$$

$$c_3 = \frac{23qb^4}{576D} - \frac{5qb^4[b^2(1-\nu) + a^2(1+\nu)\ln b]}{48D[a^2(1+\nu) + b^2(1-\nu)]} - \frac{8qb^3a^3(2+\nu)(1-\ln b)}{48D[a^2(1+\nu) + b^2(1-\nu)]} +$$
$$+ \frac{3qb^2a^4(3+\nu)(1-\ln b)}{48D[a^2(1+\nu) + b^2(1-\nu)]} - \frac{M_T a^2 b^2(1-\ln b)}{D[a^2(1+\nu)b^2(1-\nu)]} = c_3(b, M_T) \quad (20)$$

When structuring latter relation, after the numbering of each successive summand in c_3, we write:

$$c_3 = c_3(b, M_T) = c_{31}(b) - c_{32}(b) - c_{33}(b) + c_{34}(b) - c_{35}(b, M_T)\,,$$

where:

$$c_{31}(b) = \frac{23qb^4}{576D}\;;$$

$$c_{32}(b) = \frac{5qb^4[b^2(1-\nu) + a^2(1+\nu)\ln b]}{48D[a^2(1+\nu) + b^2(1-\nu)]}\;;$$

$$c_{33}(b) = \frac{qb^3a^3(2+\nu)(1-\ln b)}{6D[a^2(1+\nu) + b^2(1-\nu)]}\;;$$

$$c_{34}(b) = \frac{qb^2a^4(3+\nu)(1-\ln b)}{16D[a^2(1+\nu) + b^2(1-\nu)]}\;;$$

$$c_{35}(b, M_T) = \frac{M_T a^2 b^2(1-\ln b)}{D[a^2(1+\nu)b^2(1-\nu)]}\;;$$

The necessity for such structuring is caused by the need to assess the accentuation effect on the individual values diameter deflection of the central hole of the grille as well as the temperature of the bending moment.

For the further functional dependence between the thickness of the knife blade $\delta_н$, and blade grille h, we introduce, for the constants of the integration, the modified expressions in accordance with the dependencies:

$$c_i = \frac{B_i}{D} \quad (21)$$

Inserting the obtained values of c_1, c_2, c_3 in relation (9), we obtain the general solution for the bending of the circular ring grille in the form of:

$$W = \frac{qr^4}{64D} - \frac{qbr^3}{18D} + c_1(b, M_T)\frac{r^2}{4} + c_2(b, M_T)\ln r + c_3(b, M_T)$$

or

$$W = \frac{1}{D}\left[\frac{qr^4}{64} - \frac{qbr^3}{18} + B_1(b, M_T)\frac{r^2}{4} + B_2(b, M_T)\ln r + B_3(b, M_T)\right] \quad (22)$$

Taking into account that we are interested in the maximum values of the deflections which are reached in the coordinates of the ring $r = a$, finally we obtain the desired quantity in the form of:

$$W_{max_p} = W|_{r=a} = \frac{qa^4}{64D} - \frac{qba^3}{18D} + c_1(b, M_T)\frac{a^2}{4} + c_2(b, M_T)\ln a + c_3(b, M_T) \qquad (23)$$

The first feature of this solution is that when we are using the obtained ratio to estimate the deflection of the perforated plate, it is necessary to consider the influence of the significant amount of the holes in the output of the screw grille on the cylindrical rigidity value, which substantially reduce the value of the moment of the resistance to the bending.

Considering the macro deformation processes and taking into account the symmetry of the arrangement of the perforation holes, the additivity of the moment of inertia in the bending, as well as neglecting the edge effects of the local stresses concentration at the boundaries of the holes, the corrected value of the cylindrical rigidity can be written as follows:

$$D = \frac{Eh^3}{12(1-\nu^2)}\left(\frac{a - n_r d - b}{a}\right), \qquad (24)$$

where: n_r – number of holes in the perforated section of the annular circular plate (grille); d – diameter of the holes of the screw output grille, m; E – Young's modulus of the material of the plate, Pa; h – thickness of the grille (the plate), m.

Taking into account the ratios (23) and (24), the equation (22) can be written in the form which is convenient for analysis:

$$W_{max_p} = \frac{12(1-\upsilon^2)a}{E(a - n_r d - b)h^3}\left[\frac{qa^4}{64} - \frac{qba^3}{18} + B_1\frac{a^2}{4} + B_2\ln a + B_3\right]. \qquad (25)$$

The second feature of the obtained mathematical model of the perforated circular ring grille deformation is a consideration of the effect of the temperature bending moment M_T on the plate deflection.

In general, the temperature dependence of the bending moment on the temperature difference at the outside and the inside of the screw output grille can be written as:

$$M_T = \frac{E}{1-\nu}\int_{-h/2}^{h/2} \alpha \Delta T_{(z)} Z dZ, \qquad (26)$$

where: α – the coefficient of the thermal expansion of the plate material, K^{-1}.

Suggesting that the temperature distribution T in the plate thickness is linear, we can write:

$$\Delta T = \frac{T_B - T_H}{h} Z \,,$$

where: T_B, T_H – the temperature of the inner and the outer surfaces of the plate, K.

Substituting ΔT in (26) and integrating, we obtain the desired value of the temperature bending moment in the form of:

$$M_T = \frac{E\alpha(T_B - T_H)}{12(1-\nu)} h^2 \qquad (27)$$

DISCUSSION

In order to calculate the obtained mathematical model (23) of the annular circular perforated plate deflection, under a uniformly effect of the distributed over the area lateral load and temperature bending moment, which is applied on the outer ring contour, we use the following parameters:

$q = 3{\cdot}10^5$ Pa; $b = 5{\cdot}10^{-3}$ m; $a = 30{\cdot}10^{-3}$ m; $\nu = 0{,}3$; $E = 2{,}1{\cdot}10^{-11}$ Pa; $h = 4{\cdot}10^{-3}$ m; $d = 3{\cdot}10^{-3}$ m; $n_r = 3$; $T_v = 301$ K; $T_n = 296$ K; $\alpha = 10^{-5}$ K^{-1}.

According to the equation (27), we determine the value of the temperature bending moment as following:

$$M_T = \frac{2.1 \cdot 10^{11} \cdot 5 \cdot 10^{-3}}{12(1-0{,}3)} 9 \cdot 10^{-6} = 11.25 \text{ H}$$

The cylindrical rigidity of the plate is, according to the ratio (24), as follows:

$$D = \frac{2.1 \cdot 10^{11} \cdot (4 \cdot 10^{-3})^3 \cdot (30 \cdot 10^{-3} - 3 \cdot 3 \cdot 10^{-3} - 5 \cdot 10^{-3})}{12(1-0{,}3^2) \cdot 30 \cdot 10^{-3}} = 656.41 \text{ H} \cdot \text{m}$$

For the convenience calculation of the deflection we find the characteristic value of the denominators in the c_1, c_2, c_3:

$$[a^2(1+\nu) + b^2(1-\nu)] = [(30 \cdot 10^{-3})^2(1+0.3) + (5 \cdot 10^{-3})^2(1-0.3)] = \\ = 11.7 \cdot 10^{-4} + 0.175 \cdot 10^{-4} = 11.875 \cdot 10^{-4}$$

Reference values are the values of:
$\ln b = \ln(5{\cdot}10^{-3}) = -5.298$
$\ln a = \ln(30{\cdot}10^{-3}) = -3.507$

The ratios (18–21) give:

$C_1 = –0.1147$; $B_1 = –75.290$;
$C_2 = 1.4635 \cdot 10^{-6}$; $B_2 = 960.656 \cdot 10^{-6}$;
$C_{31} = 0.0114 \cdot 10^{-6}$; $C_{32} = –0.1549 \cdot 10^{-6}$; $C_{33} = 3.136 \cdot 10^{-6}$;
$C_{34} = 10.124 \cdot 10^{-6}$; $C_{35} = 2.045 \cdot 10^{-6}$;
$C_3 = 5.109 \cdot 10^{-6}$; $B_3 = 3353.6 \cdot 10^{-6}$.

The maximum deflection value of the plate we calculate as the following mention in Formula (23)

$$W_{max_p} = \frac{3 \cdot 10^{+5} \cdot 81 \cdot 10^{-8}}{64 \cdot 656.41} - \frac{3 \cdot 10^5 \cdot 5 \cdot 10^{-3} \cdot 27 \cdot 10^{-6}}{18 \cdot 656.41} +$$
$$+(-0.1147)\frac{9 \cdot 10^{-4}}{4} = +1.4635 \cdot 10^{-6} \cdot (-3.507) + 5.109 \cdot 10^{-6} =$$
$$= 5.784 \cdot 10^{-6} - 3.42 \cdot 10^{-6} - 25.8075 \cdot 10^{-6} -$$
$$-5.132 \cdot 10^{-6} + 5.109 \cdot 10^{-6} = 23.466 \cdot 10^{-6}(\mathrm{m}) \cong 23.5 \text{ mkm}$$

Task 2. Determine the deflection of the knife blade.

The second problem is not so difficult and its solution can be broken down into (Bezukhov, 1968; Pisarenko et al., 1975; Sokolov, 1983) two components.

The first component of the movement f_1 is caused by the knife blade bending, which is under the action of the uniformly distributed over the surface load (pressure of raw meat):

$$f_1 = \frac{q \cdot S(a-b)^4}{8EJ}, \tag{28}$$

where: S – the blade width, m; J – The moment of inertia of the cross section of the blade in the bending, m^4;

The value of φ is defined by the well-known (Bezukhov, 1968) ratio:

$$J = \frac{S\delta_H^3}{12}, \tag{29}$$

Here $\delta_н$ – the thickness of the knife blade, m.

Then the expression (28), for the maximum deflection, can be written as following:

$$f_1 = \frac{3q(a-b)^4}{2E\delta_H^3}, \tag{30}$$

The second component of the movement is caused by the bending of the blade which is under the influence of the temperature bending moment.

The feature of the deformation of the knife blade is the omni directional movements owing to the load $f_1 > 0$ and the temperature bending moment: $f_2 < 0$.

Thus, we write for M_T (Birger & Mavlyutov, 1986):

$$f_2 = \int_b^a \int_b^a \frac{M_T}{EJ} drdr = \frac{-M_T}{2EJ} (a-b)^2 \,. \tag{31}$$

The total deflection of the blade takes the value:

$$f = f_1 + f_2 = \frac{qS(a-b)^4}{8EJ} - \frac{M_T S(a-b)^2}{2EJ}$$

or

$$f = \frac{(a-b)^2 S}{2EJ}\left[\frac{q}{4}(a-b)^2 - M_T\right]. \tag{32}$$

After the solution to the second problem (32), we can write the conditions of the compatibility of the grille and the knife blade deformation, providing the uniform internal stresses in their junction, and, thus, the minimum deterioration rate will be as following:

$$f \; = W_{max_p}. \tag{33}$$

$$\frac{(a-b)^2 S}{2EJ}\left[\frac{q}{4}(a-b)^2 - M_T\right] = W_{max_p}$$

Taking into account Formula (29), we obtain the ratio for the calculation of the required knife blade thickness:

$$\frac{3(a-b)^2}{2E\delta_H^3}[q(a-b)^2 - 4M_T] = W_{max_p} \tag{34}$$

$$\delta_H = \sqrt[3]{\frac{3(a-b)^2[q(a-b)^2 - 4M_T]}{2EW_{max_p}}} \tag{35}$$

Calculations for the same kind of materials of the grille and the knife give the value of:

$$\delta_H = \sqrt[3]{\frac{3 \cdot 625 \cdot 10^{-6}[3 \cdot 10^5 \cdot 625 \cdot 10^{-6} - 4 \cdot 11.25]}{2 \cdot 2.1 \cdot 10^{11} \cdot 23.5 \cdot 10^{-6}}} = \sqrt[3]{2707 \cdot 10^{-11}}$$
$$= \sqrt[3]{27.07} \cdot 10^{-3} = 3 \cdot 10^{-3} m = 3 \text{ mm}$$

Thus, to ensure the same deformations of the cutter grille and the knife blade, that are the equidistant elastic lines, which can ensure the minimal deterioration and the minimal knife blunt, should be used the mutual ratio (25), expressed in the terms of 'h' and (34) in the general case, to write functional iteration (relative M_T and B_i) dependence $\delta_н = \delta_н(h)$:

$$\delta_H = \frac{h}{2}\sqrt[3]{\frac{(a-b)^2[q(a-b)^2 - 4M_T](a - n_r d - b)}{a(1-\nu^2)\left[\frac{qa^4}{64} - \frac{qba^3}{18} + B_1\frac{a^2}{4} + B_2 \ln a + B_3\right]}}\,. \quad (36)$$

In actual load conditions of the cutter grille and the knife of the screw, the values $\delta_н$ and h, as numerical calculations, are close.

Considering the special case when we can neglect the presence of the thermal bending moment ($M_T = 0$), the center hole ($b = 0$) and the grille perforation ($n_r = 0$), from the ratio (36) we obtain:

$$\delta_н = 2.06\ h.$$

CONCLUSION

The mathematical model of the process of the raw meat grinding in the screw (Pelenko & Kuzmin, 2009; Pelenko et al., 2012; Pelenko et al., 2013) allows us to estimate the level of the influence of each of more than 20 designs – technology and kinematic factors on the efficiency (productivity) of the meat grinder.

We were able to demonstrate that It was revealed that one of the factors affecting the quality of the grinding process is the tightening torque of the screw output grille, the value of which at this point is only calculated qualitatively. It results in the rapid blade blunting and depreciation of the knife – grille pair.

The methods of system analysis were able to provide the optimal design scheme of the screw output grille fixing (Scheme 14).

The mathematical model of the deflection of the perforated grille has been developed, that grill is loaded by the uniformly distributed mechanical stress across its surface and the thermal bending moment on the outer annular border. The equation of the cutting blade elastic line of the screw knife has been generated.

Based the condition of the screw grille and the knife blade compatibility deformations, we obtained the analytical dependence between the structural and technological characteristics, which allowed us to minimize the depreciation value of the grille and the knife, as well as to reduce the energy intensity of the grinding process.

REFERENCES

Andrianov, A. 1982. The reliability improving of the meat grinders (screws) based on the analysis of technological and operational impacts. *Abstract of the diss. on the degree of candidate of technical sciences. Moscow Technical Institute of the meat and dairy industry*, Moscow, 18 pp. (in Russian).

Aret, V.A., Verboloz, E.I., Pelenko, V.V., Pelenko, F.V. 2012. The external friction in the modeling of the screw extruder work. *Scientific Magazine ITMO. Series: Processes and equipment for food production* **1**, 10. (in Russian).

Bezukhov, N.I. 1968. *The bases of the theory of the elasticity, the plasticity and the creep*. Higher. School, Moscow, 512 pp. (in Russian).

Birger, I.A. & Mavlyutov, R.R. 1986. *The strength of materials*: Study guide. Science. Ch. Ed. Physics-mat.lit., Moscow, 560 pp. (in Russian).

Chizhikova, T.V. 1978. The Increasing of the durability prospects and the operational reliability of the cutting parts of the cutting meat machines. *Meat Industry of the USSR* **38**, 27–31 (in Russian).

Dozhzhel, L.G. 1982. *The joists, plates and the covers*. Science. Ch. Ed. Physics-mat.lit., Moscow, 568 pp. (in Russian).

Gorbatov, V.M., Rud, A.N., Rud, V.N. 1977. The restoration of the screw knives with the process of the welding of the work surfaces. *Meat Industry of the USSR* **2**, 37–38 (in Russian).

Pelenko, V.V., Zuev, N.A., Olshevskiy, R.G., Azaev, R.A., Shibanov, A.I., Kuzmin V.V. 2008a. The review of the foreign screws and faucets for the meat / [electronic resource]: an electronic scientific magazine '*Processes and equipment for food production.*' *– E-zine. – St. Petersburg: SPbGUNiPT* **1**. – March 2008 (in Russian).

Pelenko, V.V. Zuev, N.A., Olshevskiy, R.G., Azaev, R.A., Kuzmin, V.V. 2008b. The fundamental features of the cutting food process with the blade tool / [electronic resource]: an electronic scientific magazine *'Processes and equipment for food production.' – E-zine. – St. Petersburg: SPbGUNiPT* **1**. – March 2008 (in Russian).

Pelenko, V.V., Zuev, N.A., Bobrov, S.V., Malyavko, D.P., Malyugin, G.I., Tsuranov O.A. 2014a. The problems of the development of the theory and practice of the industrial production of the grinding-cutting equipment // *Scientific Journal ITMO. Series: Processes and equipment for food production* **1** (17), 45. (in Russian).

Pelenko, V.V., Zuev, N.A., Olshevskiy, R.G., Ivanenko, V.P., Kryisin G.A. 2014b.The analytical and experimental evaluation of the influence of the friction torque in the kinematic pair knife-grille on the grinder productivity. *Scientific Magazine ITMO. Series: Processes and equipment for food production* **4**, 169–181. (in Russian).

Pelenko, V.V., Aret, V.A., Kayka, A.H., Tarabanovskiy, F.G., Olshevskiy, R.G., Bobrov S.V., Zuev N.A. 2013.The development of a mathematical model of the process of the raw meat grinding in the screw. *Scientific Magazine ITMO. Series: Processes and equipment for food production* **2**, 49. (in Russian).

Pelenko, V.V., Malyavko, D.P., Bobrov, S.V., Olshevskiy, R.G., Zuev, N.A., Tarabanovskiy F.B. 2012. The substantiation of the shape and size of the holes in the grille output of the screw - grinder. *Scientific Magazine ITMO. Series: Processes and equipment for food production* **1**, 46 (in Russian).

Pelenko, V.V. & Kuzmin, V.V. 2009.The optimization of the cutting edge form of the knife blade for the screw during grinding the refrigerated or defrosted raw meat. *News of Educational institutions. Food technology* **1**, .95–96. (in Russian).

Pelenko, V.V., Ivanenko, V.P., Olshevskiy, R.G. 2014c. The experimental determination of the energy amount to overcome the output grille torque of the screw /Collection of the scientific works of professors and graduate // *Problems and priority areas of the development of the commodity research, technology, organization and food hygiene.* SPB GTEU, Saint Petersburg. (in Russian).

Pelenko, V.V., Ivanenko, V.P., Olshevskiy, R.G. 2014d. The mathematical model of the grinding process in the screws/Collection of the scientific works of professors and graduate // *Problems and priority areas of the development of the commodity research, technology, organization and food hygiene.* SPB GTEU, Saint-Petersburg. (in Russian).

Pelenko, V.V., Zuev, N.A., Dmitrenko, M.I., Azaev, R.A., Olshevskiy, R.G., Krasnov, I.B. 2006. The development of the dynamic characteristics measurement system of the grinding-cutting equipment. *Scientific Magazine ITMO. Series: Processes and equipment for food production* **2**, 8–10. (in Russian).

Pelenko, V.V., Aret, V.A., Vasilev, D.A., Morozov, E.A., Pelenko, F.E. 2008c. The moving of the processing vegetable raw materials products in the processing machines. *News of Educational institutions. Food technology* **5**–**6**, 77. (in Russian).

Pelenko, V.V., Shirshikov, A.M., Kryisin, A.G. 2000. The criteria approach to the dynamic improvement of the machines. *Machine Builder* **3**, 39. (in Russian).

Pisarenko, G.S., Yakovlev, A.P., Matveev, V.V. 1975. *Handbook of the strength of materials.* 'Naukova Dumka', Kiev, 704 pp. (in Russian).

Savruk, M.P. 1980. The plane elasticity problems for the multiply connected domain with holes and cracks. *Fiz.–meh. Mechanics of Materials* **16**, 51–56 (in Russian).

Savruk, M.P. & Timoshuk, N.V. 1987.The plane problem of the elasticity theory for a piecewise-homogeneous semi-infinite plate with elastic inclusions and cracks. //*Fiz. –meh. Mechanics of Materials* **23**, 55–61 (in Russian).

Smolentsev, Y.A. 1963. The calculation of the perforated thin-walled cylinders and plates. // *Chemical Engineering* **4**, 23–28.

Sokolov, V.I. 1983. *The bases of the design and the construction of the parts and units of the food processing equipment*. Engineering. Moscow, 447 pp. (in Russian).

Timoshenko, S.P. & Voynovskiy- Krieger, S. 1963. *Theplates and the covers*. The statepubl. of Physics-mat.lit., Moscow, 636 pp. (in Russian).

Tymoshenko, I.A. 1965. *The strength of materials*. Science. Ch. Ed. Physics-mat.lit., Moscow, 480 pp. (in Russian).

Vlasov, V.Z. 1958. *Thethinwall-spatial systems*. State publishing house of literature of the building, architecture and building. Materials. Moscow, 502 pp. (in Russian).

Voronenko, B.A., Pelenko, V.V., Polyakov, S.V., Markov, V.N. 2009.The statement and solution of the cleaning tasks for food environments. *News of Educational institutions. Food technology* **1**, 78–80. (in Russian).

Weinberg, D.V. & Weinberg, E.D. 1970. *The calculation of the plates*. 'Budivelnik', Kiev, 436 pp. (in Russian).

Agronomy Research **13**(3), 723–731, 2015

Polymeric microparticles composites with waste EPDM rubber powder

P. Valášek

Czech University of Life Sciences Prague, Department of material science and manufacturing engineering, Kamýcká 129, CZ-16521, Prague, Czech Republic; e-mail: valasekp@tf.czu.cz

Abstract. Polymeric materials filled with inorganic microparticles can be described as polymeric microparticle composites. These materials combine the various mechanical, physical and chemical properties of different phases. Waste microparticles can also be used as filler. Inclusion of these waste microparticles can optimize the required mechanical properties and decrease the price. This paper describes the possibilities of using recycled waste rubber powder in polymer composite systems. The aim of the experiment was to quantify the mechanical properties of epoxy resin (Glue Epox Rapid – with increased speed of hardening) and polyurethane (Sika Power – resin based on polyol) filled with recycled EPDM rubber powder (29 μm) gained from a Czech company and to describe the changes in the mechanical qualities with a changeable amount of microparticles. Composites were prepared with a different filler concentration of resins (5–35 volume percent). Cohesive and adhesive characteristics were chosen for the quantification of the system. Adhesive strength to the steel adherent was tested by means of lap-shear tensile strength. Cohesive strength was tested by means of tensile strength. Hardness was measured by the Shore D method. The described use of waste material is inexpensive and offers the possibility of recycling material. The application of waste EPDM powder in the area of resins is a benfitial way of material usage which should be preferred.

Key words: epoxy resin, lap-shear tensile strength, material utilization, tensile strength.

INTRODUCTION

The main damaging mechanism of reactive resin is the formation of isolated microcracks and their spreading. These microcracks often appear at the interface between particles and resin or in the area where air pores occur. An important aspect from the point of view of the strength of filled reactive plastics is adhesion defined by intermolecular forces at the interface between resin and soaked material. Cohesive characteristics are also very important; they define the strength of the mixture itself (strength at the interface between microparticles and resin). The optimal processes of hardening regarding the epoxy resin as well as the duration of the process are significantly affected by the soaking of the additive and theintermediate phase of the interaction according to Li et al. (2012). During the cross-linking process when reactive resin forms a matrix it is important to respect the technological requirements of the resin's producer – primarily to observe the prescribed hardening temperature and time. Adhesion can be observed both at the interface of the filling material and resin and on the boundary of the composite system and the adherent, to which the system is applied (Rudawska, 2008).

The utilization of rubber powder for optimizing the properties of epoxy resin is described by Schoberleitner et al. (2013). Subramaniyan et al. (2012) used recycled rubber particles for improvement of the mechanical properties of a hybrid composite – polyurethane resins filled with fibre (Kenaf). The utilization of recycled rubber along with fibres is described by Cerbu & Curtu (2011), who increased the impact resistance of the composite on the basis of epoxy resin with glass fibres and recycled rubber particles. Zhao et al. (2011) describe that waste rubber particles can be also used for thermoplastic materials (EPDM particles). The authors performed experiments to assess the effect of the particles on the mechanical properties of polypropylene. The results prove that it is possible to improve the tensile strength of filled polypropylene with 20 vol.% of EPDM particles, as well as the endurance against impact. Serenko et al. (2005) claim that the use of rubber microparticles in a polymer matrix leads to the formation of defects, i.e., microcracks, which grow in the direction of the system's tensile stress.

Mutual interaction between reactive resins, for instance in the form of epoxy or polyurethane resins, and additives on the secondary raw material basis forms new materials. These materials can have remarkable mechanical characteristics, whose definition is crucial for thedetermination of applied areas. The utilization of microparticle additives on the basis of reusable materials (secondary materials) has been discussed in the papers of many authors. It is an economically favourable and sensitive way of recycling that should be preferred among other methods.

The aim of the experiment is to describe the options for the utilization of anorganic microelements on the basis of reusable materials (EPDM of rubber powder) emerging during waste recycling in interaction with reactive resin. The following part of the experiment explores adhesive and cohesive characteristics in view of tensile strength and lap-shear tensile strength. The goal is also to verify the hypothesis about the influence of microparticle concentration in reusable material expressed in volume percentages on the resulting mechanical properties of resin.

MATERIALS AND METHODS

Preparation of test samples

The matrix was represented by the two-component epoxy resin Glue Epox Rapid and the two-component polyurethane resin Sika Power 7723. Epoxides are suitable for the field of agriculture, as they are resistant to degradation (Cierna & Ťavodová, 2013; Müller, 2013a; Müller, 2013b). Test samples were created with 5–35 vol.% (v_{pr}) of the filler (EPDM rubber powder) in the matrix. The filler was the EPDM rubber powder. This type of materials (secondary raw materials) are produced by Gumoeko, s.r.o. (Czech Republic), that specializes in recycling old and defective car and lorry tires and EPDM rubber used in cars (in accordance with the Waste Catalogue of the Czech Republic it is a non-hazardous waste). EPDM rubber (see Fig. 1) is used in the production of tubes intended for the distribution of liquids (fluids, brake fluid, etc.). EPDM rubber is very resistant to lasting deformation and also has a wide temperature range of use; it is resistant to soaking in addition to having a good resistance to polar fluids and mineral acids. Gumoeko, s.r.o. processes the waste on the technological line, which produces rubber granules fractioned to the required size with a sieve.

Figure 1. Product from the production line: EPDM rubber powder.

The resin and filler mixture was prepared by mechanical mixing. The formation of air bubbles during mechanical mixing was prevented by using an ultrasonic vat. The test samples were cast into forms made of silicone rubber and hardened according to the technological requirements of the resins' producer (see Fig. 2). The porosity was set based on the difference between the theoretical and real density which characterizes the quality of composite systems.

Figure 2. Models for forming, forms, test samples (for testing hardness, tensile strength, abrasive wear).

Laboratory tests

The standard CSN EN ISO 868 was used as a guide for determining the hardness of the composite systems. The hardness of test samples was also determined via the Shore D method. The dimensions of the tested specimens were 35 x 25 x 9 mm.

Test samples meant for determing cohesive strength by means of tensile strength were prepared according to the requirements of the standard CSN EN ISO 3167. Specimens were tested on a universal testing machine. The speed of cross beam motion was 6 mm min^{-1}. The settings for the tensile characteristics test were in accordance with the standard CSN EN ISO 527.

Overlapping assemblies were made for the lap-shear strength test in the boundary adherent-filled system according to the standard CSN EN 1465. The surface of the 1.5 mm thick steel sheets (S235J0), onto which the composite system (filled resin) was applied, was at first blasted using the synthetic corundum of the fraction F80 under the angle of 90°. In this way the average surface roughness of Ra = 1.44 ± 0.21 μm, Rz = 9.1 ± 0.34 μm was reached. Then the surface was cleaned and degreased using perchlorethylene. Surface preparation is important and should guarantee the good strength of the boundary adherent (Affatato et al. 2013; Novák 2011).

Two-body abrasion was tested on a rotating cylindrical drum device with an abrasive cloth (grain size P220; Al_2O_3 grains) according to the standard CSN 62 1466. On the drum device, the tested sample is in contact with the abrasive cloth, which covers 60 mm. During one drum turn of 360° the tested sample may have not been in contact with the abrasive cloth surface. The consequent impact of the tested sample with the drum simulates actual impact. The applied pressure force was 10 N. The mean of the tested samples was 15.5 ± 0.1 mm and their height was 20.0 ± 0.1 mm.

One-factor ANOVA, reliability level $\alpha = 0.05$ was used for statistical evaluation. The T-test was used for statistical comparison, while the zero hypothesis H_0 ($p > 0.05$) shows that the statistical sets of data are comparable.

RESULTS AND DISCUSSION

The optical analysis determined the average size of rubber powder particles to be 28 ± 16.6 μm, see histogram Fig. 3 (left). The size of most particles falls into the interval 20–30 μm (40%). The morphology of rubber EPDM dust particles is shown in Fig. 3 (right).

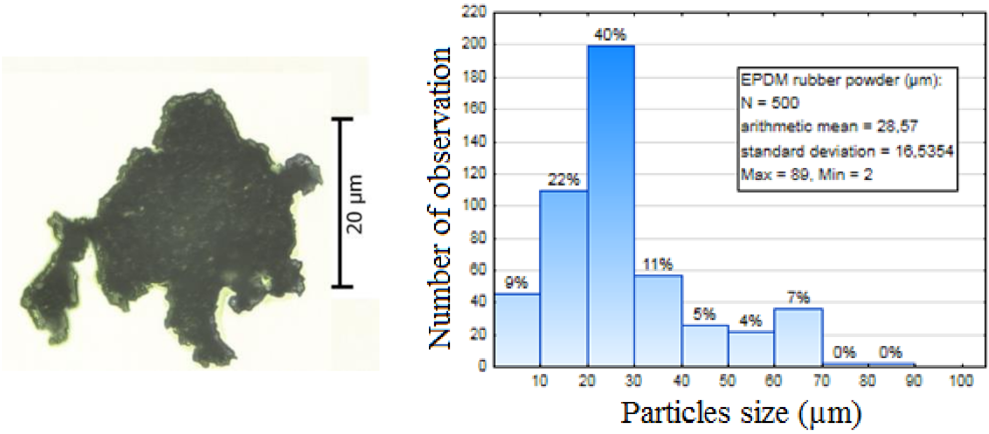


Figure 3. Histogram of the size of particles, EPDM rubber powder (right), morphology of a particle of EPDM rubber powder (left).

The lowest average porosity 5.03% was detected on the tested samples with resin Glue Epox Rapid (7.04% Sika Force 7723). Porosity and density of filled resin are shown in Table 1.

Table 1. Density and porosity of filled resins

Resin (EP/PU)	v_{pr} (%)	Density (g cm^{-3})	Porosity (%)
Glue Epox Rapid	5	1.15	5.34
Glue Epox Rapid	10	1.15	4.42
Glue Epox Rapid	15	1.15	5.06
Glue Epox Rapid	20	1.15	4.19
Glue Epox Rapid	25	1.14	6.22
Glue Epox Rapid	30	1.14	4.32
Glue Epox Rapid	35	1.14	5.67
Sika Force 7723	5	1.48	6.38
Sika Force 7723	10	1.46	8.69
Sika Force 7723	15	1.44	5.95
Sika Force 7723	20	1.42	8.90
Sika Force 7723	25	1.41	7.63
Sika Force 7723	30	1.39	6.27
Sika Force 7723	35	1.37	5.46

The hardness of the filled resin (Shore D) is shown in Fig. 4. While the ratio of EPDM rubber powder in the resin increased, the hardness decreased from about 11.2 to 78.7 ± 1.0 (Glue Epox Rapid), the hardness of the polyurethane resin Sika Force 7723 decreased from about 16.7 to 50.9 ± 2.4. The coefficient of variation related to the measuring did not exceed 4.8%.

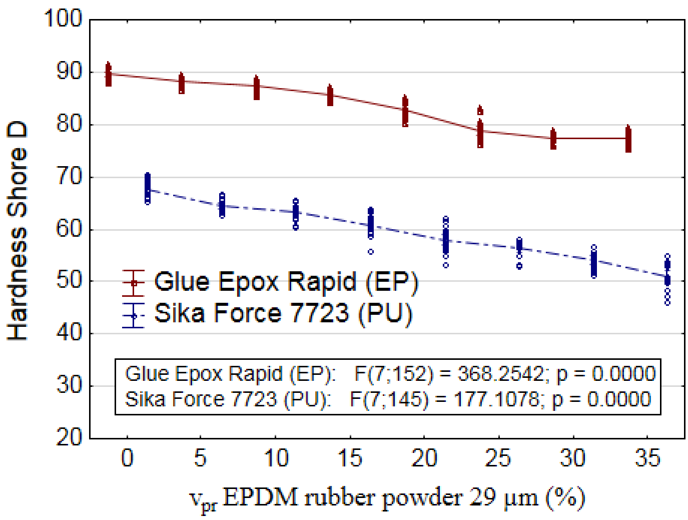


Figure 4. Influence of the EPDM rubber powder on resin hardness – Shore D.

The decrease in lap-shear strength was proved with increasing the percentage of EPDM rubber powder (see graphical illustration and results of ANOVA, Fig. 5) in the mixture but the presence of 5% EPDM powder did not lead to a statistically demonstrable decrease in shear strength, see the results of a statistical analysis in Table 2 (zero hypothesis H_0 confirms the hypothesis – there are no statistically significant differences between the compared sets of data, Glue Epox Rapid p = 0.38 and Sika Force p = 0.37). The higher percentage of rubber EPDM powder in these resins led to a decrease in hardness. The presence of rubber EPDM powder significantly increased the dispersion of measured values; this dispersion is revealed in the values of the coefficient of variation (up to 18% for Sika Force 7723).

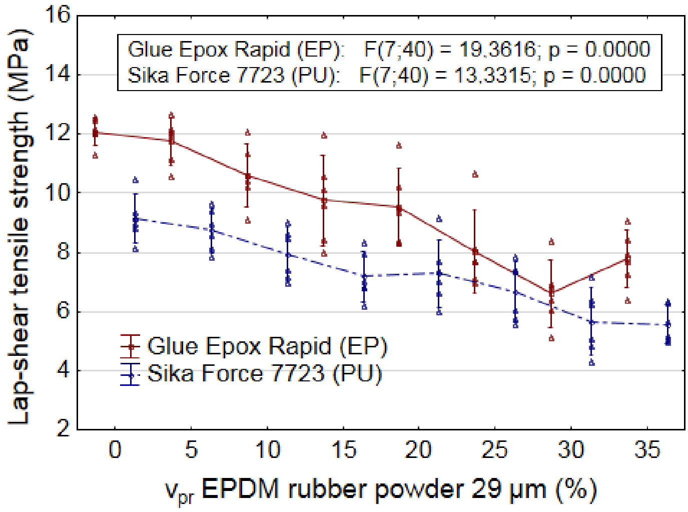


Figure 5. Impact of rubber EPDM powder on lap-shear tensile strength.

Table 2. Statistical analysis (T-test) – lap-shear tensile strength

T-test H_0; $\mu_1 = \mu_2$; $(p > 0,05)$	v_{pr} (%)						
Resin	**5**	**10**	**15**	**20**	**25**	**30**	**35**
0%: 5–35% / Glue Epox Rapid(EP)	**0.38**	0.01	0.00	0.00	0.00	0.00	0.00
0%, 5–35% / Sika Force 7723 (PU)	**0.37**	0.03	0.00	0.01	0.00	0.00	0.00

The used resins were characterised by cohesive failure. While the percentage of EPDM rubber powder (20–30%) increased, a predominate and special cohesive failure (SCF) occurred. The thickness of the layer filled resin between the adhesive and adherend increased with a higher percentage of EPDM rubber powder.

Tensile strength decreased verifiably while the percentage of EPDM rubber powder in the resin (see Fig. 6) increased. The strength of the resin Glue Epox Rapid decreased from about 36.61 MPa to 13.48 ± 2.39 MPa and the strength of the Sika Force 7723 decreased to the value 2.34 ± 0.78 MPa (3.49 MPa decrease). The coefficient of variation of the measurement increased with the inclusion of microparticles (filler) and reached the value of 33.5% (Sika Force 7723: 35%).

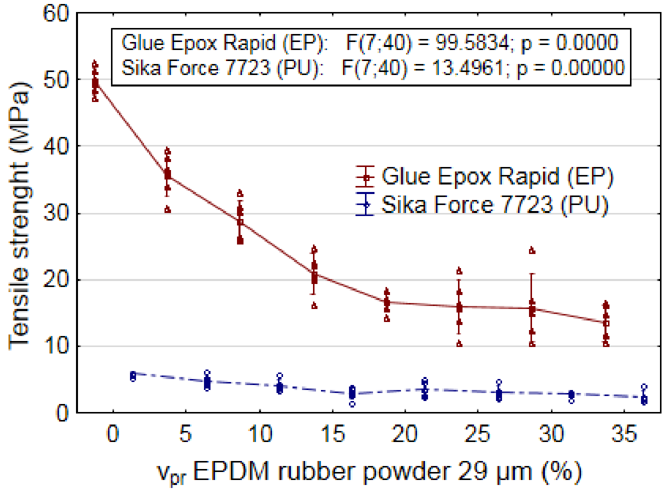


Figure 6. The influence of rubber EPDM dust on tensile strength.

The statistical analysis is shown in Table 3: there is a statistically significant difference between the compared sets of data in all cases. Abrasive wear resistance decreased when EPDM rubber powder was added (see Fig. 7).

Table 3. Statistical analysis (T-test) – lap-shear tensile strength

T-test H_0; $\mu_1 = \mu_2$; $(p > 0,05)$	v_{pr} (%)						
Resin	**5**	**10**	**15**	**20**	**25**	**30**	**35**
0%: 5–35% / Glue Epox Rapid (EP)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0%, 5–35% / Sika Force 7723 (PU)	0.02	0.00	0.00	0.00	0.00	0.00	0.00

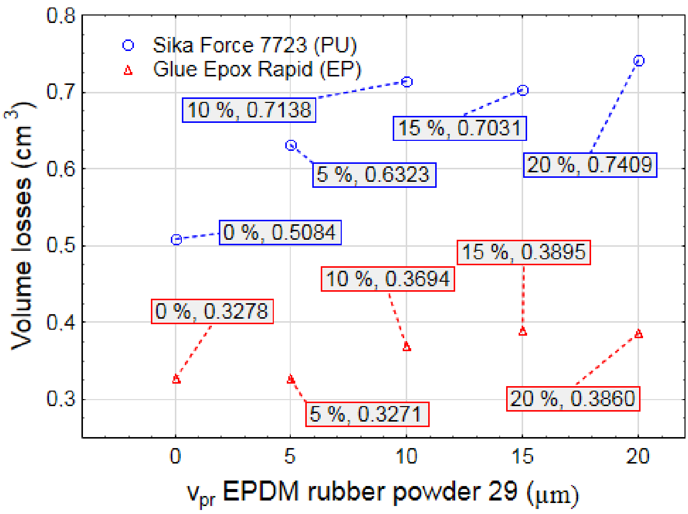


Figure 7. Abrasive wear resistance of test samples (volume losses) – abrasive cloth P220.

The experiment proved that the used epoxy polyurethane resins are able to form a new material with microparticle fillers on the basis of a secondary raw material. The viscosity of the used epoxy and polyurethane resins allowed to cast the samples without any difficulty. These conclusions are in compliance with the statements of many authors (Partridge, 1989; Müller, 2014) who confirmed the suitability of epoxy and polyurethane resins filled with different kinds of particles in their papers. Porosity was proved in the casted filled resins on the basis of their weight and volume (the difference between theorectical and real density). Porosity also became evident during the optical analysis of surface refraction performed with a stereoscopic microscope. The porosity of individual samples did not reach 10%. The higher values of porosity of the filled resins in question could be caused by the secondary characteristics of microparticles but may be also arise from the procedure with which the microparticle and resin mixture was prepared.

The occurrence of air bubbles could be decreased, for instance, with the use of vacuum for the preparation of filled resin. The low tensile strength of resin filled with the microparticles of rubber confirms the conclusion of Sereneko et al. (2005), who show that the use of rubber microparticles in the polymer matrix leads to the formation of defects, i.e., microcracks, which spread in the direction of the tensile force of the system. The defects were evident on the refraction surfaces in the surroundings of the rubber particles. The decrease in the tensile strength of the resin filled with rubber dust (EPDM) is confirmed by Schoberleitner et al. (2013). These conclusions were proved correct owing to the experiment that was performed.

CONCLUSIONS

The results of this paper provide a range of application areas for the products produced by companies involved in waste processing. The results can be also used by companies that did not offer their products to be used for the purposes of this experiment, as well as companies which use epoxy or polyurethane resins.

The use of secondary raw materials generally reduces the cost of resins (Valasek, 2014). The price of the Resin Glue Epoxy Rapid (15 EUR Kg^{-1}) may be reduced by 29% (i.e. 4.4 EUR) with a 35% inclusion of rubber particles. However, it is necessary to take into account the reduced mechanical properties described in this paper. The advantage in areas of application can be rubber's ability to dampen impacts. For example, in agriculture, Müller et al. (2013) refer to the possibility of using adhesive bonds (resin) filled with rubber particles to fix the functional areas of soil processing tools – rubber‘s ability to absorb impacts can be used, while the shear strength of the material is good. The experiment confirmed that filled resins with a 5% concentration of the filler in both epoxy and polyurethane resins have the same shear strength as unfilled resins.

ACKNOWLEDGEMENTS. This paper was written in the course of the grant IGA TF 2015, project: Optimizing the properties of resins and adhesives filled with organic and anorganic microparticles determined with an experimental approach (2015:31140/1312/3107).

REFERENCES

Affatato, S., Ruggiero, A., Grillini, L. & Falcioni, S. 2013. On the roughness measurement of the knee femoral components. BIOMODLORE 2013, Vilnius Gediminas Technical University Press Technica, 16–18.

Cerbu, C. & Curtu, I. 2011. Mechanical characterization of the glass fibres/rubber/ resin composite material. *Materiale Plastice* **48**, 93–97.

Čierna, H. & Ťavodová, M. 2013. Using the design of experiment method to evaluate quality of cuts after cutting aluminum alloy by AWJ. *Manufacturing technology* **13**, 303–307.

Li, M., Yuan, C., Wang, S.K., Potter, K. & Zhang, Z.G. 2012. Evolution of the wettability between carbon fiber and epoxy as a function of temperature and resin curing. *Journal of Applied Polymer Science* **128**, 4095–4101.

Müller, M. 2014. Influence of adhesives storing temperature on adhesive bond strength. *Manufacturing Technology* **14**, 71–75.

Müller, M. 2013a. Research of renovation possibility of machine tools damage by adhesive bonding technology, *Manufacturing Technology* **13**, 504–509.

Müller, M. 2013b. Research of liquid contaminants influence on adhesive bond strength applied in agricultural machine construction, *Manufacturing Technology*, **11**, 147–154.

Müller, M., Chotěborský, R. & Valášek, P. 2013. Unusual possibility of wear resistance increase research in the sphere of soil cultivation, *Tehnicki Vjestnik* **20**, 641–646.

Novák, M. 2011. Surface duality hardened steels after grinding. *Manufacturing technology* **11**, 55–59.

Partridge, Ivana K. 1989. Advanced Composites 1. ed. London: Elsevier Applied Science, 440 pp.

Rudawska, A. 2008. Swobodna energia powierzchniowa i struktura geometryczna powierzchni wybranych kompozytów epoksydowych. *Polimery* **53**, 452–456.

Serenko, O.A., Bazhenov, S.L., Nasrullaev, I.N., & Berlin, Al.Al. 2005. The effect of particle dimensions on the shape of formed defects in a particulate filled composite. *Vysokomolekularnye Soedineniya. Ser.A Ser.B Ser.C – Kratkie Soobshcheniya* **47**, 72 pp.

Schoberleitner, C., Archodoulaki, V.M., Koch, T., Lüftl, S., Werderitsch, M. & Kusching, G. 2013. Developing a sealing material: Effect of epoxy modification on specific Physical and Mechanical Properties. *Materials*, **6**, 5490–5501.

Subramaniyan, S.K. Mahzan, S., Ghazali, M.I., Ismon, M. & Zaidi, A.M.A 2012. Mechanical behavior of polyurethane composite foams from kenaf fiber and recycled tirerubber particles. *Applied Mechanics and Materials 3rd International Conference on Mechanical and Manufacturing Engineering*, 861–866.

Valášek, P. 2014. Long-term degradation of composites exposed to liquid environments in agriculture. *Scientia Agriculturae Bohemica* **45**, 187–192.

Zhao, D., Li, J., Liu, Z., Liu, Z. & Zhao, W. 2011. Modification of PP with waste rubber powder. *China Synthetic Resin and Plastics*, **28**, 34–36.

Agronomy Research **13**(3), 732–738, 2015

Pressure distribution measurement system PLANTOGRAF V12 and its electrodes configuration

J. Volf*, J. Svatos, P. Koder, V. Novak, S. Papezova, V. Ryzhenko and J. Hurtecak

Czech University of Life Sciences Prague, Faculty of Engineering, Kamycka 129, CZ-16521 Prague, Czech Republic; *Correspondence: volf@tf.czu.cz

Abstract: This paper describes Plantograf V12, which is used for the investigation of the pressure distribution between an object, e.g. a foot sole or a tire tread pattern, and the transducer. It can be used for analysing steps, assessing the great joints and improving stability, as well as in the fields of sport medicine and car industry. The system processes variable time pressure signals in real time. The instrument has 16,400 sensors (with a diameter of 2.5 mm each in a matrix arrangement of 128 x 128) concentrated in the active area as large as 500 x 500 mm; it is able to sample and process up to 1,000 frames per second. A full frame is created by all 16,400 sensors. The pressure distribution frame is represented in 256 colour levels in a 2D or 3D model view and it is possible to post-process the measured data on a PC. The design of the electrodes, the properties of the transducers, the operating software and the pressure distribution measurements in biomechanics are presented in this article.

Key words: Plantograf, conductive elastomer, electrodes, pressure distribution, tactile transducer.

INTRODUCTION

Plantograf V12 is a tactile transducer that is able to pick up tactile information from a particular object and convert this information into an electrical signal. This sensor is used in the following applications: measurement of static and dynamic pressure distribution, human steps analysis, sitting position analysis, pressure distribution, the analysis of a flat human foot, and the analysis of the status of great joints (Volf et al., 1997; Volf et al., 2001). Plantograf V12 should fulfil the following conditions: the sensor should not affect the measured pressure distribution results, it should measure both static and dynamic load, and it should have sufficient sensitivity and accuracy in each point of the sensor matrix for the given application. These parameters are specified in a table of technical parameters of the Plantograf. This paper focuses on the description of the Plantograf V12 matrix design, the optimal electrode size determination, and the properties of the operating software.

MATERIALS AND METHODS

Transducer design

Plantograf V12 was designed with a view to minimizing the influence on the matrix measuring points and maximizing the matrix point sensitivity. The matrix design is shown in the patent application. Conductive elastomer CS 57–7 RSC is used as a converter between the force and electrical resistance (CS 57–7 RSC, 1980; Souza et al., 2005; Soares et al., 2006; Barman & Guha, 2006). Part of the Plantograf V12 cross-section is shown in Fig. 1. Both electrodes are corroded onto a single Cuflex film (the commercial name for elastic printed circuit) placed on the bottom part of the sensor matrix. Between the electrodes, changes in elastomer resistance are measured (Trinkl et al., 2011). The surface of each electrode is completely covered. The conductive elastomer and the electrodes are protected from mechanical wear by a non-conductive flexible material – the protective coating (Volf et al., 2012).

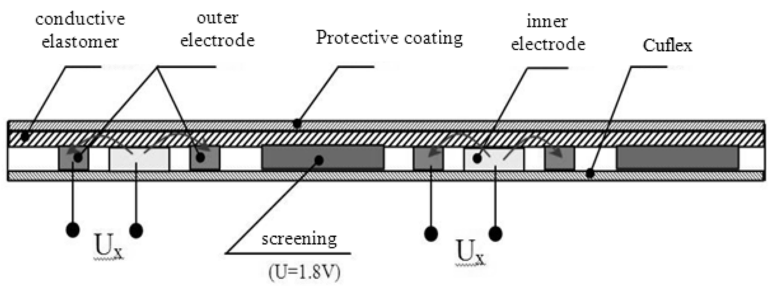


Figure 1. Cross-section of Plantograf V12.

Fig. 2 shows the principal layout of the electrodes at two adjacent sensors of the transducer. Real layout is more complex and it is realized by a multiply printed circuit. The arrow at the picture indicates the direction of the current between two circular electrodes of the sensor. It means that the current flows from the inner electrode through the conductive elastomer to the outer electrode. The common electrode, supplied by a voltage of 1.8 V, is used to mutual separation of individual sensors, which prevents – by hardware – the mutual interaction of the sensors.

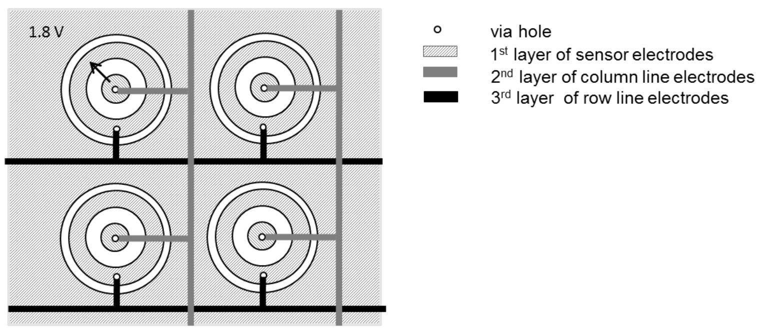


Figure 2. Four tactile sensors of the measurement matrix (the arrow indicates a change in sensor resistance).

Plantograf V12 uses new electronic circuits that are protected by a European patent (Novak & Volf, 2013). The electronic circuits consist of high-speed analogue-to-digital converters (ADC). Every ADC with an 8-bit resolution digitizes the signal from a simple RC circuit, where R represents sensor resistance. The counter measures the discharging period of capacitor C in the RC circuit. There are 128 such RC circuits – as many as the number of columns in transducer sensors. As a result, a full transducer line is converted at once. The converted samples are then processed for visualization (frames). All functions and control are integrated into a Xilinx Spartan 3 FPGA. These changes allowed the miniaturizing of the circuit and improved the speed of the whole system significantly. Currently the estimated rate is approximately 1,000 frames per second for a real time measurement. The sensors' resistance values correspond to a digitized signal using 8 bit ADC (i.e. 0–255 levels).

Software description

The device is designed to measure pressure (point value) from the contact forces' transducer, record it and provide a basic assessment. All previously measured data can be reverse-read to SW and processed (as if they were just measured), or they can be monitored and processed externally. The programme is not created as a closed unit; rather, it is a modular concept. SW is created by WIN 32 Microsoft NET C# (DirectX graphic output). The users can easily create their own (for example mathematical) blocks using the so-called libraries. The device can be easily run from a connected PC. During each measuring, several parameters can be set independently, e.g. visualization of the recording speed, change of transducer signal gain from 0.5x to 5x, zero set of the input signal, trigger mode of recording, and synchronizing with other recording devices. All the recorded data can be stored in several data formats, e.g. working DAT files, TXT text files, BMP pictures or DivX or XviD video records.

The operating software provides not only the monitoring and storage of the measured data, but also basic processing. During the monitoring, various operations are possible, such as displaying and rotating the frames, displaying the pressure centre and the histogram, creating custom horizontal and vertical cuts or selected regions and calculating their own pressure centres, creating a custom colour scale, making 2D and 3D visualizations, creating video files from the recorded values, and lastly exporting the measured data into EXCEL. Besides display operations, the software also allows mathematical processing, e.g. creating a file record for a selected cut or region and including the cut course in all the (selected) frames. The record may also contain additional statistical data (minimum, maximum, sum, average value, COP, histogram etc.).

RESULTS AND DISCUSSION

Optimal electrode size determination

A basic measurement task was carried out to determine the optimal electrode type for the application to give the sensors maximum measuring sensitivity. The measurement was performed automatically at a robotized workplace. All the measurements were performed in a static mode. The applied pressure was calculated from the diameter of the known electrode and the applied force was measured by the Hottinger transducer

DF2S-3. In this testing process the sensor's properties relative to the electrodes' design were measured; six different designs of the sensor electrodes were evaluated.

The sensor electrodes had the following sizes and names: Ø*E* = 2 mm, Ø*d* = 0.4 mm, *M* = 0.1 mm – ***LH***; Ø*E* = 2 mm, Ø*d* = 0.1 mm, *M* = 0.1 mm – ***PH***; Ø*E* = 2.5 mm, Ø*d* = 0.4 mm, *M* = 0.25 mm – ***LD***; Ø*E* = 2.5 mm, Ø*d* = 0.1 mm, *M* = 0.25 mm – ***PD***; Ø*E* = 3.5 mm, Ø*d* = 0.4 mm, *M* = 0.25 mm – ***OB***; Ø*E* = 3.5 mm, Ø*d* = 0.4 mm, *M* = 0.25 mm – ***SB***.

The sizes of the measured sensor electrodes are displayed in Fig. 3.

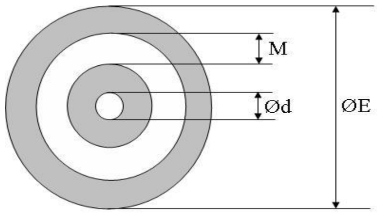


Figure 3. Sizes of the measured electrodes.

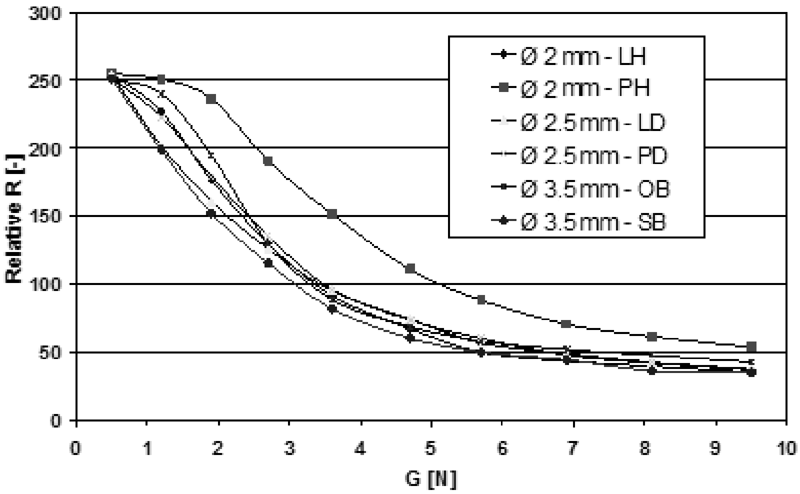


Figure 4. Relative dependence of sensor resistance on the loading force *G* for different electrode types.

Electrodes *OB* and *SB* have the same electrode size. Construction number 5 has placed the conductive elastomer separately only at the measuring sensor. Construction number 6 has got the conductive elastomer over its whole surface of the sensor matrix. Three different sensors for every design were selected for measurements. For the every selected sensor loading and unloading characteristic in the force range of 0.5 N – 9.5 N was measured 10 times. Uncertainties type A, B and C were calculated. Because of lucidity, only average values of the measurements are shown in Fig. 4.

Technical parameters and output of Plantograf V12

Electrodes of the type LD were selected for the final Plantograf V12 design. The following technical parameters were obtained:

Patient mass up to 150 kg; *rated pressure range* 5–100 kPa; *permissible overload (lower sensitivity)* 1.4 MPa; *tire loading* 3,000 kg; *permissible overload (higher sensitivity)* 14 MPa; *transducer active area* 500 x 500 mm; *number of sensors* 16,400 pcs; *sensor diameter* 2.5 mm; *transducer supply voltage* +5 V; *digital output* 256 levels; *frame frequency* 1 kHz.

Some of the areas of applications of the device are presented in Figs 5 and 6. Fig. 5 shows images of human soles in a biomechanical application of the system. Fig. 6 demonstrates a potential industrial usage of the system in analysing the pressure distribution between a tire and the road, as well as a further capacity of Plantograf – the determination of the centre of gravity using special computing software.

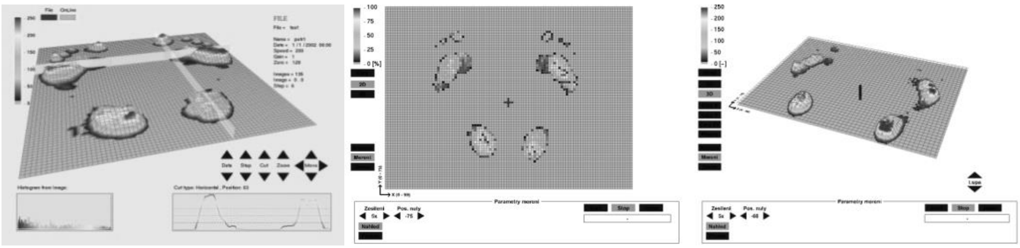


Figure 5. 2D and 3D images of human soles.

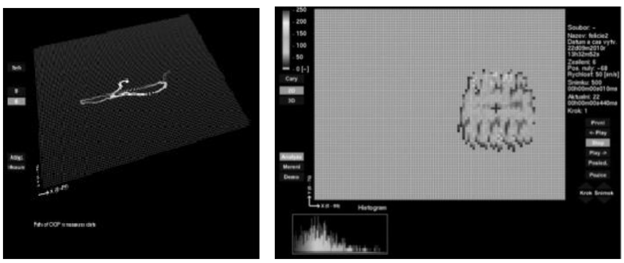


Figure 6. Determination of the centre of gravity and pressure distribution between a tire and the road.

The resulting frames have a 256 level colour scale. An unloaded sensor is indicated by the colour grey, while loaded sensors are coloured from blue to red, representing a fully loaded sensor.

Comparison with the competition

In comparison with PLANTOGRAF V12, the competing products TEKSCAN, RSSCAN and XSENSOR have the following drawbacks, among others:

- Limited recording period (buffer loading) – very short at high frequencies, longer at lower frequencies; one may not even manage to cross the sidewalk without the buffer already loading.

- Limited access to the data – measuring can be done in one walking direction only; the data are already pre-processed by software, RAW data (directly measured data) are unavailable; unstable software; the selection of arbitrary sections of the area is unavailable; one unanimous mask only; sometimes square regions. The software can analyse the sole of the foot only, it is unable to analyse other shapes.
- The number of sensors in the monitoring area is smaller, just 4,500 (each one measuring 5.0 x 7.6 mm). The specified maximum frame frequency of 300–500 Hz is comparable with that of Plantograf.
- In addition to sensor density and speed, the main advantages of our Plantograf include the SW modular concept, where SW can be arbitrarily extended depending on the needs of the user. Furthermore, the measured data export enables arbitrary data processing by the user.

CONCLUSIONS

This paper described the design, properties and technical parameters of Plantograf V12. The design of the tactile transducer Plantograf V12 is the newest in the Plantograf Vxx line.

Measurement results show that sensor sensitivity varies by the design of the sensor matrix. Design type PH has the lowest sensitivity (Fig. 1), while design type SB has the highest one. The results confirm the possibility of using miniature sensors in a Plantograf system to measure the pressure between a subject (e.g. a human sole, tire, etc.) and the transducer. The device can be utilized efficiently both in medicine and in the automotive industry.

ACKNOWLEDGEMENTS: The measurements were carried out in the framework of the IGA project of the Faculty of Engineering, Czech University of Life Sciences in Prague, reg. No. IGA 31200/1312/3131, entitled 'Experimental Research of Suitable Conductive Inks for Plantograf Measuring System and Electronic System Development'.

REFERENCES

Volf, J., Holy, S. & Vlcek, J. 1997. *Using of Tactile Transducer for Pressure Distribution Measurement on Sole*, Sensor and Actuators A62. Physical, ELSEVIER SEQUOIA S.A., pp. 556–561, Lousanne, Switzerland.

Volf, J., Papezova, S., Vlcek, J., Otahal, J., Novak, P. & Holy, S. 2001. *Transducer for Pressure Distribution Measurement and its Practical Tests.* In.: The 5th World Multi- Conference on Systemics, Cybernetics and Informatics SCI 2001. Orlando 2001, Florida USA, p.575. ISBN 980-07-7555-2.

Volf, J., Trinkl, A., Ruzicka, M. & Novak, M. 2009. *Optimal Size Determination of Tactile Sensor Plantograf V08 and its Electrodes*. 26th Symposium on Advances in Experimental Mechanics. Leoben, Austria. ISBN: 978-3-902544-025.

Trinkl, A., Volf J., Novak, M., Ruzicka M. & Vlcek J. 2011. *Plantograf V09 and Optimal Size Determination Sensor Electrodes.* The 15th World Multi-Conference on Systemics, Cybernetics and Informatics (WMSCI 2011), Orlando, Florida, USA, pp. 32–35. ISBN 978-1-936338-30-6.

Volf, J., Trinkl, A., Novak, M., Bilek, J., Prikner, P. & Neuberger, P. 2012. *Plantograf V12 with Optimal Size Determination Sensor Electrodes and its Using for Pressure Distribution*

Between Tire and Road. In: XX World Congress IMEKO, Busan, pp. 1–4, ISBN 978-89-950000-5-2 95400.
Novak, M. & Volf, J. 2013. *The Electronic Circuit for Evaluation Information from Transducers with Variable Electrical Resistivity.* European patent No.: 2414799, Munich.
Souza, F.G., Michel, R.C. & Soares, B.G. 2005. *A methodology for studying the dependence of electrical resistivity with pressure in conducting composites*. POLYMER TESTING **24**(8), 998–1004.
Soares, B.G., Amorim, G.S., Souza, F.G., Oliveira, M.G. & Pereira da Silva, J.E. 2006. *The in situ polymerization of aniline in nitrile rubber*. SYNTHETIC METALS **156**(2–4), 91–98.
Barman, S. & Guha, S.K.: *Analysis of a new combined stretch and pressure sensor for internal nodule palpation.* SENSORS AND ACTUATORS A-PHYSICAL **125**(2), 2006, 210–216.
Technical documentation of the conductive composite elastomer CS 57–7 RSC, Yokohama Rubber Co.Ltd.Japan, 1980.

VII ERGONOMICS

Agronomy Research **13**(3), 741–749, 2015

Workload and health of older academic personnel using telework

R. Arvola* and Ü. Kristjuhan

Tallinn University of Technology, Tallinn School of Economics and Business Administration, Tallinn, Estonia; *Correspondence: rene.arvola@ttu.ee

Abstract. Aim of the study was to measure telework usage and to explore interactions between health, workload and telework. Telework is work that is carried out outside the central office, involving new technology that permits communication. Work carried out at any time, at any place, has been very common in the case of research institutes and universities. This type of work has advantages and disadvantages for both an employee and employer. The study of telework was carried out in Tallinn University of Technology (TUT) where working at home has been very common for a long time. The questionnaires were sent to academic personnel. The study shows that academic employees preferred teleworking for better concentration on work and saving time and money. There was no significant difference in telework usage by age and teleworkers had fewer complaints about tired eyes, arterial hypertension and stress.

Key words: telework, work hours, diseases, stress.

INTRODUCTION

Telework is work that is carried out outside the central office (often, on the go and at home), involving new technology that permits communication. Concept of telework was first introduced as telecommuting by Jack Nilles in 1976 (Nilleset al., 1976). It has much increased in many developed countries in Europe, America and Asia during the last decades. People have worked in homes from time immemorial. Teleworking hasn't 'invented' any new places to work and principally new problems. It is a complex phenomenon that creates possibilities of a number of issues at present. It is important to redesign work life and support the work ability of older workers so that they are able and willing to work longer than before (Ilmarinen, 2009). Telework may be one of the options that quite easily provide flexibility to work life including older workers. The common myth that has to be dispelled is that older people have more difficulties when working with information communication technology.

Work carried out at any time, at any place, has been very common in the case of research institutes and universities. This practice supports understanding that work does not refer to a physical place, but rather more to a set of activities carried out by people. This type of work has advantages and disadvantages for both an employee and employer. There are also circumstances when teleworking has more advantages or disadvantages. Teleworking proposes new challenges, as it raises the chances of people working in places which are not tailor-made as most workplaces. Many people like freedom to choose the place for work.

However it may reduce the results of work through less control. People who work too many hours from outside the central office experience more stress and health problems. In some occasions there is also threat of decreasing physical activity or overeating which may lead to increase of body weight.

According to common understanding telework usage depends on workers age. Generally, young people are considered to be more interested in working outside the central office by using computers, mobile phones, tablets and internet, but some data (Arvola, 2009) were disproving this well-known position – young people were using less telework compared to their elder colleagues.

The average age of academic staff is relatively high compared to most white-collar workers and it is increasing at present as is the age of all work-force in Estonia. Experienced and qualified academic employees remain on the job for a long time. By law no person may be discriminated on the basis of age in Estonia. While most legal, organisational, psychological and social aspects of telework have been widely studied according to the scientific literature, less attention has been paid to problems connected to the age of academic personnel and the influence on their health (see The Oxford Handbook, 2012).

Sharit et al. (2009) studied managerial experience from a large variety of companies in the United States. The results presented a mixed picture with respect to the employability of older workers as teleworkers, and strongly suggested that less experienced managers would be more resistant to hiring older people as teleworkers (Sharit & Czaja, 2009).

AGEING AND HEALTH

Ageing is an accumulation of various types of damage in organism. A much longer life in healthy and youthful body has been human greatest dreams. Most ordinary people think that it is impossible.

Health depends on workload. High workload of older people is harmful. There is close relationship between biological ageing and age-associated pathologies in humans. Age associated diseases appear as a result of ageing. They develop from ageing changes in the organism. Distinction of ageing from diseases is separating undefinable from undefined (Evans, 1988).

European culture is fixed on eternal youth and middle-age. In official statistics, age-groups are for youth and middle-aged (20–24, 25–29 years etc.) and mostly up to 60 years. All older people are 'older'. Medical research about older subjects is much rarer compared in people less than 65 years old. As a result of these peculiarities of medical research we don't know well about hundreds of physiological parameters of older persons. We don't exactly even know what the best weight and blood pressure is for older people. Many research articles showed that Body Mass Index (BMI) for 65+ should be less than 25 (bigger BMI is worse), but many showed that BMI > 25 is the best for health of older people. In 13 studies, Chapman (2010) found increased mortality only above a BMI of 27–28.5 for 65+.

There is need for experimental and longitudinal studies. Limitation of longitudinal studies on older workers is difficulties for that during years workers change professions and causes of this are very different, sometimes unhealthy working conditions.

SUBJECTS AND METHODS

The study of telework was carried out in Tallinn University of Technology (TUT) where working at home has been very common for a long time. At present many retired professors (emeritus) participate in scientific work of the university at home. The research sample consisted of 259 academic staff members of TUT who were agree to participate and answer questionnaire and whose responses were suitable for analysis. The sample size was enough regarding the representativeness of the survey. Actual sample size is greater than minimum sample size (100,39) that was calculated as following (see Eq. 1) (Arvola, 2006).

$$
\begin{aligned}
&n = \frac{t^2 \sigma^2 N}{\Delta^2 N + t^2 \sigma^2} = 100{,}39 \\
&t = 0{,}95 \\
&\Delta = 0{,}5
\end{aligned}
\quad (1)
$$

The purpose of the study was to measure telework usage to identify the factors that have influence on health. The questionnaire consisted of open-ended (e.g. factors that influence teleworking, personal benefits concerning telework, disadvantages concerning telework) and closed-ended questions (incl. telework usage, about teachers' mastery working with ICT equipment, about the size of their family, about the number and pages of publications and hours spent on scientific work (working with literature, planning and carrying out the research). Data about the time spent commuting between the university and home and about income were also included. Respondents were asked also about their health complaints concerning particular issues (e.g. high blood pressure and stress) on the scale 1–3, where 1 – do not occur, 2 – occurs rarely, 3 – occurs.

The criteria for participating in survey was occupation (holding academic position, e.g. professor, lecturer, researcher). People older than 45 years were considered as older workers. Questionnaires were sent to academic staff by e-mail and by paper. Survey population was 1,253 academic employees in TUT. Questionnaires were sent on paper and by e-mail. 260 questionnaires were completed and returned. 259 of the questionnaires were considered to be suitable for analysis. One returned questionnaire was removed, because the respondent declared significantly more telework hours (70 hours a week) compared to second most intensive teleworker (42 hours a week). Therefore final sample size was 259 and response rate was 21%.

RESULTS AND DISCUSSION

Data from survey in TUT showed that older academic staff is productive (Kristjuhan & Taidre, 2010, 2012, 2013). The productivity was highest in age group 56–65 years. Older academic staff published more articles per year compared to their younger colleagues.

According to telework usage survey in TUT in 2006 teleworking is widespread. There were no significant differences in teleworking usage by gender, but men tend to do 1 hour more telework a week compared to women. Majority (90%) of academic staff members that were 40 years old and younger evaluated their computer skills upper-medium and professional level (Fig. 1). It was 52% in age group over 50 years. But only 12 respondents (that was for instance 5% in age group 61–70 years) said that they can use a little when asked about their computer skills (e.g. 5% in age group 61–70 years). As results show, the vast majority of senior academic staff members do not have significant difficulties concerning working with computers. These survey results help to reject the common belief of elderly and ICT relationships. Academic staff members in TUT use computers regularly for filling their work tasks. Most of the work is organised in the way that the physical place of work do not matter and they have the access to information system and documents from any place that has internet connection.

But as the gathered data was measured through self-evaluation, there is still a possibility that difference in self-evaluation and objective skills still exists. The survey did not provide answer for question if younger employees have higher estimation on their computer skills compared to their elder colleagues.

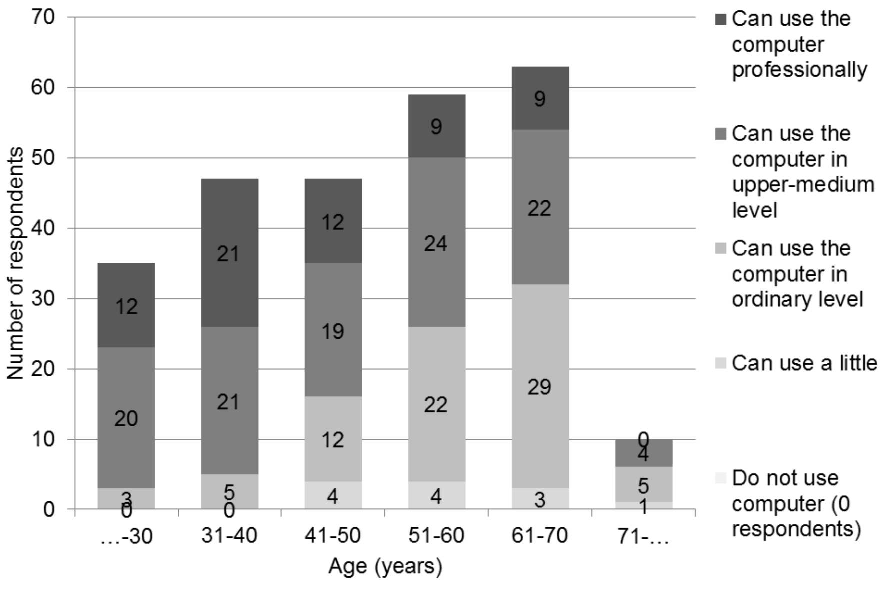


Figure 1. Computer skills self-evaluation (number of respondents) by age.

Present research shows that usage of telework doesn't depend on academic staff members' age (Arvola, 2009). Older academic staff used telework just a little more (see Fig. 2) than younger ones, but no significant correlation exists between age and telework usage. Nevertheless unlike in other age groups it was difficult to find respondents up to 30 years old who use telework more than 20 hours a week. In fact there was only one respondent in the youngest age group (36 respondents in this age group in total) whose estimation on telework usage in a week exceeded 20 hours.

With respect to overall stress level perceived working from office compared to working from outside the office (e.g. from home) the overall stress was perceived more often when working from office (Fig. 3). Most respondents did not perceive stress. 7% perceived higher or rather higher stress when teleworking while 49% respondents perceived lower or rather lower stress.

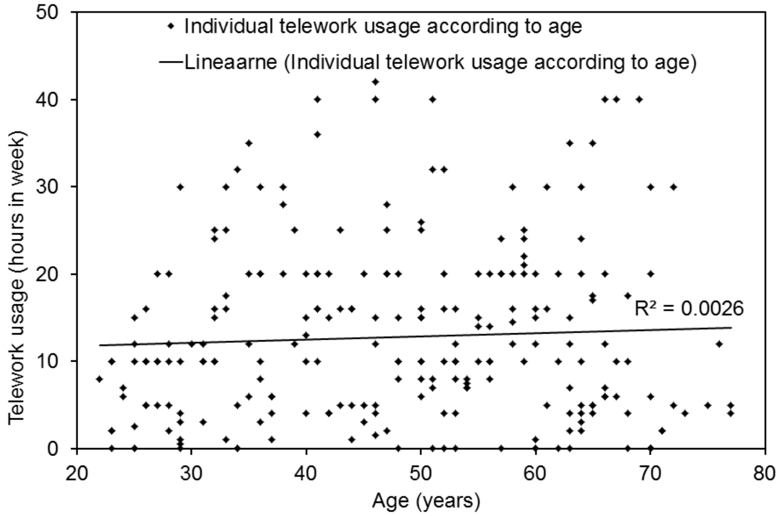


Figure 2. Telework usage and age.

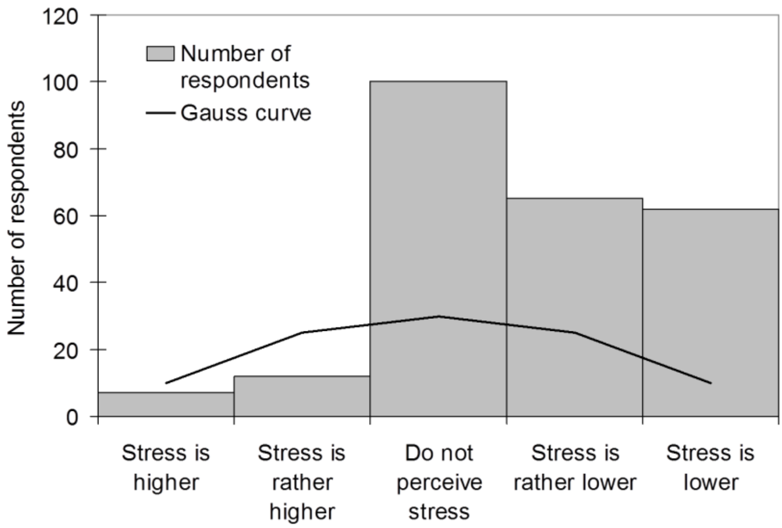


Figure 3. Perceived stress level of employee when working outside the office compared to stress level at the office.

Complaints of stress and hypertension varied according to same pattern by telework usage: non-teleworkers complained the most; respondents that teleworked 1 to 20 hours per week had least complaints; and teleworking more than 20 hours per week brought a slight increase in complaints that still remained lower compared to non-teleworkers' complaint's level (Fig. 4 and 5). In Figs 4, 5 and 6 X-axis represents number of responses on assessment scale 1–3, where 1 – do not occur, 2 – occurs rarely, 3 – occurs. Telework usage did not caused significant increase in complaints of tired eyes, but as for stress and blood pressure, non-teleworkers had more complaints (Fig. 6). Survey results were not giving solid justification for the increase of complaints that go together with more teleworking.

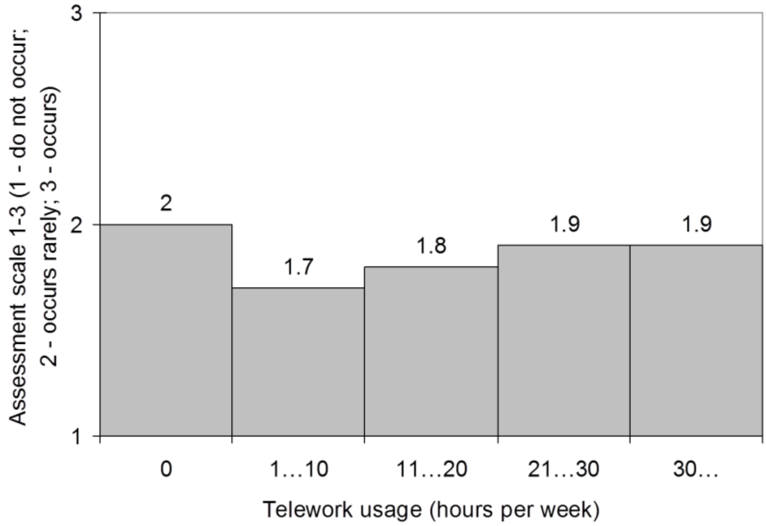


Figure 4. Complaints on stress.

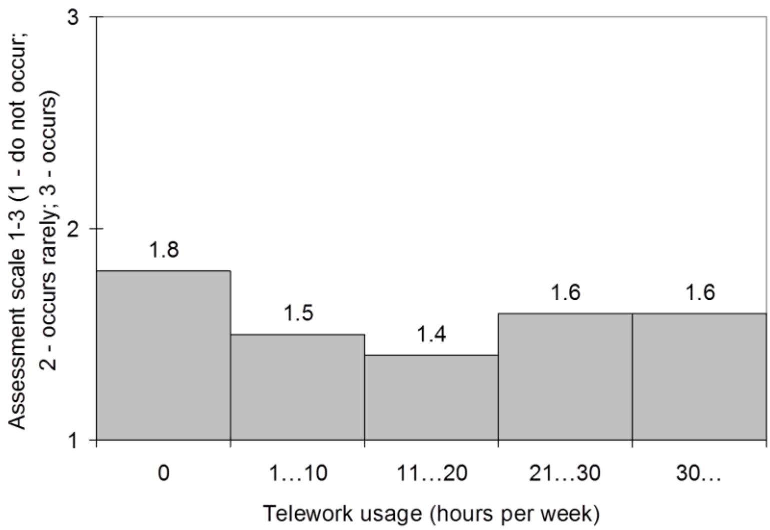


Figure 5. Complaints on hypertension.

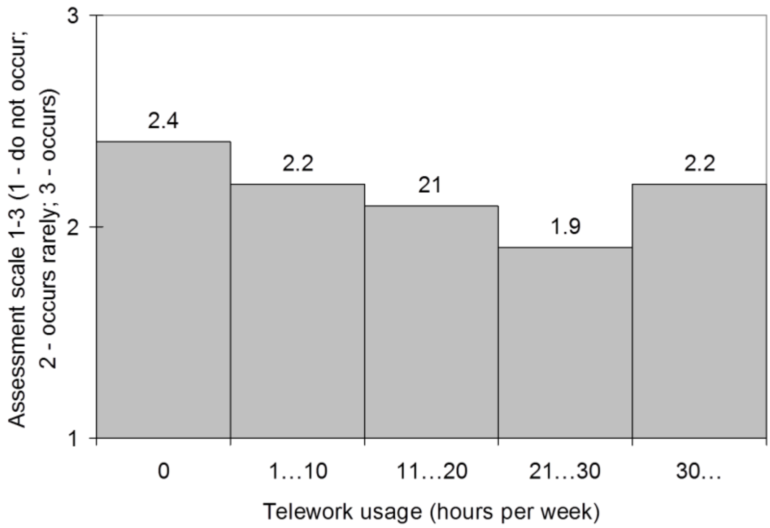


Figure 6. Complaints on tired eyes.

Lifelong employment in universities is enabled only in some countries (e.g. the United States). Second careers are possible for older specialists, including former academic staff, but academics have substantially changed the characteristics of their working activity. They start up their own firms, begin working as consultants and so on. Often these changes result in massive changes in lifestyle that can affect their competitiveness and health. Should specialists older than 65 be working in universities, either full-time or part-time when they want and are productive?

In the past, it was rare to encounter such aged academic staff among faculty members. At present older persons are healthier and the working conditions are better. Older people have more time for work – their children have grown up. This means that they also have more time to rest and recover their work ability.

It is often thought that senior academic staff offer experience, while the young offer new knowledge. However, knowledge is derived from experience. Peak work ability mostly comes earlier, but specialists are employed for their skills when they have yet to reach this peak.

Most specialists are rarely interested in the questions of older healthy (not with decrepit) workers. These questions are mainly new for them. They don’t pay attention that there are some overlooked important benefits for employers of the old specialists: accumulated knowledge, work experience and discipline.

In order to telework as good working conditions at home as at traditional workplace are necessary: good posture, body movements to avoid a static position all the time, task lighting, avoiding glare on the monitor. Working conditions can be better at home than in office because of greater flexibility. It is important to keep to a 'work day ritual'. Compared with traditional workplaces the problems of overwork are more probable and workers should not exaggerate. When workers feel tired they can make a pause more easily compared to traditional workplaces. Teleworkers do sometimes agreements with employer on number of telework hours, e.g. in universities of the United States.

Among older academic staff there are more people with disabilities compared to younger ones. Older persons have more health disorders acquired during their lifetime. These disabilities depend on biological ageing, and their living and working conditions. However there is also much positive and these disabilities are mostly not hindrances for teleworkers activity.

The study shows that a majority of academic employees preferred teleworking for better concentration on work and saving time and money (see Fig. 7). There was no significant difference in telework usage by age and telework didn't increase complaints about tired eyes, hypertension and stress. Research of some other authors (Lundberg and Lindfors, 2002) show that blood pressure is lower working at home than at office.

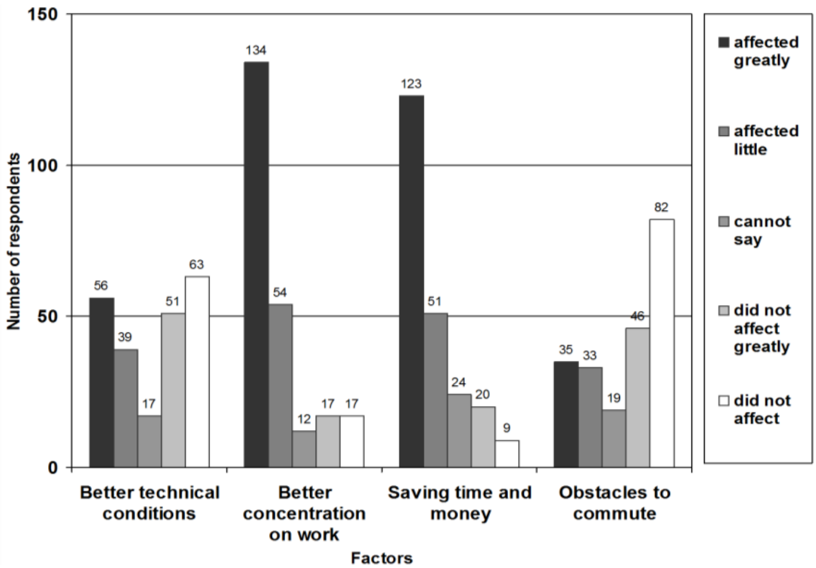


Figure 7. Factors affecting teleworking preference.

CONCLUSION

The study shows that teleworking among academic staff is widespread and for some people even tacit. Irrespective of age academic staff members use ICT (incl. computers and internet) obviously and there are no evidence supporting the myth that older people difficulties with ICT and teleworking is not for older people. Academic employees preferred teleworking for better concentration on work and saving time and money. Factor that had least effect on telework preferences was obstacles to commute. There was no significant difference in telework usage by age and gender. Teleworkers had fewer complaints about health, tired eyes, hypertension and stress. Survey did not explained the reasons why more teleworking hours involve more complaints regarding stress, blood pressure and tired eyes, but as academic staff very often faces heavy work load, it might be caused by simple overwork.

Further research is necessary to provide new knowledge about telework impact on people's life.

REFERENCES

Arvola, R. 2009. Telework as a Tool for Extending Work Life. In Kristjuhan, Ü., Arvola, R. (eds): *Extending the Work Life. Collection of Articles.* Tallinn University of Technology Press, pp. 110−115.

Arvola, R. 2006. Telework as a solution for senior workforce: research at Tallinn University of Technology. *Working papers in economics (TUTWPE)* / Tallinn University of Technology, School of Economics and Business Administration 19, pp 35−49.

Chapman, I.M. Obesity paradox during aging. In: Mobbs, C.V. & Hof, P.R. 2010. (eds). *Body Composition and Aging. Interdiscipl. Top Gerontol.* Basel, Karger, **37**, pp. 20–36.

Evans, J.G. 1988. Aging and disease. In: Evered, D. and Whalen, J. eds. *Research and the Aging Population.* Chichester, Wiley, pp. 38–57.

Ilmarinen, J. 2009. Aging and work: An international perspective. In: *Aging and Work.* Czaja S.J & Sharit, J. (eds) Baltimore, J. Hopkins University.

Kristjuhan, Ü. & Taidre, E. 2010. Postponed aging in university teachers. *Rejuvenation Res*. 13, 2–3, 353−355.

Kristjuhan, Ü. & Taidre, E. 2012. High work ability in the scientific activity of older and experienced academics. Work-*A Journal of Prevention Assessment & Rehabilitation* **41**(S1), 313−315.

Kristjuhan, Ü. & Taidre, E. 2013.Workability of older academics. *Agronomy Research* **11**(2), 441−448.

Lundberg, U. & Lindfors, P. 2002. Psychophysiological reactions to telework in female and male white-collar workers. *J Occup Health Psychol.* Oct; **7**(4), 354−364.

Nilles, J.M., Carlson, F.R., Gray, P. & Hanneman, G.J. 1976. The telecommunications-transportations tradeoff: options for tomorrow. New York

Sharit, J. & Czaja, S.J. 2009.*Telework and older workers*. Aging and Work. Ed. Czaja S.J and Sharit, J. (eds) Baltimore, J. Hopkins University.

Sharit, J., Czaja, S.J., Hernandez, M.A. & Nair, S.N. 2009.The Employability of Older Workers as Teleworkers: An Appraisal of Issues and an Empirical Study. *Hum. Factors Ergon. Manuf.* **19**(5) 457−477.

The Oxford Handbook of Work and Aging. 2012. Hedge, J.W. & Borman, W.C. (eds) Oxford University Press.

Agronomy Research **13**(3), 750–758, 2015

Assessment of the impact of the shape of the handle on the ergonomics of operating a handbrake

M. Hruška[1,*], J. Kuchař[1], L. Libich[1] and P. Jindra[2]

[1]Czech University of Life Sciences Prague, Faculty of Engineering, Department of Technological Equipments of Buildings, Kamýcká 129, CZ-16521 Prague 6 – Suchdol, Czech Republic; [*]Correspondence: jabko@tf.czu.cz
[2]Czech University of Life Sciences Prague, Faculty of Engineering, Department of Vehicles and Ground Transport, Kamýcká 129, CZ-16521 Prague 6 – Suchdol, Czech Republic

Abstract. This thesis addresses the ergonomic problem of conflict between hand-operated mechanical brakes and center rests on certain types of vehicles. The hand brake is one of the basic means of control of a personal vehicle and its smooth and comfortable mastery directly affects traffic safety and driver well-being. The paper outlines a possible solution to this problem through the shape of the mechanical handbrake handle. The proposed solution is validated by using Tecnomatix Jack, which is primarily intended for solving ergonomic problems in the context of Digital Human Modeling. Specifically, in order to verify the solution, the Comfort Assessment tool is used, which in itself contains several published studies looking at driver comfort in accordance with the bending of specific joints. The results of this thesis can be used for future mechanical handbrake designs in cars.

Key words: Handbrake, Driver Ergonomics, Digital Human Modeling, Personal vehicle.

INTRODUCTION

Currently, the issue of the ergonomics of passenger car cabins is considered an increasingly important part of the structure of a new vehicle (Ge et al., 2007; Wang et al., 2007). An optimally ergonomically-designed driver platform, as well as the crew of the car, plays a significant role in vehicle safety and the wellbeing of the driver and passengers (Reed, 1998). Today, the economic success of the car often depends on the ability to optimally design all of the control and communication elements of the vehicle. The mechanical handbrake is among the basic control elements of cars. Despite the emergence of many alternative solutions, for example on the basis of electronic controls, the mechanical handbrake is still widely used. It can be assumed that conventional control of a handbrake will not disappear in the future. However, the conventional solution for handling a handbrake, along with the armrest for the right hand (on the left side of the car for right-hand driving), creates a classic ergonomic problem whose solution has not yet been sufficiently and satisfactorily defined.

For safe handling of a mechanical handbrake, the driver must involve virtually all the major muscles and three major joints of the upper limb – shoulder joint (*articulatio humeri*), elbow joint (*articulatio cubiti*) and wrist joint (*articulatio radiocarpalis*). In addition, in order to grip the *(flexi)* handle of the mechanical handbrake, the driver must use also use finger joints. In some cases, movement of the torso is also involved, which helps the upper limb in reaching the handle. Even though the mobility of the upper limbs of a healthy person is very large, there is a range of rotation of each of the joints during which a person can feel considerable symptoms of discomfort (Kapandji, 2007). These ranges can be achieved when operating conventionally-designed and situated mechanical handbrakes while interacting with the armrest. This paper deals with one possible solution to this ergonomic problem, which is based on the structural and shape adjustment of the handle of the mechanical handbrake.

In order to resolve the above problem, a hypothesis was formulated that suitably adjusting the design of the handle of a mechanical handbrake will decrease the amount of flexion required for each of the affected joints, and thus improve the overall level of ergonomic solutions for passenger cars.

MATERIALS AND METHODS

All of the measurements described below are shown in degrees and are based on a so-called basic anatomic position, which is important for determining the direction and extent of bending of each joint and represents the zero reference position for all of the derived measurements. This position is defined as an erect position with upper limbs hanging loosely at the sides of the body with palms facing forward. The position of the lower limbs is not important for the case being evaluated, and will therefore not be examined in this investigation.

Software and analytical tools

In order to accurately identify and test the hypothesis, the Tecnomatix Jack software tool was used, which is primarily designed to assess the ergonomics of a person, and which contains the analytical tools for evaluating the above hypothesis.

In practice, it is very difficult to physiologically define the natural range of motion of a person's individual joints. There are a number of values in professional literature that are divergent in degrees, and that is why ranges that are defined by the Tecnomatix Jack program were used for this study. This program uses the knowledge of several ergonomic studies that deal with the comfort of a driver while driving (Porter & Gyi, 1998; Krist, 1994). It also uses these ergonomic studies, inter alia, for determining the ranges of rotation of the joints of the upper limbs specified below.

Table 1 shows the bending ranges of individual joints of the upper limb as they are set out in the basic module of the Tecnomatix Jack program. According to basic human physiology findings, the elbow joint can be bent in only one plane, and therefore only values of angles on the Y plane are used.

Table 1. Ranges of rotation of the joints of the upper limb according to the Tecnomatix Jack program

Joint	X(°)	Y(°)	Z(°)
Articulatio humeri	0–180	-45–135	-135–90
Articulatio cubiti	–	0–142	–
Articulatio radiocarpalis	-85–100	-45–45	-113–77

Spatial situation of the location of a mechanical handbrake in a passenger car

Due to the differences in the design of individual types of vehicles, it is evident that the structure and relative position of the handbrake handle and armrest will vary in individual vehicle models. It is not the aim of this study to describe a specific solution, but rather the general principles, and thus a model universal solution was created which does not assume the particular dimensions of any real type of vehicle, but instead only serves to demonstrate the chosen principle of the solution. This solution, however, is generally dimensionally-based on mid-sized VW vehicles. The aim of this study is not to identify specific, precise dimensions and values, as they are very variable with respect to statistical models of the population.

In order to create a spatial arrangement model, the following dimensions were determined:

- Height of armrest above the lower level of the seat.
- Height of the axis of the handle of the handbrake above the lower level of the seat.
- Distance of the axis of the handle of the handbrake from the longitudinal axis of the seat.

As is evident from Fig. 1, the test environment is based on the classic location of the mechanical handbrake and armrest.

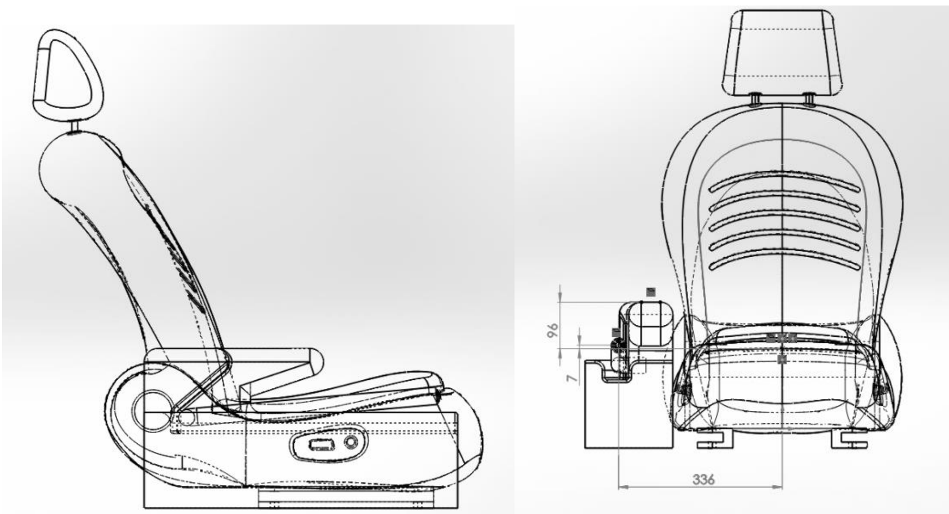


Figure 1. Situational drawing of a general seat in a passenger car with armrest and handbrake.

It is clear that in particular due to the influence of height-adjustable seat, the spatial situation will change depending on the height of the seat. Therefore, it is necessary to select one test position, which in this case represents a distance of 96 mm between the top edge of the armrest and the axis of the handle of the handbrake, 7 mm between the axis of the handle of the handbrake and the lowest point of the seat, and 336 mm between the axis of the handle of the handbrake and the longitudinal axis of the seat. In order to operate a conventional mechanical handbrake, as described above, the driver must achieve limiting bends, in particular in the wrist Joint (*articulatio radiocarpalis*), as was empirically determined. These torsions are achieved with this solution despite the fact that there is practically a direct interaction between the forearm and the armrest (see Fig. 2), and hence this leads to the inconvenient deformation of the forearm.

Figure 2. Position of the driver when gripping the handle of the mechanical handbrake with a classic design

Solution Methodology

In order to confirm the hypothesis that an appropriate adjustment to the handle design of the mechanical handbrake handle will lead to a reduction in the required flexion of each affected joint, initial conventional solutions were defined based on the classic placement of the mechanical handbrake and armrest in a passenger vehicle. Furthermore, structural modifications were designed for the handle, and both solutions were implemented as a 3D model and transferred to the Tecnomatix Jack program, where they were numerically analysed and verified.

A 50 percentile male dummy from the ANSUR (Clauser, 1988) database was used in the Tecnomatix Jack testing program. It had a height of 176 and weight of 78 kg for testing both solutions. At the beginning, the dummies used for all imaging solutions have the same working position based on the position of the driver while driving the vehicle. A difference in the positions of individual dummies only occurs in the event of rotation of joints necessary for achieving a handle of the mechanical handbrake so as to avoid penetration between the forearm and the body of the armrest. The bends of other joints remain the same so long as there is no rotation caused by movement of the upper limb. These secondary movements of joints relate in particular to the spine.

A simple comparison of the rotation of individual angles of the joints of dummies in various positions was used for evaluation, as well as the comfort of the driving position according to the Dreyfuss 3D study (Tilley, 2002). The comfort values presented in Henry Dreyfuss Associates 'The Measure of Man and Woman' (Tilley, 2002), represent a compilation of comfort values from a variety of sources. These sources include Grandjean, Pheasant and NASA studies (Grandjean, 1987; NASA, 1978; Pheasant & Chasle, 1986). These data are more general than either Rebiffé or Grandjean, applicable to most sitting tasks. In some regards, the Dreyfuss 3D study uses a different methodology for evaluating the range of bending of joints than the basic Tecnomatix Jack module, wherein, on the basis of own parameters, it defines the level of comfort of the driver in a determined position. Yet the main parameters defining the bending of the joints of the upper limb and the bending of the torso are defined similarly to the basic Tecnomatix Jack module.

RESULTS AND DISCUSSION

In order to achieve smaller angles of bending of the individual involved joints, it was necessary to choose a design modification that would primarily minimize the bending of the wrist Joint *(articulatio radiocarpalis).* After a series of tests, an optimal solution was chosen in which the mechanical handbrake handle was rotated by 110° toward the driver (Fig. 3). This structural adjustment was implemented as a 3D model and then confirmed in the Tecnomatix Jack program. Based on the methods described above, it was experimentally ascertained that such a selected handle shape better corresponds to the natural physiological position of the upper limb than the conventionally used solution (Fig. 4).

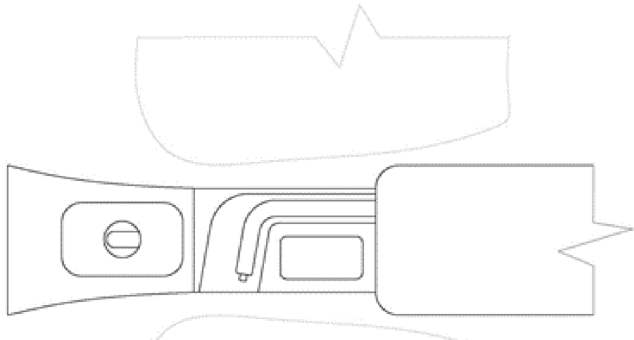


Figure 3. Overview of the designed structural solution with the handle bent at an angle of 110°.

Figure 4. Position of the driver whilst gripping the handle of the handbrake with the structural design solution in both extreme positions.

Tables 2 and 3 show the resulting measured values of angles during bending of all of the involved joints. It is evident from the values that in particular during bending of the wrist joint *(articulatio radiocarpalis),* the newly selected structural solution significantly reduced the ranges of bending (Table 1). The original solution forced drivers to achieve maximum torsion of the wrist joint on two levels, indicating a high degree of discomfort during the control process.

Table 2. Ranges of rotation of the joints of the upper limb according to the Tecnomatix Jack program

		Elbow	Wrist rotation			Shoulder rotation		
		Y	Y	X	Z	Elevation	Ant/Post	Rotation
	Ranges (°)	**0–142**	**-45–45**	**-85–100**	**-113–77**	**0–180**	**-45–135**	**-135–90**
New	Down (°)	11	5	10	**77**	49	74	-33
handbrake	Up (°)	63	4	33	62	21	59	-20
Classic	Down (°)	21	-16	-40	**77**	51	75	-126
handbrake	Up (°)	92	**-45**	8	**77**	9	58	-35

Table 3. Ranges of rotation of the upper torso and rotation of the torso in the area of the L5 vertebrae according to the Tecnomatix Jack program

		Rotation of the upper torso			Torso rotation - L5		
		Flex	Axial	Lat	Y	Z	X
	Ranges (°)	**-52–84,5**	**-43–43**	**-40–40**	**-6,5–11**	**-2–2**	**-4–4**
New	Down (°)	74	-5	15	**11**	-1	3
handbrake	Up (°)	73	0	0	**11**	0	0
Classic	Down (°)	74	-9	15	**11**	-1	3
handbrake	Up (°)	74	-5	15	**11**	0	3

In order to achieve optimal gripping of the handbrake, it is also necessary to involve the movement of the spinal vertebrae and upper torso. In this area, it is once again necessary to base the results on the principle of the depiction of the human body as in the Tecnomatix Jack program. Movements of the spine and upper torso are divided into two parts – the upper part of the torso bends smoothly via the progressive involvement of all of the vertebrae (shown in Table 3 – the values of 'rotation of the upper torso') and the entire torso as a unit with the pivoting point at the L5 vertebra (shown in Table 3 – the values of 'torso rotation – L5'). In terms of the bending of the spinal vertebrae, the changes between the conventional and the modified solutions are not as evident as in the case of the upper limb. Nevertheless, it is necessary to specify them within the complex perspective on the issue.

The proposed solution was also subjected to testing using the Dreyfuss 3D study. The comfort studies describe comfortable joint posture ranges. The graphs (Figs 5, 6, 7, 8) shows the name of the joint, a bar graph indicating the current deviation from the mode, and text values for the current value, as well as the range and mode of the comfort range. The mode is the 'most often adopted' posture. Fig. 5 and 6 show the main differences in the evaluation of the comfort of the driving position between the conventional and modified solutions when the handbrake is in the down position.

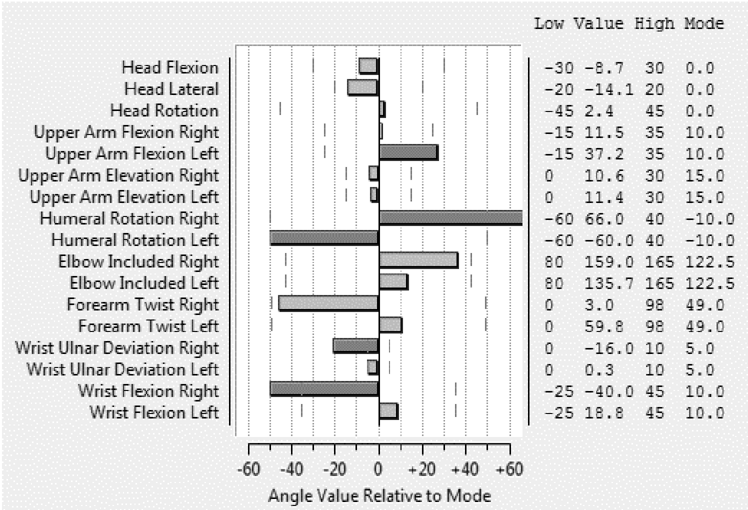


Figure 5. Conventional solution – down position.

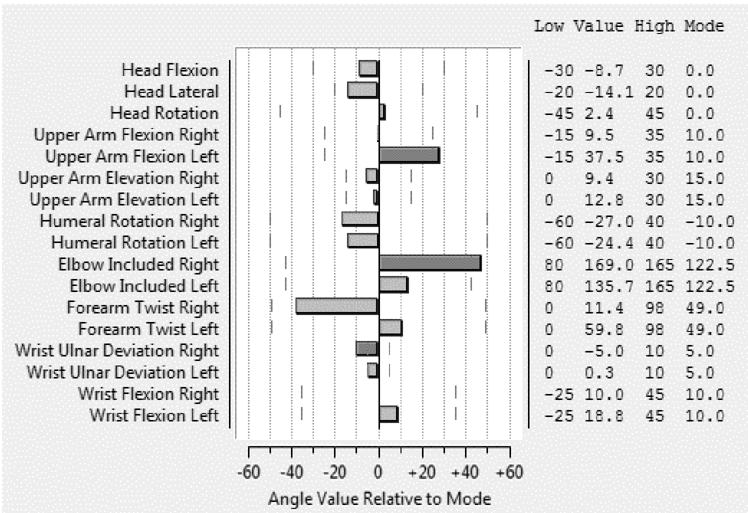


Figure 6. Modified solution – down position.

Figs 7 and 8 show the main differences in the evaluation of the comfort of the driving position between the conventional and modified solutions with the handbrake in the up position. The dark grey-marked values represent the state when the joints achieve bending angles that are defined as uncomfortable. The graphs show that even according to the Dreyfuss 3D study, the modified solution exhibit better results than the conventional arrangement, in particular in the wrist area.

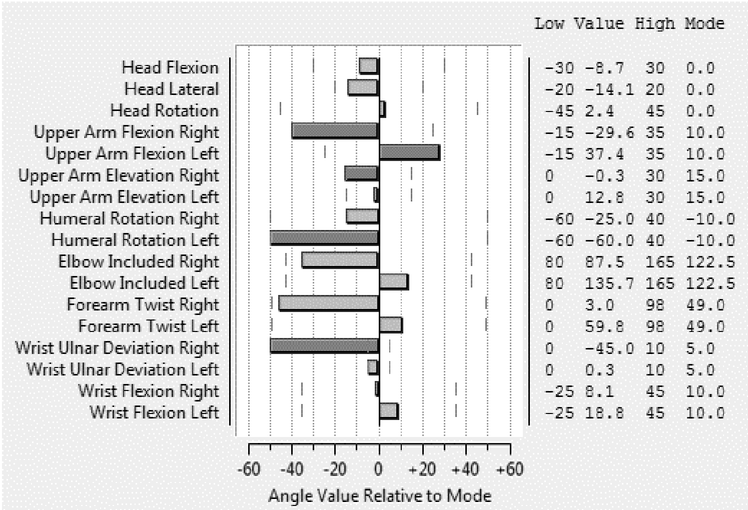


Figure 7. Conventional solution – up position.

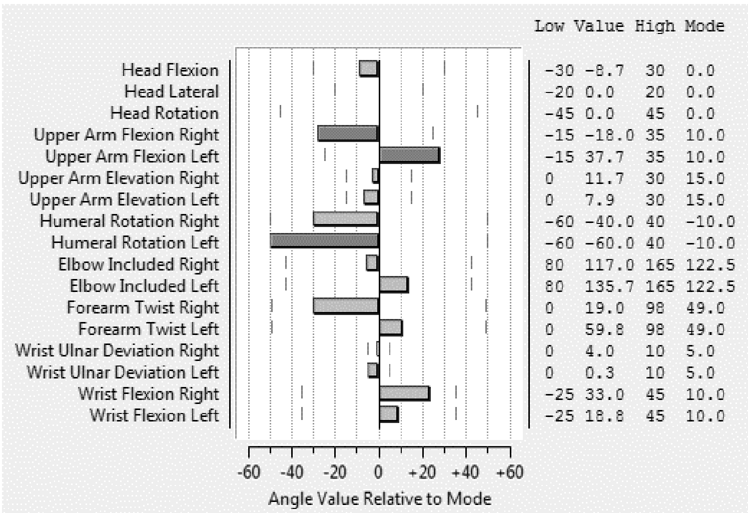


Figure 8. Modified solution – up position.

CONCLUSIONS

The measured values of the solution of the ergonomic conflict of the mechanical handbrake and armrest in a passenger car that are shown above indicate that this solution offers the possibility to significantly improve the comfort of drivers. Despite the fact that in view of the aforementioned facts it is not possible to precisely dimensionally specify the solution, the solution can be utilized as a general concept in terms of an approach to the structural solution of the handling of a mechanical handbrake. In the model arrangement of the handbrake, seats and armrest position that is described in this paper, important differences were ascertained in the values of the bending of the joints of the upper limb between the classic solution and the proposed solution. In particular in the case of the wrist joint, these are notable differences, and it can therefore be stated that the use of the structural design solution with the bent mechanical handbrake handle significantly increased the comfort of the driver. The proposed solution can be described as a technologically easily-resolvable change to the cab structure, and it would not be necessary to invest economically-significant development and production costs in order to implement the solution.

ACKNOWLEDGEMENTS. This study was financed by a project of the Czech Agricultural University in Prague (IGA 2014:31170/1312/3123).

REFERENCES

Ge, B.Z., Tian, Q.G., Young, K.D., Sun, Y.C. 2007. *Color 3D digital human modeling and its applications to animation and anthropometry*. Lecture Notes in Computer Science – Digital Human Modeling. 4561: 82–91.

Clauser, C.E., Gordon, C.C., McConville, J.T, Tebbetts, I. 1988. *Selection of Dimensions for an Anthropometric Database Volume:1 Rationale, Summary, and Conclusion*. Natick, MA; U.S. Army Natick Research, Development, and Engineering Center. NATICK/TR-86/053.

Grandjean, E. 1987. *Ergonomics in computerized offices*. Philadelphia: Taylor & Francis, 1987, viii, 227 p. ISBN 02-034-8975-6.

International Journal of Automotive Technology. 2010. **11**(2). ISSN 1229–9138. http://link.springer.com/10.1007/s12239-010-0030-4. Accessed 31.1.2015.

Kapandji, Adalbert Ibrahim. 1982. *The physiology of the joints: annotated diagrams of the mechanics of the human joints*. 2. English ed. Edinburgh: Churchill Livingstone, 1982, 283 p. ISBN 04430250451.

Krist, R. 1994. *Modellierung des Sitzkomforts eine experimentelle Studie*. Weiden: Schuch, 130 p. ISBN 3926931205.

NASA. 1978. *Anthropometric Sourcebook*. NASA Reference Publication No. 1024, Houston TX: NASA.

Porter, J.M. and Gyi, D.E. 1998 Exploring the optimum posture for driver comfort. *Int. J. of Vehicle Design* **19**(3), 255–266.

Pheasant, S. & Chasle. G. 2006. *Bodyspace: anthropometry, ergonomics, and the design of work. 3rd ed.* Boca raton: Taylor, 332 p. ISBN 04-152-8520-8.

Reed, M.P. 1998. *Statistical and Biomechanical Prediction of Automobile Driving*. Ph.D. Dissertation. University of Michigan. USA.

Robbins, D.H. 1983. *Anthropometry of Motor Vehicle Occupants, 2: Mid-sized Male, 3: Small Female and Large Male*. UMTRI-83-53-2. University of Michigan.

Tilley, AR. 2002. *The measure of man and woman: human factors in design*. Rev. ed. New York: Wiley, 98 p. ISBN 04-710-9955-4.

Wang, M.J.J., Wu, W.Y., Lin, K.C., Yang, S.N., Lu, J.M. 2007. Automated anthropometric data collection from three-dimensional digital human models. *International Journal of Advanced Manufacturing Technology* **32**, 109–115.

Agronomy Research **13**(3), 759–764, 2015

Dust pollution in University offices

P. Kic

Czech University of Life Sciences Prague, Faculty of Engineering, Kamycka 129, CZ-16521 Prague 6, Czech Republic; e-mail: kic@tf.czu.cz

Abstract. The aim of this paper is to present results of microclimatic research focused mainly on dust pollution in several offices of Departments in the Faculty of Engineering at Czech University of Life Sciences Prague. The attention is paid to the dimensions of the room, floor covering, furniture, equipment, ventilation, frequency of the use and period of the year. In the frame of this research the concentration of air dust was measured by special exact instrument Dust-Track aerosol monitor. After the installation of different impactors the PM_1, $PM_{2.5}$, PM_4, PM_{10} size fractions were also measured. The obtained results of measurements were evaluated by the statistical instruments and concentrations of different size of dust particles were analyzed. Results of different indoor conditions were generalized. Based on the results of measurements practical recommendations for the design, use, cleaning and ventilation of these types of rooms and buildings were summarised in the conclusions.

Key words: air, dust fractions, floor, indoor environment, measurement.

INTRODUCTION

Dust is one of the most common pollutants, which people face in everyday life and in their work activities. By dust we understand air pollution particles of matter that dispersed in the air create aerosols. Dust is characterized by a concentration, size and properties of dispersed particles. On all of those characteristics depends the influence on health. The harmful effect of dust on humans is very wide. Evaluation of dust depends on the origin, nature and size of the dust particles, on its concentration in the air, but also on the length and conditions of action, and on the human individual sensitivity to dust. The attention to dust is paid in many research works, e.g. Skulberg et al.(2004), Bouillard et al. (2005), Mølhave (2008), Mølhave et al. (2009), Buchholz et al. (2011), Nõu & Viljasoo (2011), Brodka et al. (2012).

Particles of internal dust are generated primarily by internal surfaces and devices of buildings, textile materials used in the interior, sloughing skin cells from people, etc.; part of household dust comes from atmospheric dust outside.

Over many years of research, it was found that the effect of solid dust particles on health depends mainly on their size. Particles bigger than 100 µm have relatively little importance for human health, because due to its considerable weight quickly settle. The size of dust particles is 1 to 100 µm, particles larger than 30 µm, are known as coarse dust in the environment and in normal conditions also quickly settle. In terms of human respiratory tract larger particles do not cause major problems, since they are recorded on the hairs in the nose and do not penetrate further into the airways (Hollerova, 2007).

Inhalable fraction of dust means a set of airborne dust particles that can be inhaled through the nose or mouth. Respirable fraction means the weight fraction of inhaled particles which penetrates into the respiratory tract where is no *ciliated epithelium* and in alveoli.

Particles smaller than 10 μm (Particulate matter PM_{10}) are of great biological importance because they can penetrate behind the larynx into the lower airways. Therefore these particles are called inhaled particles or thoracic particles. These particles can settle in the bronchial tubes ($PM_{2.5}$), or penetrate into the alveoli (PM_1) or to the blood (nanoparticles) and cause health problems (Hollerova, 2007).

Fromme et al. (2007) evaluated indoor air quality and dust particle fractions (PM_{10} and $PM_{2.5}$) in 64 schools during the winter and summer. The winter concentrations PM_{10} = 91.5 μg m^{-3} and $PM_{2.5}$ = 19.8 μg m^{-3} were significantly reduced in summer PM_{10} = 64.9 μg m^{-3} and $PM_{2.5}$ = 12.7 μg m^{-3}. Heidorf et al. (2009) measured PM_{10} in classrooms with objective to study impact of cleaning. Intensified cleaning showed a significant decrease in all classrooms from 79 ± 22 μg m^{-3} to 64 ± 15 μg m^{-3}.

Problems of dust inside the houses and rooms are also as the dust can be source of house dust mites which are present indoors wherever humans live. Positive tests for dust mite allergies are extremely common among people with asthma. According to the WHO (2000) and Hurley et al. (2005) long-standing increased concentration of dust particles PM_{10} results in an increase in total mortality.

As the university staff spend a large portion of days in the internal environment of buildings and rooms, it is important to know what the situation inside their offices is. The aim of this paper is to present results of microclimatic research focused mainly on dust pollution in several offices of Departments in the Faculty of Engineering at Czech University of Life Sciences Prague.

MATERIALS AND METHODS

This research work and measurements of the actual values were carried out in three offices of Departments in the Faculty of Engineering at Czech University of Life Sciences Prague. All rooms are situated in the same building, two of them in the same corridor in the third floor, one in the second floor. The rooms have the same dimensions: floor area about 20 m^2, volume 66 m^3 and inside is one person.

The first office (A) is equipped with 12 upholstered chairs and the floor covers PVC flooring, the second office (B) is furnished with 8 upholstered chairs and the floor covers carpet covering from wall to wall, the third office (C) is equipped with 5 upholstered chairs and the floor covers PVC flooring.

Offices A and B were during the measurement within normal operating conditions (relatively well organised and clean), two days after cleaning. Office C was also two days after cleaning, but the lockers were opened, taking out a lot of books, research reports, papers, etc., (total chaos, disarray). There was also measured in this office another day (C_2), immediately after cleaning (wiping down the floor).

The total concentration of air dust was measured by special exact instrument Dust-Track aerosol monitor. After the installation of different impactors the $PM_{10,}$ PM_4, $PM_{2.5}$, PM_1 size fractions of dust were also measured. Measured dust inside the offices is not aggressive, it has properties as house dust, therefore, as a criterion for evaluation of the measured values was selected the limit level of outdoor dust, which is 0.050 mg m^{-3} (50 µg m^{-3}).

The 90 data of dust concentration for total dust as well as of each fraction size in each room were collected. The obtained results of dust measurements were processed by Excel software and verified by statistical software Statistica 12 (*ANOVA* and *TUKEY HSD Test*).

RESULTS AND DISCUSSION

Principal results of dust measurement are summarized and presented in the Figs 1–4 and Tables 1, 2. The Fig. 1 presents results of measurement inside the office A. The average concentration of total dust pollution was lower than limit level 0.050 mg m^{-3}. About 15% are large particles of dust over PM_{10}, which is not so dangerous from the human health point of view. About 54% of dust was size fraction PM_1 which can cause health problems.

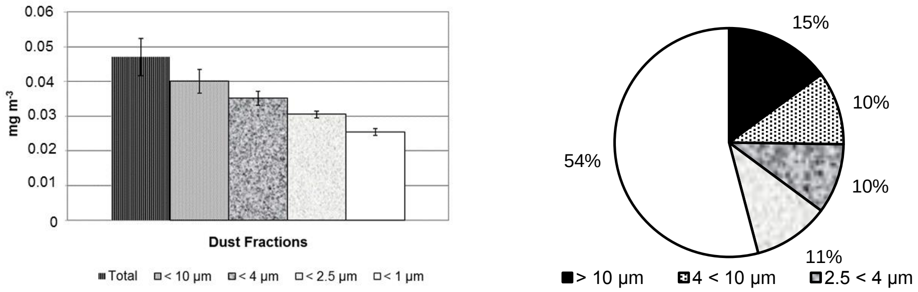


Figure 1. Concentrations and percentage of size distribution of dust fractions inside the office A.

Fig. 2 presents results of measurement inside the office B. Average concentration of total dust pollution was lower than limit level 0.050 mg m^{-3}. About 55% of dust was size fraction PM_1 which can penetrate into the alveoli and cause health problems. The smallest percentage of dust fractions about 8% is the large particle of dust over PM_{10}. It can be supposed, that the biggest dust particles are fixed in the carpet.

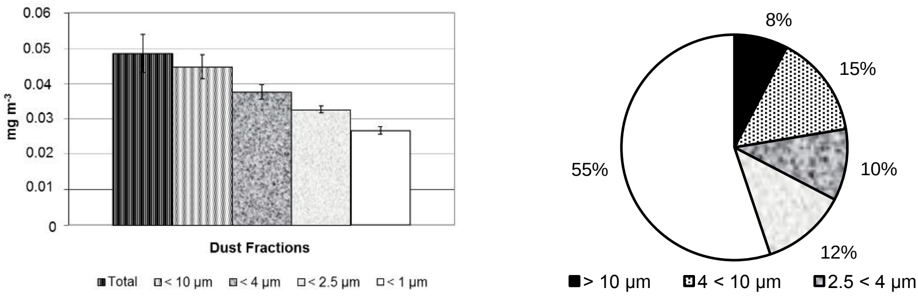


Figure 2. Concentrations and percentage of size distribution of dust fractions inside the office B.

Fig. 3 presents results of measurement inside the office C. The average concentration of total dust pollution was lower than limit level 0.050 mg m^{-3}. About 54% of dust was size fraction PM_1 which can cause health problems. About 14% are the large particles of dust over PM_{10}, which are not so dangerous for the human health.

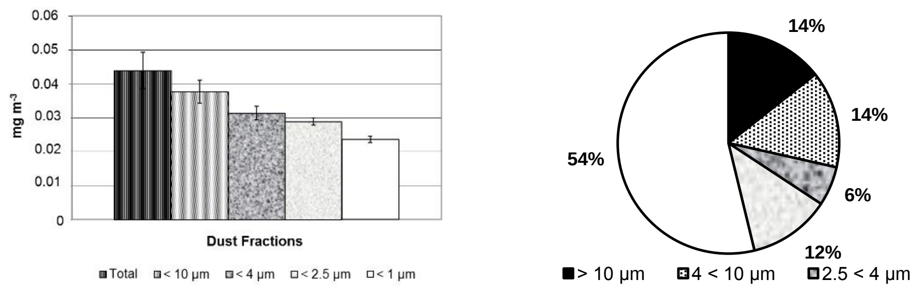


Figure 3. Concentrations and percentage of size distribution of dust fractions inside the office C.

The results of dust measurements were compared by statistical analyse (Table 1). The total dust concentration in the room C was significantly lower than the concentrations in the rooms A and B. Concentrations in the rooms A and B could be considered as equal (*TUKEY HSD Test*, P = 0.43). The other all differences between concentrations of fractions in all offices were statistically significant (*TUKEY HSD Test*, $P \leq 0.05$).

Table 1. Mean values in µg m^{-3} of total dust concentration and concentration of dust fractions PM_{10}, PM_4, $PM_{2.5}$ and PM_1 in offices A, B and C. Different letters (a, b, c) in the superscript are the sign of high significant difference (*ANOVA; Tukey HSD Test*; $P \leq 0.05$)

Office	Concentration total	Concentration of dust fractions			
		PM_{10}	PM_4	$PM_{2.5}$	PM_1
A	47 ± 5^{a}	40 ± 3^{a}	30 ± 2^{a}	30 ± 1^{a}	25 ± 1^{a}
B	48 ± 5^{a}	45 ± 4^{b}	38 ± 2^{b}	33 ± 1^{b}	27 ± 1^{b}
C	44 ± 7^{b}	38 ± 4^{c}	31 ± 1^{c}	29 ± 1^{c}	24 ± 1^{c}

The floor covering in the rooms A and C enables easy cleaning by wiping the floor with a wet rag. To know the effect of wiping, the measurement of dust was repeated in the room C two hours after the wiping of the floor. The results of the measurement (C_2) are presented in the Fig. 4.

These results were compared with the measurement before the wiping and statistically evaluated (Table 2). The all differences between total dust concentrations and all fractions in both measurements were statistically significant (*TUKEY HSD Test*, $P \leq 0.05$).

All dust concentrations (total dust as well as size fractions) in the room C after the wiping C_2 were significantly lower than before the cleaning. It is obvious from the Fig. 4 that mainly the percentage of largest particles was reduced from 14 to 5%. On the contrary, the percentage of the smallest particles increased from 54 to 72%.

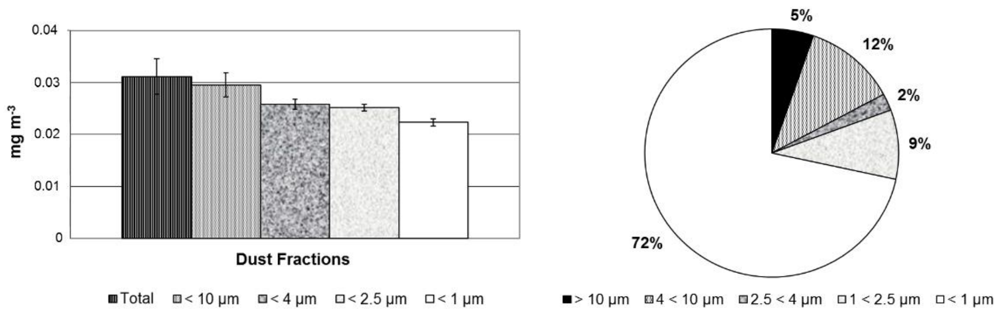


Figure 4. Concentrations and percentage of size distribution of dust fractions inside the office C after the wiping of the floor C_2.

Table 2. Mean values in µg m^{-3} of total dust concentration and concentration of dust fractions PM_{10}, PM_4, $PM_{2.5}$ and PM_1 in office C before and after wiping C_2. Different letters (a, b) in the superscript are the sign of high significant difference (*ANOVA; Tukey HSD Test*; $P \leq 0.05$)

Office	Concentration total	Concentration of dust fractions			
		PM_{10}	PM_4	$PM_{2.5}$	PM_1
C	44 ± 7^a	38 ± 4^a	31 ± 1^a	29 ± 1^a	24 ± 1^a
C_2	31 ± 3^b	30 ± 2^b	26 ± 1^b	25 ± 1^b	22 ± 1^b

CONCLUSIONS

The results of measurements in the University offices showed that:

- average concentrations of dust in offices was not over the level 0.050 mg m^{-3},
- the biggest percentage of dust particles are small size particles PM1,
- rather bigger influence on the indoor pollution by dust has floor covering, especially the carpets are the source of dust,
- floor PVC covering is more suitable for the floor than the carpet, as it enables easy cleaning of floor by wiping, which is important for reduction of dust inside the rooms,
- the equipment which is used inside the room, especially the cloth seats furniture, rather increases the indoor air pollution by dust,
- previous factors are more important than the total chaos and disarray inside the room.

ACKNOWLEDGEMENT. Author is grateful and expresses many thanks to the colleagues who enabled him to carry out all measurements inside their offices.

REFERENCES

Bouillard, L., Michel, O., Dramaix, M. & Devleeschouwer, M. 2005. Bacterial contamination of indoor air, surafaces, and settled dust, and related dust endotoxin concentrations in healthy office builgings. *Ann. Agric. Environ. Med*. **12**, 187–192.

Brodka, K., Sowiak, M., Kozajda, A., Cyprowski, M.& Szadkowska-Stanczyk, I. 2012. Biological contamination in office buildings related to ventilation/air conditioning system. *Medycyna Pracy* **63**(3), 303–315. (in Polish).

Buchholz, S., Krein, A., Junk, J., Gutleb, A.C., Pfister, L. & Hoffmann, L. 2011. Modelling, measuring, and characterizing airborne particles: Case studies from southwestern Luxembourg. *Critical reviews in environmental science and technology* **41**(23), 2077–2096.

Hurley, F., Hunt, A., Cowie, H., Holland, M., Miller, B., Pye, S. & Watkiss, P. 2005. *CBA methodology for the Clean Air for Europe (CAFE). Volume 2: Health Impact Assessment.* AEA Technology Environment, Didcot, 133 pp.

Fromme, H., Twardella, D., Dietrich, S., Heitmann, D., Scierl, R., Liebl, B. & Rüden, H. 2007. Particulate matter in the indoor air of classrooms – exploratory results from Munich and surrounding area. *Atmospheric Environment* **41**, 854–866.

Heudorf, U., Neitzert, V. & Spark, J. 2009. Perticulate matter and carbon dioxide in classrooms – The impact of cleaning and ventilation. *Int. J. Hyg. Environ. Health.* **212**, 45–55

Hollerova, J. 2007. Prasnost na pracovisti. *http://www.szu.cz/tema/pracovni-prostredi/prasnost-na-pracovisti.* Accessed 29.1.2015 (In Czech).

Mølhave, L. 2008. Inflammatory and allergic responses to airborne office dust in five human provocation experiments. *Indoor air*. **18**(4), 261–270.

Mølhave, L., Pan, Z., Kjærgaard, S.K., Bønløkke, J.H., Juto, J., Andersson, K., Stridh, G., Löfstedt, H., Bodin, L. & Sigsgaard, T. 2009. Effects on human eyes caused by experimental exposures to office dust with and without addition of aldehydes or glucan. *Indoor air*. **19**(1), 68–74.

Nõu, T. & Viljasoo, V. 2011. The effect of heating systems on dust, an indoor climate factor. *Agronomy Research* **9**(1), 165–174.

Skulberg, K., Skyberg, K., Kruse, K., Eduard, W., Djupesland, P., Levy, F. & Kjuus, H. 2004. The effect of cleaning on dust and the health of office workers: an intervention study. *Epidemiology* **15**(1), 71–78.

World Health Organisation (WHO). 2000. Air Quality Guidelines for Europe. WHO regional Publications, European Series, No. 91. Copenhagen, 273 pp.

The effect of static magnetic field on heart rate variability – an experimental study

T. Koppel[1,*], I. Vilcane[2], M. Carlberg[3], P. Tint[1], R. Priiman[4], K. Riisik, H. Haldre[4] and L. Visnapuu

[1]Tallinn University of Technology, Department of Work Environment and Safety, Ehitajate tee 5, EE19086 Tallinn, Estonia; [*]Correspondence: tarmo.koppel@ttu.ee
[2]Riga Technical University, Institute of Occupational Safety and Civil Defence, Kalnciema Street 6, LV-1048 Riga, Latvia
[3]Department of Oncology, Faculty of Medicine and Health, Örebro University, SE-701 82 Örebro, Sweden
[4]Institute of Environmental Health and Safety

Abstract. The aim of this study was to investigate the effect of weak static magnetic fields on human heart rate variability (HRV). So far, literature has mainly focused on the health effects induced by strong static magnetic fields. HRV is a temporal fluctuation of heart rate, which the literature has shown to be an adequate indicator for assessing the state of the autonomic nervous system. By autonomic nervous system one could also assess in real time if and when the organism falls into stress. In this blind experiment the subjects were exposed to 150 microTesla magnetic field for a few minutes. The heart activity of the subjects ($n = 116$) was recorded and the dynamics of the HRV frequency components i.e. reaction of the sympathetic and parasympathetic nervous system analyzed by repeated measures analysis of variance (ANOVA). No statistically significant difference ($p < 0.05$) were found in low frequency (LF), high frequency (HF), total power (TP), HF/TP ratio, LF/HF ratio nor between hear rate (HR) means in between the exposure and pre- or post-control stages of the experiment. However, observations made by the researchers suggest, that a small portion of the population may indeed be affected by slightly elevated static magnetic fields but the screening method needs further elaboration.

Key words: static magnetic field, heart rate variability, HRV, autonomic nervous system.

INTRODUCTION

Scientific literature is scarce in regard to studies on weak static magnetic fields effects on humans. The literature has mainly focused on strong magnetic fields, such as present in industrial processes like electrolysis, aluminum production and other activities which consume a lot of electrical current. Also, strong static magnetic fields can be encountered close to magnetic resonance tomography (MRT) devices and some other medical therapy devices. Close to such instruments the magnetic field may vary extend from hundreds of milliTeslas to few Teslas. In comparison, the natural magnetic field in Estonia is about 51 microTeslas (μT). The public safety limit for static magnetic fields in Estonia is 40 milliTeslas (mT) (MS, 2002). Based on the new European directive (2013/35/EU) the maximum allowed occupational exposure is even higher: 2 or 8

Teslas (T) depending on whether the environment is controlled or not (EP, 2013). The afore mentioned safety limits are set to prevent well known sensory or health effects induced by the static magnetic field. The field strength applied in this study is several orders of magnitude lower than legal safety limits. Such low field strengths may also be encountered near larger ferromagnetic objects, e.g. construction supporting structures where a lot of iron is applied.

HRV is an expression of a heart rate variation in time in between consecutives heartbeats (R-R interval). The recorded R-R intervals compose a rythmogram that is subjected to a time domain analysis (mean and standard deviation of heart rate) and frequency domain analysis (power in the low and high frequency spans and total spectral power TP over all of these spans).

In recent times HRV has found more use as both diagnostic tool and therapeutic guide in the field of medicine. HRV has been confirmed as a diagnosis tool for the state of the autonomic nervous system (Malik et al., 1996; Melillo et al 2011) and as a predictor of survival in heart failure cases (Ho et al., 1997).

Chronic heart failure is associated with autonomic dysfunction, that can be quantified by measuring HRV. A reduction in standard deviation of all normal RR intervals (SDNN) identifies patients at high risk of death and is a better predictor of death due to progressive heart failure than other conventional clinical measurements (Nolan et al., 1998).

Altered HRV and heart rate dynamics have found to have prognostic significance for the progression of coronary artery disease and mortality after certain heart conditions (Jokinen, 2003). HRV biofeedback has been successfully used to decrease major depressive disorder (Karavidas, 2008).

HRV has been utilized only by some researchers to investigate the effects from the electromagnetic fields. Andrzejak et al. (2008) exposed 32 students to a radiofrequency electromagnetic field from a mobile phone call (20min) and found an increase in parasympathetic tone while sympathetic tone was reduced: low frequency (LF) / high frequency (HF) ratio got lower during the call (Andrzejak et al., 2008).

Parazzini et al. exposed subjects to a full power (2W) of a GSM mobile phone and concluded that there were no statistical significant effect on the main (R-R mean) and most of the rest HRV parameters due to the EMF exposure. However, a weak interaction between some HRV parameters (SDNN, TINN, and triangular index in time domain and LF power in frequency domain analysis) and RF exposure was observed (Parazzini et al., 2007). The group’s later analysis using nonlinear dynamics of HRV on the same data set, also showed no statistically significant effect due to GSM exposure (Parazzini et al., 2013).

Wilén et al. (2007) investigated HRV of the radiofrequency (RF) plastic sealer operators (n = 35) and found a significantly increased total power (TP) and very low frequency (VLF) power during nightshift amongst RF operators as compared to the control group. The RF sealer operators exhibited relative increase in parasympathetic cardiac modulation, which the authors hypothesized to be a result of chronic low level RF exposure on the thermoregulatory mechanism of the body, rather than from the non-thermal mechanism on the cardiovascular system (Wilén et al., 2007).

A study by Bortkiewicz et al. (2006) concluded that worker exposed to elevated levels of 50 Hz electromagnetic fields influences neurovegetative regulation of the cardiovascular system: the relative risk of decreased HRV was significantly higher in the exposed group as compared to the control (OR = 2.8). According to their findings, VLF exhibit significantly more power in the exposed group and even correlate with the exposure; also, in the exposed group there were more people with dominant sympathetic function (LF/HF>1) (65%) than in controls (47%) (Bortkiewicz et al., 2006).

All consumer electronics must comply with legally set safety limits, which 1) in case of radiofrequency fields are set to prevent health effects from heating of the tissues, 2) to prevent electric stimulation of peripheral and central nervous system tissues (1Hz-10MHz) and 3) to prevent vertigo and other physiological effects related to disturbance of the human balance organ resulting from moving in a static magnetic field (ICNIRP 1998; CEC 1989 & 1999; EP 2013). The scientific literature has also suggested other health effects, e.g. Bioinitiative report (2010; 2012), but these are yet not well accepted/confirmed by the whole scientific community, as the underlying mechanism is often unclear and the experiments are not always repeatable (Bioinitiative, 2010 & 2012; EHFHRAN, 2010).

The literature does not however provide studies done involving HRV-analysis and weak static magnetic fields from the point of view of this study. However, there exists a niche of research of fluctuations in the natural magnetic field of the Earth and their induced health effects. Some of these studies have investigated HRV during magnetic storms. Cornélissen et al. (2002) in their review article concluded magnetic field fluctuations to decrease heart rate variability. Such magnetic storm events were seen mostly to decrease spectral power of VLF (< 0.04Hz) and LF band (0.04–0.15Hz) and no influence on HF band (0.15–0.40Hz) (Cornélissen et al., 2002; Chibisov et al., 1995; Otsuka(ed.) Proceedings, 2000).

This study was conducted to investigate the effect of weak static magnetic fields on human heart rate variability (HRV).

MATERIALS AND METHODS

The current study is about exposing the subject to a weak static magnetic field and analyzing the dynamics of heart rate variability. The nominal field strength at the center of the subject's head is ~150 μT which in case of static magnetic fields may be classified as very weak.

The subjects of the study are voluntaries in different ages. The measurements were conducted in the companies and other types of organizations and facilities, where the members of that organization were invited to participate in the study. People under heart medication were excluded from the sample. Also, people who reported their health being weak or sick were also excluded from the sample. The test was performed individually with each subject. The subject was placed in a private space separated from the test operators. The subject had no view on what the operators were doing. In selecting the sitting place for the subject, it was sought that all the emotional stimuli would be minimized in the room.

Other environmental electromagnetic field parameters were also checked prior to the test: 1) low and intermediate frequency electric field, 2) low and intermediate frequency magnetic field and 3) radiofrequency electromagnetic field. Also the electromagnetic emissions from the research instruments were under the control. All electronics devices were removed from the measurement area (including mobile phones). By measuring the afore-mentioned components of the electromagnetic field almost the entire spectrum of the EMFs were taken under the control.

In order to exclude other external factors influencing the test, attention was paid also to other environmental factors. A national standard EVS-EN 15251:2007 was used as a guideline for controlling lighting, noise, indoor air quality (excluding the exchange of air) and temperature (ES, 2007).

The research instrumentation consisted of 1) equipment used for magnetic field generation and 2) heart rate measurement instruments. Static magnetic field was generated using an electromagnetic air-core coil, distanced 0.3 m from the center of the head (Fig. 1).

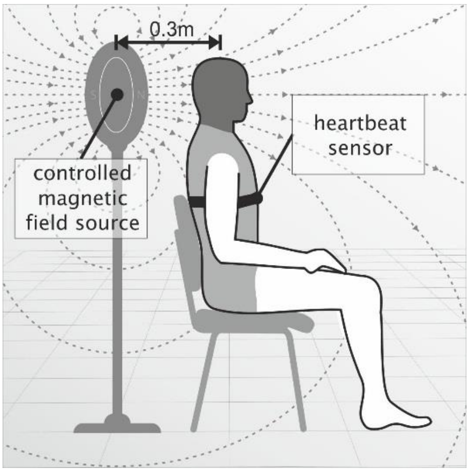


Figure 1. The placement of the subject and the magnetic field source.

The set nominal magnetic field (150 μT at the center of the head) was checked by magnetometric measurements. Measurements were conducted using a fluxgate triple axis magnetometer Walker Scientific FGM-5DTAA. Voltage dynamics at the electromagnetic coil's terminals were checked with a 60 MHz oscilloscope (Hantek DSO-2150).

By moving from the center of the head towards the electromagnetic coil, the magnetic field also increases, therefore the backside of the head was exposed to somewhat higher magnetic field (~200 μT). The diameter of the electromagnetic coil was 0.4m which guaranteed wide exposure to the whole head region. The magnetic field was switched on by the operator from a distance, using a specialized control unit.

Heart rate variability was registered and analysis on the autonomic nervous system reaction was performed in real-time with a non-invasive hard- and software system Nerve-Express 2.4 (Heart Rhythm Instruments, Inc. NY USA). The system registers subject's each heartbeat (R-R interval) and distributes these into 192-beat episodes. The reaction to the intervention is determined by calculating the heart rate variability during the selected episode (a period of 192 heartbeats). Frequency domain measures were applied to calculate the power in the bands of 0.033–0.07 Hz (low frequency-LF2), 0.07–0.15 Hz (low frequency-LF1), 0.033–0.15 Hz (LF+LF2), 0.15–0.5 Hz (high frequency-HF) and total spectral power (TP) over all three bands (0.033–0.5 Hz). The analysis mainly focuses on the HF band.

The dynamic behavior of the nervous system is used to assess the effect the magnetic field has on the individual.

The heartrate is registered using a heartrate monitor chest strap sensor, that forwards the signal to the hardware receiver by a 5.3 kHz radio signal, which is connected to a laptop personal computer (Fig. 2).

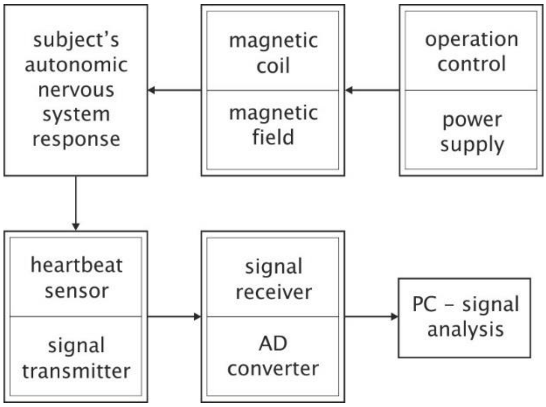


Figure 2. The setup of the research instrumentation and the context of collecting the data.

The subjects were asked to sit in a comfortable position and to refrain oneself from sudden or larger physiological movements, since these may alter the behavior of the heartrate variability. In order to exclude the effect on cardiovascular activity from changing the posture (from walking/standing to sitting), it was also required that prior to testing the subject would have been in a sitting position for a sufficient time.

The subjects were also instructed to avoid any emotional burden during the test – this meant avoiding any negative or positive emotional thoughts. In turn the subjects were asked to watch outside of the window (at the trees and landscape) or at the corresponding picture on the wall or the nature video on the computer screen. During the test the room was kept quiet and nobody was allowed to address the subject.

The operator activated the magnetic field by a remote unit. Nominal magnetic field was established and dropped smoothly: 100% magnetic field was deployed in 0.15 sec from switching and it dissipated in 1 sec after switch-off.

Blind experiment criteria were followed in setting up the test. The measurement period was divided into episodes of 192 heartbeats, consequently each episode took about 2–3 min, depending on the heart rate. During the test there was one exposure episode and several control episodes. The subject was not informed when the exposure to the magnetic field would take place, neither when one or another episode would start or end. The turn of the exposure episode was selected randomly, given that previously there had been at least two control episodes. The operator also sought that prior to the exposure episode the nervous system would exhibit stability in two pre-control episodes. This procedural requirement would minimize the possibility of false positives from variations in cardiovascular activity.

The values for pre-control (the stage right before the exposure), exposure and post-control stages were compared using repeated-measures ANOVA with Huynh–Feldt correction followed by linear contrasts for pairwise comparisons. All variables except HF/TP were log-transformed prior to analyses to normalize the distributions. For HF/TP square-root transformation was used. The statistical level of significance was set to $p = 0.05$. The statistical analyses were done using StataSE 12.1 (Stata/SE 12.1 for Windows; StataCorp, College Station, TX).

RESULTS AND DISCUSSION

The measurements were performed in Estonia and Latvia.

The sample ($n = 116$) consisted of 84 females and 32 males. The youngest person was 20 and the oldest 83 years of age. The age distribution of the sample is following:

20–34y – 40 persons; 35–49y – 41 persons; 50–64y – 25 persons; 65+y – 10 persons.

A repeated measures analysis of variance (ANOVA) with Huynh-Feldt correction was done to assess if there is change in subjects' HRV indicators when measured before (i.e. pre-control episode, right before the exposure), during (exposure episode) and after (post-control episode) the exposure to the magnetic field. The results of the ANOVA show no statistically significant effect ($p < 0.05$), as shown in Table 1 (results from linear contrasts i.e. pairwise comparisons, are shown as p-values; the values for HF, TP, LF/HF, LF1, LF2 and HR were log-transformed and the values for HF/TP were square-root transformed prior to analysis). Thus, there is no statistically significant evidence in temporal differences for HF, TP, LF/HF, LF1, LF2, HR and HF/TP ratio. Also, each pairwise comparison proved neither to be statistically significant ($p < 0.05$).

Table 1. Tests of differences between pre-control, exposure and post-control for HF (ms^2), TP (ms^2), LF1 (ms^2), LF2 (ms^2), HR (bpm), HF/TP ratio (n = 116)

	HF	TP	LF/HF	LF1	LF2	HR	HF/TP
Repeated-measures ANOVA overall comparisons							
Pre-control ($\bar{x}$)	3,188.5	7,529.9	3.77	2,118.4	2,072.4	75.6	0.347
Exposure ($\bar{x}$)	3,164.4	7,671.2	3.87	2,310.3	2,041.6	75.4	0.352
Post-control ($\bar{x}$)	3,392.4	8,604.5	6.32	2,761.2	2,306.5	75.4	0.329
p-value	0.58	0.79	0.19	0.25	0.22	0.62	0.16
Linear contrasts							
Pre-control vs exposure (*p*)	0.98	0.80	0.74	0.35	0.12	0.41	0.66
Pre-control vs post-control (*p*)	0.37	0.67	0.17	0.09	0.92	0.39	0.16
Exposure vs post-control (*p*)	0.38	0.50	0.09	0.46	0.15	0.97	0.06

$\bar{x}$ = mean; p = p–value

However, the observations made by the researchers indicate that the effect of the magnetic field might still be real for some individuals, which would require a larger sample size and more detailed statistics to show with statistical significance. While monitoring individual tests in real-time (*Nerve–Express* software), the researchers found, the autonomic nervous system balance fluctuation to correlate with the exposure to the magnetic field in a number of cases. Some individuals seemed to react to the magnetic field with a decrease in the spectral components power (LF n = 2; HF n = 9) while others showed increase (LF n = 5; HF n = 16).

Next, a measurement of a 20y old man is presented, representing an individual with suspected reaction to the elevated static magnetic field (Figs 3–4). It is a typical case, where pre- and post-control stages differ from the exposure stage (3rd). Subject's heart rate variability decreased at the 3rd stage when the exposure to the magnetic field took place. Fig. 3 shows weaker variability amplitude at the 3rd stage of the rythmogram, whereas at the 4th stage (no magnetic field) the variability recovered. Fig. 4 indicates weaker power at the frequency span of 0.04–0.15 Hz (LF); total of four stages are pictured, episodes 1, 2 and 4 were without magnetic field.

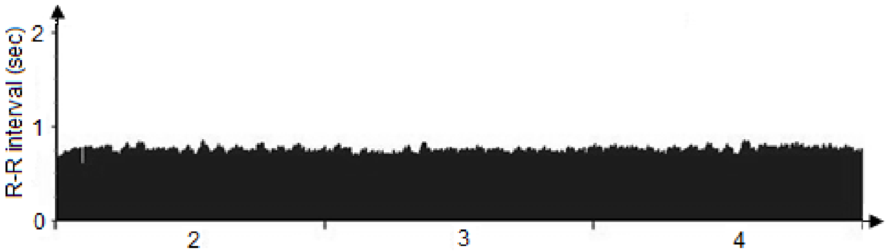


Figure 3. Heart rate rythmogram of a twenty year old male subject whose heart rate variability decreased at the 3rd episode (exposure); vertical axis – R-R interval (sec); horizontal axis – episodes (each episode consists of 192 heartbeats).

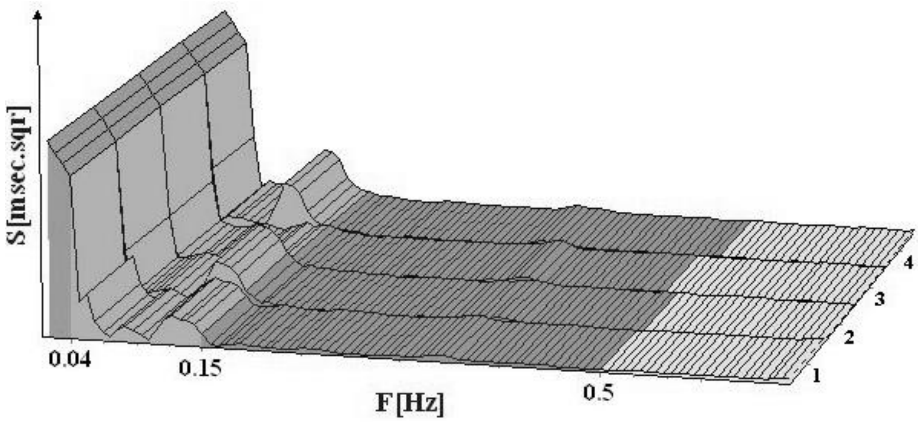


Figure 4. Spectral function of a twenty year old male subject; exposure at the 3rd stage; vertical axis – relative amplitude of spectral harmonics (S, msec²); horizontal axis – frequencies (Hz).

The literature does not however provide much studies like this one. HRV decrease discussed by Cornélissen et al. (2002), Chibisov et al. (1995), Otsuka(ed.), (2000). Proceedings, 2000 are related to the fluctuations in the static magnetic field of the Earth, which in essence are time-varying and not static.

The authors suggest follow-up studies, to utilize questionnaires to find out what personal traits and health characteristics may explain the change in the HRV due to the exposure to the static magnetic field. Such questionnaire would also investigate subjects' exposure to other electromagnetic fields in a daily life.

Future research should encompass more subjects, to have a reliable assessment on how much of the population are affected by the elevated magnetic field. Attention should also be paid on testing the same individual on more than one occasion – to find out if the reaction occurs also on other day or time of day.

Considering the short length of the exposure, it is also worth investigating if longer exposure to the same field strength would result in reaction in more people. Follow-up studies should also clarify, why some people exhibit reaction and others not. The cofounding factor may be the general status of health, sporting habits, diet and environmental sensitivity to other risk factors (e.g. noise). It is also worth investigating, if those that reacted to the elevated static magnetic field would also react to other parts of the electromagnetic spectrum: 1) low frequency, 2) intermediate frequency and 3) radiofrequency electric, magnetic and electromagnetic fields.

CONCLUSIONS

This study has suggested that some people may exhibit change in the heart rate variability as a reaction to weak static magnetic fields. However the results are not statistically significant. The finding may be considered worth of further investigations since 1) the used field strength resides below the legal safety limit and 2) the exposure was short term (~2½ min).

Since the magnetic field source was positioned close to the subject, one must also consider that the field was not homogeneous. Therefore the affecting factor may not only be the elevated magnetic field itself, but also the abrupt gradient of the field. However sudden head movements can be excluded as a causing factor, since subjects were well instructed to move only slowly, if at all.

It's possible that we are dealing with an individual sensitivity – some members of the public may react to the magnetic field, whereas others don't. Atlasz et al. (2006) exposed their sample to the radiofrequency electromagnetic field and noticed that 9% of the subjects had alterations in their HRV after the exposure, though their sample size was small (n = 35).

REFERENCES

Andrzejak, R., Poreba R, Poreba, M., Derkacz, A., Skalik, R., Gac, P., Beck, B., Steinmetz-Beck, A., Pilecki, W. 2008. The influence of the call with a mobile phone on heart rate variability parameters in healthy volunteers. *Industrial Health* **46,** 409–417.

Atlasz, T., Kellényi, L., Kovács, P., Babai, N., Thuróczy, G., Hejjel, L., Hernádi, I. 2006. The application of surface plethysmography for heart rate variability analysis after GSM radiofrequency exposure. *J. Biochem. Biophys. Methods* **69,** 233–236.

BioInitiative Working Group 2007. Bioinitiative report: A Rationale for a Biologically Based Public Exposure Standard for Electromagnetic Fields.

BioInitiative Working Group, Sage, C. & Carpenter, D.O. (Editors). 2012. BioInitiative Report: A Rationale for a Biologically-based Public Exposure Standard for Electromagnetic Radiation. *http:// www.bioinitiative.org*. Accessed 31.12.2012.

Bortkiewicz, A., Gadzicka, E., Zmyślony, M., Szymczak, W. 2006. Neurovegetative disturbances in workers exposed to 50 Hz electromagnetic fields. *International Journal of Occupational Medicine and Environmental Health* **19**(1), 53–60.

CEC-Council of the European Communities. Council Directive 89/336/EEC of 3 May 1989 on the approximation of the laws of the Member States relating to electromagnetic compatibility (89/336/EEC), Official Journal L 139, 23/05/1989 P. 0019–0026.

CEC–Council of the European Communities. Recommendation of the Council 1999/519/EC on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz). *Official Journal of the European Communities*, 30. 7. 1999.

Chibisov, S.M., Breus, T.K., Levitin, A.E., Drogova, G.M. 1995. Biological effects of planetary magnetic storms. *Biofizika* **40**, 959–968.

Cornélissen, G., Halberg, F., Breus, T., Syutkina, E.V., Baevsky, R., Weydahl, A., Watanabe, Y., Otsuka, K., Siegelova, J., Fiser, B., Bakken, E.E. 2002. Non-photic solar associations of heart rate variability and myocardial infarction. *Journal of Atmospheric and Solar-Terrestrial Physics* **64**(5–6), 707–720.

EHFHRAN–European Health Risk Assessment Network on Electromagnetic Fields Exposure 2010. Risk Analysis of human exposure to electromagnetic fields, report D2 of EHFRAN project. *http://efhran.polimi.it/docs/EFHRAN_D2_final.pdf.* Accessed 6.12.2014.

EP-European Parliament. Directive 2013/35/EU of the European Parliament and the Council of 26 June 2013 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (20th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC) and repealing Directive 2004/40/EC. *Official Journal of the European Union* 29.6.2013.

ES-Estonian Standards Center. Estonian Standard EVS-EN 15251:2007 Source data for planning and assessing the energy efficiency of the buildings based on the quality of the indoor air, thermal comfort, lighting and acoustics. Inure July 2007 (in Estonian).

Heart Rhythm Instruments Inc. 2002. Nerve-Express System Guide & User's Manual, NJ USA.

Ho, K.K., Moody, G.B., Peng, C.K., Mietus, J.E., Larson, M.G., Levy, D., Goldberger, A.L. 1998. Predicting survival in heart failure case and control subjects by use of fully automated methods for deriving nonlinear and conventional indices of heart rate dynamics. *Circulation.* **96**(3), 842.

ICNIRP-International Commission of Non-Ionising Radiation Protection 1998. Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields. *http://www.icnirp.de/documents/emfgdl.pdf.* Accessed 1.12.2014.

Jokinen, V. 2003. Longitudinal changes and prognostic significance of cardiovascular autonomic regulation assessed by heart rate variability and analysis of non-linear heart rate dynamics. Department of Internal Medicine, University of Oulu.

Kravidas, M. 2008. Heart rate variability biofeedback for major depression. *Biofeedback* **36**(1), 18–21.

Malik, M., Bigger, J.T., Camm, A.J., Kleiger, R.E., Malliani, A., Moss, A.J., Schwartz, P.J. 1996. Heart rate variability: Standards of measurement, physiological interpretation, and clinical use. *Eur Heart J* **17**, 354–381.

Melillo, P., Bracale, M., Pecchia, L. 2011. Nonlinear Heart Rate Variability features for real-life stress detection. Case study: students under stress due to university examination. *BioMedical Engineering OnLine* **10**, 96.

Nolan, J., Batin, P.D., Andrews, R., Lindsay, S.J., Brooksby, P., Mullen, M., Baig, W., Flapan, A.D., Cowley, A., Prescott, R.J., Neilson, J.M., Fox, K.A. 1998. Prospective study of heart rate variability and mortality in chronic heart failure: results of the United Kingdom heart failure evaluation and assessment of risk trial (UK-heart). *Circulation* **15**, 1510.

Otsuka, K. (ed.). 2000. *Proceedings, First International Symposium, Workshop on Chronoastrobiology & Chronotherapy (Satellite Symposium, Seventh Annual Meeting, Japanese Society for Chronobiology)*. Kudan, Chiyodaku, Tokyo, 11.11.2000.

Parazzini, M., Ravazzani, P., Tognola, G., Thuroczy, G., Molnar, F.B., Sacchettini, A., Ardesi, G., Mainardi, L.T. 2007. Electromagnetic Fields Produced by GSM Cellular Phones and Heart RateVariability. *Bioelectromagnetics* **28**, 122–129.

Parazzini, M., Ravazzani, P., Thuroczy, G., Tognola, G., Molnar, F.B., Ardesi, G., Sacchettini, A., Mainardi, L.T. 2013. Nonlinear heart rate variability measures under electromagnetic fields produced by GSM cellular phones. *Electromagnetic Biology and Medicine* **32**(2), 173–181.

SM-Regulation by the Minister of Social affairs. Limit values for non-ionizing radiation in living and recreational spaces, learning environments and measurement of the levels of non-ionizing radiation. RTL 2002, 40, 563, 21.02.2002 nr 38 (in Estonian).

VV-Regulation by the Government of the Republic. Safety limit values for physical risk factors in the work environment and the order of measurement of the prameters of risk factors, 25.01.2002 nr 54, RT I 2002, 15, 83 (in Estonian).

Wilén, J., Wiklund, U., Hörnsten, R., Sandström, M. 2007. Changes in heart rate variability among RF plastic sealer operators. *Bioelectromagnetics* **28,** 76–79.

Agronomy Research **13**(3), 775–785, 2015

Job specific risk factors, demographic parameters and musculoskeletal disorders among military personnel depending on type of service

E. Merisalu[1,*], M. Vähi[2], S. Kinnas[3], M. Oja[4], K. Sarapuu[5], O. Novikov[5], M. Pärnapuu[6], E. Indermitte[7], K. Lea[8] and H. Orru[7]

[1]Institute of Technology, Estonian University of Life Sciences, Institute of Technology, Kreutzwaldi 56, EE51014 Tartu, Estonia; [*]Correspondence: eda.merisalu@emu.ee
[2]Institute of Mathematical Statistics, University of Tartu, Liivi 2, EE50409 Tartu, Estonia
[3]Institute of Physics, University of Tartu, Ravila 14c, EE50411 Tartu, Estonia
[4]Institute of Technology, University of Tartu, Nooruse 1, EE50411 Tartu, Estonia
[5]General Head Quarters, Estonian Defence Forces, Juhkendali 58, EE15007 Tallinn, Estonia
[6]Medical Centre, Medical Company, 1st Infantry Brigade, Estonian Defence Forces, Rae Põik 1, EE76806 Paldiski, Estonia
[7]Department of Public Health, University of Tartu, Ravila 19, EE50411 Tartu, Estonia;
[8]Civil Aviation Admisnistration, Estonia

Abstract. Current study aimed to analyse the prevalence of job specific risk factors (JSRF) and musculoskeletal disorders (MSDs) among military personnel depending on demographic factors and type of service. An anonymous questionnaire study was carried out in five departments of Estonian Defence Forces (EDF) among local service personnel (LSP) and the Peace Corp personnel (PCP) arrived back from mission. The average response rate was 38.7% (LSP 31.9% and PCP 77.6%). In LSP group there were 44.7% male participants, with mean age 39.2 ± 11 years, length of service in present position 5.8 ± 4.9 years and work load of 37.9 ± 8.4 hours per week. In PCP group 97.4% were males, with mean age 27.5 ± 5.7 years, service length on present position 3.1 ± 2.6 years and work load of 84.3 ± 60.9 hours per week. The dominant JSRF in LSP was 'demand for constant concentration' (76.5%) and night work (57%) in PCP (group difference $p < 0.0001$). 'Fast movements' and 'lifting loads >40 kg' were the specific tasks most often reported in mission. 'Job insecurity' was more often reported by the female; 'night work' and 'work-rest disbalance' by the male military personnel ($p< 0.001$).The prevalence of MSDs was higher among women and LSP than in men and PCP group ($p< 0.05$). In LSP mild to moderate discomfort reported by 2/3 because of neck-shoulder strain and by ½ because of lower back pain. In conclusion, MSDs seems to depend more on demographic parameters and type of service than JSRFs. Further studies are needed to focus on predictive factors of MSDs among military personnel.

Key words: job specific risk factors, demographic parameters, musculoskeletal disorders, military personnel.

INTRODUCTION

Musculoskeletal injuries are recognized as a leading health problem in the military, but the size of the problem is underestimated. Injury rates during military training are high, ranging from 6 to 12 per 100 male recruits per month during basic training and up to as high 30 per cent per month for Naval Special Warfare training (Kaufman et al., 2000). More than 7,000 MSDs were identified in 2006 among nondeployed, active duty service members from military medical surveillance in USA. Most of MSDs (82%) were classified as inflammation and pain caused by overuse, followed by joint derangements (15%) and stress fractures (2%). The knee or lower leg (22%), lumbar spine (20%), and ankle/foot (13%) were leading body regions. When these injuries are combined with acute traumatic injuries, there could be 1.6 million injury-related medical encounters each year in total in US army alone (Hauret et al., 2010). Injury-related musculoskeletal conditions are common in young and active population: about 2/3 involve lower back pain, followed by cervical and midback pain syndromes. Some predictive factors associated with spine-area pain are similar to those observed in civilian cohorts, such as psychosocial distress, heavy physical activity or lifestyle. Risk factors specific to military personnel include concomitant psychological trauma, extreme noise and vibration exposure, heavy combat load requirements, and urban dismounted ground operations (Cohen et al., 2012). A study of the Danish army showed similar musculoskeletal problems in different service types (infantry, signal, combat service support, engineers, and artillery). Working as a gunner for less than 2 years increased the risk of reporting neck pain (p = 0.011) and working as a loader increased the risk of shoulder pain (p = 0.017) (Nissen et al., 2009). Health statistics of Estonian military personnel (2008) demonstrated that MSDs ranked 2nd and occupational injuries 3rd among total cases of health problems according to primary health checks in the units of Medical Centres, EDF. Duties in service when injuries took place were: a) in service (n = 217): direct external causes, e.g. hot war (n = 13), vehicle traumas (n = 21) and military training (n = 145); b) sport (n = 152) and c) leisure activities (n = 74). A total of 500 injuries were recorded in Estonia in 2007, where half of all cases were lower limb traumas, including bone fractures and the same prevalent – microtraumas as cutaneous blisters and frictions (Merisalu et al., 2009). Similar results have been shown in previous studies about training and combat environment, where the loads have been associated with an increased risk of lower limb overuse injuries (foot blisters, metatarsalgia, stress fractures, knee pain ets) (Birrell et al., 2007). A study of health of Finnish male military personnel showed that the group with the longest sickness absences (> 7 days) exhibited lower muscle fitness in three of four tests and shorter running distance compared to the groups with shorter sickness absence (p < 0.001). In addition, high Body Mass Index (BMI), poor muscle fitness and poor aerobic endurance were associated with increased sickness absence (Kyröläinen et al., 2008). Risk factors of neck pain were analysed in 629 office workers of Belgium military personnel. More than ¾ of respondents reported neck pain as life-long problem and more than half of them reported neck pain once per week at least (De Loose et al., 2008).

The study of US Army personnel indicated the need to consider the interaction between workplace factors and gender on disability in the military personnel and to pay more attention on back-related disorders and prevent musculoskeletal disability risk in women (Feuerstein et al., 1997). The study among British Army recruits demonstrated that gender was not an independent risk factor for injury, suggesting that lower levels of aerobic fitness are the primary cause of the greater incidence of injury among female recruits during initial training (Blacker et al., 2008). In US Military Academy stress fracture incidence was much higher in women than in men, indicating increased stress fracture risk for smaller tibial and femur sizes (Cosman et al., 2013).

Musculoskeletal injuries are the leading healthcare problem for military members in missions. Since 2003 the start of operations in Iraq musculoskeletal complaints continued to be a primary cause of disability and have been reported to cost up to $500 million annually (George et al., 2007). Mortality rate among US military subjects in Bosnia-Hertsegovina (1996) was 1 case per 100 soldiers in week (Sanchez et al, 2001). There are many factors that lead to musculoskeletal complaints, but the extended periods of walking and marching under heavy loads was the major problem. Wearing of combat boots and walking long distances with univorm and loads of 20 to 60 kg impact on plantar pressure distributions during gait (Goffar et al., 2013). One infantry unit that collected data during deployment to Afghanistan in 2003 reported an average fighting load of 29 kg, an approach march load (for more prolonged operations) of 46 kg, and an emergency approach march load (in which certain transportation resources were unavailable) of 60 kg across several missions (Birrellet al., 2007). Musculoskeletal pain was common during peacekeeping mission in Swedish military personnel on 6 months duty in Afghanistan. About 70% of 344 respondents to a questionnaire reported any MSD, where 17% of respondents had pain both in lumbar spine and shoulders and 14% in lower extremities. Low pain and low disability were reported by 57% (grade I), high pain with low disability reported by 36% (grade II) and any pain with high disability 5% (grade III) (Glad et al., 2012).

So, as shown in the number of studies, the influence of job specific factors and gender on mortality are clearly demonstrated among military personnel. The purpose of the present study was to describe work related risk factors and prevalence of MSDs among Estonian military personnel depending on demographic parameters in local (domestic) service and in missions.

MATERIAL AND METHODS

Subjects

Based on the statistics of EDF (2008) there were in total 3,199 subjects in the EDF register. The study group was selected by random sample method and consisted of 841 subjects from five departments of EDF and named as local service personnel (LSP). The Peace Corp personnel (PCP) was time selected, *i.e.* completed by the subjects (n = 147) who arrived from the missions after 6 months duty in Afganistan and Iraq. The total sample size was 988 subjects.

Questionnaire

The questionnaire was compiled following the validated questionnaires used among service occupations in the national and international studies (Mykletun, 1997; Põlluste & Merisalu, 2007). The questionnaire consisted of nine parts, where demographic and general data (age, gender, rank, unit and length of service, working hours), questions about working environment (unbalanced work-rest conditions, need for constant concentration, job insecurity, monotonous and night work; tasks in active operations: work in constraint posture, fast repetitive movements, lifting loads, creeping with loads, computer work) (n = 11) and musculoskeletal problems of different body parts (n = 13) were included. The exposure to risk factors was measured on a 3-point scale, where: 1 – never, 2 – sometimes, 3 – often. Musculoskeletal disorders (MSDs) in different body parts were measured on a 4-point scale; where: 1 – no discomfort, 2 – mild discomfort but not disturbing, 3 – moderate discomfort that makes working difficult, 4 – discomfort leading to sick leave.

The data was analysed using Statistical Package *SPSS*.22.0. Frequency tables were used to describe the sample by gender, age, work load, service length and risk factors. The χ^2-test and Fisher's exact test was used to compare differences by gender, JSRFs and MSDs between the service groups (LSP/PCP). Spearman and Pearson correlation analyses were used to describe relationships between demographic factors (age, service length, working hours), JSRFs and MSDs.

Procedure

The anonymous guestionnaire study was carried out in five departments of EDF, from October 2008 to March 2009. The participation was voluntary and anonymous. Voluntary participation was promoted with the help of an individual informed consent letter, where the purpose of study, possible outcomes and practical benefits were explained. The signed informed consent letter in closed envelope and filled questionnaire in a separate closed envelope was put into a sealed box. The contract between the Estonian Ministry of Defence and the research structure (University of Tartu) was signed (25.07.2008 no 9.2.-10./5450). The agreement with the departments of the EDF and the permission of the Research Ethics Committee, University of Tartu were pursued before the study (173/T-16, 21.08.2008).

RESULTS

The study group consisted of 841 subjects from 5 departments. The sample size of LSP was 268 subjects (response rate 31.9%) and of PCP 114 subjects (rensponse rate 77.4%). In total 382 responded, with an overall response rate 38.7% (Table 1).

Table 1. Composition of the study group by the type of service (LSP and PCP) (n, %)

Name of group	Target group (n)	Study group (n)	Response rate (%)
LSP	841	268	31.9
PCP	147	114	77.6
Total	988	382	38.7

Demographic and general data of the sample by the service groups are shown in Table 2. In the LSP group there were 55.3% (n = 149) female and 44.7% (n = 119) male respondents with mean age of 39.2 ± 11.0 years. There was a gender difference in mean age – the men were younger than women (p = 0.0001). In the LSP group the mean total length in service was 9.5 ± 5.8 years and in the present position 5.8 ± 4.9 years. The mean working time in the LSP group was 37.9±8.4 hours per week. The women had longer service length and worked longer hours than men (p = 0.0001). By rank they were military servants (46.3%), non-commissioned officers (31.7%), officers (20.8%) and not defined (1.2%).

In the PCP group the majority was male (97.4%), with mean age of 27.5 ± 5.7 years, with mean service length of 5.9 ± 3.9 years and having worked in the present position for 3.1 ± 2.6 years. PCP group worked long hours (on average 84.3 ± 60.9 hours in a given week), and female personnel even more (132.0 ± 62.4 hours). The distinct differences were observed between gender groups by service length and work load ($p < 0.0001$). By rank there were 57.0% ($n = 65$) non-commissioned officers, 36.8% ($n = 42$) soldiers and 6.2% ($n = 7$) officers.

Table 2. Demographic and general data by the type of service and gender (mean, SD, max, min and *p* – difference between the groups)

Parameter	Mean	SD	Min	Max	Group difference, *p*
Age (years)					
Total LSP	39.2	11.0	20.0	70.0	LSP>PCP 0.0001
Male	35.5	9.9	21.0	70.0	
Female	42.2	11.0	20.0	67.0	M<F 0.007
Total PCP	27.5	5.7	20.0	49.0	
Male	27.5	5.8	20.0	49.0	
Female	27.0	4.6	23.0	32.0	-
Total service length (years)					
Total LSP	9.5	5.8	0.1	40.0	LSP>PCP 0.0001
Male	10.9	6.0	0.1	40.0	
Female	8.2	5.3	0.2	35.0	M>F 0.005
Total PCP	5.9	3.9	1.0	18.0	
Male	5.9	3.9	1.0	18.0	
Female	6.8	2.0	4.5	8.0	M<F 0.001
Years in present position					
Total LSP	5.8	4.9	0.1	40.0	LSP>PCP 0.0001
Male	5.5	5.6	0.1	40.0	
Female	6.0	4.3	0.2	16.0	-
Total PCP	3.1	2.6	0.5	13.0	
Male	3.0	2.6	0.5	13.0	
Female	8.0	0	8.0	8.0	F>M 0.0001
Work load (hours per week)					
Total LSP	38.0	8.2	5.0	50.0	LSP<PCP 0.0001
Male	37.6	9.4	5.0	50.0	
Female	38.4	6.9	8.0	48.0	M<F 0.007
Total PCP	84.4	61.0	5.0	178.0	
Male	82.8	60.7	5.0	178.0	
Female	132.0	62.4	60.0	168.0	-

The exposure to the JSRFs in LSP and PCP is shown in the Table 3. The highest mean score on the 3-point scale was measured in 'demand for constant concentration' (2.7) for LSP group and 'night work' (2.6) for PCP group. At the same time, 'demand for constant concentration' was a risk factor for ¾ of LSP and ½ of PCP group. Job insecurity because of organisational changes was a more disturbing factor for LSP, compared to PCP group ($p < 0.0001$). 'Night work' and 'disbalanced work-rest ratio' were the most frequent risk factors for PCP, compared to LSP group ($p < 0.0001$).

Table 3. Exposure to job related risk factors (%) by the type of service (LSP and PCP)

Job specific factor	Mean, on 3-p scale LSP/PCP	Never		Sometimes		Often		Group differnce, *p*
		LSP	PCP	LSP	PCP	LSP	PCP	
Routine work	2.0/2.0	23.4	23.2	53.3	51.8	23.4	25.0	-
Night work	1.6/2.6	46.1	1.8	41.4	41.2	12.5	57.0	0.0001
Work & rest disbalance	1.7/2.0	45.7	28.1	41.1	43.0	13.2	28.9	0.0001
Job insecurity because of organisational changes	1.9/1.6	26.3	53.0	56.9	38.1	16.9	8.8	0.0001
Constant concentration	2.7/2.4	6.2	14.9	17.4	34.2	76.5	50.9	0.0001

Results for exposure to JSRFs on active operations are presented in Table 4. Less than half of respondents worked with fast precised movements ‘sometimes’ or ‘often’. About 1/3 of PCP lifted loads above 40 kg ‘sometimes in month’.

Table 4. Exposure to the job related risk factors specific to PCP active operations

Job tasks in mission	Mean, 3-p scale	Never		Sometimes		Often	
		n	%	n	%	n	%
Lifting loads 20–40 kg	1.1	98	88.3	12	10.8	1	0.9
Lifting loads >40 kg	1.4	67	60.4	40	35.1	4	3.6
Constraint position	1.1	98	88.3	12	10.8	1	0.9
Fast precised movements	1.5	60	54.1	44	39.6	7	6.3
Creeping with loads	1.2	92	82.9	14	12.6	5	4.5
Computer work	1.2	86	77.5	24	21.6	1	0.9

The comparison of musculoskeletal complaints by body region and severity in LSP and PCP groups are shown in the Table 5. MSDs were registered more often among the LSP group ($p < 0.05$). In the latter, ‘mild to moderate discomfort’ was reported because of neck-shoulder strain (69.2%), the lower back (54.8%) and feet pain (41.4%). Fingers’, wrist, neck-shoulder, upper-back and foot pain were the symptoms causing more discomfort for LSP group, compared to PCP ($p < 0.05$). ‘Mild to moderate discomfort’ because of knee pain was reported by 45% and neck shoulder strain by 38.7% of PCP group. The most frequent cause of sick leave for LSP was lower back pain (1.9%) and for PCP – heel pain (2.7%).

Gender differences of JSRFs are shown in Fig. 1. The men were more often exposured to ’night work’ and ’work-rest disbalance’, and the women to ’job insecurity because of changes in the organisation’ ($p < 0.001$).

’Night work’ correlated negatively with age ($r = -0.45$, $p < 0.001$) *i.e.* younger military members and male had higher exposure to ’night work’. Long working hours and ’work-rest disbalance’ correlated positively with ’night work’ ($r = 0.32$ and $r = 0.29$, respectively).

Table 5. Musculoskeletal complaints by body region and severity (%) among LSP and PCP (*p* –group difference)

MSD/ body region	Mean, 4-p scale	No discomfort		Mild discomfort		Moderate discomfort		Caused sick leave		
	LSP/PCP	LSP	PCP	LSP	PCP	LSP	PCP	LSP	PCP	p^*
Fingers' numbness	1.3/1.2	71.9	85.6	25.9	13.5	1.9	0.9	0.4	-	0.022
Hands'weakness	1.2/1.1	79.8	86.5	16.4	12.6	3.8	0.9	-	-	-
Wrist pain	1.4/1.1	71.2	86.5	23.1	13.5	5.8	-	-	-	0.001
Elbow pain	1.3/1.1	78.9	88.3	16.5	10.8	4.6	0.9	-	-	-
Neck-should strain	1.9/1.4	30.8	60.4	53.6	36.0	15.6	2.7	-	0.9	0.0001
Hips' pain	1.2/1.1	81.5	88.3	13.9	10.8	4.2	0.9	0.4	-	-
Knee pain	1.5/1.5	56.4	54.1	37.5	39.6	5.8	5.4	0.4	0.9	-
Heel pain	1.3/1.2	77.3	82.9	18.5	12.6	3.9	1.8	0.4	2.7	-
Foot pain	1.5/1.2	57.9	77.5	35.3	21.6	6.1	-	0.8	0.9	0.0001
Tiredness in feet	1.4/1.2	70.4	80.2	24.9	18.9	4.3	0.9	0.4	-	-
Numbness in feet	1.2/1.1	78.5	85.6	19.2	14.4	2.3	-	-	-	-
Upper back pain	1.4/1.3	62.8	75.7	32.6	21.6	4.7	2.7	-	-	-
Lower back pain	1.7/1.5	43.3	55.0	44.8	39.6	10.0	4.5	1.9	0.9	-

*Fisher's exact test

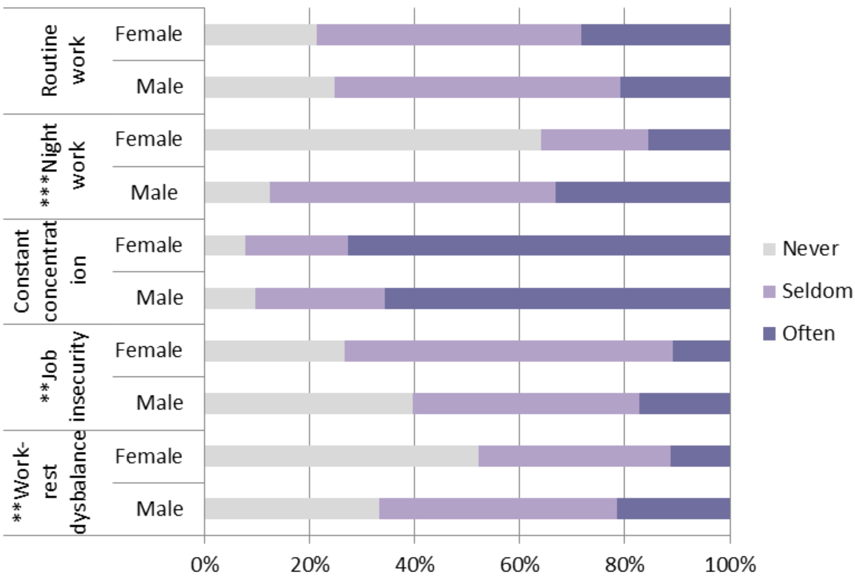


Figure 1. Gender differences of job related risk factors (**$p < 0.001$, ***$p < 0.0001$).

Gender differences in prevalence of MSDs are shown in the Fig. 2. Neck-shoulder strain, pain in lower and upper back, feet, wrist and hands caused more discomfort for female service personnel, compared to the men ($p < 0.05$).

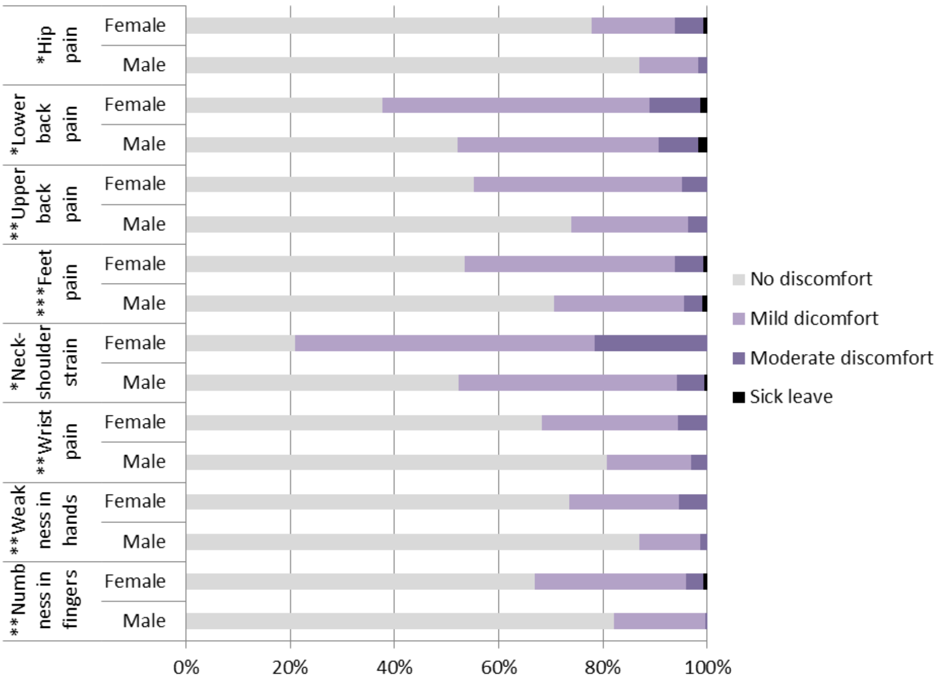


Figure 2. Gender differences in prevalence of MSDs among military personnel (*$p < 0.05$, **$p < 0.001$, *$p < 0.0001$).

Correlation analysis of demographic parameters and MSDs showed that prevalence of neck-shoulder strain was higher in female ($r = 0.34$) and older military personnel ($r= 0.31$, $p < 0.001$). Distinct intercorrelations were observed between the MSDs in different body regions ($p < 0.001$). Direct intercorrelations were seen between numbness in fingers and weakness in hands ($r = 0.53$), between wrist and elbow pain and numbness in feet and fingers ($r = 0.48$ both), between foot and elbow pain, and wrist and neck pain ($r = 0.40$ in both), knee and heel pain ($r = 0.41$).

DISCUSSION

In the present study the demographic data, JSRFs and MSDs were taken under the analysis. The results were compared between two groups depending on type of service – the group of local military service and missions. The women in the local military service had higher mean age and longer years in present position and worked longer hours than the male counterparts. The women and older personnel were more often confronted with 'job insecurity because of organisational changes' and they reported more neck-shoulder strain. The male and younger personnel reported more often 'night work' and 'disbalanced work-rest conditions'. Long working hours correlated positively with 'work-rest disbalance' and 'night work'.

A number of preliminary studies have analysed the causes and prevalence of MSDs among military personnel (Feuerstein et al., 1997; Birrell et al., 2007; George et al., 2007; Blacker et al., 2008; De Loose et al, 2008; Hauret et al., 2010; Cohen et al., 2012; Cosman et al., 2013). Our study results showed some similarities with earlier research. In LSP group 'mild to moderate discomfort' was reported by 2/3 of respondents because of neck-shoulder strain and among half because of lower back pain. De Loose et al. (2008) showed that more than ¾ of respondents in military service had neck pain as life-long problem. Nissen and co-authors (2009) demonstrated that higher risk of neck pain was seen in gunners working in military service less than 2 years and an increased risk of shoulder pain was observed among loaders. Few systematic analyses about demographic parameters, JSRFs and MSDs have been published (Feuerstein et al., 1997; Blacker et al., 2008; Cosman et al., 2013; Cubata et al., 2014).

Up to now few research has been done in comparing health risks and MSDs between Peace Corp and local military service groups. Hotopf et al. (2006) compared the symptoms of regular personnel in UK and peacekeeping corp in Iraq and in latter they didn't see worse health outcomes, apart from a modest effect on multiple physical symptoms. In our study the distinct difference in prevalence of JSRF and MSDs in LSP and PCP was observed. High work load, 'work-rest disbalance', work in night shifts, 'lifting loads' and doing 'fast precised movements' were characteristic JSRFs in mission. Relatively few health complaints were reported by PCP group. Less than half of them assessed 'mild to moderate discomfort' because of knee pain or neck-shoulder strain and few of them (2.7%) took sick leave because of heel pain. Contrary to our results high morbidity rate among US military subjects in Bosnia-Hertsegovina was observed, where walking and marching under heavy loads was the major problem leading to MSDs in US army (Sanchez et al., 2001; Goffar et al., 2013). Musculoskeletal complaints among US Peace Corp in Iraq since 2003 continued to be a primary cause of disability and have been reported to cost up to $500 million annually (George et al., 2007). Till now no calculations about EDF costs have published in Estonia.

Low prevalence of MSDs among our PCP can be explained by their younger age, excellent physical preparedness for missions and relatively short length of military service. They were healthy young men able to work long hours in night time. They managed well with their health conditions during 6 months' mission. However, according to primary health checks in the units of Medical Centres of EDF, in total 500 injuries were recorded among local service people in 2007 (Merisalu et al., 2009). Thereon, more serious outcomes with musculsoskeletal disabilities and lost lives in missions have been registered. Based on the statistics of EDF (2015) since 2004 there are 130 peacekeepers injured and 11 death cases registered in Estonia.

Indeed, we must preserve lives of young military people and decrease high prevalence of MSDs, increasing military readiness and decreasing the costs associated with poor outcomes and treatment (Gates & Huard, 2005). The human factors engineering purpose is to enhance mission effectiveness with enhanced combat systems. New technologies enable warfighters to work more effective manner with fewer personnel. While the tradeoffs between new technologies and numbers of operators needed are complex, strong evidence suggests that these manpower savings can be significant and have the potential to accelerate military transformation (Osga & Galdorisi, 2007).

CONCLUSIONS

The results of the present study demonstrate quite stressful milieu in the local military service with demand for constant concentration and high job insecurity because of structural changes. These factors were more characteristic to less experienced, female and older personnel. The job related risk factors and MSDs significantly differed by type of service. Because of military service is ever popular among young women more attention could be payed to gender differences in the nearest future. Globalisation of military structures, continuing technological modernisation and increasing pressure on widening defence ability in Eastern Europe predict higher mental and physical pressure and morbidity among military personnel in Estonia. Further studies are needed for analysing relationship between JSRFs and MSDs and disability among military personnel. Preventing risks in military service enables better management of health conditions and guarantees higher work ability of military personnel, depending on age and gender.

AKNOWLEDGEMENTS. This study was supported by the Research Foundation of the Estonian Defence Ministry (25.07.2008 nr 9.2.–10./5450). The research team is thankful to EDF for openness and collaboration in carrying out this study.

REFERENCES

Birrell, S.A., Hooper, R.H., Haslam, R.A. 2007. The effect of military load carriage on ground reaction forces. *Gait & Posture* **26**, 611–614.

Blacker, S.D., Wilkinson, D.M., Bilzon, J.L., Rayson, M.P. 2008. Risk factors for training injuries among British Army recruits. *Mil. Med.* **173,** 278–286.

Cohen, S.P., Gallagher, R.M., Davis, S.A., Griffith, S.R., Carragee, E.J. 2012. Spine-area pain in military personnel: a review of epidemiology, etiology, diagnosis, and treatment. *The Spine Journal* **12**(9), 833–842.

Cosman, F., Ruffing, J., Zion, M., Uhorchak, J., Ralston, S., Tendy, S., McGuigan, F.E.A., Lindsay, R., Nieves, J. 2013. Determinants of stress fracture risk in United States Military Academy cadets. *Bone* **55**(2), 359–366.

De Loose V., Burnotte, F., Cagnie, B., Stevens, V., Van Tiggelen, D. 2008. Prevalence and risk factors of neck pain in military office workers. *Mil. Med*. **17**3, 474–479.

Feuerstein, M., Berkowitz, S.M., Peck, C.A. 1997. Musculoskeletal-related disability in US Army personnel: prevalence, gender, and military occupational specialties. *J. Occup. Env. Med.* **39**(1), 68–78.

Gates, C. & Huard, J. 2005. Management of skeletal muscle injuries in military personnel. *Operat.* Techn. *Sports Med*. **13**(4), 247–256.

Glad, D., Skillgate, E., Holm, L.W. 2012. The occurrence and severity of musculoskeletal disorders in Swedish military personnel during peacekeeping operations in Afghanistan. Eur. Spine J 21(4), 739–744.

George, S.Z., Childs, J.D., Teyhen, D.S., Wu, S.S., Wright, A.C., Dugan, J.L., Robinson, M.E. 2007. Rationale, design, and protocol for the prevention of low back pain in the military (POLM) trial (NCT00373009). *BMC Musculoskeletal Disorders* **8**, 92–103. doi:10.1186/1471-2474-8-92.

Gubata, M.E., Piccirillo, A.L., Packnett, E.R., Niebuhr, D.W., Boivin, M.R., Cowan, D.N. 2014. Risk factors for back-related disability in the US army and marine corps. *Spine* **39**(9), 745–753.

Goffar, S.L., Reber, R.J., Christiansen, B.C., Miller, R.B., Naylor, J.A., Rodriguez, B.M., Walker, M.J., Teyhen, D.S. 2013. Changes in dynamic plantar pressure during loaded gait. *Phys. Ther.* **93**(9), 1175–1184. doi: 10.2522/ptj.20120103. Epub 2013 Apr 11.

Hauret, K.G., Jones, B.H. Bullock, S.H., Chervak, M.C., Canada, S. 2010. Musculoskeletal injuries: Description of an under-recognized injury problem among military personnel. Am. J. Prevent. *Med.* **38**(1)(Suppl), S61–S70.

Hotopf, M., Hull, L., Fear, N.T., Browne, T., Horn, O., Iversen, A., Jones, M., Murphy, D., Bland, D., Earnshaw, M., Greenberg, N., Hughes, J.H., Tate, A., Dandeker, R.C., Rona, R., Wessely, S. 2006. The health of UK military personnel who deployed to the 2003 Iraq war: a cohort study. *Lancet* **367**, 9524, 1731–1741.

Kaufman, K.R., Brodine, S., Shaffer, R. 2000. Military training-related injuries: Surveillance, research, and prevention. *Am. J. Prevent. Med.* **18**(3) (Suppl.), 54–63.

Kyröläinen, H., Häkkinen, K., Kautiainen, H., Santtila, M., Pihlainen, K., Häkkinen, A. 2008. Physical fitness, BMI and sickness absence in male military personnel. *Occup. Med.* **58**(4), 251–256.

Merisalu, E., Orru, H., Taavet, T. 2009. *Work environment and health of military personnel*. The report. Tartu, 64 pp (in Estonian).

Mykletun, R.J. 1997. *Working environment and health*. Stavanger, 5 pp.

Nissen, L.R., Guldager, B., Gyntelberg, F. 2009. Musculoskeletal disorders in main battle tank personnel. *Mil. Med.* **174**(9), 952–957.

Osga, G. & Galdorisi, G. 2007. Human factors engineering: An enabler for military transformation through effective integration of technology and personnel. Proposed track. C2 assessment and cognitive analysis. *STAR* **45**(19), 35 pp.

Põlluste, K. & Merisalu, E. 2007. Staff satisfaction with their job and working environment in Estonian hospitals. *Eesti Arst* **3**, 173–182 (in Estonian).

Sanchez, J.L.Jr., Craig, S.C., Kohlhase, K., Polyak, C., Ludwig, S.L., Rumm, P.D. 2001. Health assessment of U.S. military personnel deployed to Bosnia-Herzegovina for operation joint endeavor. *Mil. Med.* **166**, 470–474.

Agronomy Research **13**(3), 786–791, 2015

Reliability of biometric identification using fingerprints under adverse conditions

V. Nídlová[1,*] and J. Hart[2]

[1]Czech University of Life Sciences Prague (CULS), Faculty of Engineering, Department of Electrical Engineering and Automation, Kamýcká 129, CZ-16521 Prague, Czech republic; [*]Correspondence: nidlova@tf.czu.cz
[2]Czech University of Life Sciences Prague (CULS), Faculty of Engineering, Department of Technological Equipment of Buildings, Kamýcká 129, CZ-16521 Prague, Czech republic

Abstract. Biometric user identification is highly topical these days. The most well-represented method is fingerprint identification, to which this study is also dedicated. However, we cannot forget other methods such as scanning the bloodstream, retina and iris, facial recognition, etc. Four reading devices were tested in this study. Tests were carried out both under standard and adverse conditions. Adverse conditions included situations such as cold finger, cooled damp finger, heated finger, soaked finger, finger with a layer of instant glue, and dirty finger (soil). All tests performed under adverse conditions simulated realistic industrial plant environments. The results of the measurements showed that the measured reliability values do not correspond to those claimed by the manufacturers. It is necessary to adapt and perfect these biometric identification systems for use in industrial areas, as they are often used in these areas as access or attendance systems.

Key words: biometrics detector identification systems, fingerprints, user's false rejection.

INTRODUCTION

Nowadays, there are many methods by which persons at a workplace can be identified. These include identification based on entering a password or numerical code, as well as chip systems and identification (ID) cards. All of these methods are transferable in a certain way. Biometric identification systems have been developed as the safest method for entering protected buildings. These systems make identifications on the basis of the unique biometric characteristics of an individual (Jain et al., 1997).

Biometric systems are used not only as identification systems serving for entry into guarded buildings (access systems), but also as attendance systems. It is very important to be aware of the fact that such systems are used in numerous jobs. They can be found in the banking sector, medical sector and automobile industry, steelworks and in a number of other fields. This is where the issue of their reliability becomes important. Every manufacturer specifies for each scanner the percentage of erroneous acceptance and refusal of the user, but the question is under what conditions? For attendance systems, verification occurs under standard conditions, wherein, for example, fingerprint-based identification requires the verified parts of the finger to be free of impurities. But when these systems are used as access systems, there is a risk of a decrease in reliability. One example of such risks is their use in industrial areas, where absolute cleanliness of the palm and fingers cannot be expected (Lourde & Khosla, 2010). For these reasons, a number of measurements were carried out, which indicate the need to improve the biometric identification systems, if they are used under more adverse conditions.

MATERIALS AND METHODS

The testing focused on the reliability of the selected biometric identification system under adverse conditions. Measurements were carried out in the security technology laboratory at the Technical Faculty of the Czech University of Life Sciences in Prague, and the measurements were carried out under laboratory conditions. These conditions are based on standards ČSN EN 50133, ČSN ISO/IEC 19794, ČSN ISO/IEC 19794, ČSN ISO/IEC 27006, ČSN ETSI EN 302 77, as well as on the recommendations of the relevant manufactures.

80 test subjects participated in the measurements. The testing was always done in twenty cycles. The test subjects included 16 women and 64 men aged 21–62. Two devices were selected for the measurements that only identified on the basis of fingerprints (scanner TAC-05 MFF and scanner F7), and two dual systems that identified on the basis of fingerprints and facial features (Multibio 700 and IFace 302).

All tested biometric systems had an optic sensor. The use of the first optic sensors was recorded between the 1960s and 1970s. These sensors work on the basis of FTIR – – Frustrated Total Internal Reflection technology. This is a laser beam or a thick bundle of optical fibres illuminating the surface of the finger from below, which is placed to the transparent plate of the sensor. The reflected light flux is scanned by the CCD (Charge Couplet Device) element. Papillary lines and furrows determine the amount of reflected light, wherein the ridges reflect more light than the furrows. However, the CCD element does not use the reflection of light from the furrows as a means of evaluation (Hlaváč & Šonka, 1992; Jain et al., 1999).

Erroneous rejection of a user means that an authorized user is not let into a building via the identification devices. If this happens rarely, the user repeats the entire identification process and is then admitted into the building. Erroneous rejection of a person can have many causes (incorrectly placed finger on the scanner, wet finger, cold finger, injured finger, dirty finger, etc.). The probability of the erroneous rejection of a user can be calculated using the following formula (Ashbourn, 2000; Rak et al., 2012):

$$\mathrm{FRR} = \frac{\mathrm{NFR}}{\mathrm{NEIA}} . 100\ [\%] \qquad (1)$$

where: FRR – False rejection of a user; NFR – Number of False Rejections; NEIA – Number of Enrollee Identification Attempts.

The measurements were performed both under standard and adverse conditions, focusing on the different types of tests that can arise under realistic conditions. Tests were divided into the following:

- **standard identification** – this identification was carried out on washed and cleaned hands. Based on the results acquired from the standard identification, the measurements were then extended to tests under adverse conditions;
- **cold fingers** – it was first necessary to cool the fingers of the test subjects to the same temperature range of 20–25 °C. This was done by using ice prepared into moulds. Each mould was covered with waterproof foil in order to prevent dampening the measured finger. This simulated the cold outdoor environment. Each measurement was preceded by a fifteen minute cooling of the finger and then the finger was placed on the surface of the sensor;
- **cooled damp finger** – for cooled damp finger, the measurements were carried out in the same manner as for cooling a dry finger, except for the part with the waterproof foil. During the measurement, the finger was cooled directly with the ice. As the ice melted, it slightly dampened the skin of the finger. The finger was then not dried, which caused the required wet surface;
- **heated finger** – during this measurement, it was first necessary to determine a method for heating a finger to temperature range of 50–55 °C. Initially, the finger was heated with hot water in a container, but this method was rejected because the water cooled. In order to ensure the same conditions for all of the test subjects, and that the measurement was relevant, a USB (Universal Serial Bus) heater was chosen to heat the finger, to which a digital temperature sensor was attached. The heating temperature was constantly 55 °C, but temperature losses are expected during the short movement of the finger from the heater to the sensor of the scanner. That is why the specified temperature range is 50–55 °C;
- **soaked finger** – soaking of the finger was very important for the testing. Such a case may occur during normal work and domestic situations. The fingers were soaked using water in a container. The liquid was heated to 40 °C using the USB heater. Each subject dipped their finger for 20 minutes. After removing the finger from the water bath, it was dried with gauze and tested on the measuring panel;
- **finger with a layer of instant glue** – instant glue was selected because it creates a solid hard coating. This coating is transparent and very thin. When the glue is applied and it dries, the papillary lines deteriorate, while individual scanners make verifications according to these lines;
- **dirty finger (soil)** – dust acquired from a vacuum cleaner bag was used for these measurements. The dust was mixed with peat to prepare the required mixture. Each test subject rubbed this mixture between their palms before the measurement was carried out.

The values stated by manufacturers were identical for all of the tested scanners, namely FRR $\leq$ 1%.

Table 1 displays the percentage of reliability of individual types of biometric identification systems for standard and adverse conditions.

Table 1. Percentage results of user's false rejection under standard and adverse conditions

Condition	TAC-05, %	F7, %	IFace 302, %	Multibio 700, %
Standard identification	2.00	7.50	9.00	9.50
Cold finger	2.75	8.25	9.15	9.75
Cooled damp finger	5.25	10.35	12.25	10.75
Heated finger	1.00	6.75	7.50	8.25
Soaked finger	5.00	13.25	14.50	10.25
Finger with a layer of instant glue	96.75	99.75	99.75	99.50
Dirty finger (soil)	49.19	57.63	65.00	60.00

RESULTS AND DISCUSSION

The measured values proved that identification based on fingerprints is imperfect under more adverse conditions. Four scanners from various manufacturers were tested: two multi-functional scanners combined with a detection function of characteristic facial features, and two normal scanners that evaluated only fingerprints.

Fig. 1 shows that the average value of false rejection of user under adverse conditions for all biometric readers greatly exceed the value specified by the manufacturer. All producers specify that the value of the false rejection of user is less than 1%. All the tested systems were intended for outdoor use. Therefore, they should have succeeded well in the performed tests. It is important to point out that the measurement showed that the type of adverse conditions is very important. From Table 1 it is evident that when papillary lines are better visible, the error value is lower. It would be useful for producers to take these measurements into account.

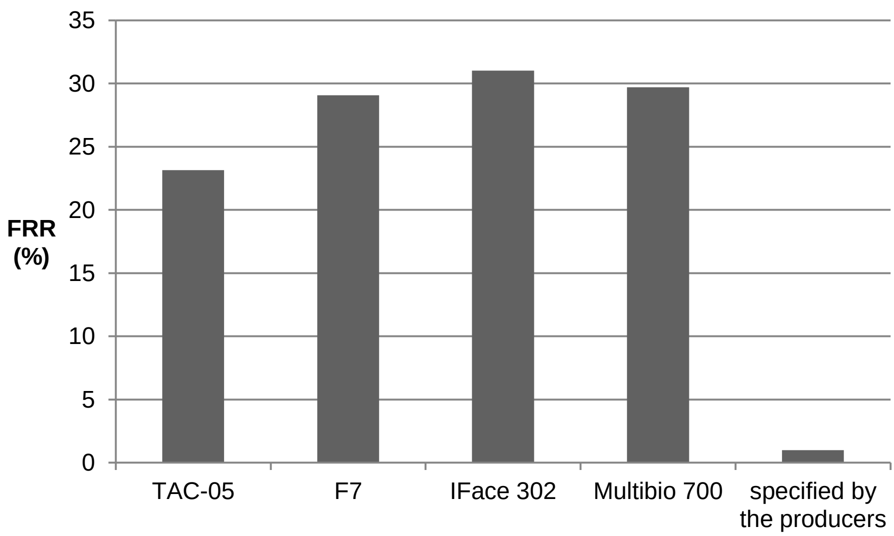


Figure 1. Graphical comparing of the average values of the false rejection of users under adverse conditions for each tested biometrics system and specified by the producers under standard conditions.

The measurement results clearly show that the use of more modern, dual biometric readers is less secure. From the author's point of view, it is unnecessary to continue developing new devices and new biometric methods unless the reliability of existing systems is improved. It is important for new systems to avoid the errors of the existing systems. These issues are also discussed by the author Yoon, who in his article 'Altered Fingerprints: Analysis and Detection' refers to the possibility of sabotaging systems through the creation of a synthetic fingerprint, etc. He also modifies the algorithm in order to be immune to this sabotage (Yoon et al., 2012). In contrast, author Jain focused on the development of a new device for identification of a person. As a unique characteristic, he chose the entire surface of the palm. Compared to a small fingerprint, minutiae are more clearly visible on entire surface of the palms. The tests showed that the new device operates with 78% reliability, and it can thus be tested in practice (Jain et al., 2009).

Based the acquired values, it is possible to recommend the users to consider whether the rate of reliability of these systems is sufficient for the protection of their spaces before using the biometric identification systems. It should also be considered that the biometric systems should be combined with other entry protection options such as PINs, ID cards, passwords or the possibility of interconnection with security systems (Straus & Porada, 2007; Heřman et al., 2008).

CONCLUSIONS

The values stated by manufacturers were identical for all of the tested scanners, namely FAR $\leq$ 0.0001% and FRR $\leq$ 1%. For systems that only work with fingerprints, these values were on average lower than those of combined detectors, which shows that when two technologies are combined, some component is always slightly suppressed.

When acquiring a biometric identification system, it is first necessary to consider how important access protection is for the given organization or institution, as individual devices vary within an extensive price scale. For attendance or security for a normal company, a better-quality fingerprint scanner would be sufficient; this type of identification is very fast, but very simple falsification of prints is a problem. For stronger protection, it is suitable to use systems tested both under laboratory and normal conditions, the result of which are satisfactory for the user. The measurements proved error rates and deficiencies in four of the frequently used fingerprint identification systems.

The measurements carried out show that the reliability of scanners is lower than stated by the manufacturer, and that is why biometric identification systems are rather often used as attendance systems. However, companies that use such systems as access systems should be aware of the fact that what they want to protect with them is not fully safe. For biometric systems used to protect entry, users should utilize their alternative entry possibilities, for instance identification based on biometric data in combination with a password, access card or chip, wherein both types of data would be necessary for entry.

ACKNOWLEDGEMENTS. This is a project supported by the IGA 2015 The University Internal Grant Agency (Inovace systémů pro verifikaci člověka dle jeho charakteristických rysů).

REFERENCES

Ashbourn, J. 2000. Biometrics. Advanced Identity Verification, Springer-Verlag, London.

Heřman, J. 2008. . Electrical and telecommunications installations, Verlag Dashöfer, Prague.

Hlaváč, V., Šonka, M. 1992. Computer Vision, Grada, Prague.

Jain, A.K., Hong, L., Pankanti, S., & Bolle, R. 1997. An identity-authentication system using fingerprints. *Proceedings of the IEEE* **85(**9), 1365–1388.

Jain, A., Bolle, R., Pankanti, S. 1999. Biometrics. Personal Identification in Networked Society, Kluwer Academic Publishers, Norwell, Massachusetts, USA.

Jain, A.K., Feng, J.J. 2009. Latent Palmprint Matching. IEEE Transactions on pattern analysis and machine intelligence, pp. 1032–1047.

Lourde, M. & Khosla, D. 2010. Fingerprint Identification in Biometric Security Systems. International *Journal of Computer and Electrical Engineering* **2**(5), 852–855.

Rak, R., Matyáš, V., Říha, Z. 2012. Biometrics and personal identity in forensic and commercial applications, Grada Publishing, a.s., Prague.

Straus, J, & Porada, V. 2007. Frensic biomechanical application in criminalistic. In Forensic Science International.

Yoon, S., Feng, J.J., Jain, A.K. 2012. Altered Fingerprints: Analysis and Detection. IEEE Transactions on pattern analysis and machine intelligence, 451–464.

Agronomy Research **13**(3), 792–809, 2015

Estimation of safety performance by MISHA method and the benefits of OHSAS 18001 implementation in Estonian manufacturing industry

Õ. Paas*, K. Reinhold and P. Tint

Tallinn University of Technology, Faculty of Economics, Institute of Business Administration, Chair of Work Environment and Safety, Ehitajate 5, EE19086 Tallinn, Estonia; *Correspondence: onnela.paas@gmail.com

Abstract. The paper concentrates on safety auditing as a tool for assessment of safety system and safety management in Estonian manufacturing enterprises. The aim of the research was to estimate the safety performance in Estonian manufacturing industry and explore the benefits of OHSAS 18001. Different available safety auditing methods are described. During 2014, 8 (OHSAS 18001-certified organisations) and 8 (non-certified organisations) Estonian enterprises from different branches of manufacturing were interviewed using MISHA method which is in accordance with the present requirements and is the most comprehensive. The results showed that non-certified organisations could be sub-divided into 2 categories: organisations which belong to a larger corporation or concern and locally established and owned companies. The latter showed the lowest scores as in these firms there are deficiencies in several OHS activity areas. Safety activities in a company depend strongly on consistency. Safety needs commitment and systematic approach. If one of the key elements of safety management system is missing, then it can be seen in the results of other framework elements. Our study demonstrates that OHSAS 18001 certificate automatically will not ensure high safety activities in the company. However, following the OHSAS 18001 standard gives a good incentive for a systematic safety activity in all levels in the company and promotes strong improvement process put in use. MISHA method can be successfully used for evaluating safety management systems in manufacturing industry, but it has to be kept in mind that some modifications may be needed due to national differences in safety activities.

Key words: safety audit, safety management system, OHSAS 18001, safety performance, MISHA method.

INTRODUCTION

Safety management system (SMS) is designed in order to deal with occupational health and safety (OHS) in a systematic way by the following activities: setting company's safety targets and objectives; designating roles and responsibilities for safety personnel; planning and performing the hazards mitigation; monitoring, measuring, and improving the on-going system and its effectiveness (Robson & Bigelow, 2010). Measurement is a key step in any management process and forms the basis of continual improvement (HSE, 2001). If measurement is not carried out correctly, the effectiveness of the SMS is undermined and there is no reliable information to inform managers how well the health and safety risks are controlled.

Various evaluation methods can be used for assessing the different aspects of the SMS. The most commonly used methods are: (1) measurement on safety performance through injury and accident statistics, (2) safety audits and (3) management reviews. Safety performance measurement through injury and statistics rates may be problematic due to under-reporting. An emphasis on injury, ill-health and accident rates as a measure, particularly when related to reward systems, can lead to such events not being reported in order to 'maintain' performance. Additionally, injury and accident statistics reflect rather the outcomes than the causes. Safety audit, on the other hand, is a means of directly and comprehensively measure the implementation and effectiveness of company's SMS and covers all the aspects (Karapetrovic & Willborn, 2000). The primary purpose of measuring safety performance is to provide information on the progress and current status of the strategies, processes and activities used by an organisation to control risks to health and safety. The performance measurement system - auditing - must cover each element of the SMS as demonstrated in Fig. 1. For example, the measuring process should establish that a written health and safety policy statement exists, meets legal requirements and best practice, is up to date; and is being implemented effectively.

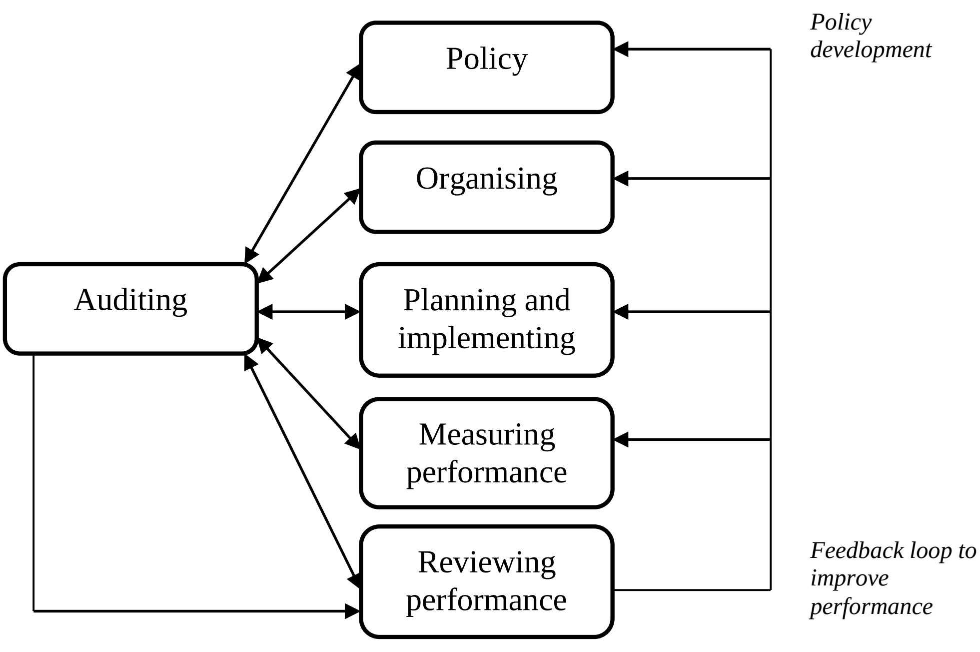


Figure 1. Auditing and performance measurement within the safety management system (adopted from HSE, 2001).

Fernández-Muniz et al. (2007) have significantly expanded the construct in recent years, suggesting an effective SMS should contain six important subfactors: safety policy, incentives for employee participation, training, communication, planning, and control. Fernández-Muniz et al. (2007) included a separate factor of employee involvement. Thus, the additional research in safety management area is needed in the following areas in SMS-s: safety policy, procedures and rules; training; communication;

incident reporting and analysis; safety audits and inspections; rewards and recognition; employee engagement; safety meetings/committees; suggestions/concerns; discipline (Bakker & Schaufeli, 2008; Frazier et al., 2013; Trauman et al., 2013a; Trauman et al., 2013b).

Several safety management related standards, directives, and regulations have been published after 1990's. This progress has been noticeable especially in Europe. The BS 8800 (BSI, 1996) has become the first widely spread general safety management standard. In 1999 the first version of OHSAS 18000 (OHS Assessment Series) was released. The Series consisted of two specifications: 18001 provided requirements for an OHS management system and 18002 gave implementation guidelines. It was intended to help organizations to control OHS risks. Since its publication, OHSAS 18001 has gained considerable acceptance worldwide and has a revised version OHSAS 18001:2007 (OHSAS Project Group, 2007). The fundamental objective of this standard is to support and promote good practice in the area of OHS via a systematic and structured management (Chang and Liang, 2009; Fernández-Muniz et al., 2012b). Another reason for implementation is the need of competitiveness as it enables the organisation to demonstrate to interested parties that the company has an adequate and functioning SMS.

The OHSAS specification is applicable to any organisation that wishes to: (a) establish an SMS to eliminate or minimise risk to employees and other interested parties who may be exposed to OHS risks associated with its activities; (b) implement, maintain and continually improve an SMS; (c) assure itself that the system complies with its stated OHS policy; and (d) demonstrate compliance with this standard to others (OHSAS Project Group, 2007).

Several researchers have demonstrated that OHSAS 18001-certified organisations have an adequate and functioning SMS in order to control occupational hazards (Chang and Liang, 2009; Fernández-Muniz et al., 2012a) and have a stronger management commitment, better organized safety training, higher workers' involvement in safety, more efficient safety communication and feedback, explicit safety rules and procedures, fairer safety behaviour and reasoned safety promotion policies (Vinodkumar & Bhasi, 2011; Fernández-Muniz et al., 2012b). Abad et al. (2013) demonstrates that OHSAS 18001 can be seen as a strategic cost-control tool in order to create and maintain a safe working environment and through it, lower the rate of workplace accidents and interruptions in the production process.

Several instruments have been developed (Diekemper & Spartz, 1970; Eisner & Leger, 1988; Collision & Booth, 1993; SafetyMap, 1995; Dyjac et al., 1998; Redinger & Levine, 1998; Kuusisto, 2000; Bunn et al., 2001; Pearse, 2002; LaMontagne et al., 2004). Authors of the current study started with D&S method (Diekemper & Spartz, 1970; Tint et al., 2010b). However after the analyses of different methods, the MISHA (Method for Industrial Safety and Health Activity Assessment (Kuusisto, 2000)) method was chosen based on its comprehensiveness and compliance with high expectations for health and safety. As the results for the MISHA instrument (Kuusisto, 2000) can be considered preliminary (compared to other methods which do not apply), since they were investigated in only workplace for the final version of the instrument, the authors have decided to test this method.

The aim of this research was to estimate the safety performance in Estonian manufacturing industry and determine the benefits of OHSAS 18001 certification.

The main objectives were: (1) to evaluate the available safety auditing methods and determine the most relevant for manufacturing industry, (2) to conduct safety interviews in 16 industrial companies in order to find the gaps in safety activities and performance and (3) to examine the positive outcomes of OHSAS 18001 for real safety performance.

MATERIALS AND METHODS

On the basis of critical overview of the existing auditing methods, MISHA method (Kuusisto, 2000) as the most innovative was chosen for the current study. The MISHA method considers the following area of industrial activities: A. organization and administration (safety policy and safety activities in practice, personnel management); B. participation, communication, and training; C. work environment (physical work environment, psychological working conditions, hazard analysis procedures); D. follow-up (occupational accidents and illnesses, work ability of the employees, psychological work ability).

To select industrial companies for the research, the database of Estonian Association for Quality (2014) was scanned. By January 2014, 178 Estonian companies owned OHSAS 18001 certification. The scan showed that 32% of certified firms come from manufacturing sector. The authors contacted each of these firms and explained briefly the purpose and the scope of the research. Finally eight companies (representing main manufacturing areas in Estonia such as printing, textile, metal, food industry etc.) agreed to participate which was enough to perform a qualitative study. In order to compare the results with non-certified organizations, eight companies with similar background were selected. The data collection was performed during 2014, when 8 (OHSAS 18001-certified organisations, group I) + 8 (non-certified organisations, group II) Estonian enterprises from different branches of manufacturing participated in 25 interviews with employers, middle-level safety personnel and with safety responsible persons. Altogether 55 questions were asked from each of the person interviewed (MISHA method). Once data collection had ceased, the first author and the interviewer (ÕP) re-heard the records, and checked the coding strategy used for consistency and ensured that all questions had been answered. The second author (KR) then listened to the records and made notes about understanding the answers. After that, the two first authors discussed the answers of each company to come to a good level of agreement about the results (Table 2, 3 and 4). Table 1 presents the characteristics of the examined enterprises – the activity area, lifetime, size, the overall assessment on safety by an expert-interviewer, if OHSAS 18001 is implemented, and the persons interviewed (position and age).

RESULTS AND DISCUSSION

The results described were derived from on-site observations as well as from employee interviews and calculations by MISHA method. According to MISHA method, the total activity scores (Table 2) varied 73.94…93.33 for OHSAS 18001-certified organisations (group I) and 29.10…88.08 for non-certified organisations (group II). This demonstrates that normally, companies who have implemented OHSAS 18001 benefit from it in safety performance as the activity scores are considerably higher than for non-certified companies.

Table 1. The characterisation of enterprises investigated (N = 16)*

Id. of the company	The activity area	Life-time, years	Size, employees	The overall assessment on safety** Likert scale***	OHSAS 18001 imple-mented	The persons interviewed: position, age
K (Int 1)	Textile industry	11–25	50–249	3	–	Production manager, 38
L (Int 2–4)	Plastic industry	11–25	50–249	4	+	Quality manager, 41 Safety manager, 62 WER, 25
M (Int 5)	Furniture industry	> 50	50–249	4	+	Personnel manager, 64
N (Int 6)	Heat industry	> 50	50–249	5	+	Quality and environment manager, 58
O (Int 7)	Printing industry	1–10	< 50	2	–	Production manager, 36
P (Int 8–9)	Metal industry	> 50	≥ 250	5	–	Safety manager, 35 Trade union representative, 60
Q (Int 10–12)	Elect-ronics industry	11–25	≥ 250	5	–	Quality manager, 36 Safety specialist, 42 WER, 53
R (Int 13–15)	Food industry	> 50	≥ 250	4	–	Safety specialist, 62 WER I, 34 WER II, 39
S (Int 16–18)	Elect-ronics industry	11–25	≥ 250	5	+	Quality manager, 59 Safety manager, 39 WER, 66
T (Int 19)	Metal industry	> 50	≥ 250	5	+	Safety manager, 64
U (Int 20)	Food industry	> 50	≥ 250	5	+	Safety manager, 37
V (Int 21)	Metal industry	1–10	< 50	4	–	Production manager, 36
W (Int 22)	Wood processing industry	1–10	≥ 250	4	+	Quality manager, 47
X (Int 23)	Food industry	> 50	≥ 250	5	+	Safety chief specialist, 68
Y (Int 24)	Glass industry	11–25	< 50	3	–	Production manager, 41
Z (Int 25)	Textile industry	11–25	≥ 250	2	–	Health and safety manager, 67

*Companies are listed and coded in chronological order; **assessed by expert-interviewer; ***Likert scale: 1 – poor, 2 – average, 3 – good, 4 – very good, 5 – excellent;
Abbreviations: Id. – identification; Int – interview, WER – working environment representative.

Table 2 also demonstrates that the activity scores for OHSAS 18001-certified organisations vary slightly while the activity scores of non-certified companies differ considerably more – which means that the safety level depends on ownership, size of the company, dedication and attitudes of the top management, knowledge and resources availability and the consistency of safety activities in the company. However, the scores also show that some companies with no OHSAS 18001 certification can function as safely as the ones having the certification; mainly due to affiliation to a larger international consolidated company with developed safety systems.

The activity scores of the study showed that non-certified companies can be subdivided – 4 companies (P, Q, R and V) belonging to Nordic or global corporations (scores 79.80…88.08) and 4 companies (K, O, Y and Z) which are locally established and owned (scores 29.10…52.73). It shows that the safety management systems owned and run by local businessmen may lack in several OHS activity areas. The reasons may lay behind lack of resources, knowledge and skills, time while companies belonging to corporations are able to prioritize safety more. Examining results among group I (OHSAS 18001-certified organisations), there is no difference in scores between locally owned businesses (companies L, M) and international corporations (N, S, T, U, W, X).

Table 2. Activity rating according to framework elements calculated by MISHA method (grey rows – OHSAS 18001-certified companies; white rows – without certification; total score=100)

Identification	A: Organisation and administration	B: Training and motivation	C: Work environment	D: Follow up	Total activity score
K	31.88	57.58	60.00	44.44	46.67
L	85.02	68.69	74.07	42.59	73.94
M	85.51	78.79	75.56	61.11	78.79
N	92.75	87.88	80.00	66.67	85.45
O	24.64	33.33	35.56	22.22	29.09
P	86.96	96.97	90.00	69.44	87.88
Q	88.89	97.98	81.48	83.33	88.08
R	85.51	86.87	74.07	59.26	79.80
S	91.30	90.91	79.26	75.93	86.26
T	89.86	87.88	75.56	83.33	84.85
U	84.06	78.79	71.11	72.22	78.18
V	89.86	69.70	84.44	77.78	83.03
W	69.57	81.82	80.00	72.22	75.15
X	97.10	100.00	88.89	77.78	93.33
Y	31.88	54.55	57.78	16.67	41.82
Z	37.68	60.61	73.33	44.44	52.73

Looking at the results according to activity areas (Table 2), the following general conclusions can be drawn:

- The OHSAS 18001-certified organisations gain very high scores for element A (organization and administration) which is mainly establishment of written documents (formal safety). Non-certified companies have low scores for element A when they are locally owned and high scores when they belong to a larger consolidated company.
- The differences for element B (training and motivation) are not as high as for element A as training is strictly regulated by national legislation and therefore, each company, certified or non-certified, has to follow the requirements.

- Scores for element C (work environment) are high; vary slightly for certified companies and are lower and vary more for non-certified companies. The difference comes mainly from lack of dealing with psychological risk factors.
- Scores for element D (follow up) vary both for certified and non-certified companies. It represents the real safety performance, registration and investigation of accidents and absenteeism as well as the measurements of workability of employees. As parts of this is not regulated by legislation, the scores are diverse.

Table 3 and 4 represent the mean scores (0–3 scale) according to the activity area by MISHA method. Each four-category framework element consists of 3 activity areas which are examined by specific 55 items in the form of various interview questions/considerations.

Table 3. The mean scores (0–3 scale) according to the activity area (A and B) by MISHA method

Identifi-cation	A1*	A2*	A3*	B1*	B2*	B3*
	Organisation and administration			Training and motivation		
K	0.36 ± 0.67	1.63 ± 0.92	1.50 ± 0.58	1.67 ± 0.58	1.50 ± 1.29	2.00 ± 0.82
L	2.58 ± 0.50	2.67 ± 0.44	2.25 ± 0.88	1.56 ± 0.77	1.75 ± 1.37	2.75 ± 0.50
M	2.91 ± 0.30	2.25 ± 0.46	2.25 ± 0.96	2.33 ± 1.15	2.00 ± 0.82	2.75 ± 0.50
N	3.00 ± 0.00	3.00 ± 0.00	2.50 ± 0.58	2.67 ± 0.58	2.25 ± 0.50	3.00 ± 0.00
O	0.73 ± 0.65	0.75 ± 1.04	0.75 ± 0.50	1.00 ± 0.00	1.00 ± 0.82	1.00 ± 0.82
P	2.68 ± 0.56	2.63 ± 0.58	2.38 ± 0.48	2.83 ± 0.29	2.88 ± 0.25	3.00 ± 0.00
Q	2.76 ± 0.34	2.67 ± 0.36	2.42 ± 0.32	2.78 ± 0.38	3.00 ± 0.00	3.00 ± 0.00
R	2.76 ± 0.34	2.46 ± 0.43	2.25 ± 0.50	2.56 ± 0.51	2.50 ± 0.43	2.75 ± 0.17
S	2.97 ± 0.10	2.58 ± 0.43	2.42 ± 0.57	2.78 ± 0.38	2.67 ± 0.27	2.75 ± 0.50
T	2.82 ± 0.40	2.88 ± 0.35	2.00 ± 0.00	2.67 ± 0.58	2.25 ± 0.96	3.00 ± 0.00
U	2.64 ± 0.50	2.50 ± 0.53	2.25 ± 0.50	1.33 ± 1.15	2.75 ± 0.50	2.75 ± 0.50
V	2.55 ± 0.93	3.00 ± 0.00	2.50 ± 0.58	1.67 ± 1.15	1.75 ± 0.96	2.75 ± 0.50
W	2.36 ± 0.81	1.88 ± 0.83	1.75 ± 0.50	1.67 ± 1.53	2.75 ± 0.50	2.75 ± 0.50
X	3.00 ± 0.00	3.00 ± 0.00	2.50 ± 0.58	3.00 ± 0.00	3.00 ± 0.00	3.00 ± 0.00
Y	0.09 ± 0.30	2.13 ± 0.99	1.00 ± 0.00	2.00 ± 1.00	1.50 ± 1.29	1.50 ± 0.58
Z	0.36 ± 0.92	2.25 ± 1.04	1.25 ± 0.50	1.00 ± 0.00	1.75 ± 0.50	2.50 ± 0.58
Mean	2.16 ± 1.08	2.39 ± 0.59	2.00 ± 0.57	2.10 ± 0.69	2.21 ± 0.62	2.58 ± 0.58

***A1:** Safety policy; **A2:** Safety activities in practice; **A3**: Personnel management; **B1**: Participation; **B2**: Communication; **B3:** Personnel safety training.

According to Table 3, it can be seen that B3 (personnel safety training) obtained the highest mean score (2.58 ± 0.56) which is not surprising as Estonian legislation specifies the requirements for training and in-service training regarding OHS in detail (Resolution…, 2000). As seen from Table 4, B3 is followed by C1 (physical work environment), by score 2.52 ± 0.37, which demonstrates that companies generally know how to control occupational hazards such as physical and chemical risk factors; and proves that interviewed companies prioritize workplace risk assessment as one of the main requirement in OSH legislation in Estonia. The third highest score, 2.39 ± 0.59 points, is occupied by activity area A2 (safety activities and practice) where the items are strongly related to OHS legislation (e.g. obligations to elect working environment representatives, formulating duties for safety manager, etc.). The lowest score, 1.02 ± 0.44, was calculated for D2 (workability employees) which is very likely connected with Estonian tax system where employer has to give strong evidence of expenses on connectedness of employees' health promotion or otherwise a high fringe benefit tax applies (Income Tax Act, 1999). Therefore, employers are not always eager to invest in health promotion.

Table 4. The mean scores (0–3 scale) according to the activity area (C and D) by MISHA method

Identifi-cation	C1*	C2*	C3*	D1*	D2*	D3*
	Work environment			Follow up		
K	2.22 ± 0.97	1.33 ± 0.58	1.00 ± 1.00	1.33 ± 0.15	1.50 ± 0.71	1.00 ± 0.00
L	2.59 ± 0.32	1.78 ± 0.69	1.56 ± 0.96	1.67 ± 0.53	0.33 ± 0.47	2.00 ± 0.00
M	2.44 ± 0.53	2.00 ± 0.00	2.00 ± 1.00	2.33 ± 0.58	1.50 ± 0.71	1.00 ± 0.00
N	2.67 ± 0.50	2.33 ± 0.58	1.67 ± 0.15	2.33 ± 0.58	1.00 ± 0.00	3.00 ± 0.00
O	1.44 ± 0.53	0.67 ± 0.58	0.33 ± 0.58	0.67 ± 0.58	1.00 ± 0.00	0.00 ± 0.00
P	2.94 ± 0.17	2.50 ± 0.50	2.17 ± 0.29	2.33 ± 0.58	1.25 ± 0.34	3.00 ± 0.00
Q	2.70 ± 0.35	2.11 ± 0.69	2.00 ± 1.00	3.00 ± 0.00	1.50 ± 0.24	3.00 ± 0.00
R	2.56 ± 0.60	1.78 ± 0.07	1.67 ± 1.15	2.78 ± 0.38	0.17 ± 0.24	3.00 ± 0.00
S	2.70 ± 0.51	1.67 ± 1.00	2.11 ± 0.77	2.89 ± 0.19	1.00 ± 0.47	3.00 ± 0.00
T	2.67 ± 0.50	1.33 ± 0.53	2.00 ± 1.00	3.00 ± 0.00	1.50 ± 0.71	3.00 ± 0.00
U	2.44 ± 0.73	1.00 ± 1.00	2.33 ± 1.15	3.00 ± 0.00	0.50 ± 0.71	3.00 ± 0.00
V	2.67 ± 0.50	2.33 ± 1.15	2.33 ± 0.58	3.00 ± 0.00	1.00 ± 0.00	3.00 ± 0.00
W	2.78 ± 0.67	1.67 ± 1.53	2.00 ± 1.00	3.00 ± 0.00	0.50 ± 0.71	3.00 ± 0.00
X	3.00 ± 0.00	2.33 ± 0.58	2.00 ± 1.00	3.00 ± 0.00	1.00 ± 0.00	3.00 ± 0.00
Y	2.11 ± 0.93	1.33 ± 0.58	1.00 ± 0.00	0.33 ± 0.58	1.00 ± 0.00	0.00 ± 0.00
Z	2.33 ± 0.87	2.00 ± 1.00	2.00 ± 0.00	1.67 ± 0.58	1.50 ± 0.71	0.00 ± 0.00
Mean	2.52 ± 0.37	1.76 ± 0.52	1.76 ± 0.55	2.27 ± 0.89	1.02 ± 0.44	2.13 ± 1.26

***C1**: Physical work environment; **C2**: Psychological working conditions; **C3**: Hazard analysis procedures; **D1**: Occupational accidents and illnesses; **D2**: Work ability of the employees; **D3**: Social work environment.

The next section presents the responses and differences between OHSAS 18001-certified organisations and organisations without it related to specific activity areas given in MISHA method (Kuusisto, 2000) through quantitative and qualitative data (interviews).

A1 Safety Policy

Interviews revealed that all examined organisations without OHSAS 18001 and local ownership do not hold any kind of written safety policy. Safety and health activities are performed following the current legislation. As the OHS Act of Estonia (1999) does not require a written policy in paper, then in normal conditions, it is not created. These companies which belong to a larger corporation have a written policy with the authority of the concern.

The examined OHSAS 18001-certified organisations, had all a written safety policy; however the implementation of it was different depending on the affiliation to a larger international group/concern. Those companies belonging to an affiliated group, are able to make very few modifications in the safety policy as it is usually a fixed document. Some changes can be made in order to comply the requirements in national legislation. The content and volume of a safety policy depends on policy makers' approach: some have just a few general paragraphs about company's safety commitment followed by comprehensive implementation guidelines or a more detailed extension (a separate document) where main safety activities and procedures are described. Other OHSAS 18001-certified organisations have one single extensive safety policy document covering all areas (the role and importance of safety, safety goals, main safety activities and their administration, description of safety tasks and responsibilities etc.); while only a part of it is introduced to employees (often being up on the notice-board of manufacturing unit). It came out from the interviews that even when dissemination of safety policy among employees is usually quite well-organized, the companies do not prioritize informing external bodies such as clients, sub-contractors or authorities, although OHSAS 18001 requires it (OHSAS Project Group, 2007). Normally, the policy (or a shorter version of it) is presented on the company's webpage in order to make it available for all external bodies. There is often no clear practice how to inform about the changes in policy document after the revision.

One of the safety managers from the food processing industry summarized:
'When our partners sign or renew a contract and come to our territory, we introduce them the new policy or changes in the policy – usually during the training course'. – Company X, Int 23.

Normally, the safety policy lists the required documents such as work instructions and instructions for line-managers' and supervisors' safety duties, but how to perform and follow the duties is often unclear and unwritten. For example, the companies have no clear overview or guidelines which tools and knowledge should be used for effective safety training, no evaluation is given about the effectiveness of the training etc. In several cases, it was stated as follows:
'The supervisors' and line managers' performance how to train our employees, comes with experiences and additional training. There are no guidelines or good tips written in paper for them'. – Company L, Int 3; Company M, Int 5; Company S, Int 18; Company V, Int 21; Company Z, Int 25.

A2 Safety activities in practice

In both types of companies – group I and group II, safety personnel and their responsibilities are usually designated. In smaller companies, no full-time safety manager is hired; often a production manager or personnel manager fulfils the duties during the working hours. All companies had elected a working environment representative according to the OHS Act (1999). In the larger companies (over 50 employees), the Working Environment Council has to be appointed/selected; the frequency of meetings varies depending on the size of the company and the number of discussions needed – from one up to four times per year.

In both groups of companies, there were deficiencies in safety awareness and knowledge: in most companies no system and clear picture existed how safety and health aspects can be taken into account in the design of new workplaces and processes. The exceptions were 3 OHSAS 18001-certified organisations and 2 non-certified organizations who employ their own engineers in order to find out new solutions for health and safety in the company.

One good example was an enterprise in food industry:
'We have a list of health and safety aspects which need to be taken into account when creating new workplaces'. – Company X, Int 23.

A3 Personnel management

In most of the companies, short-term plans about human resources are made; but no long-term views are generated. The interviewees explained it with the fact that everyday life has shown that market needs change quickly.

The weakest part in several companies was the policy how to ensure elderly personnel's work ability.

A company (in paper industry) argued:
'We cannot allow ourselves discrimination, so we don't prefer one group of people to another – so therefore, there are no advantages for elderly people'. – Company W, Int 22.

Another company (in metal industry) answered:
'We only have young workers, so we don't need to think about the aging workforce yet'. – Company V, Int 21.

A few companies (Companies S and R) admitted that they would benefit from a document or a guideline where elderly personnel's' appreciation is justified. Even when there is no such written document available, the companies applied various activities in order to maintain the employees' health (including aging workforce) for instance providing a masseuse, massage chairs, thermotherapy, a neurologist, exercise equipment on-site etc.

The smaller the company is, the less the individual career planning is done. An example of attitude by production managers (in clothing industry):
'There are many sewers, but only 4 positions for line managers. There is practically no possibility to make a career if you have chosen to do sewing work in our company'. – Company K, Int 1; Company Z, Int 25.

A good example is from another small-scale company (Company V) in metal industry where a matrix has been created on a notice-board where workers' abilities and skills are ranked against equipment complexity: the more skills the person has, the more complex work can be performed by him and the more possibility he has for career promotion.

Normally, an evaluation about candidate's health and safety knowledge is not performed during the selection of new personnel. The reason lies mainly on low skilled workforce availability in Estonia.

B1 Participation

In many investigated companies, OHSAS 18001-certified or non-certified organisations, the weak point is the communication between supervisor and employee. The interviews revealed that immediate intervention is not efficiently practiced. Often, the communication is limited to certain times per week; for example:
'We don't interfere at once. We have a practice to go and gather all the problems and have an audit once a week. Then, we try to find the solutions'. – Company N, Int 6.

During interviews, only one company out of 16 admitted that they practice immediate intervention also among peers and not only by supervisors:
'The best practice in our company is, that my colleague will say to me at once if I do something wrong or unsafe'. – Company V, Int 21.

Concerning employee participation into the workplace design, there are almost no companies (no differences between group I and group II) who involve employees in order to alter workplace safer or healthier. The exceptions are the companies who employ design engineers.

B2 Communication

Companies' communication practices were generally in high level. Interviewees stated that the communication was organized effectively and sufficiently; for instance different communication tools were used: wall-boards, e-mails, internal leaflets, intranet etc. Some companies in the group II do not practice management information meetings for all personnel in regular basis, but in the group I it was predominant. Differences were dedicated in suggestions for improvement between group I and II. OHSAS 18001 states that there should be a procedure for collecting employees' suggestions (OHSAS Project Group, 2007). In the group II companies stated that suggestions for improvements are collected orally (Company O, V and Z) which means that no written procedure exists. Among group I, several company representatives mentioned that it is not common that the person who makes the suggestion can complete it afterwards. In Company X, the interviewee stated:
'The persons who have made the suggestions, will have the opportunity to complete the proposed improvements (all suggestions that have been evaluated to be suitable for implementation)'. – Company X, Int 23.

It means that there will be a team assigned to help him/her to complete it. However, several other companies were not convinced that everyone should have this chance as they may not have sufficient knowledge and skills for solving the problem.

In both groups employees were one or another way rewarded for the suggestions made (from verbal gratitude to monetary rewards).

The arrangement of health and safety campaigns in companies is strongly connected to company's practices (no difference between group I and II). For instance, companies U, V, X have strong culture for regular campaigns. The most common campaigns arranged were 'Occupational health days'; lectures on HIV, alcohol, smoking, healthy nutrition, reflectors; sport activities etc.

Another example comes from company in wood processing industry:
'We have no campaigns, but there are focus areas each year'. – Company W, Int 22.

B3 Personnel safety training

The need for safety training was evaluated on a regular basis on almost all companies. When preparing work instructions, several companies mentioned that managers and supervisors participate in preparation of the instructions. Employees participate more seldom. All companies stated that employees have seen work instructions, but whether they always act according to them, is questionable. A lot of companies (M, N, P, Q, R, U, S, T, W, X) stated that they check on regular basis (audit) whether employees follow the instructions or do not.

Several companies (P, Q, R, S, U, V) stated that they involve employees in all levels of the work instruction preparation process. Other companies (K, O, Y, Z) use mainly supervisors when preparing the work instructions. It is widely known among companies that when instructions are updated, they need to be replaced and the old ones removed from the workplaces. As work permits are regulated by Estonian legislation (for example, Machinery Safety Act (2002)), then the companies who need these permits, keep them up-do-date.

Generally, all companies are able to assess working environment hazards, especially physical hazards such as noise, lighting, indoor climate and manual handling of loads. In some level ergonomics assessments are performed as well. It appeared that indoor climate and factors influencing it produce the most diverse opinions and challenges:

'While designing the new building, everything was taken into account in order to install the most suitable ventilation system. However, our employees complain about draught all the time and have an opinion that the ventilation system isn't built efficiently'. – Company S, Int 17.

All companies in group I show a very high level of assessment of chemical hazards and risk of major hazards. These factors are explored thoroughly because of the integrated system – all interviewed OHSAS 18001-certified organisations are certified also after ISO 14001 (ISO, 2004) which pays special attention to chemicals used in the enterprise. Some companies in group II, consider chemical exposure essential as well: for instance, in a company in metal industry (Company P), a chemical specialist has been employed.

A very few companies handle off-the-job safety – travelling between home and the workplace:

'We have drawn instructive lines from the territory to the bus station in order to have a safe lift home'. – Company R, Int 11.

The interviews indicated that the maintenance of machines and equipment and the cleanliness of the plant area depends rather on the size of the company than the affiliation or owning the OHSAS 18001 certificate. In smaller companies, employees are expected to keep the workplace in order and clean it after the end of the shift as well as do the small daily maintenance. Example from a printing industry:

'Our employees fix the small problems themselves. We call for outsourced service only when something breaks down and needs a specialist attendance'. – Company O, Int 7.

Some other companies (R, S, W) answered that they have minimized the off-the-job safety risks by offering a bus to transport the employees home after their shifts.

The difference arising among OHSAS 18001-certified companies compared to non-certified companies is the on-going and continuous improvement activity in order to establish better working conditions (see the section B2).

C2 Psychological working conditions

In examined companies, psychological aspects are not considered while designing new workplaces. During work process, the working load is usually monitored and evaluated – however, psychological factors are often neglected. Some companies ignore the problem:

'We do not have any stress factors in our company; so we really don't need to deal with it, thankfully'. – Company U, Int 20.

It turned out that working in isolation is often a privilege and not a psychological hazard because in recent years, people tend to feel that open-plan offices are psychologically more challenging than private offices. However, working alone is a problem in some of the investigated companies (U, W) – working in the nature, on sites.

Some of the physical hazards contribute into psychological hazards as well:

'My head is ringing as the production line is next to my office and it disturbs my work all the time'. – Company S, Int 16.

There were no differences between group I and group II companies while dealing with psychosocial hazards. In conclusion, it can be said that the knowledge about psychosocial hazards among managers in Estonia is still low.

C3 Hazards and analysis procedures

Risk assessment has been conducted in all interviewed companies (however, the quality of the assessment was not assessed during the visits to the enterprises). Many companies presented the results of measurements of working conditions, however, many of them were conducted several years ago and the situation may not be the same anymore. In all companies of group I, the risk assessment report lead to the preparation of an action plan. Three companies (K, O and Y) in group II confessed that no action plan has put together after the risk assessment procedure.

All companies except one (O) carry out personnel's health surveillance: they have an activity plan on an annual basis. However, the efficiency and quality of occupational health service varies greatly. It rather depends on a size of the company than whether it is certified by OHSAS 18001 or is not. General trend is the following: the larger the company, the more collaboration between the company and occupational health service provider. In small companies, an occupational health doctor contributes to the maintenance of employees' health through the health inspection and health control decision. Only few companies (P, S, U, X) confirmed that they get a detailed analysis of the results on a regular basis (once or twice per year) by occupational health physician, but many lack it. A company in furniture industry said:

'It would be essential to have the summary of the results sent to the top management – this way, they would see the employees' problems and understand their responsibility better'. – Company M, Int 5.

Generally, occupational health service specialists do not participate in employees' training, except in two companies (S, Z, R) who have invited specialists to give some lectures about specific health issue. However, this agreement is signed separately from general health surveillance service. This is the reason why most companies do not deal with it.

Safety organizations participate in safety analysis of the companies through occupational hygiene measurements and performing risk assessment. There is no good practice that the staff of safety organizations represents their results to management and employees. This, again, is usually not a part of the contract. Usually, the results of measurements and risk assessment is introduced by safety manager.

D1 Occupational accidents and illnesses

In group I, all companies keep statistics on accident rates and use it as a reference when new goals for safety improvement are done. In group II, those who belong to a larger affiliation or concern, report on a regular basis which consists the presenting of occupational accidents and illnesses statistics. In group II, companies K, O, Y and Z do not calculate statistics on accident rates. In Company W (less than 50 employees) they act very seriously on accidents and their causes: the root causes are sought, action plan is made, reasons are presented to all employees, information goes to wall-boards. When we look at the investigation of the near-accidents, then in group I it is done 100%. In group II, it is done, too, but not consistently. For example in companies S, W, R the near-accidents reporting is connected with yearly goals. The company decides how many near misses there have to be reported in a year per person as the statistics (Heinrich, 1941) shows that the more accidents the more near-misses exist. In these companies who do not integrate it to yearly goals, the near-accidents reporting rate is very low.

Absenteeism is often followed, but as Estonian legislation (Personal Data Protection Act, 2007) does not allow the separation of reasons of absenteeism, the results are often not analysed and used for goal setting.

D2 Work ability of the employees

As mentioned in section A3, there is generally no policy how to ensure elderly personnel's work ability. None of the companies had a systematic view for the rehabilitation for persons' whose work ability has decreased. However, some companies (P, Q, R, S, U, X, Z) offer various activities in order to maintain the employees' health: providing a masseuse, massage chairs, thermotherapy, a neurologist, exercise, equipment on-site etc.

Most companies answered negatively for the question about redesigning workplace for the persons who have difficulties in coping with the work. The answer was simple:
'Sorry, we can't do it and there is no similar work to offer'. – Company R, Int 11.

Or the next explanation:
'Our shifts are 12 hours long. If someone wants to work for 6 hours, we have difficulties to find another person with the same need'. – Company R, Int 11.

Companies K and S look at each case individually and try to provide the most suitable solutions:
'We have some workers who work 6 hours instead of 8 because of health reasons. As this is done every day, there is no particular work delays or unexpectancies'. – Company K, Int 1.

In the several companies, the work satisfaction survey is conducted regularly (usually outsourced), but psychological hazards questionnaires are hardly used. Some companies stated that dealing with this issue depends strongly on the managements' attitudes and knowledge.

A good example of emphasizing the psychological stress factors:
'We use occupational psychologists in order to help our supervisors to detect and solve the problems between the team members and how to intervene when stress level becomes too high'. – Company Z, Int 25.

D3 Social work environment

As mentioned in D2, companies in group I have a clear system how to measure social climate – they conduct regular work satisfaction surveys (except one company) either once or twice a year. Often, these surveys come from the concern they belong to or are outsourced. Interviews revealed that 4 companies (K, O, Y, Z) do not conduct these surveys. Most of them explained that they do not find it necessary in order to improve employees' health.

CONCLUSIONS

In conclusion, following statements can be presented:

1. According to the results, the companies can be divided into 3 different categories: (1) OHSAS 18001-certified organizations, (2) organisations which belong to a larger corporation or concern but are not OHSAS 18001-certified and (3) non-certified, locally established and owned companies. Clearly, OHSAS 18001-certified organizations show the highest scores.

2. The safety activities in a company depend strongly on consistency. The study showed that safety needs commitment and systematic approach. If one of the key elements of safety management systems is missing, then it can be seen in the results of other framework elements. For instance, lack of safety policy may influence the consistency in safety activities, the safety communication and safety knowledge and vice versa. These results are in line with the earlier studies (Tint et al., 2010b; Fernández-Muniz et al., 2012a; Reinhold et al., 2015).

3. Implementation of OHSAS 18001 automatically will not ensure high safety activities in the company. However, holding an OHSAS 18001 certificate, creates a basis for a systematic work in the area of safety management, hazards identification and prevention, and promotes strong improvement process put in use. Other authors (Ma et al., 2001; Fernández-Muniz et al., 2012b) have demonstrated, too, that OHSAS 18001 is only the first step towards the systematic and successful management of safety work. Besides that, companies need to have a favourable safety climate (a strong management commitment with the support of their workforce) (Fernández-Muniz et al., 2012b).

4. Concerning working conditions and occupational hygiene, all companies are able to assess work environment hazards. However, in OHSAS 18001-certified companies the control of chemical hazards and major accident hazards, is in very high level while non-certified organisations show the lower commitment to chemical safety. However, there are 2 good examples in non-certified organisations: a company in metal industry employs a chemical specialist and a company in food industry who outsources

company-specific chemical safety training. Physical hazards like noise and illumination are well managed in all interviewed companies, some challenges are faced with thermal conditions e.g. temperature, airflow and inefficiency of ventilation system. Ergonomics is valued by almost all enterprises; however dealing with it systematically and effectively depend on the size and consistency of the company. The maintenance of machines and equipment and the cleanliness of the plant area depends rather on the size of company than the affiliation or owning the OHSAS 18001 certificate. In smaller companies, employees are expected to keep the workplace in order and clean it after the end of the shift as well as do the small daily maintenance. The knowledge about psychosocial hazards among managers in Estonia is still low and there were no differences between group I and group II while dealing with psychosocial hazards. Our study results indicate that psychosocial work environment is not only difficult to measure, but problematic to detect its dimensions and find suitable solutions and control measures. A study conducted in Denmark (Hohnen & Hasle, 2011) showed a similar result – OHSAS 18001-certified manufacturing company had difficulties in dealing with psychosocial work environment as referred too complex, with multiple causes and too complicated for management to articulate clearly.

5. All interviews were conducted by using the MISHA method questionnaires. MISHA method offers a more comprehensive possibility to evaluate SMS in present-day society: it emphasizes among other activity areas on top management commitment and safety knowledge, psychosocial hazards and integration of personnel management. By reference to previous authors' experiences with other audit methods (Tint et al., 2010a; Tint et al., 2010b), for instance D&S method is a rough and outdated method. Some criteria in it are very easy to meet, too much emphasis is put on fire and industrial hygiene control, less attention is paid to follow-up and auditing. Compared to some other methods, developed in the USA (ISRS-Generic (Collision & Booth, 1993, Goodyear Tire and Rubber Company audits (Dyjack et al., 1998)), MISHA gives less attention to off-the-job safety. Although MISHA method can be successfully used for evaluating safety management systems in manufacturing industry, it has to be kept in mind that some modifications may be needed due to national differences in safety activities. For instance, occupational health service principles and structure vary from country to country.

As the result of the investigation and using the elements of the OHSAS 18001, the model for safety management in the small and medium-sized enterprises will be proposed.

REFERENCES

Abad, J., Lafuente, E. & Vilajosana, J. 2013. An assessment of the OHSAS 18001 process: Objective drivers and consequences on safety performance and labour productivity. *Safety Science* **60**, 47–56.

Bakker, A.B. & Schaufeli, W.B. 2008. Positive organizational behavior: Engaged employees in flourishing organizations. *Journal of Organizational Behavior* **29**, 147–154.

BSI (British Standard Institution). 1996. BS 8800:1996. *Guide to occupational health and safety management systems*. BSI, London.

Bunn, W.B., Pikelny, D.B., Slavin, T.J. & Parlkar, S. 2001. Health, safety, and productivity in a manufacturing environment. *Journal of Occupational and Environmental Medicine* **43**(1), 47–55.

Chang, J.I. & Liang, C.L. 2009. Performance evaluation of process safety management systems of paint manufacturing facilities. *Journal of Loss Prevention in the Process Industry* **22**(4), 398–402.

Collison, J.E. & Booth R.T. 1993. An evaluation of two proprietary health and safety auditing systems. *Journal of Health and Safety* **9**, 31–38.

Diekemper, R.F. & Spartz, D.A. 1970. A quantitative and qualitative measurement of industrial safety activities. *ASSE Journal* **12**, 12–19.

Dyjack, D.T., Levine, S.P., Holtshouser, J.L. & Schork, M.A. 1998. Comparison of AIHA ISO 9001-based occupational health and safety management system guidance document with a manufacturer's occupational health and safety assessment instrument. *American Industrial HygieneAssociation Journal* **59**(6), 419–429.

Eisner, H.S. & Leger, J.P. 1988. The international safety rating system in South African mining. *Journal of Occupational Accidents* **10**,141–160.

Estonian Association for Quality. 2014. Database of Certificates. http://eaq.ee/sisu/sertifikaatide-andmebaas. Accessed 05.01.2014 (in Estonian).

EVS 18001:2007 (OHSAS 18001). *SMSs*. Estonian Centre for Standardization (in Estonian).

Fernández-Muñiz, B., Montes-Peón, J.M. & Vázquez-Ordás, C.J. 2007. Safety culture: analysis of the causal relationships between its key dimensions. *Journal of Safety Research* **38**, 627–641.

Fernández-Muniz, B., Montes-Peon, J.M. & Vazques-Ordas, C.J. 2012a. Occupational risk management under the OHSAS 18001 standard: analysis of perceptions and attitudes of certified firms. *Journal of Cleaner Production* **24**, 36–47.

Fernández-Muniz, B., Montes-Peon, J.M. & Vazques-Ordas, C.J. 2012b. Safety climate in OHSAS 18001-certified organisations: Antecedents and consequences of safety behaviour. *Accident Analysis and Prevention* **45,** 745–758.

Frazier, B.F., Ludwig, T.D., Whitaker, B. & Roberts, D.S. 2013. A hierarchical factor analysis of a safety culture survey. *Journal of Safety Research* **45**, 15–28

Heinrich, H.W. 1941. Industrial accident prevention. McGraw-Hill, 448 pp.

Hohnen, P. & Hasle, P. 2011. Making work environment auditable – A ‘critical case’ study of certified SMSs in Denmark. *Safety Science* **49**, 1022–1029.

HSE. Health and Safety Executive. 2001. A guide to measuring health and safety performance. http://www.hse.gov.uk/opsunit/perfmeas.pdf Accessed 30.01.2015.

Income Tax Act. 1999. RT I 1999, 101, 903. https://www.riigiteataja.ee/en/eli/ee/Riigikogu/act/520012015019/consolide. Accessed 02.01.2015.

ISO. 2004. ISO14001:2004 Environmental management systems – Specification with guidance for use.

Karapetrovic, S. & Willborn, W. 2000. Generic audit of management systems: Fundamentals. *Managerial Auditing Journal* **15**(6), 279–294.

Kuusisto, A. 2000. Safety management systems: Audit tools and reliability of auditing. [dissertation] Tampere (Finland): Tampere University of Technology.

LaMontagne, A.D., Barbeau, E., Youngstrom, R.A., Lewiton, M., Stoddard, A.M. & McLellan, D. 2004. Assessing and intervening on OSH programmes: Effectiveness evaluation of the Wellworks-2 interventions in 15 manufacturing worksites. *Occupational & Environmental Medicine* **8**, 651–660.

Ma, C.-M., Chen, W.-H., Hung, C.L. 2001. How to Implement the Occupational Health & Safety Management System. Foundation of Taiwan Industrial Service. Taipei.

Machinery Safety Act. 2002. RT1 I 2002, 99, 580. https://www.riigiteataja.ee/akt/129062014040. Accessed 02.02.2015 (in Estonian).
Occupational Health and Safety Act. 1999. RT I 1999, 60, 616. https://www.riigiteataja.ee/akt/108102014007. Accessed 31.01.2015.
OHSAS Project Group. 2007. OHSAS 18001:2007. SMSs – requirements.
Pearse, W. 2002. Club Zero: Implementing OHSMS in small to medium fabricated metal product companies. *Journal of Occupational Health and Safety – Australia New Zealand* **18**(4), 347–356.
Personal Data Protection Act. 2007. RT I 2007, 24, 127. https://www.riigiteataja.ee/akt/112072014051. Accessed 02.02.2015 (in Estonian).
Redinger, C.F. & Levine, S.P. 1998. Development and evaluation of the Michigan occupational health and safety management system assessment instrument: a universal OHSMS performance measurement tool. *American Industrial Hygiene Association Journal* **59**, 572–581.
Reinhold, K., Järvis, M. & Tint, P. 2015. Practical tool and procedure for workplace risk assessment: Evidence from SMEs in Estonia. *Safety Science* **71**, Part C, Jan, 282–291.
Resolution of the Ministry of Social Affairs. 2000. No. 80 of 14 December 2000. Procedure for Training and In-service Training regarding Occupational Health and Safety. State Gazette in Estonia, RTL 2001 35, 469.
Robson, L.S. & Bigelow, P.L. 2010. Measurement properties of occupational health and safety management audits: A systematic literature search and traditional literature synthesis. *Canadian Journal of Public Health* **101**(Suppl 1), 34–40.
SafetyMap. 1995. A guide to occupational health and safety management systems 1995. Health and Safety Organization, Victoria, Australia. 52 pp.
Tint, P., Paas, Õ., Järvis, M. & Tuulik, V. 2010a. Safety Management at Medium- and Small-Scale Enterprises in Estonia. *Journal of International Scientific Publications: Ecology and Safety* **4**(1), 300–310.
Tint, P., Paas, Õ. & Reinhold, K. 2010b. Cost-effectiveness of safety measurers in enterprises. *Inzinerine Ekonomika-Engineering Economics* **21**(5), 485–492.
Traumann, A., Reinhold, K. & Tint, P. 2013a. The model for assessment of health risks of dust connected with wood manufacturing in Estonia. *Agronomy Research* **11**, 471–478.
Traumann, A., Tint, P., Järvik, O. & Oja, V. 2013b. Management of health hazards during shale oil handling. *Agronomy Research* **11**, 479–486.
Vinodkumar, M.N. & Bhasi, M. 2011. A study on the impact of management system certification on safety management. *Safety Science* **49**, 498–507.

Agronomy Research **13**(3), 810–819, 2015

An analysis of engineering students' knowledge on the topic of occupational health and safety

J. Paju* and S. Kalle

Tallinn University of Technology, Tallinn School of Economics and Business Administration, Department of Business Administration, Academia road 3, EE12618 Tallinn, Estonia; *Correspondence: jana.paju@ttu.ee

Abstract. Occupational health problems often result of poor knowledge of safety requirements and inadequate personnel training, especially considering specific tasks at work. A questionnaire was distributed to university students to respond, in order to analyse their answers and achieve following objectives: (1) to pinpoint the students' knowledge prior to the start of the course; (2) to reveal how many students have had experience with occupational health and safety (OHS) topics before starting the course; (3) to determine whether the knowledge of students with prior experience is greater; (4) to identify the most difficult topics or domains. The obtained results showed that the average test score was 50.2% (n = 151). Students with prior knowledge on OHS (n = 53) did not get higher test scores (*p-value* = 0.12; α = 0.05). The objectives of the study were achieved. Further studies considering the efficiency of both teaching and learning are to be conducted.

Key words: OHS, occupational health and safety course, knowledge.

INTRODUCTION

Most occupational health problems are conditioned by poor knowledge of safety requirements and inadequate (personnel) training. To improve the situation several educational institutions (such as universities and vocational education centrums) in Estonia provide courses covering different aspects of occupational health and safety (OHS) in their curricula. Those courses, (targeted mostly to students of the educational institutions itself) are more than necessary, as it is common knowledge that young and new workers experience very high rates of occupational injuries. For example in Europe workers aged 18 to 24 have 50% higher probability to have an occupational accident (Occupational health and safety strategy 2010–2013). This age group of workers is the same wherein our study group is. Usually it is believed that the employees' age is in correlation with occupational injury studies (Breslin & Smith, 2006) have shown that short job tenure is correlated with occupational injury, rather than young age. On the other hand, young people have less work experience, as they are just starting their careers.

To thoroughly understand our motivation to conduct such study in Estonia, a brief overview of the situation in states' approach towards OHS topics is needed. Also an overview of the interest group is given.

Combining the results from the Statistics Estonia's database on Social Life and The Statistical Yearbook of Estonia (2014) data can be obtained considering the number of workers injured in registered occupational accidents during the period of 2005–2013. The Table 1 refers to the aforementioned data. Do note, as it is mentioned in the Statistical Yearbook of Estonia (2014), the data considering the registered accidents at work is underestimated, as not all of the occurring accidents are reported to the Labour Inspectorate. The Statistics Estonia has estimated the number to be almost 2.5 times higher than reported, based on the Labour Force survey.

Table 1. Workers injured in registered accidents at work during 2005–2013

Total of employed people (in thousands)	2005	2006	2007	2008	2009	2010	2011	2012	2013
	615.6	651.7	657.6	656.0	593.9	568.0	603.2	614.8	621.3
	Accidents per 10,000 workers (including fatal accidents)								
Below 24 years of age	10.5	11.1	10.5	11.5	8.6	10.1	11.3	12.5	12.5
Aged 25–34	12.7	12.7	12.7	14.5	11.7	13.2	15.4	16.5	16.8
Aged 35–44	12.1	11.5	11.3	12.1	9.2	11.4	12.8	13.2	11.9
Aged 45–54	12.3	12.6	12.9	13.6	10.9	12.0	11.6	13.5	13.2
Aged 55–64	6.7	7.0	8.1	8.9	7.8	8.7	9.4	10.1	10.9
Above 64 years of age	1.3	1.2	1.2	1.6	1.2	1.2	1.5	1.6	2.0
Total of accidents per 10,000 workers	55.7	56.1	56.6	62.1	49.5	56.6	62.0	67.5	67.3
Total of the accidents reported to the Labor Inspectorate	3,431	3,653	3,723	4,075	2,939	3,215	3,741	4,148	4,180

Schulte et al. (2005) discuss the option that even if young workers have the knowledge on OHS topics, they might not be able to put it into practice, due to their lack of experience, and perhaps even due to the lack of self-confidence to raise safety and health issues with more experienced co-workers or within the workplace.

The necessity for personnel training in enterprises and companies remains, as the Table 1 and Fig. 1 indicate. The OHS related in-service trainings (i.e. the trainings that are enabled to employees during the course of their employment) are seldom if ever offered to employees to attend outside the company's own structure. Järvis et al. (forthcoming 2015) have investigated the employee's possibility to continuously improve their knowledge. The results indicated that 30% of the workers state to have the possibilities, 35% consider to have no possibilities. Approx. 1/10 of the workers were very satisfied with opportunities for both development and gaining knowledge. At the same time 50% of the respondents considered their possibilities 'limited'. The survey consisted of 1,757 participants.

The Ministry of Social Affairs has emitted the 'Occupational health and safety strategy 2010–2013' wherein is shown the synopsis based on The Labour Inspectorate's study results on occupational accidents and risk assessments. It is claimed, that the knowledge of the OHS risks and risk-management is poor, in terms of Estonian employers and employees both. The situation could be aggravated because the primary training and tutelage in a work-environment or on a position is often implemented by the employer. Järvis et al. (forthcoming 2015) have indicated that 89% of employees claimed to receive OHS related information from their employers or supervisors, 82% of employers claimed the same. Disjointedness and lack of systematic promotion of OHS topics is widespread in Estonia although promotional materials intended for employers are composed and distributed by the state. Too often the high-quality work-environment is not appreciated. As one of the potential causes of the aforementioned problems, it has been referred to the fact, that the OHS topics are not attended to as early as during the studies of basic or general education (Occupational health and safety strategy 2010–2013).

In reality the condition has somewhat improved since 2010, when the strategy for 2010–2013 was ratified. There has been some OHS promotion, such as lectures and courses from Estonian Labour Inspectorate to both employers and working environment specialists. New web-sites have been created and developed for promoting occupational safety, providing additional information on the topic and improving the overall quality of risk assessments.

When communing with employers, their attitude shows unwillingness to understand that some of specific knowledge on OHS can only be learned during the work. Employers expect the trainees or new workers to have good or sufficient knowledge on OHS topics, even on positions which require basic or general education. On a tangential note – studies on the subject have not been conducted yet in Estonia and aforementioned statement is rather an observation than a verified fact. Järvis et al. (forthcoming 2015) have found that the employee's knowledge of OHS topics can seldom be considered good as only 6% of employers and as little as 4% of employees receive their OHS information from specialists. At other times the info is gained from potentially ineligible employer.

As the employers often believe the workers to have more knowledge on OHS topics than employees actually do, the resources to train the worker might be inadequate.

When enabling the training to the employee, the employers will most certainly consider the sufficiency of the training course. But also workers' a priori knowledge must be considered. How to do this?

To be able to consider the topics of in-service trainings and lifelong learning at all, first the qualities of the employee must be considered. As the group of interest of the current study is aged 18–24, the extent of knowledge of the young people taking up their duties is enquired.

In our study this will done by comparing the research results of two groups of students that have not yet participated in any university OHS courses during their studies. One of those groups have no a priori knowledge on the topic, the other group has come into contact with OHS topics during their work in enterprises.

The aim of this study is not to extend the results to generalised population. Rather, the study is conducted to obtain data about the knowledge of a part of population by answering the following questions: (1) to pinpoint the students' knowledge prior to the start of the course; (2) to reveal how many students have had experience with OHS topics before starting the course; (3) to determine whether the knowledge of students with prior experience is greater; (4) to identify the most difficult topics or domains.

The objective is to use the information about student's a priori knowledge to estimate the usefulness of OHS courses in the future.

MATERIALS AND METHODS

To conduct the study a questionnaire was created (from now on referred as the test). The test was then given to Bachelor study students of Tallinn University of Technology to be answered. The test was anonymous; the sample consisted of the volunteers from all the students who had to take the Occupational health course during 2014 spring term. The testing was carried out in the beginning of their first lesson of the course.

The selection consisted of 151 students (114 male, 37 female, aged 19 to 24 from 8 different engineering and technology specialties (Electrical Engineering, Earth Sciences, Geotechnology, Electrical Power Engineering, Thermal Power Engineering, Product Development and Production Engineering, Mechatronics, Chemical and Environmental Technology), of whom 53 had had prior experience in OHS topics due to their employment or practice in an enterprise. Specific information considering the extent of their prior experience was not collected (whether they had attended to any training courses or if they had held e.g. the position of a working environment representative). With the help of the questionnaire we aimed to pinpoint the students' knowledge of the topic in beginning of the course, rather than to compare the results of students with or without a priori knowledge.

The 17 multiple choice questions (MCQ) in the questionnaire (shown in Table 2) were developed specifically for this study and chosen to show student's knowledge on different OHS topics that are also addressed during the course. It should also be noted, that during the course several topics are discussed in great detail. This is due to the fact that during the course the students have to acquire knowledge that will be helpful to them whether they are future employers or employees in different specialities and work environments.

Table 2. The questions used in the 'Educational Diagnostic Test on OHS Topics' questionnaire (some of the questions consisted of several sub-questions)

No	Question	Correct answer	The average score of the question (%)
1.	Choose the correct meaning to each of the CLP Pictograms or safety and health signs*	*1a.* Strong oxidizer *1b.* Is carcinogenic *1c.* Wear eye protection *1d.* Laser radiation	45.5
2.	Which of those hazards can cause Raynaud Syndrome?	Excessive vibration	11.3
3.	Which of those blood pressure values can be considered normal or healthy?	110/75	76.2

Table 2 (continued)

4.	Choose the correct statement to characterize following OHS related occupations and positions*: *4a* working environment representative *4b.* working environment specialist *4c.* ergonomist *4d.* working environment council	*4a.* is a representative elected by employees in occupational health and safety issues *4b.* is an engineer competent in the working environment field (who has received training concerning the topic and whom the employer has authorised to perform occupational health and safety duties). *4c.* evaluates the potential effect of physical and physiological risk factors on workers' health in work environment. *4d.* is a body for co-operation between an employer and the employees' representatives which resolves occupational health and safety issues within the enterprise.	55.6
5.	Which of those relative humidity values can be considered as the optimum for a good work environment?	40–60%	24.5
6.	Which of those can be defined as a chemical hazard? *	*6a.* CO_2 *6b.* Asbestos	78.8
7.	Which of those can be defined as a biological hazard? *	*78a.* Blood *7b.* Staphylococcus	47.7
8.	Which of those can be defined as a physical hazard?*	*8a.* Noise *8b.* Insufficient lighting	54.0
9.	Which of those can be defined as a psychological hazard?*	*9a.* Bulling *9b.* Boring and monotonous work	71.2
10.	What is the maximum value for domestic noise in Estonia, given in dB (A)?	80	23.2
11.	With which physical hazard the term 'glare' agrees with and what does it mean?	Lighting – the term indicates lighting conditions where the light is too strong, even blinding	40.4
12.	Which of those sentences shows the right correlation between 'hazard' and 'risk'?	Risk shows the probability of negative effects caused by a hazard	54.3
13.	Which of those values is considered to be sufficient maintained illuminance for office work?	500 lx	19.9
14.	Lyme's disease is a zoonosis that is carried by which creatures?	Ticks	12.6

Table 2 (continued)

15.	How much can the CO2 levels inside a renovated building exceed the outside levels?	500 ppm	7.3
16.	The question consists of a picture, which shows a worker and his working area. Students need to mark all the named problems in the MCQ that should be attended to improve the conditions. *	*16a.* Display screen is at the right height *16b.* Hand should be bent ~90° from the elbow *16c.* Worker does not need a foot support *16d.* Workers wrists should not rest on the table *16e.* The space between the chair and the back of the worker's knee must be approx. the size of the workers fist.	47.0
17.	The question consists of a picture, which shows a working area. Students need to mark all the named problems in the MCQ that should be attended to improve the conditions. *	*17a.* Workplace may be uncomfortable due to glare due to direct sunlight *17b.* The mould needs to be removed and repelled, to eliminate the risk on workers' health *17c.* Illuminance uniformity the working area is not sufficient *17d.* Air humidity during autumn is too high *17e.* The temperature is fitting throughout the year	59.9

This question consists of several sets of multiple choices, in all of which correct answers occur. The number of sets is indicated in the answers column.

In order to assure the reliability of the questionnaire no open questions were used. Each correct answer gave one point. Scoring was measured by adding up the points and calculated into a scale of 100 percent. The questions were created in accord with several standards (both Estonian and European), Estonian legislation and best practices of OHS.

Do note: (1) the questionnaire was created in Estonian and thereby some of the questions might seem unreasonable, as the terminology in English might describe the essence of some of the phenomenon better than the relevant term in Estonian; (2) each set of answers (from questions 1 to 15, included) also had an option 'I am not aware'; (3) The questions 16 and 17 had different structure than all the other 15 questions (although they were also MCQs), as 16th and 17th question were designed to evaluate the students common sense rather than knowledge of facts.

During the analysis of results, statistical calculations (t-test) were carried out using Microsoft Excel (2013). The significance level was set to 0.05.

RESULTS AND DISCUSSION

The lowest score of the test was 25.7% (20 year old male Electrical power engineering student) and the highest of the test was 80.0% (19 year old male Thermal power engineering student who, according to his own words, did not have prior OHS knowledge). The average test score of all the participants was 48.9% (n = 151).

As it has been referred to earlier, the test had 2 different types of questions.

Therefore Table 3 indicates the scores of the test from different aspects. While comparing the average scores, it is obvious that the 'fact questions' were more difficult to the students than the 'common sense questions'.

Students were asked if they had knowledge on OHS topics prior to the course. 53 students had prior experience in OHS from 1 to 60 months. Students with prior knowledge on OHS did not get higher test scores (*p-value* = 0.13; α = 0.05). Statistically significant difference was not observed while comparing different question (Q 1...15 vs Q 16...17) and experience groups.

Table 3. Results of the test

	Minimum result (in %)	Average result (in %)	Maximum result (in %)	Average standard deviation
Whole test (Questions 1–17)	25.7	48.9	80.0	35.8
1^{st} part of the test (Questions 1–15)	16.0	47.1	80.0	37.3
2^{nd} part of the test (Questions 16–17)	0.0	53.4	100.0	24.5

The average score for students without experience was 46.9% (n = 98). In comparison, the scores of students with at least 6 months of experience in OHS field had results that varied from 28.6% to 65.7%. The average score for the 53 students who claimed to have any prior knowledge was 51.9%.

The average scores of the test (and each question) are shown in Fig. 1.

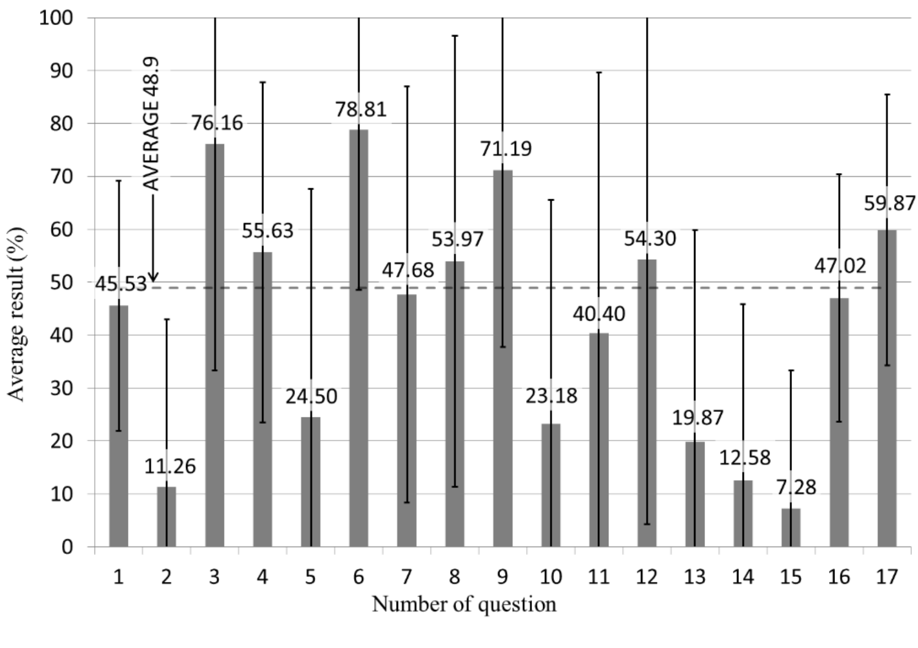


Figure 1. Individual question's average score and error bars (on horizontal axis) and the overall average score (dashed line).

Do note – the questionnaire had its limitations due to the fact that all of the topics of the course were known not to be covered in equal thoroughness; therefore it was undesirable to create a questionnaire that would be too time-consuming for the students to answer.

As Fig. 1 indicates, the students found questions (Q) 2, 5, 10, 13, 14, and 15 difficult. The easiest was the question about chemical hazards (Q6) with the average score of 78.8%. Students found it difficult to answer to questions with specific diseases' names like Raynaud syndrome (Q2) and Lyme's disease (Q14). The study also showed that students are unaware of the working environment normative values on air humidity (Q5), noise (Q10), lighting (Q13) and carbon dioxide (Q15).

From the radar chart (Fig. 2) one can see how students' prior experience with OHS topics (in months) influenced their average score within different sets of questions.

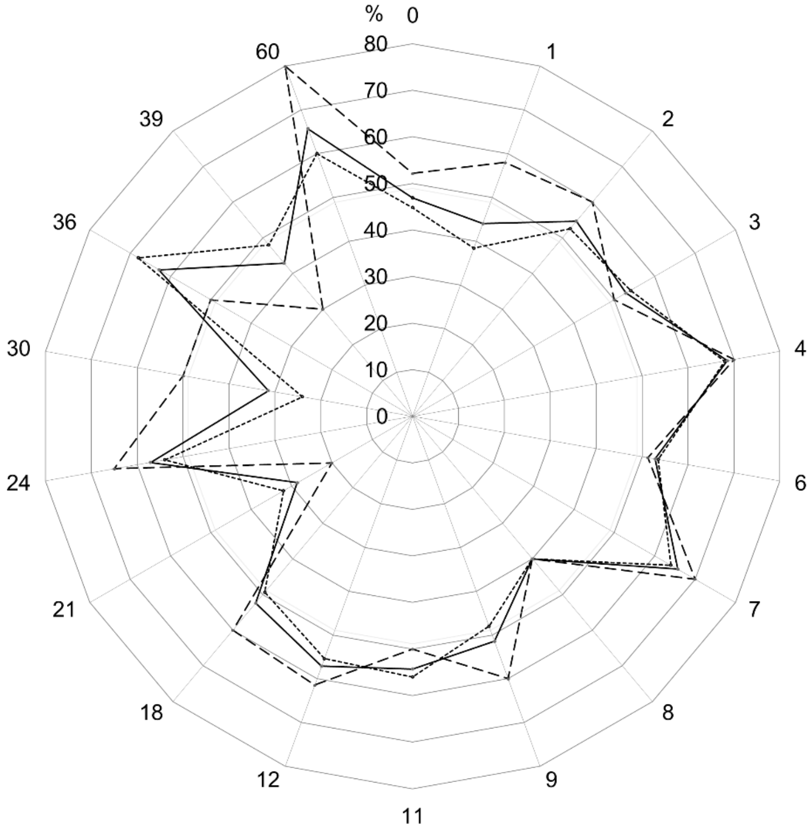


Figure 2. Radar chart showing students' experience in months (outside circle) and students score in % (0–90%). The gray area indicates the overall average and values below average of the test. Average values of the whole test (the questions (Q) 1–17, black line), average values of different parts of the test: Q1–15 (dotted line), Q16–17 (dashed line).

Do note, students did not divide evenly between different experiences categories (there was 98 students without prior knowledge, 30 students with 1–6 months experience and 23 students with experience varying from 6 to 60 months). Fig. 2 indicates that when answering to questions 16 and 17 that do not require factual knowledge students received (regardless of the students' experience) higher score values than to questions 1 to 15. The average score of question 16 suggests that even though all the respondents have personal experience of using a computer workplaces, their own mere experience does not allow them to get higher results when answering the question considering the ergonomics of the workplace. Despite the fact that the question 16 was rather a common sense question than a factual one, students failed to achieve higher results than the overall average of the test. Thus being uninformed of even some of the facts, common sense can lead to misinterpretation of the situation. But their ability to relate to a certain working environment is stronger (question 17), as the results are higher. This could be explained by the fact that question 17 consisted of several physical and biological hazards that are more obviously dangerous or disturbing than working in a wrong posture. Also, it is questionable whether a young and healthy human being who has not practiced 8 hour shifts of sedentary work can relate to the hazards of poor posture.

By the Estonian law the employers are obligated to train and also inform their employees on the subjects of: (1) company's work environment risk assessment; (2) measurement results anterior to the assessment and (3) legal normative values. As the employers are bind to inform the workers on the measurement results and normative values, the topics are also covered in the lectures of the course. Therefore the questions considering the normative values have also been included to the test.

As at least 53 students were working before or during their studies, the test score on the subject of normative values should have been higher. This raises several questions: (1) do employers inform their employees on normative values or do they presume that educational institutions do it instead; (2) how should each worker obtain knowledge on new values, if the normative values change due to developments in hazards control. During the year 2013 Estonian Labour Inspectorate's workers visited and supervised 2,665 companies. Their visits showed that a lot of companies (n = 1,589) failed to instruct their employees (Estonian Labour Inspectorate, 2013). This statistics suggests that OHS courses in higher education are necessary, otherwise young employees would be uninformed of even the most general knowledge considering risks and hazards that can accompany different professions. But employers must admit that as each workplace is different, all specific nuances of a workplace cannot be foreseen and therefore the students cannot be taught to avoid any particular situations in specific environments. During such courses only the fundamentals of risks and hazards can be taught, as well as health-sustaining and constructive attitude towards OHS topics can be created. Young and/or new workers can only learn OHS skills by themselves. This can only be done through their own experience during accomplishing tasks under the supervision of a qualified professional and an expert of OHS, rather than be taught in a lesson.

CONCLUSIONS

The students' knowledge and experience on OHS topics prior to the start of the course were mapped, the most difficult topics and domains were pinpointed. The results show that (1) students with prior experience did not get better test scores and (2) generally students are unaware of normative values on noise, air humidity, carbon dioxide and lighting.

The questionnaire had its limitations due to the fact that all of the topics of the course were not covered in equal thoroughness. Therefore the results might not show each student's definite knowledge.

The exploration is ongoing, as collected data is still being processed and further studies considering the efficiency of both teaching and learning are to be conducted.

ACKNOWLEDGEMENTS. We would like to thank all of our colleagues who let us survey their students for the purpose of this study.

REFERENCES

Breslin, F.C. & Smith, P., 2006. Trial by fire: a multivariate examination of the relationship between job tenure and work injuries. *Occupational Environmental Medicine* **63**(1), 27–32.

Estonian Labor Inspectorate 2013. http://www.ti.ee/fileadmin/user_upload/failid/dokumendid/Meedia_ja_statistika/Toeoeter vishoiu_ja_toeoeohutuse_jaerelvalve/TT_ja_TO_2013.pdf. Accessed 16.01.2014.

Järvis, M., Virovere, A. & Tint, P., (forthcoming, 2015). Formal Safety Versus Real Safety: Quantitative and Qualitative Approaches to Safety Culture – Evidence from Estonia. In: *Proceedings of the Latvian Academy of Sciences*

Occupational health and safety strategy 2010–2013. (ratified by The Minister of Social Affairs J. Pevkur in February 2010) https://www.sm.ee/sites/default/files/content-editors/eesmargid_ja_tegevused/Too/Tookeskkond/ttto_strateegia_2010–2013.pdf. Accessed 16.01.2014.

Schulte, P.A., Stephenson, C.M., Okun, A.H., Palassis, J. & Biddle, E. 2005. Integrating Occupational Safety and Health Information Into Vocational and Technical Education and Other Workforce Preparation Programs. *American Journal of Public Health* **95**(3), 404–411.

Statistics Estonia's database: Social Life, WQA01: Registered accidents at work by sex and age group. http://pub.stat.ee/px-web.2001/Dialog/varval.asp?ma=WQA01&ti=REGISTERED+ACCIDENTS+AT+WOR K+BY+SEX+AND+AGE+GROUP&path=/I_Databas/Social_life/19Worklife_quality/02 Accidents_at_work/&lang=1. Accessed 13.04.2015

Statistics Estonia's database: Social Life, ML217: Employed persons by sex and status in employment. http://pub.stat.ee/px-web.2001/Dialog/varval.asp?ma=ML217&ti=EMPLOYED+PERSONS+BY+SEX+AND +STATUS+IN+EMPLOYMENT&path=/I_Databas/Social_life/09Labour_market/04Emp loyed_persons/02Annual_statistics/&lang=1. Accessed 13.04.2015

The Statistical Yearbook of Estonia, 2014. http://www.stat.ee/publication-download-pdf?publication_id=36393. Accessed 16.01.2014.

Agronomy Research **13**(3), 820–828, 2015

Work-related musculoskeletal symptoms in industrial workers and the effect of balneotherapy

V. Pille[1], V.-R. Tuulik[2], S. Saarik[2], P. Tint[1,*], T. Vare[2] and R. Sepper[1]

[1]Tallinn University of Technology, Ehitajate 5, EE19086 Tallinn, Estonia
[2]Tallinn University Haapsalu College, Lihula 1, EE90507 Haapsalu, Estonia
[*]Correspondence: piia.tint@ttu.ee

Abstract. The aim of the paper is to present balneotherapy (mud treatment) effect in the rehabilitation and prevention of work-related musculoskeletal disorders (MSDs) of industrial workers. Balneotherapy significantly reduces the muscle pain complaints of the employees. The m.abductor pollicis brevis muscle tension measured decreased after the balneotherapy. The study included overall 114 industrial workers (91 female and 23 male persons from garment and woodworking industries) with professional overuse of the upper extremities. The average age of the workers was 49.1 (from 22 to 75) years, their average length of the service was 16.2 years. The main result of the questioning of the workers about the pain regions: there was quite a high incidence of musculoskeletal pain in the investigated workers with a work-related upper extremity syndrome: neck 68.4%, shoulders 63.2%, elbows 42.1% and wrists 78.9%. In the course of the study, balneotherapy was applied to 19 (13 female and 6 male) industrial workers who had pain at least in two regions of the body. The average age of these workers was 50.6 years and the average length of the service 21.3. After the balneotherapy, the 19 industrial workers' complaints of pain in the neck and in the wrists decreased from 2.37 to 1.13 points ($p = 0.05$) and from 3.25 to 1.03 points ($p = 0.007$) respectively on the VAS pain scale. Objective measurement of muscle fatigue with a myotonometer showed the decrease in the stiffness of hand muscles (Abd poll brev, right: from 278 nM^{-1} until 342 nM^{-1}, $p = 0.006$). The results indicated that more attention should be paid to the early diagnostics and preventive measures.

Key words: physical overload, musculoskeletal disorders, myotonometry, industrial workers, balneotherapy.

INTRODUCTION AND THEORETICAL BASIS

A work-related musculoskeletal disorder (MSD) develops slowly, stealthily; however, there is also a possibility that chronic musculoskeletal pathology may develop, which is often the cause of permanent incapacity for work. This is why it is essential that attention should be paid to early diagnostics of work-related MSDs as well as to preventive interference both for changing the working order and for commencing early treatment with a view to helping to prevent the development of chronic MSDs and to preserve the workers' ability to work (Reinhold et al., 2008; Oha et al., 2010; Öztürk & Esin, 2011; Pille et al., 2014).

The project studying the incidence of MSDs in working age population, *Fit for Work Europe*, covered 27 European countries, and within the framework of the study a report regarding each participating country was prepared. The *Fit for Work Estonia* report was completed in 2011. The report indicated that MSDs reduce the working ability of at least half of the workers in Estonia. In 2009, the ability to work was limited in 59% of workers aged between 15 and 64 due to long-term hand, foot, back or neck problems. The problems are especially frequent in 40- to 65-year old women. Estonia is among the topmost EU member states where workers worry most about work damaging their health (in the opinion of 59% of the workers as compared to the average of the European Union, which is 33% (Zheltoukhova & Bevan, 2011).

In many European countries, incl. Finland, MSDs come second to psychic disorders as causes of permanent loss of ability for work (Martimo, 2010). Most of the MSDs cause local discomfort, muscle tension or pain; joint mobility may be impaired, which, in its turn, prevents people from coping with their everyday tasks. Almost all MSDs are physical load sensitive, even if the disorder is not work-related, physical load may aggravate the symptoms. In the most cases, there are combined causes for MSDs. However, the physical load of work, work intensity, and working and rest time regime have a significant role in the development of various MSDs. Excessive physical load, repetitive motion, and forced positions have a burdensome effect (Tammaru et al., 2004; da Costa & Vieira, 2010). Overwork brings about an accumulation of potassium and free radicals in muscle cells, which may cause damage to muscle cell membranes and to mitochondrial energy production (Hägg, 2000; Toomingas et al., 2011).

In the case of static muscle work, when a muscle contracts, the intramuscular pressure increases and the blood flow decreases. Insufficient blood flow may lead to oxygen deficiency in the muscle and, consequently, to a number of biochemical processes, which may produce pain (Toomingas et al., 2011). In case of non-specific muscle pains, their relation to repeated work motions has been proved (Macfarlane et al., 2000).

In Tartu University, a methodology and equipment for diagnosing the functional state of skeletal muscles has been developed (myotonometry). The method comprises recording, by means of an acceleration transducer, the response of a superficial skeletal muscle or a part thereof to mechanical impact, and an analysis of the signal by means of a dedicated computer program. The criteria developed make it possible to perfect the diagnostics of the functional state of skeletal muscles (Vain, 2002).

The myotonometric method of muscle study may be used for early detection of work-related MSDs as well as for assessment of the difficulty of physical work for individual workers (Roja et al., 2006). The basic indicators of the skeletal muscle condition are frequency and stiffness. Frequency characterizes the muscle tension. In a normal muscle, the muscle tension at rest is slight, but frequency increases when the muscle is energized. Stiffness characterizes the muscle's capacity to resist its shape-shifting power. The values of stiffness are in the range 150 to 300 Nm^{-1}, depending on the type of the muscle (Vain, 2002).

One of the possibilities of relaxing a muscle and decreasing pain is heat application (Dehghan & Farahbod, 2014). The physiological effects of heat therapy include pain relief and increases in blood flow, metabolism, and elasticity of connective tissues. There is a limited overall evidence to support the use of topical heat in general; however, randomized controlled trials (RCTs) have shown that heat-wrap therapy provides short-term reduction in pain and disability in patients with an acute lower back pain and provides significantly greater pain relief of delayed-onset muscle soreness than does cold therapy (Decoster et al., 2005; Folpp et al., 2006; Verhagen et al., 2013;

Malanga et al., 2015).

According to the systematic review by Nakano (2012), the static stretch alone can improve the range of motion and this can be potentiated by the application of heat. Heat is an effective adjunct to developmental and therapeutic stretching techniques and should be the treatment of choice for enhancing ROM in a clinical or sporting setting. The effects of heat or ice on other important mechanical properties (e.g. passive stiffness) remain equivocal and should be the focus of future study (Bleakley & Castello, 2013).

The aim of the paper is to present balneotherapy's (mud treatment) effect in the rehabilitation and prevention of work-related musculo-skeletal disorders (MSDs) of the industrial (garment and woodworking) workers.

The hypothesis of the study is: the balneotherapy decreases the muscle tension and pain that employees feel?

MATERIAL AND METHODS

Subjects

The study included 114 industrial workers with professional overuse of the upper extremities. There were 91 women and 23 men in the group with an average age of 49.1 (22–75 years); their average length of service was 16.2 years. The workers were investigated by the questionnaire on the pain regions and pain strength. The 19 workers of the group who reported pain in the two or more regions of the upper extremities due to the work overload, received balneotherapy which took place at the outpatient clinic in 10 sessions. The data of the investigated subjects are presented in Table 1.

Table 1. The data on the subjects of the study

	Total number of investigated workers N = 114; 23M; 91F			The workers who underwent the balneotherapy N = 19; 6M; 13F		
	Mean	SD	Range	Mean	SD	Range
Age (years)	49.1	11	22–68	50.6	9.37	22–65
BMI (kg m^{-2})	27	5.4	18–37	26.3	2.42	21–29
Length of service (years)	16.2	10.2	0.5–48	21.3	13.9	3–47

M – male persons; F – female persons

Assessment of musculoskeletal pain

The workers' musculoskeletal complaints were assessed on the basis of the Nordic Questionnaire. The intensity of pain was assessed from 1 to 10 on the Visual Analogue Scale (VAS). The questionaries' forms were filled out by the workers (N = 114).

Hand-grip strength

The hand-grip pain was measured with hand dynamometry. Three trials for both the extremities were carried out (the best of three was taken as the result), in standing positions, hands next.

Balneotherapy

The number of patients in the balneotherapy group was 19 (13 women and 6 men, the average age of 50.6 years and with the average length of the service of 21.3 years. The workers stated that their average working time was 7.65 hours on each workday.

The average body mass index of male and female subjects was accordingly 26.41 and 26.23. The average handgrip strength of the male subjects was 46.66 kg for the right and 46.91 kg for the left hand; the respective indices of the female subjects were 27.87 kg and 24.96 kg.

In our study, we used warm (42 °C) mud application as thermal stimulation of the painful regions. 42 °C (Seese et al., 1998) has been proved to be the most effective temperature for improving the blood flow. During the balneotherapy period, no changes were made to their usual work and domestic activities.

Myotonometry

The Myoton 3 myotonometer was used in the current study. The following indicators of the thumb muscles (*abductor pollicis brevis* and *adductor pollicis)* were measured: frequency characterizing muscular tension and stiffness characterizing the property of a muscle to resist the deforming force. Those muscles were selected because of the intensive work with repetitive hand movements caused by the muscle tension in the thumbs (Radford et al., 2006).

M. abductor pollicis brevis abducts the carpometacarpal and metacarpophalangeal joints of the thumb in a ventral direction perpendicular to the plane of the palm. The muscle assists in opposition and may assist in flexion and medial rotation of metacarpophalangeal joint.

M. adductor pollicis adducts the carpometacarpal joint, and both adducts and assists in the flexion of the metacarpophalangeal joint, so that the thumb moves toward the plane of the palm (Kendall et al., 2005).

The hand muscles were measured using the Myoton-3 in the sitting position at rest. The patient had to sit in a comfortable position and relax the muscles completely during the measurement.

Statistics

The mean and standard deviation (SD) were calculated in the course of the measurements. The student t test was used. The statistical significance of the t test was $p = 0.05$.

RESULTS AND DISCUSSION

Assessment of musculoskeletal pain

The results of the Nordic Questionnaire on the pain regions and of the VAS scale on the pain strength were as follows. There were 36 (32%) people who had no pain in the neck (Table 2), 32 (28%) people who had pain below 5.0 on the VAS scale, and 46 (40%) people whose pain in the neck was ≥ 5.0 (severe pain) on the VAS scale. The average pain in the shoulder region was the same as in the neck (VAS = 3.5). The number of people who had pain in the shoulders was 38 (33%), among them 23 (20%) people felt pain below 5.0, and 53 (46%) people's pain was ≥ 5.0 on the VAS scale. Less pain was reported in the elbow joints: there were 50 (44%) people, who had no pain; 25 (22%) people had pain below 5.0 and 39 (34%) people's pain was ≥ 5.0 on the VAS scale. The number of people reporting pain in the wrists was the highest. There were 27 (24%) people, who had no pain, 26 (23%) people who had pain below 5.0, and 61 (54%) people whose pain was ≥ 5.0. The spine was also remarkably painful in our study group: there were 31 (27%) people who had no pain, 27 (24%) people who had pain below 5.0 and 56 (49%) people whose pain was ≥ 5.0 on the VAS scale.

Table 2. The regions of pain and the number/percentage of workers reported by the Nordic Questionnaire and VAS scale

The body region	No pain	Pain < 5.0 by VAS	Pain by VAS ≥ 5.0
Neck	36 (32%)	32 (28%)	46 (40%)
Shoulders	38 (33%)	23 (20%)	53 (47%)
Elbow joints	50 (44%)	25 (22%)	39 (34%)
Wrists	27 (24%)	26 (23%)	61 (53%)

Increased stiffness, tenderness and muscle pain, particularly in the neck and shoulder regions, were common work-related complaints in our study group. An average level of pain in the group of 114 industrial workers' (measured on the scale of 0–10) was 3.5 in the neck and shoulder, 2.7 in the elbow joints, 4.2 in the wrists and 4.3 in the spine on the VAS pain scale. Due to the need of different treatment strategies for the mild, moderate and severe pain, we analyzed also a group of persons who had mild or moderate pain (pain less than 50% of maximum intensity), which could be treated with warm application.

All the 19 persons who were chosen for the balneotherapy group complained of two or more local pain regions (Table 3). 13 workers (68.4%, I group) complained of neck pain, and the average pain on the VAS scale was 2.37. After the treatment, the pain decreased to an average pain level of 1.13 points and the change was statistically significant ($p < 0.05$). We saw the same positive dynamics after the balneotreatment on wrists. Wrist pain was declared in 15 cases (78.9%) in this group; that was also the most often reported pain region with an average intensity of pain of 3.23 on the VAS.

Table 3. Health complaints assessed by the Nordic Questionnaire and pain by the VAS scale

Area of pain	Complaints (number of workers and percentage of subjects) before treatment	Intensity of pain (0–10) before treatment	Complaints (number of workers and percentage of subjects) after treatment	Intensity of pain (0–10) after treatment
Neck	13 (68.4%)	2.37	7 (36.8%)	1.13 ($p < 0.05$)
Shoulders	12 (63.2%)	2.43	7 (36.8%)	1.07 ($p < 0.12$)
Elbow joints	8 (42.1%)	1.87	4 (21.1%)	0.63 ($p < 0.12$)
Wrists	15 (78.9%)	3.25	6 (31.5%)	1.03 ($p < 0.007$)

After the treatment, 6 workers (26.3%, II group) still had pain, but the average intensity of the pain was 1.03 on the VAS. The change was statistically significant ($p < 0.007$).

There were two regions: the shoulder and elbow joints, where we saw positive changes in the pain on the VAS scale, but these changes were not statistically significant in this small group.

As a rule, pain was suffered over an extended period of time: 71% of the study subjects named 30 days and more as the duration of the pain.

The results of the myotonometric measurements

The results of the myotonometric measurements were analyzed by means of the Student t-test. Objective measurement of the 19 workers' hand muscles with a myotonometer for frequency and stiffness of *M. add pollicis brevis* did not show any statistically significant changes in this group due the balneotherapy (Table 4). There was a statistically significant decrease only in the frequency and stiffness of the *m. abd pollicis brevis.* It could be explained that the left hand gets probably less overloaded and will repair better and faster. *M. abd pollicis brevis* is an extensor and therefore its stiffness is more important than the flexors' stiffness regarding the range of motion in the joints.

The questions was raised: is there any comorbidity responsible for persisting muscle stiffness? In the II group (6 people) with wrist region tenosynovitis, operated for *syndr. Canalis carpalis, MCF joint arthrosis,* their muscles did not show positive changes in stiffness and frequency in myometrical measurements after the treatment (Table 4, 5).

Table 4. The II-group (n = 6) muscle frequency

Muscle site	Side	Frequency (Hz) before treatment		Frequency (Hz) after treatment		
		mean	SD	mean	SD	p-value
Abd poll brev	left	18.63	4.72	19.35	4.15	0.71
	right	18.37	4.18	22.73	4.79	0.01*
Add poll	left	16.1	1.98	16.7	4.47	0.79
	right	15.6	1.82	17.13	3.06	0.35

Table 5. The II group (n = 6) muscle stiffness

Muscle site	Side	Stiffness (Nm^{-1}) before treatment		Stiffness (Nm^{-1}) after treatment		
		mean	SD	mean	SD	p-value
Abd poll brev	left	295.17	72.55	309.0	64.96	0.616
	right	278.0	65.30	342.0	56.31	0.006*
Add poll	left	272.17	45.35	297.17	48.46	0.110
	right	280.5	40.94	280.67	38.62	0.990

*$p < 0.05$ = significant difference before and after treatment

The I group (13 persons) with no chronic diseases in the wrist region showed positive and significant changes in the myometrical measurements – a statistically significant decrease in stiffness and frequency of *m. abductor pollicis brevis* (Table 6, 7). The stiffness and frequency of M. *adductor pollicis* were quite low (left 16.31 and right

16.45) already before the treatment and did not show any significant changes after the treatment.

Table 6. The I group (n = 13) patients muscle frequency

Muscle site	Side	Frequency (Hz) before treatment	SD	Frequency (Hz) after treatment	SD	
		mean		mean		p-value
Abd pollicis brev	left	19.72	4.97	16.68	4.23	0.0259*
	right	21.29	3.88	16.21	4.98	0.0065*
Add pollicis	left	16.31	1.97	16.92	3.96	0.4374
	right	16.45	1.89	16.65	3.03	0.8128

Table 7. The I group (n = 13) patients muscle stiffness

Muscle site	Side	Stiffness (Nm^{-1}) before treatment	SD	Stiffness (Nm^{-1}) after treatment	SD	
		mean		mean		p-value
Abd pollicis brev	left	313.85	63.50	254.46	54.45	0.0022*
	right	313.31	65.98	248.87	48.32	0.0126*
Add pollicis	left	288.46	42.10	287.31	38.42	0.9123
	right	285.15	40.56	290.92	39.54	0.5449

*p < 0.05 = a significant difference before and after treatment

Discussion

The myotonometrical measurements and the professional analysis of the results enable to determine the 'key' muscles under tension connected with the exact work movements of the person. With the use of the myotonometric muscle testing, it is possible to evaluate the level of occupational muscle overload and dynamically follow up the 'key' muscles after the physio-/balneotherapy.

After balneotherapy, the 19 industrial workers' complaints of pain in the neck and in the wrists decreased from 2.37 to 1.13 points ($p < 0.05$) and from 3.25 to 1.03 points ($p < 0,007$) respectively on the VAS pain scale. The change is statistically significant. There was no significant lessening of pain according to the pain scale in the study subjects whose pain syndrome persisted. The group who had persisting complaints after the treatment had chronic problems in the wrist area. It should also be taken into account that most of the workers studied (71%) had an established (exceeding 30 days) muscle pain syndrome.

As regards the myotonometrically measured parameters, a certain decrease in muscle stiffness could be observed. The changes were better in the extensors (*m. abductor pollicis*) and in the group of people without hard chronic comorbidities in the measured wrist region. The stiffness of extensors (*abductor pollicis)* was higher than in the flexors (M. *adductor pollicis)* already before the treatment. The reason could be that the extensors had a higher static overload due the work activity.

The assessment of the muscle tension by means of the myotonometric method makes it possible to select out the workers who need the treatment and preventive measures in order to prevent the development of chronic MSDs.

There was quite a high incidence of musculoskeletal pain in the 114 investigated workers with a work-related upper extremity syndrome: neck 68.4%, shoulders 63.2%, elbow 42.1% and wrists 78.9%. The results indicated that more attention should be paid to early diagnostics and preventive measures in order to reach the average of the European Union, which is 33% (Zheltoukhova et al., 2011).

CONCLUSIONS

On the basis of the study it may be concluded that the work-related musculoskeletal complaints of pain could be changed by balneotherapy. Balneotherapy (in our study warm mud applications) is one of the old possibilities of treating joint and muscle diseases using heat, and therefore can be used for the rehabilitation of the work-related MSDs without hard comorbidities.

In the course of the study, balneotherapy was applied to 19 industrial workers (from garment and woodworking industries). By the means of balneotherapy, work-related musculoskeletal complaints of pain decreased significantly. Objective measurements with a myotonometer showed a decrease in the stiffness of hand muscles.

Further research will be necessary for working out of the methodology of using the myotonometric measurements of muscles in different work conditions.

REFERENCES

Bleakley, C.M., Costello, J.T. 2013. Do thermal agents affect range of movement and mechanical properties in soft tissues? A systematic review. *Archives of Physical Medicine and Rehabilitation* **94**, 149–163.

da Costa, B.R., Vieira, E.R. 2010. Risk factors for work-related musculoskeletal disorders: A systematic review of recent longitudinal studies. *American Journal of Industrial Medicine* **53,** 285–323.

Decoster, L.C., Cleland, J., Altieri, C. & Russell, P. 2005. The effects of hamstring stretching on range of motion: a systematic literature review. *Journal of Orthopaedic and Sports Physical Therapy* **35,** 377–387.

Dehghan, M. & Farahbod, F. 2014. The efficacy of thermotherapy and cryotherapy in pain relief in patients with acute low back pain, a clinical trial study. *Journal of Clinical and Diagnostic Research*, **8**(9), 1–4.

Folpp, H., Deall, S., Harvey, L.A. & Gwinn, T. 2006. Can apparent increases in muscle extensibility with regular stretch be explained by changes in tolerance to stretch? Australian Journal of Physiotherapy 52, 45–50.

Hägg, G. 2000. Human muscle fiberabnormalities related to occupational load. *European Journal Applied Physiology* **83**,159–165.

Kendall, F.P., Kendall McCreary, E., Provance, P.G., Rodgers, M.M. & Romani, W.A. *Muscles testing and function with posture and pain*. 2005. Lippinccott Williams & Wilkins, 261–262.

Macfarlane, G.J., Hunt, I.M. & Silamn, A.J. 2000. Role of mechanical and psychosocial factors in the onset of forearm pain: prospective population based study. *BMJ* **321**, 676–679.

Malanga, G.A., Yan, N. & Stark, J. 2015. Mechanisms and efficacy of heat and cold therapies for musculoskeletal injury. *Postgraduate Medicine* **127**, 57–65.

Martimo, K.-P. 2010. Musculoskeletal disorders, disability and work. *People and Work Reseach Reports 89*, Tampere.

Nakano, J., Yamabayashi, C., Scott, A. & Reid, W.D. 2012. The effect of heat applied with stretch to increase range of motion: a systematic review. *Physical Therapy in Sport* 13, 180–188.

Oha, K., Viljasoo, V. & Merisalu, E. 2010. Prevalence of musculoskeletal disorders, assessment of parametres of muscle tone and health status among office workers. *Agronomy Research* **8**, 192–200.

Pille, V., Tuulik. V.-R., Tint, P., Tuulik, V. & Hazak, A. 2014. Physical overload disease detection and prevention of workers with professional upper limb overuse. *Safety and Technogenic Management. RTU Scientific Publications* **6**, (in press).

Radford, J.A., Burns, J., Buchbinder, R., Landorf, K.B. & Cook, C. 2006. Does stretching increase ankle dorsiflexion range of motion? A systematic review. *British Journal of Sports Medicine* **40**, 870–875.

Reinhold, K., Tint, P., Tuulik, V. & Saarik, S. 2008. Innovations at workplace: Improvement of ergonomics. *Engineering Economics* **60**, 85–94.

Roja, Z., Kalkis, V., Vain, A., Kalkis, H. & Eglite, M. 2006. Assessment of skeletal muscule fatigue of road workers based on heart rate monitoring and myotonometry. *Journal of Occupational Medicine and Toxicology* **20**, 109.

Seese, T.M., Harasaki, H., Seidel, G.M. & Davies, C.R. 1998. Characterization of tissue morphology, angiogenesis, and temperature in the adaptive response of muscle tissue to chronic heating. Laboratory Investigations **78,** 1553–62.

Zheltoukhova, K., Bevan, S. 2011. *An operational Estonia?* Musculo-skeletal disorders and the Estonian Labour Market. The Work Foundation. Part of Lancaster University (in Estonian).

Tammaru, M., Srompl, J., Maimets, K. & Hanson, E. 2004. The value of the qualitative method for adaptation of a disease-specific quality of life assessment instrument: the case of the Rheumatoid Arthritis Quality of Life Scale (RAQoL) in Estonia. *Health and Quality of Life Outcomes* **2**(69), 4–12.

Toomingas, A., Mathiassen, S.E. & Tornqvist, E.W. 2011. Occupational Physiology. Engineering and Transportation, **Amazon.com**. **Inc**., Seattle.

Vain, A. 2002. *Myotonomethry*. Tartu, 32–33 (in Estonian).

Verhagen, A.P., Bierma-Zeinstra, S.M., Burdorf, A., Stynes, S.M., de Vet, H.C. & Koes, B.W. 2013. Conservative interventions for treating work-related complaints of the arm, neck or shoulder in adults. Cochrane Database Systematic Reviews, Dec 12; 12:CD008742.

Öztürk, N. & Esin, N. 2011. Investigation of musculoskeletal symptoms and ergonomic risk factors among female sewing machine operators in Turkey. *International Journal of Industrial Ergonomics* **41**, 585–591.

Agronomy Research **13**(3), 829–835, 2015

Team learning and self-management for video display terminal employees with chronic neck-shoulders pain

I. Roja[1], Z. Roja[2] and H. Kalkis[2,3,*]

[1]Outpatient Department, Riga 1st Hospital; Bruninieku 5, LV-1005 Riga, Latvia
[2]Ergonomics Research Centre, University of Latvia; Kr. Valdemara 48, LV-1013 Riga, Latvia
[3]Faculty of Economics and Management, University of Latvia; Aspazijas blvd. 5, LV-1050 Riga, Latvia; [*]Correspondence: henrijs.kalkis@lu.lv

Abstract. In Latvia occupational musculoskeletal disorder – chronic neck-shoulders pain (NSP) – is a common complaint in the general population, also in video display terminal (VDT) employees in their giving age, working in bank and agriculture system, and such patients with chronic NSP load markedly the public health care service. The biopsychosocial influence on pain for VDT employees is team learning (TL) with self-management (SM) strategies: pain-blocking imagery, mind-body relaxation, cognitive restructuring of unpleasant physical and emotional experience, improvement of workplace relations and organizational culture. The aim of the research was to evaluate the effectiveness of using TL and SM one month course for bank and agricultural advisory services VDT employees, females and males, suffering from chronic moderate NSP. The structured self-administrated questionnaire was carried out to find out which body parts suffer from pain during workload, information on work-related ergonomic and psychosocial risk factors was collected during face to face interviews. During testing for TL and SM course with follow-up assessment was selected 21 VDT employees (females = 11, males = 10; age between 22 and 50). The intensity of NSP was determined by using the Numeric Pain Rating Scale (NPRS), life quality assessment was analysed with Quality of Life Scale (QOLS), p-value, confidence interval was calculated. Patients were asked to keep a Pain Diary during treatment course. The results indicated decrease in neck-shoulders pain intensity, and positive quality of life changes after TL and SM intervention in video display terminal (VDT) employees. Statistically significant reduction in pain intensity after TL and SM intervention by the biopsychosocial influence on pain according NPRS was among males, and the life quality according to QOLS score – among females. The necessity to perform patient's objective clinical examinations, subjective tests of self-esteem, to keep a Pain Diary during treatment course has been proved in our research.

Key words: chronic moderate neck-shoulders pain, video display terminal employees, team learning, self-management.

INTRODUCTION

The experience of pain at work is a complex phenomenon, which includes bodily as well as psychosocial and ergonomic risk factors components. There are physical, psychosocial, and individual risk factors of chronic moderate NSP (Ariëns et al., 2001; Larsson et al., 2007;). Continual negative stress at work can also cause muscle tension with pain and depressed mood (Banks & Kerns, 1996). Nowadays chronic moderate pain is defined as pain that has lasted longer than three to six months, with scored pain intensity at moderate (5–7) on a scale of 1 (no pain) to 10 (worst imaginable) (Thienhaus & Cole, 2002). A chronic pain patient is an individual with sensitized nervous system and illness behavior experience (Marras et al., 2000; Roja et al., 2007).The biopsychosocial influence on pain for such employees in the multidisciplinary treatment of pain`s complex is team learning (TL) with self-management (SM) strategies: pain-blocking imagery, cognitive restructuring of unpleasant physical and emotional experience with social distress reduction therapy, improvement of workplace relations and organizational culture by education of VDT employees about their unhealthy stereotypical work conditions, specific characteristics of work strain, interpersonal conflicts, and how to conduct best practice (Korth, 2000; Vince, 2001). Hence, the aim of the research was to evaluate the effectiveness of using TL and SM intervention for bank and agricultural advisory services VDT employees in their giving age suffering from chronic moderate NSP.

MATERIALS AND METHODS

During one year period (2014) 31 patients (females = 16, males = 15), age between 22 and 50, bank and agricultural advisory services VDT employees suffering from chronic moderate NSP, took part in our investigation. Mean duration of pain was 5.1 ± SD 1.5 months and mean duration of professional experience was 9.2 ± SD 3.0. The inclusion criteria for investigation were: chronic moderate NSP; full consent to participate in the study, in accordance with the revised Helsinki Declaration, article II; all employees wished non-pharmacologic chronic pain relief by TL and SM, because they have had a negative previous experience with medication therapy.

The exclusion criteria for investigation were: acute NSP; cervical herniated disc symptoms in the neck; muscle disease; high blood pressure; oncologic problems; psychiatric disease; having not been to mandatory medical examinations.

The structured self-administrated Standardized Nordic questionnaire was carried out to find out which body parts suffer from pain during workload with maladaptive thoughts and unhealthy postures at workplace (Kuorinka et al., 1987).

Information on work-related ergonomic and psychosocial risk factors was collected during face to face interviews. During testing for TL and SM course with follow-up assessment at 3 and 6 months by taking into account the exclusion criteria for investigation was selected 21 bank and agricultural advisory services VDT employees (females = 11, males = 10). The intensity of NSP before and after TL and SM session was determined by using the Numeric Pain Rating Scale (McCaffery & Beebe, 1989): the patient is asked to indicate the intensity of current, best, and worst pain levels experienced over the past 24 hours on a scale of 0 (no pains) to 10 (worst pain imaginable).

Life quality assessment with The American Chronic Pain Association Quality of Life Scale (QOLS; Cowan et al., 2003) was realized in males and females by self-administered interview format before and after TL and SM course: QOLS is meant to help individuals by measuring each 10 activity levels (to work, to socialize, to exercise functions, to perform household chores), and consists of 0 to 10 variables (0 = 'non-functioning; feel hopeless and helpless about the life' and 10 = 'normal daily activities, job, social and family life'). Highest score possible is 100 (in conformity with 0 to 10 numeric rating scales for each 10 questionnaires), therefore, QOLS rating scores in results figure are displayed as Total scores/10. Patients were asked to keep a Pain Diary during treatment course. The acquired results were processed, using statistical data processing software SPSS.16 (SPSS Inc., Chicago, IL) according to popular descriptive statistical methods; p-value, confidence interval (95% CI) was calculated, reliability interval (inter-rater agreement) was calculated, and Cohen`s Kappa (k) coefficient was determined (coefficient identifies connectivity of the experimental data, the number of participants and the correlation of the participants` acceptance of the experimental data) (Landis, 1977; Thompson et al., 1998).

RESULTS AND DISCUSSION

It was found that 31 bank and agricultural advisory services VDT employees in their giving age suffering from chronic moderate NSP had unpleasant physical and emotional experience with stereotyped maladaptive, depressive thoughts about pain, stressful unhealthy postures at workplace.

VDT employees complained about chronic NSP in the last six months, caused by workload, psychosocial and individual risk factors, duration of computer use was 6–7 hours per day. All employees wished non-pharmacologic chronic pain relief by biopsychosocial influence on pain. During testing for TL and SM one month course 10 employees (5 females and 5 males) had exclusion criteria for investigation, biopsychosocial influence on pain was denied for such individuals, and they were sent to additional examinations in order to particularize diagnosis. 21 employees (11 females and 10 males) were under one month TL and SM course evaluation (4 sessions, once a week, 60 minutes long one session) by mind-body relaxation training with pain-blocking imagery, cognitive restructuring of unpleasant physical and emotional experience with positive self-influence, improvement of workplace relations and organizational culture.

The results (seen in Fig. 1) indicated decrease in pain intensity from 5.57 at the beginning of TL and SM course till 1.14 ($p < 0.05$) at the end of TL and SM course in 9 females (81%), and accordingly in 8 males (80%) – from 6.33 till 1.0 ($p < 0.05$). Statistically significant reduction in pain intensity after TL and SM intervention by the biopsychosocial influence on pain according to NPRS was among bank and agricultural advisory services VDT male employees. These results can be explained with analysis of the females` Pain Diary entry which is giving evidence that responsibilities for managing the work-family interface typically fall on women`s shoulders: negative job and family stress can cause muscle tension with pain. It is in accordance with research data about generations of female workers, which have no skills to manage their occupational careers along with their family 'career', occupational and family goals (Thompson et al., 1999).

Analysis of the acquired QOLS scores in statistically significant the age groups allows concluding that after TL and SM one month course for 7 females (63%; $n = 11$) and 3 males (30%; $n = 10$) the life quality according to QOLS increased, significantly – for females (seen in Fig. 2 and Fig. 3). These results can be explained with analysis of the females` and males` Pain Diary entry which is giving evidence that VDT male employees, chronic pain patients, in the age between 23 and 44 still feel hopeless and helpless about the life also after the neck-shoulder chronic pain reduction. It is in accordance with research data about depressed males of working age in the workplace without employee-focused intervention approach for prevention of job-related psychological complaints (Furlan et al., 2012).

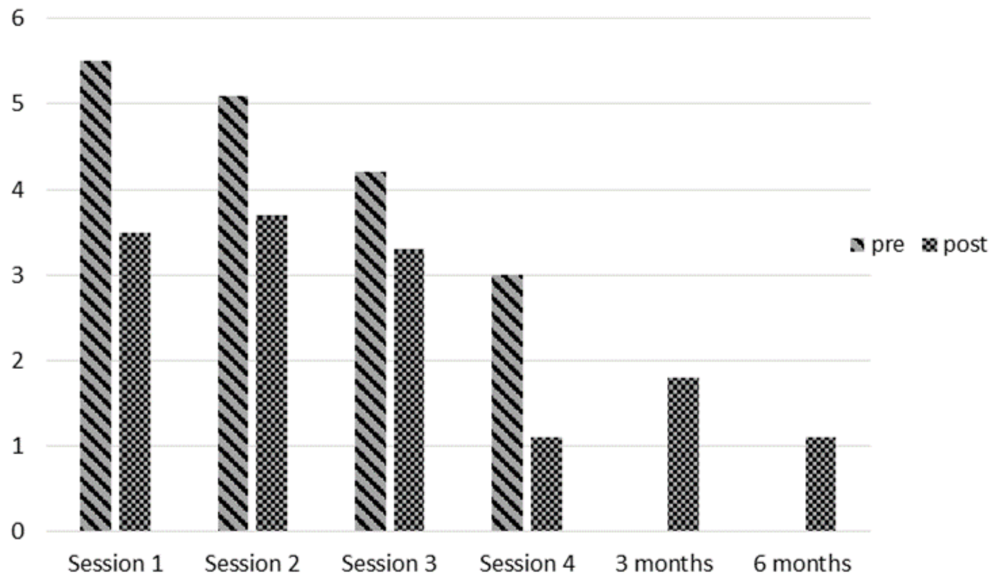


Figure 1. Pre- to post-intervention changes in composite pain intensity during one month TL and SM sessions with follow-up after 3 and 6 months in VDT female employees according to NPRS (vertical axis: pain intensity; 95% confidence interval: CI).

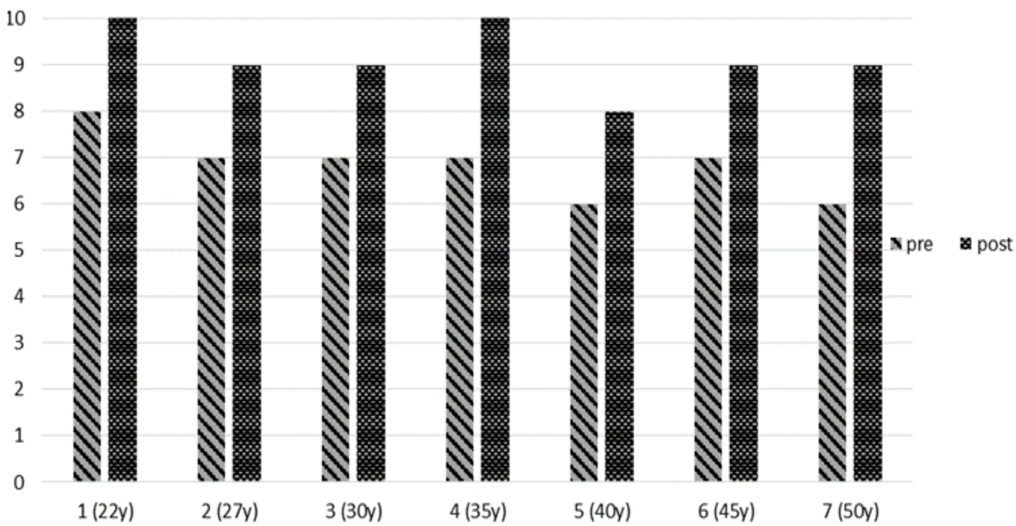


Figure 2. Mean QOLS scores for females before and after TL and SM course (vertical axis: QOLS scores/ 10; $p < 0.05$; Cohen`s Kappa – κ varies 0.76–0.88).

Our study checked out that VDT employees suffering from pain at the beginning of the TL and SM course had unpleasant physical and emotional experience at the end of the workday, but such mental and physical fatigue after the workday diminished at the conclusion of the one month TL and SM course. Self-reported ergonomic and psychosocial risk factors associated with NSP during a working day in both sexes were ‘prolong sitting, static posture, twisting posture’, ‘limited rest period’, ‘stressful situations as high demands, time pressure, job strain, conflict of generations, low social support from superiors and colleagues’, and ‘dissatisfaction with job and family life’. It is in accordance with recent research about chronic working in the sitting position, called `forced position` as a cause for pain in the musculoskeletal system, about stressful working environment as a cause for pain in musculoskeletal system, also as a cause for seediness and bad occupational health (Bergquist, 1984; Bongers et al., 2006; Sirge et al., 2014).

The necessity to perform patient's objective clinical examinations, subjective tests of self-esteem, to keep a Pain Diary during TL and SM course has been proved in our research. Bank and agricultural advisory services VDT employees noted in their Pain Diaries that there were no assessment of postural stress of the trunk and upper limbs in connection with musculoskeletal disorders, there were no prevention of musculoskeletal disorders and negative psychosocial risk factors in their workplaces, in that connection they noted that TL and SM course with education of VDT employees about their unhealthy stereotypical work conditions and how to conduct best practice helped to improve workplace relations and organizational culture.

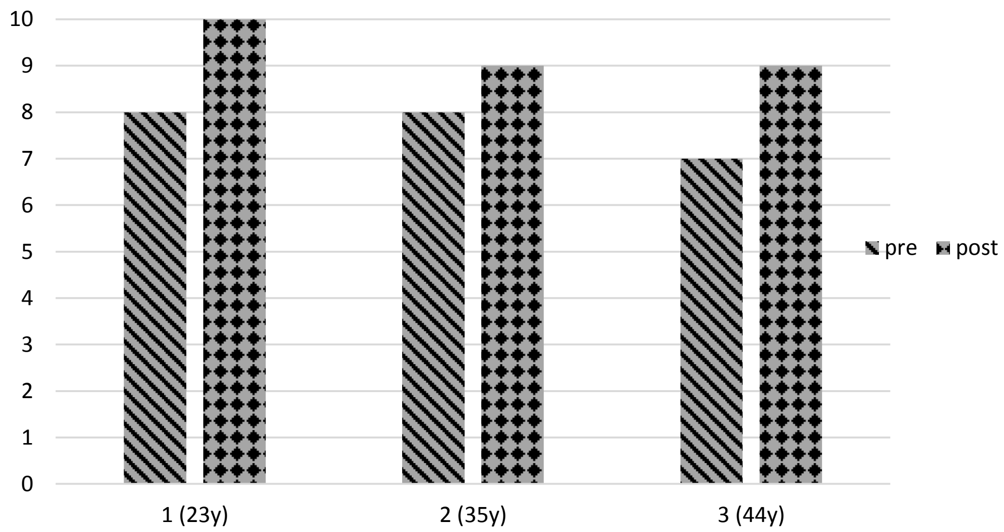


Figure 3. Mean QOLS scores for males before and after TL and SM course (vertical axis: QOLS scores/ 10; $p < 0.05$; Cohen`s Kappa – κ varies 0.67-0.86).

Mind-body self-practice and workout for shoulders and arms (by keeping the shoulders relaxed during use the keyboards, by moving shoulders, and the like) for employees was very important for reducing the intensity and suffering associated with chronic pain, and helping with posture. Females and males in their Pain Diaries noted that TL and SM with education was possibility to form effective break time without addiction from necessity to have a smoke or to hurry up backlog (81% of females and 70% of males before TL and SM course had addiction during break time to have a smoke or to hurry up backlog).

Follow-up assessment at 3 and 6 months after TL and SM course indicated lasting reduction in pain intensity for males and females, which can be explained by benefits of positive self-influence during TL and SM intervention and by activation the participation of the employed persons and employers together with the health care specialists in the creation of safer work environment. It is in accordance with recent research about educational and practical work importance for VDT employees in connection with possibility to form positive individual brainwork and conduct it without postural stress of the trunk, neck and shoulders (Dainoff, 2000; Robertson et al., 2003; Roja et al., 2009).

CONCLUSIONS

From this study, it has been concluded that use of TL and SM one month course for VDT employees in their giving age suffering from chronic moderate neck-shoulders pain is an effective biopsychosocial influence on pain in the multidisciplinary treatment of pain`s complex. Positive self-influence regarding bank and agricultural advisory services VDT employees of both genders during the TM and SM course with social distress reduction therapy allowed for developing healthy self-evaluation and new ways of social communication that was proved in our research by the follow-up data.

REFERENCES

Ariëns, G.A, Van Mechelen, W., Bongers, P.M., Bouter, L.M & Van der Wal, G. 2001. Psychosocial Risk Factors for Neck Pain: A Systematic Review. *Am J Ind Med*. **39**, 180–193.

Banks, S.R., & Kerns, R.D. 1996. Explaining high rates of depression in chronic pain: A diathesis-stress framework. *Psychological Bulletin* **119**, 95–110.

Bergquist, U.O. 1984. Video display terminals and health. *Scand J Work Environ Health* **10**(2), 62–67.

Bongers, P.M., IJmker, S., van den Heuvel, S., Blatter, B.M. 2006. Epidemiology of work related neck and upper limb problems: psychosocial and personal risk factors (Part I) and effective interventions from a bio behavioural perspective (Part II). *J Occup Rehabil*. **16,** 279–302.

Cowan, P., Kelly, N. 2003. Quality of Life Scale: a measure of function for people with pain. The American Chronic Pain Association (ACPA), Rocklin, CA.

Dainoff, M.J. 2000. Safety and health effects of Video Display Terminals. *In: Harris, R.L., editor. Patty`s industrial hygiene. 5th ed*. New York, NY, USA; Wiley, 1125–1162.

Furlan, A.D., Gnam, W.H., Carnide, N.I., Amick III, B.C., DeRango, K., McMaster, R., Cullen, K., Slack, Tesha, Brouwe, S., Bultmann, U. 2012. Systematic review of intervention practices for Depression in the Workplace. *J Occup Rehabil.* **22**, 312–321.

Marras, W.S., Davis, K.G., Heaney, C.A., Maronitis, A.B., Allread, W.G. 2000. The influence of psychosocial stress, gender, and personality on mechanical loading of lumbar spine. *Spine*, **1:25**(23), 3045–3054.

Korth, S.J. 2000. Single and double-loop learning: Exploring potential influence of cognitive style. *Organization Development Journal* **18**(3), 87–98.

Kuorinka, I., Jonsson, B., Kilbom, A., Vinterberg, H., Biering-Sorensen, F., Andersson, G. et al. 1987. Standardised Nordic questionnaire for the analysis of musculoskeletal symptoms. *Appl Ergon*, **18**, 233–237.

Landis, J.R., Koch, G.G. 1977. The Measurement of Observer Agreement for Categorical Data. *Biometrics*, USA, **33**, 159–174.

Larsson, B., Søgaard, K., Rosendal, L. 2007. Work related neck-shoulder pain: a review on magnitude, risk factors, biochemical characteristics, clinical picture and preventive interventions. *Best Pract Res Clin Rheumatol,* **21**(3), 447–463.

McCaffery, M., Beebe, A. 1989. Pain: Clinical Manual for Nursing Practice. *Mosby St. Louis, MO.*

Robertson, M.M., O`Neil, M.J. 2003. Reducing musculoskeletal discomfort: effects on an office ergonomics workplace and training intervention. *Int J Occup Saf Ergon* **9**(4**)**, 491–502.

Roja, Z., Roja, I., Kalkis, V., Kaļķis, H., Dirina-Laganovska, I. 2007. Communication with the computer – is it comfort or discomfort? Ergonomics solutions will be helpful for you! *University of Latvia, Ergonomics Research Center*. 1–23.

Roja, Z., Kalkis, H., Roja, I., Kalkis, V., Vetra, A. 2009. The Significance of Early Multidisciplinary Rehabilitation in Health Promotion for Workers with VDT Suffering from NSAH Complaints. *International Journal of Rehabilitation Research*, **32**(1), 70–80.

Sirge, T., Ereline, J., Kums, T., Gapeyeva, H., Pääsuke, M. 2014. Musculoskeletal symptoms, and perceived fatigue and work characteristics in supermarket cashiers. *Agronomy Research* **12**(3), 915–924.

Thienhaus, O., Cole, B.E. 2002. Classification of pain. In Weiner R.S. Pain management: A practical guide for clinicians (6 ed.). *American Academy of Pain Management*.

Thompson, C., Beauvais, L. & Lyness, K. 1999. When work-family benefits are not enough: The influence of work-family culture on benefit utilization, organizational attachment, and work-family conflict. *Journal of Vocational Behavior* **54**, 392–415.

Thompson, M.L., Myers, J.E., Kriebel, D. 1998. Prevalence odds ratio or prevalence ratio in the analysis of cross sectional data: what is to be done? *Occup Environ Med*. **55**, 272–277.

Vince, R. 2001. Organizational learning: A personal view. *International Journal of Management and Decision Making* **2**(1), 2–7.

Agronomy Research **13**(3), 836–845, 2015

EMG measurements of thumb muscles of nurses and caregivers

J. Sepp[1*], M. Järvis[2], P. Tint[2], V. Siirak[2] and Reinhold, K.[2]

[1]Tallinn Health Care College; Tallinn University of Technology, Faculty of Economics, Institute of Business Administration, Ehitajate 5, EE19086 Tallinn, Estonia
[2]Tallinnn University of Technology, Faculty of Economics, Institute of Business Administration, Ehitajate 5, EE19086 Tallinn, Estonia
[*]Correspondence: jaana.sepp@ttk.ee

Abstract. The number of ageing people in Estonia is increasing. Convenience for personnel in the nursing homes for the elderly and enabling high-quality care is essential. This includes new work methods to relieve the physical burden of nursing workers and the mental stress decreasing interventions. In the theoretical part of the paper, the physical and psychosocial risk factors of nurses and caregivers are dealt with. **The aim** of the study is to measure the *m. abductor pollicis brevis* fatigue in connection with the physical stress of nurses and caregivers. The experimental part of the paper concentrates on the physical stress factors. Electromyography (eMotion EMG) is used as the method for the determination of the nursing workers' thumb muscle's (*m. abductor pollicis brevis)* fatigue. The results show the linear dependences between the level of fatigue of the thumb muscles at the beginning and at the end of an 8-hour workday; between the EMG signals from the muscles in the resting state and after a 5-minute strained state. The interviews with the nurses showed that the renewal of equipment and rooms in the nursing homes is the main factor to prevent the physiological stress at workplaces (pain in the hands, low back pain etc.). In the newly built nursing homes with modern equipment, the workers are satisfied and no physiological stress was noticed.

Key words: psychological stress, fatigue, nursing homes, nurses working conditions, job satisfaction.

INTRODUCTION AND THEORETICAL BASIS

Nursing and caregiving are considered both physically and psychologically demanding jobs (Kim et al., 2010). The main risk factors may lead to the musculoskeletal disorders (MSDs). The work of nurses and caregivers in the Estonian hospitals and nursing homes is considered physically and mentally stressful. The number of ageing people and nursing homes in Estonia is increasing. There is a need for new work methods to relieve both the physical burden of nursing workers and for interventions decreasing the mental stress (Põlluste et al., 2007; Risk…, 2007; Merisalu et al., 2011; Freimann et al., 2013). According to the studies on the relationship between nurses' working conditions and musculoskeletal disorders, the focus is placed mainly on these physical and ergonomic conditions (Karasek & Theorell, 1994; Trinkoff et. al., 2003; Kim et. al, 2010). In addition, high physical workload, workplace demands and lack of control over work could lead to a stress and illnesses (Leijon et al., 2007). The main health problems for the medical staff (Anon., 2007) were reported as follows: stress, pain in the lower back, aching shoulders and feet, and the heart rhythm disorders.

Studies of gerontology and nursing (Zimmermann, et al., 2005; Noelker et al., 2006; Saarnio et al., 2012; Woodhead et al., 2014) emphasize the stress and burnout of the nursing staff; the need for the social support and to find the possibilities to enhance the job satisfaction for workers in the nursing homes. The relationship and the conflicts between the nursing staff and the residents' families were investigated by Abrahamson et al. (2009).

Long-term care nursing staff (Woodhead et al., 2014) are subject to considerable occupational stress and report high levels of burnout, yet little is known about how stress and social support are associated with burnout in this population. The results of the study showed that the greater occupational stress was associated with more emotional exhaustion, more depersonalization, and less with the personal accomplishment. They demonstrated that the support from the supervisors and friends or family members, reassurance of worth, opportunity for nurturing were associated with less emotional exhaustion and higher levels of personal accomplishment. The survey data from personal interviews with 338 nursing assistants employed at 22 skilled nursing facilities showed that the nurses' personal stressors require careful attention from supervision. Employee Assistance programs and training for supervisors in team building, communication, and motivational skills are needed to promote more positive relationships among nurses (Woodhead et al., 2014).

A Finnish study (Saarnio et al., 2012) showed that the nursing staff mostly felt that they did not have enough time to provide good care to the patients, and that gave them a troubled conscience. They also felt that the demanding work taxed their energy, a conscience being that they could not give their own families and loved ones the attention they would have liked.

A summarized report on safety risks in the Estonian nursing homes in the capital area was carried out by Peeker (2012).

To measure the physical risk factors, electromyography (EMG) has been used as a valuable tool for many years (Kumar & Mital, 1996), mainly for the investigation of the muscles' fatigue. It is a technique for evaluating and recording the electrical activity produced by skeletal muscles. According to previous studies (Westgaard et al., 1996), the use of EMG is based on the problem of musculoskeletal complaints in the workplace. EMG was used both for intentional muscular efforts and at electrostimulation and reflectory induced muscle contractions' conditions in order to estimate muscle activity (internal exposure) and thereby provide an estimation of the risk of a future development of a health problem (Fig. 1).

Physical burden is a part of the conceptual model presented here for possible influences that various factors (individual and in the working environment) may play in the development of musculoskeletal disorders, it includes processes that could occur within a person and possible outcomes, which may be influenced by individual factors, such as psychological stress. The working environment domain includes the following parts: organizational factors (working hours and shift, and type of ward), and physical/ ergonomic and psychosocial working conditions (Fig. 1).

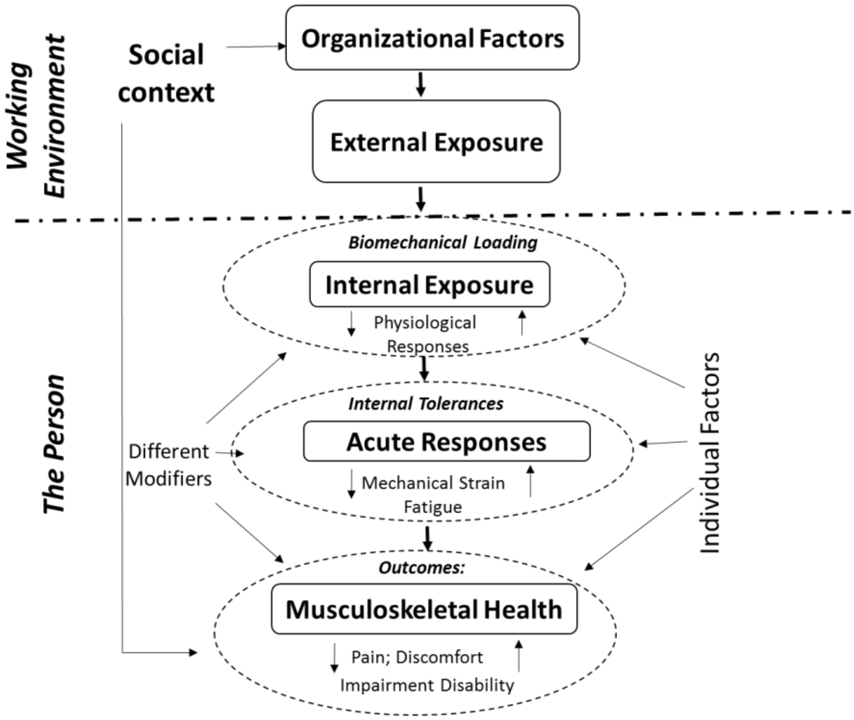


Figure 1. A conceptual model of the possible roles and influences that various factors may play in the development of the musculoskeletal disorders (adapted from Westgaard et al., 1996; National Research Council, 2001).

In light of the above theoretical discussion of the literature survey, the research questions are:

1. Is there any difference in workplace ergonomics *(fatigue of m. abductor pollicis brevis, some additional questions in the course of the interview of the workers)* in different nursing homes in Estonia depending on the state of the building and/or equipment for the ageing people staying there and accordingly in the working conditions?
2. How high is the physical fatigue of nurses and caregivers (EMG measurements)?
3. Are there any other problems that stress the workers connected with the character of their work (consistent care of people with dementia)?

The article proceeds as follows: the next section outlines the materials and methods used in the research. The results of the electromyography measurements and some additional problems in the workplace ergonomics of nursing homes staff are presented. The authors' recommendations and arguments conclude with a view of implications of the new work methods to relieve the physical burden of nursing workers.

MATERIAL AND METHODS

The study group

The study covers four different nursing homes (A, B, C, D) in Estonia (the number of nurses involved in the study was: institution A – 12; B – 6; C – 6; D – 10). Most of the nurses and caregivers (total number of investigated persons n = 34) were female (only 2 male persons). The average age of the nurses (n = 25) and caregivers (n = 7) was 46 years. Participation in the investigation was voluntary.

The working conditions of nurses depend substantially on the building where the nursing home is situated (on the building state, the existence of the aids, the temperature of the air).

Nursing home A is located in a new building, which is operating from September 2014. All equipment there is new in contrast to the previous home near the new building. Therefore, the nurses were very satisfied with the working conditions.

Nursing home B is located in a 2-storey house built in 1965; the latest repair work was done two years ago (in 2012). The rooms for patients are clean, warm, but the possibilities to move from their rooms to the corridor or to the restroom or balcony with wheelchairs are restricted by the doorframes. The house was not built for the nursing home needs. One male caregiver (45 years old) who lives in the same nursing home makes the hardest work (for example, lifting of patients). Even though the working conditions for nurses are poor, they were not complaining, as the nursing home is located in the rural region where it is very difficult to find a job.

Nursing home C is located in a small and quiet town in Estonia and the main complaints of the personnel were connected with the pace of work, lack of support from the side of the leadership etc. Their old building was repaired in the 1980s, but in the process of reconstruction it was impossible to consider the nursing needs of the ageing people.

Nursing home D is located in the capital of Estonia. The building was repaired in 2012. The rooms are clean; the transpired interviews revealed the inconveniences of the nurses and the caregivers. Labor turnover there is very high. One of the nurses interviewed was on her 2nd workday, the other had been working only for 4 months, but there were also some workers who had been working for 12 years and had collected all their work experience in the health care area.

Air temperature measurements of the work environment

Temperature measurements of the air in the nursing homes were done by the multi-function instrument TESTO 435-2 intended for the indoor air quality measurements.

The standards for the temperature measurements were as follows:

- BS EN ISO 7726:2001. Ergonomics of the thermal environment. Instruments for measuring physical quantities.
- CSN- EN 15251:2007. Indoor environmental input parameters for design and assessment of energy performance of buildings, addressing indoor air quality, thermal environment, lighting, and acoustics.

Muscle fatigue measurement equipment

A 2-channel electromyograph eMotion EMG (Mega Electronics, 2014) connected to the computer was used. The computer software allows the determination of the frequency spectrum as well as the indicators of the EMG amplitude and integral. eMotion EMG is a fully automatic system for quick muscle testing, biofeedback and free-mode measurements. It is also possible to measure the fatigue of the muscle. The measurements are based on the scientifically validated analysis of frequency change in the electromyographic signal of muscles (*m. abductor pollicis brevis)* (Anon., 1992; Soderberg & Knutsen, 2000; Tuulik et al., 2000; Mewett et al., 2004). The duration of each recording was 120 sec. The length of the time cycle of the thumb muscle (*m. abductor pollicis brevis)* in the strain state was 5 minutes before the recording of the EMG signal.

Fatigue measurements

The following measurements were carried out:

1. In the nursing homes A and B, the fatigue of the thumb muscle (*m. abductor pollicis brevis)* in the resting state was measured at the beginning (8.00) and at the end of the 8-hour workday (at 17.00);
2. In the nursing homes B, C and D, the starting point was the measurement of the thumb muscle (m. abductor pollicis brevis) fatigue in the resting position and then after a 5-minute strained state of the same muscle. The fatigue of muscles was measured on the working hand (right or left).

There are two outcomes from the EMG results: 1) strength of the EMG signal (μV) and 2) per cent of the muscle fatigue (max 100).

The statistics

The correlation between the results of the beginning and the end of the workday and in the resting state and after a 5-minute strained state is presented. The ANOVA-test and t-test were used for the statistical assessment of the results.

Additional investigations

In connection with the fatigue measurements, the interviews with the working staff were carried out to solve additional problems of the workplace ergonomics. Three questions connected with the work based on 'The stress of conscience' (Saarnio et al., 2012) were presented to the workers. Each item had a 10-point scale (1–10), where higher scores indicated very much so/ certain or well.

The interviews were carried out with 34 nursing home' workers. The investigation with the eMotion EMG involved 22 workers (65% of all the investigated persons).

RESULTS AND DISCUSSION

The temperature in the nursing homes was > 22 ± 0.6 °C.

The number of the nurses with school education for health care of ageing workers was 5 (16%). The other nurses and caregivers were educated mainly for ergonomics of lifting the patients at the workplace (in the nursing homes).

The eMotion EMG system allows us to measure the signal from the muscles *(m. abductor pollicis brevis)* and the fatigue of the muscles only in the time range. It does not allow us to determine directly the coming from the muscles signals' frequency, but it is possible to measure the signals' amplitude by the electromyograms. The procedure takes max. 15 minutes per person, which is very important, as the nursing home workers have really very little time. The results of the measurements of fatigue at the beginning and at the end of the workday are presented in Table 1. The muscle is tiring during the day. The dependence between the thumb muscle (*m. abductor pollicis brevis)* signal and fatigue at the beginning and at the end of the workday is considered to be significant (Table 1; $p = 0.004$). The correlation between the thumb muscle's *(m. abductor pollicis brevis)* fatigue at the beginning and after a 8-hour workday ($n = 10$, Table 1) is shown in Fig. 2.

Table 1. The results of the *m. abductor pollicis brevis* EMG of the nurses and caregivers at the beginning and at the end of a 8-hour workday

Nurse identification/ the mean age	The strength of the EMG signal at the beginning of the workday $E1_{mean}$, µV	SD of $E1_{mean}$	Muscle fatigue at the be-ginning of the workday % of 100 max.	The strength of the EMG signal after a 8-hour workday, $E2_{mean}$, µV	SD of $E2_{mean}$	Muscle fatigue after a 8-hour workday, % of 100 max.
A1-A5*/53.5	503.0	10.2	11.5	290.0	7.7	34.5
B1-B5*/45.5	415.5	140	16.0	299.5	6.4	38.0

*A1, A2, A3, A4, A5; B1, B2, B3, B4, B5 – investigated workers.

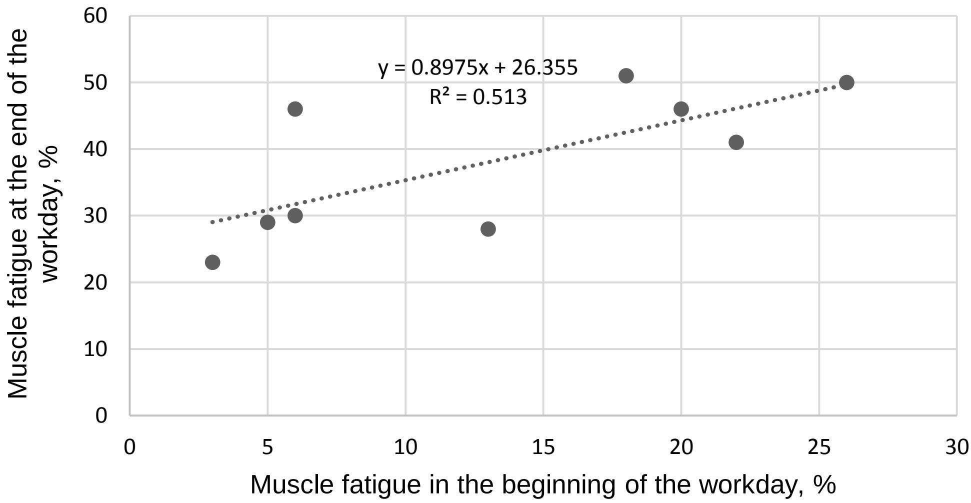


Figure 2. The correlation between *m. abductor pollicis brevis* thumb muscle fatigue at the beginning (x) and at the end of the workday (y), nursing home A&B (Table 1, $n = 10$).

In the nursing homes B, C, D, the EMG signal from the thumb muscles and the fatigue of the muscle were measured (n = 17, Table 2). The correlation between the thumb muscle's signal strength in the free state and after the 5-minute strained state is presented in Fig. 3 (p value of the results 0.002).

Table 2. The results of the *m. abductor pollicis brevis* EMG of the nurses and caregivers in the resting position and after a 5-minute strained state

Nurse identifica-tion/the mean age	The strength of the EMG signal in the free state $E1_{mean}$, μV	SD of $E1_{mean}$	The thumb muscle fatigue, %	The strength of the EMG signal in a 5-min. strained state, $E3_{mean}$, μV	SD of $E3_{mean}$	The thumb muscle fatigue, %
B1-B5/45.5	415.5	14.0	16.0	344.5	5.7	28
C1-C5/49.5	309	3.1	33.0	322	6.4	42.5
D1-D7/46.5	291.5	6.6	31.0	269.5	6.9	33.5

The data were statistically analyzed with the ANOVA-test (single factor) and t-test (two-sample assuming equal variances). P-value in both tests was between 0.004 and 0.002. This means that the dependence between the thumb muscle signal and fatigue at the beginning and at the end of the workday is considered to be significant (Table 1) as the dependence between the EMG signal in the free state and after a 5-minute strained state (Table 2).

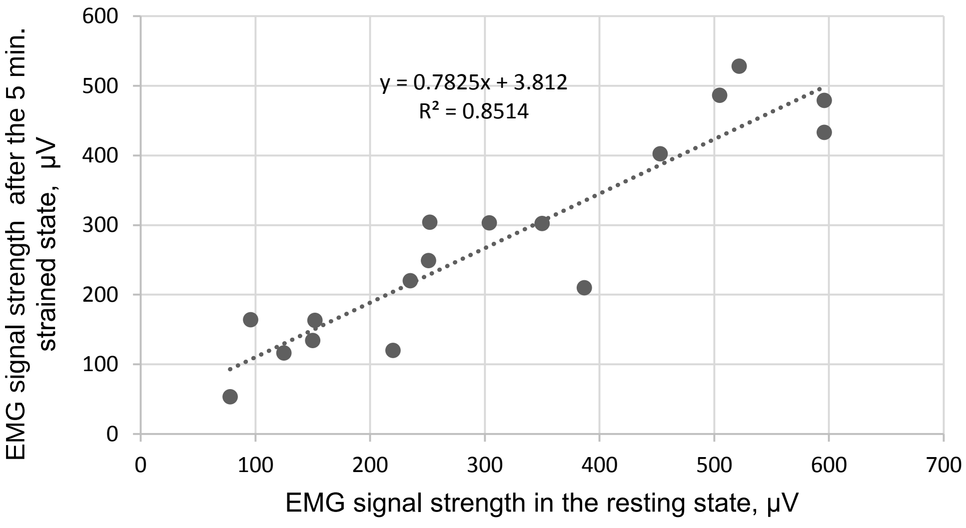


Figure 3. The *m. abductor pollicis brevis* EMG signal strength in the resting position (x) and after a 5-minute strained state (y), μV (Table 2, n = 17).

The workers were very interested in the results of electromyography. The fatigue prevention possibilities were presented to the workers after the measurements.

The results covering the three questions from the interviews that the authors considered important for the workers in the nursing homes (the assessments are given in the 10-point system) are as follows:

1. How often do you lack time to provide the care the patient needs? – 7.1
2. Do you ever have to deal with incompatible demands in your work? – 6.7
3. Is your work in health care ever so demanding that you do not have energy to devote yourself to your family as you would like? – 6.1.

The nurses are too tired to deal with their own families as they would want to; sometimes they have to deal with incompatible demands in their work. In every nursing home the nurses were interviewed at the absence of the employer. They could speak about the main important problems they have.

According to the results from the self-reported questionnaires, Estonian nurses and caregivers in all investigated nursing homes did not consider their work as physically (usually the patients are lifted by two or more persons) demanding. Nurses and caregivers usually have high workloads because of staff shortage. For instance, the question '*is the workday of 10 hours too long for you*', was answered such that time is flying so fast for themselves, because they are constantly occupied as the patients' bells are ringing all the time. Most nurses in the capital were also dissatisfied with inflexible work schedule, shift work and low salary. Nurses in the rural area did not mentioned these facts, as the nursing home is one of the few possibilities to get work in these areas.

Modern patients' lifting equipment is available in most of the nursing homes (A, C, D). Arrangements connected with lifting of physically very weak persons take time and therefore lifting equipment is not always used by the nurses and caregivers. Professional training in this field from the side of the employers is needed.

Comparisons with other studies in Estonia

An extensive study including the risk assessment of the nurses was carried out by Kadanik (2012) in SA Läänemaa Haigla (hospital in the West of Estonia). The risk assessment covered the area of the psychological and physical risk factors and was connected with the employees' job satisfaction. The subjects of the study were the risk factors of the nurses and caregivers arising from their psychosocial environment. Work overload, lack of tools and work organization were the most problematic issues of job satisfaction (Kadanik, 2012). The health of the nursing staff was influenced by the excessive workload, which was caused by the extremely intensive work (high work pace). The static posture, bad quality of tools and the lack of modern tools, as well as too short rest periods, were considered to be the most important factors that had a damaging effect on the nurses' health.

The authors suggest that the working conditions in the nursing homes have been improved during the last two years. More nurses should be employed as a prerequisite for the flexible working shifts adjusted to nurses' and caregivers' individual needs and their family demands. These activities, along with improving physical and psychosocial working conditions, could increase nurses' and caregivers' job satisfaction, wellbeing and work efficiency and would lead to increased quality of health care in the nursing homes.

The *m. abductor pollicis brevis* fatigue decreases the workability of the nurses and caregivers and increases the possibilities for developing the musculoskeletal disorders (MSDs). The changes in the EMG signal of *m. abductor pollicis brevis* give the data for prevention of MSDs to the medical doctors in the beginning stage. At present the MSDs are diagnosed only in the last stage of the disease, when the work is already disabled and very seldom it is possible to recover the workability of the muscles.

CONCLUSIONS

The measurements of the *m. abductor pollicis brevis* by electromyography showed that the muscles are tiring during the workday. The mean results in the EMG signal were: from 415.5 μV to 269.5 μV. The fatigue of *m. abductor pollicis brevis* developed from 11.5% to 42.5%.

The work of nurses and caregivers in the ageing people nursing homes is generally considered as physically demanding with a high risk for musculoskeletal disorders. The muscles are tiring and therefore the MSDs are possible. The other risk factors were as follows: work intensity, lack of time, social environment, social support, and psychological problems in the patient communication. Nurses and caregivers have high workloads because of the staff shortage.

The results from the study revealed differences in the feeling and perception of psychological stress in different nursing homes in Estonia depending on the state of the building and equipment for the ageing people staying there and accordingly the working conditions of the nurses and the caregivers.

Future research is needed to determine the fatigue in other muscles of the workers that are involved in the lifting process.

REFERENCES

Abrahamson, K., Jill Suitor, J. & Pillemer, K. 2009. Conflict between nursing home staff and residents' families. *Journal of Ageing and Health* **21**, 895–912.

Anonymous. 1992. Selected topics in surface electromyography for use in the occupational setting: expert perspectives. U.S. Department of health and Human Services. National Institute for Occupational Safety and Health, 160 pp.

Anonymous. 2007. Mental health promotion in the health care sector. E-facts 46. European Agency for Safety and Health at Work, Accessed 2.9.2014. https://osha.europa.eu/en/publications/e-facts/efact46

Freimann, T., Coggon, D., Merisalu, E., Animägi, L. & Pääsuke, M. 2013. Risk factors for musculoskeletal pain amongst nurses in Estonia: a cross-sectional study. *BMC Musculoskeletal Disorders* **14** (article 334).

Kadanik, A.-M. 2012. Assessing the health risks arising from the psychological working environment of the nursing staff in SA Läänemaa haigla. *Diploma work. Haapsalu College*, 54 pp. (in Estonian).

Karasek, R. & Theorell, T. 1994. *Healthy work: stress, productivity, and the reconstruction of working life.* New York, NY, USA: Basic Books.

Kim, I.H., Geiger-Brown, J., Trinkoff, A. & Muntaner, C. 2010. Physically demanding workloads and the risks of musculoskeletal disorders in homecare workers in the USA. *Health and Social Care Community* **18**, 445–55.

Kumar, S. & Mital, A. 1996. *Electromyography in Ergonomics*. Taylor & Francis, Great Britain by TY Press, Padstow

Leijon, O., Lindberg, P., Josephson, M. & Wiktorin, C. 2007. Different working and living conditions and their associations with persistent neck/shoulder and/or low back disorders. *Occupational & Environmental Medicine*, 64, 115–21. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2078443/. Accessed 30.1.2015.

Mega Electronics, 2014. http://www.megaemg.com/products/. Assessed 3.9.2014.

Merisalu, E., Oha, K., Freimann, T. & Sirk, T. 2011. *Work specific factors and prevalence of musculoskeletal disorders among office workers, nurses and caregivers in Estonia.* University of Latvia. The 1st Int.SC.-Pract. Conf. of the Latvian Ergonomics Society. Abstracts, p.16.

Mewett, D.T., Reynolds, K.J. & Nazeran, H. 2004. Reducing power line interference in digitised electromyogram recordings by spectrum interpolation. *Medical & Biological Engineering & Computing*, **42,** 524–531.

National Research Council and Institute of Medicine, 2001. *Musculoskeletal Disorders and the Workplace. Low Back and Upper Extremities*. Commission on Behavioural and Social Sciences and Education: pp 512.

Noelker, L.S., Ejaz, F.K. & Menne, H.L. 2006. The impact of stress and support on nursing assistant satisfaction with supervision. *The Journal of Applied Gerontology* **25,** 307–323.

Peeker, H. 2012. *The safety risks in the Estonian nursing homes*. The safety risks in the nursing homes in Tallinn and Harjumaa. Research Report. Tallinn Pedagogical Seminar, 44 pp. (in Estonian).

Põlluste, K., Alop, J., Härm, T., Merisalu, E. & Suurorg, L. 2007. Health Promoting Hospitals in Estonia: are they doing differently? *Health Promotion International* **22**, 327–336.

Risk assessment in health care. E-facts 18. 2007. *European Agency for Safety and Health at Work*. https://osha.europa.eu/en/publications/e-facts/efact18. Assessed 4.9.2014.

Saarnio, R., Sarvimäki, A., Laukkala, H. & Isola, A. 2012. Stress of conscience among staff caring for older persons in Finland. *Nursing Ethics* **19**, 104–115.

Soderberg, G.L. & Knutsen, L.M. 2000. A guide for use and interpretation of kinesiology electromyographic data. *Physical Therapy*, 80, 485–498.

Trinkoff, A.M., Lipscomb, J., Geiger-Brown, J., Storr, C.L., & Brady, B. 2003. Perceived physical demands and reported musculoskeletal problems in registered nurses. *American Journal of Preventive Medicine* **24**, 270–275.

Tuulik, V., Ferenets, R., Lass, L. & Vaht, M. 2000. *The new analysing method for the surface EMG Data*. 3rd International Conf. on Bioelectromagnetism, 8-12 Oct.2000, Bled.

Westgaard, R.H., Jansen, T. & Jensen, C. 1996. EMG of neck and shoulder muscles: the relationship between muscle activity and muscle pain in occupational settings. In Kumar, S. & Mital, A., '*Electromyography in Ergonomics'.* Taylor & Francis, Great Britain by TY Press, Padstow: 227–259

Woodhead, E.L., Northrop, L. & Edelstein, B. 2014. Stress, social support, and burnout among long-term care nursing staff. *Journal of Applied Gerontology* **33,** 1–22.

Zimmermann, S., Williams, C., Reed, P., Boustani, M., Preisser, J., Heck, E. & Sloane, P.D. 2005. Attitudes, stress, and satisfaction of staff who care for residents with dementia. *The Gerontologist* **45**, 96–105.

Agronomy Research **13**(3), 846–855, 2015

The comparison study of office workers' workplace health hazards in different type of buildings

I. Vilcane[1], V. Urbane[1], P. Tint[2,*], J. Ievins[1]

[1]Riga Technical University, Faculty of Economics, Institute of General and Civil Safety, Kalnciema Str. 6, LV-1048 Riga, Latvia
[2]Tallinn University of Technology, Faculty of Economics, Department of Work Environment and Safety, Ehitajate 5, EE19086 Tallinn, Estonia;
[*]Correspondence: piia.tint@ttu.ee

Abstract. The aim of the study is to investigate the office-workers' working conditions in the ordinary and atrium-type buildings. The indoor climate conditions in the cold season in two type of university buildings are presented. The air temperature is on the good level in the both of the buildings. The rooms in the atrium-side of the building **A** are too tight and the ergonomics is not considered designing the workplaces in the office-rooms. In the auditoriums of the building **B** it is too noisy (over 70 dB(A)) during the breaks that prevents the rest and the communication between the workers and students. The air humidity is too low in both type of the buildings (< 30% in the cold season, when the rooms are central-heated). It is recommended to moisten the air in the rooms artificially. For the health risk assessment in the workrooms a flexible risk assessment model is used. The risk levels for the indoor climate factors are different in the two type of buildings.

Key words: office-rooms, auditoriums, high schools, indoor climate.

INTRODUCTION

The main environmental issues today (Sundell, 2004) are outdoor air quality, energy use, and sustainable buildings, but not indoor air quality (IAQ). But, there is mounting evidence that exposure to IAQ is the cause of excessive morbidity and mortality. The main problem in developing countries with the indoor burning biomass for cooking and heating. The solution is a stove with the chimney. In developed regions, good ventilation, getting rid of 'Dampness' problems, an adequate testing of new materials would reduce morbidity and mortality.

The financial problems are usually the determining factor for the educational institutions in the construction of new buildings or updating of the existing ones (Valancius et al., 2013; Pikas et al., 2014). The ergonomics in the work-rooms in the buildings is usually possible to assess after the building or building-update is completed (Tint et al., 2012; Stradina et al., 2014).

The association between ventilation and health is rarely studied (Wargocki et al., 2002). The scientific evidence indicates that ventilation rates (outdoor air) below 25 l s^{-1} per person in commercial and institutional buildings are associated with an increased risk of Sick Building Syndrome (SBS), increased short-term sick leave, and reduced productivity (Wargocki et al., 2002). The conclusion from the European study (2002) was that the ventilation requirements in many existing guidelines and standards may be too low to protect occupants of offices, schools, from health and comfort problems and may not be optimal for human productivity. Higher ventilation rates can increase energy costs in relation to building operation, but it is also possible recover energy. The new energy recovery systems have been developed today (Valancius et al., 2013; Pikas et al., 2014) and the new standards are also available in the European area (CSN-EN 15251; EN 12464-1 etc.).

Winter indoor comfort and relative humidity: the colder the outdoor temperature is, the more heat must be added indoors for body comfort. However, the heat that is added, will cause a drying effect and lower the indoor relative humidity, unless an indoor moisture source is present. Degrees of comfort vary with age, activity, clothing, and body characteristics (Daisey et al., 2003).

The health problems inside the modernized buildings (with tight windows, central heating) are dry and stuffy air in winter (Urbane, 2004a); if the mechanical ventilation is not installed or not-rightly installed, (it is blowing on the worker and therefore switched off by the workers).

The arrangement of the lighting sources is always not correct from the standpoint of ergonomics (Urbane & Velicko, 2010). The lighting levels can be too low or too high for the task, so appropriate light levels depend on the visual task to be performed (Urbane & Velicko, 2010). Initial lighting power from all lamps decrease with age and with the effects of several factors. Recoverable light loss factors: area atmosphere (how dirty the space is); lamp burnout factor, lamp lumen depreciation, total light loss factor. Unrecoverable light loss factors are luminaire ambient temperature, voltage to luminaire etc.

The aim of the study: to investigate the shortages of design of buildings from the side of workers' safety, health and ergonomics and give the recommendations for the better solutions for arrangements of work- and study-places for people in the educational buildings.

MATERIAL AND METHODS

The study has been carried out during the cold season (outdoor air +5 to -10 °C) during the period Sept. 2014 – Jan. 2015. The workers and students work and study in different conditions (air temperature, humidity, velocity; the lighting or the workplaces, content of CO_2 in small office-rooms, noise in the workrooms and auditoriums etc.) that have to be measured using the accredited determination methods and the risk analysis has to be carried out by the occupational hygienist or other specialist in the field of occupational health and safety.

The existing risk assessment models (on the basis of BS 8800) contain the need to determine the probability of the occurrence and the severity of consequences of the influence of hazardous factors on workers. A flexible risk assessment method was worked out at Tallinn University of Technology, Chair of Work Environment and Safety (Reinhold et al., 2006). The four-step risk assessment model as the most suitable for office-rooms' risks assessment is presented in Fig. 1. The model is originally worked out from two-step to six-step for industrial rooms (Reinhold & Tint, 2009).

The investigated rooms in the building **A** (Fig. 2) were the office-rooms (Fig. 3), auditoriums and corridors (Fig. 6) and in the building **B** (Fig. 4) the office-rooms (Fig. 5), auditoriums and hallways (Fig. 7).

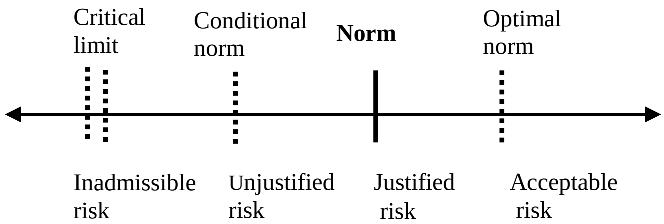


Figure 1. Four-step flexible risk assessment method.

Figure 2. The atrium of university building **A**.

Figure 3. The workroom in the building **A**.

Figure 4. The university building **B**.

Figure 5. The workroom in the building **B**.

The measuring devices used in the investigation, were: multi-function instrument TESTO 435-2 for indoor air quality (temperature, humidity, velocity and CO_2 content) measurements; light level metre TES 1332 for the measurement of lighting of workplaces; sound level metre TES 1358 for the noise measurements and the digital electrosmog analyser ME3030B for the measurements of non-ionizing electromagnetic fields.

Figure 6. The corridor in the building **A**.

Figure 7. The hallway in the building **B**.

The methods for the measurement and the exposure limits in the European Union area used in the current study are given in the following documents:

- BS EN ISO 7726:2001. Ergonomics of the thermal environment. Instruments for measuring physical quantities.
- CSN- EN 15251:2007. Indoor environmental input parameters for design and assessment of energy performance of buildings- addressing indoor air quality, thermal environment, lighting and acoustics.
- EN 12464-1:2011. Light and lighting – Lighting of work places – Part 1: Indoor work places.
- ISO 2631-1:1997. Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration – Part 1- General requirements.
- Directive 2004/40/EC of the European Parliament and of the Council of 29 April 2004 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (18th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC).
- ISO 9612:2009. Acoustics – Guidelines for the measurement and assessment of exposure to noise in a working environment.
- ISO 1999:2013. Acoustics – Determination of occupational noise exposure and estimation of noise- induced hearing impairment.

RESULTS

The results of the measurements are given in the Table 1 and Table 2.

The air temperature in the workrooms and in the auditoriums is on the good level (>20 °C) in both of the educational buildings (**A** & **B**).

The ambient air in the rooms towards the atrium (building **A**) is not fresh even if the mechanical ventilation is working. It is not possible to switch on the mechanical ventilation as it blows on the worker. The original buildings (**B**) have advantages before the atrium-type (**A**), as the natural ventilation is possible as more suitable for the human being's biological systems.

The air is too dry in the winter season (**B**), the system of artificial lighting usually not designed considering the ergonomic principles (**B**), the shortage of natural lighting in the rooms towards the atrium is very significant (**A**), the workrooms are too small and the demands of CSN-EN 15251 are not followed before the distribution of the rooms to the workers in the new buildings (**A**). The recommendations are given for prevention of similar shortages in the future and to improve the present situation in the workrooms in the part of discussion.

The noise levels in the building **B** are over the norms determined for the office and educational rooms in CSN-EN 15251 (40-45 dB(A)) caused mainly by the organizational problems in the university **B**, not from the transport outside the building **B**.

Table 1. The microclimate and lighting characteristics in the atrium-type building **A**

Room type	Indoor air temperature, °C; U^1 = 0.6 °C	Humidity, % U = 2.0%	Air velocity, m s^{-2} U = 0.01 m s^{-1}	CO_2 content, ppm U = 10 ppm	Noise, dB(A) U = ±1 dB	Lighting, lx U = 5 lx
Auditorium	20–23	25–27	0.01–0.39	550–810	55–60	350–510
Office-room towards the atrium	23–24	23–24	0.00–0.01	550–800	45–50	500–800
Office-room with windows to the outside	23–24	27–29	0.01–0.03	550–600	50–55	500–800
Corridors	21–22	25–29	0.01–0.10	450–800	55–60	150–200

U1 – uncertainty of the measurements

Table 2. The microclimate and lighting characteristics in the educational building **B** (cold season)

Room type	Indoor air temperature, °C U^1 = 0.6 °C	Humidity, % U = 2.0%	Electro-magnetic fields, nT U = 2%	Air velocity, workplace, m s^{-1} U = 0.01 m s^{-1}	Noise, dB(A) U = ±1 dB	Lighting, lx U = 5 lx
Auditorium	21–24	28–30	–	0.1	49–87	340–590
Office-rooms	24–25		21–420	0.01–1.52	42–72	286–590
Cashier/seller	20–23	27.1	850	0.01	55	350
Hallway, learning space	21–23	22–25	–	0.06–0.01	74–78	171–245
Hallway	20–21	27–29	–	0.05–0.2	66–68	7–230

U1 – uncertainty of the measurements

The risk levels for the building **A** are determined by the model (Fig. 1) and taking into account the European Standards, the national legislation (National …, 2015) and the measurement results are presented in Fig. 8.

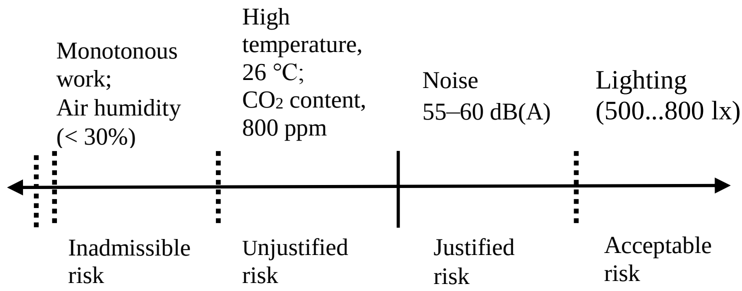


Figure 8. Assessment of work conditions using 4-step risk assessment model in building **A**.

The risk levels are determined by the model (Fig.1) and taking into account the European Standards and the national legislation (Urbane, 2004b) and the measurement results in the building B are presented in Fig. 9.

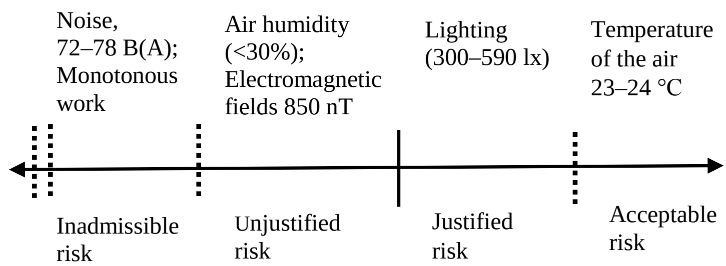


Figure 9. Assessment of work conditions using 4-step risk assessment model in building **B**.

The measurements show the differences in the health hazards level as the buildings are structurally different (ordinary (**B**) and atrium-type (**A**)). The measurement of CO_2 level in the building **A** and the measurement of non-ionizing electromagnetic fields in the building **B** were carried out at the request of the workers. The high content of CO_2 in the building **A** is caused by too small space (under 10m^2 per worker) (Table 1). The need for measuring the non-ionizing magnetic fields in the building **B** proceeds from the equipment (cashier machines, copy-machines) as the workers near-by had some health complaints (headache, dry skin) (Table 2).

DISCUSSION

In the current work the comparison of the advantages and disadvantages of the working conditions in the ordinary and atrium-type office-buildings in Latvia (building **B**) and in Estonia (atrium-type building **A**) is presented. The new atrium-type building **A** gives heat savings in winter, but causes health problems for workers as the shortage of natural lighting (inside the atrium), non-sufficient ventilation (if the windows are closed type) etc. Installation of mechanical ventilation systems in the ordinary type of buildings (**B**) has also to be very well thought-through, besides the problems in this area (ventilation) cannot always be foreseen in the stadium of repair-work design.

The novelty of the study lies in the application of the flexible risk assessment method (worked out in Tallinn University of Technology, Department of Work Environment and Safety and which differs from the standard method based on BS8800) for determination of health risk levels in ordinary and atrium-type buildings. The building type determines a lot of unforeseen health disturbances for workers which come to light when the buildings are already in use. The demands on safety, health and ergonomics management in the workplaces are needed in the stadium of the building design.

The flexible risk assessment method (in the graphic mode, Fig. 8) gives the possibility to look at a glance were the hazardous factors in the two investigated buildings in the assessment line are situated. In the building **A**, the noise and lighting level of buildings is accepted or justified, but not the air temperature nor CO_2 content and air humidity. The workers also complained about monotonous work and caused by this hazards musculoskeletal disorders (MSDs). The rehabilitation and prevention possibilities (massage) on the employers' expense are available in this building for the employees.

Air temperature and lighting of workplaces is good in the building **B** (Fig. 9), the unjustified risks are low air humidity and the level of electromagnetic fields (< 850 nT). The last is not over the norms, but is better to decrease, as the workers do not feel good. Some rearrangements of the equipment and devices or partitions could help. The inadmissible risk for educational buildings is noise level (Fig. 9): 72–78 dB(A). The warning signs: 'Keep silence, the others are learning' etc. could help.

The measurement results from the Table 1 and 2 can be placed into the model considering the exposure limits for occupational hazards in the office-rooms presented in the national resolutions and international standards.

The buildings are constructed by the building regulations (Ehitusseadus, 2002; *Buvniecibas likums*, 2014). The ergonomics has to be taken into account already in the design stage of the building. The architects are not sufficiently educated in safety and health during their studies. Therefore, the health inconveniences occur only if the building is ready. Some of the shortages are possible to correct afterwords, but those connected with the construction type of the building (ordinary or atrium-type) have sometimes peculiarities what cannot be improved.

The investigation of the work conditions and the design of workplaces in the modern buildings are very important in different countries (in cold and hot regions). The maintaining of good health of people, spending 60% of their life working inside needs scientific approaches. It is nowadays the problem for investigations in many countries (Finland, Malaysia, Czech, The Baltic States etc.).

Current study is the attempt to improve the ergonomics of teaching staff and students' workplaces in the educational buildings. Studies have shown that dry air has four main effects on the body: breathing of the dry air can cause respiratory disorders as asthma, bronchitis, sinusitis and nosebleeds; skin moisture evaporation can cause skin imitations and eye itching; irritating effects, such as static electricity which causes mild shocks when metal is touched; the 'apparent temperature' of the air is lower than what the thermometer indicates, and the body 'feels' colder. These problems can be reduced by simply increasing the indoor relative humidity. This can be done through use of humidifiers, vaporizers, steam generators, sources such as large pans, or water containers made of porous ceramics (Waterborne, 2013). The lower the room temperature is, the easier the relative humidity can be brought to its desired level.

Old times (Myhrvold et al., 1996) the CO_2 concentrations were very high and there is a correlation between the disturbing health symptoms and ventilation rate or CO_2 concentration in schools. These investigations found a statistically significant partial correlation (one-way ANOVA, $p < 0.001$) between symptoms of headaches, dizziness, heavy headed, tiredness, difficulties concentrating, unpleasant odour, and high CO_2 concentrations (1,500–4,000 ppm). Health symptoms characterized as 'irritations of the upper airways' were also higher at higher CO_2 concentrations ($p=0.024$). Organizational changes in the most companies are continuous and require flexible changes in work methods and workspaces (Kosonen & Tan, 2005). Nowadays, the carbon dioxide concentrations are high in the office-rooms if the windows cannot be opened or if there are more workplaces than allowed by the norms (< 10 m^2 per person, CSN-EN 15252). The concentration of the carbon dioxide outdoors in towns is increased particularly in summer time if the frequency of car transportation is high. It also influences on the concentration of CO_2 indoors and workers feel the air in the room not clean and fresh. Therefore and also due to the environmental issues, the worldwide demand is settled to decrease the CO_2 pollution in the environmental air.

If the noise level in the educational rooms is over the norm (40-45 dB(A)) due to the organizational problems in the university **B**, the means have to be taken to minimize the noise level to such values that the students and the professors could rest and communicate during the breaks (Resolution, 2000; Resolution, 2002).

The study-rooms and offices have to be naturally lighted during the light time (Resolution, 2000). Daylight in the offices improves sleep, physical activity and quality of life (Paul, 2014). The artificial lighting sources only help to gain the lighting level needed by the norms (EN- 12464-1:2011). Too strong lighting is also not permitted as it poses too great contrasts and tires eyes.

The atrium-type buildings are low cost establishments, therefore they are rather popular in modern construction (Pikas et al., 2014).

CONCLUSIONS

The indoor air quality in two differently designed school-buildings (**A**-atrium-type building; **B**- common-used, ordinary building) is investigated.

The results of the study show that the working and learning conditions depend on the building type, but also where this building is located. If it is located in a big town (**A**) and the ventilation is not properly designed (the ratio of the 'clean', coming from the outside and used air is not followed), the workers and the students health is in danger, the persons feel themselves drowsy and tired.

The ventilation was not adequate in both of the buildings (**A, B**). The buildings without windows which can be opened, are not allowed for the office-work.

It is suitable to use four-step risk assessment method for the risk assessment of the health hazards in the office-rooms. In the building **A** the inadmissible risk is too low air humidity (under 30%), not enough of natural lighting in the office-rooms, non-sufficient ventilation and fresh air shortage; in the university building **B** the inadmissible risk was too high noise level (until 70 dB(A)) that resists the communication between the office workers and the shortages in the ventilation of the rooms.

REFERENCES

Buvniecibas likums (Construction Law). 01.10.2014. *'Latvijas Vestnesis*', **131**(414) (in Latvian).

BS 8800. 2004. *Guide to occupational health and safety management systems*. UK: British Standard Institution.

CSN- EN 15251:2007. Indoor environmental input parameters for design and assessment of energy performance of buildings- addressing indoor air quality, thermal environment, lighting and acoustics.

Daisey, J.M., Angell, W.J. & Apte, M.G. 2003. Indoor air quality, ventilation and health symptoms in schools an analysis of existing information. *Indoor Air* **13**, 53–64.

Ehitusseadus (Building Act). 15.05.2002. *RTI 2002*, 47, 297 (in Estonian).

EN 12464-1:2011. Light and lighting – Lighting of work places – Part 1: Indoor work places.

Kosonen, R. & Tan, F. 2005. Feasibility study of a ventilated beam system in the hot and humid climate: a case-study approach. *Building and environment* **40**, 1164–1173.

Myhrvold, A.N., Olsen, E. & Lauridsen, O. 1996. *Indoor environment in schools– pupils health and performance in regard to CO_2 concentration.* Proceedings of The 7th Intern. Conf. on indoor air quality and climate, Nagoya, Japan, July, 1996. **4**, 369–374.

National Inspectorate of Estonia. 2015. *Health and safety regulations on the basis of the Occupational Health and Safety Act*. http://www.ti.ee/est/toeoetervishoid-ja-toeoeohutus/toeoetervishoiu-ja-toeoeohutuse-korraldus-ettevottes/toeoetervishoidu-ja-toeoeohutust-reguleerivad-oigusaktid/. Assessed 10.9.2014.

Paul, M. 2014. Natural light in the office boosts health. http://www.northwestern.edu/newscenter/stories/2014/08/natural-light-in-the-office-boosts-health.html. Accessed 31.01.2015.

Pikas, E., Thalfeldt, M. & Kurnitski, J. 2014. Cost optimal and nearly zero energy building solutions for office buildings. *Energy and Buildings* **74**, 30–42.

Reinhold, K., Tint, P. & Kiivet, G. 2006. Risk Assessment in Textile and Wood Processing Industry. *International Journal of Reliability, Quality and Safety Engineering* **13**, 115–125.

Reinhold, K. & Tint, P. 2009. Hazards profile in manufacturing: determination of risk levels towards enhancing the workplace safety. *Journal of Environmental Engineering and Landscape Management* **17**, 69–80.

Resolution of The Ministry of Social Affairs of Estonia. 2000. Nr. 47 from 14.07.2000. *Health care demands in schools*. RTL 2000, 86, 1286.

Resolution of the Ministry of Social Affairs of Estonia. 2002. Nr.42 from 04.03.2002. *Noise limit values in residential areas and in public buildings.* RTL 2002, 38, 511.

Stradina, G., Ievins, J., Roja, Z., Kalkis, V. & Kalkis, H. 2014. Ergonomic risks in the printing company and workers' wellbeing. *Scientific Journal of Riga Technical University. Safety of Technogenic Environment* **5**, 43–46.

Sundell, J. 2004. On the history of indoor air quality and health. *Indoor Air* **14**(Suppl 7), 51–58.

Tint, P., Traumann, A., Pille, V., Tuulik-Leisi, V.-R. & Tuulik, V. 2012. Computer users' health risks caused by the simultaneous influence of inadequate indoor climate and monotonous work. *Agronomy Research* **10**, S1, 261–268.

Urbane, V. 2004a. The Problems of an Air Conditioning of the Premises. *Publication in a Scientific Journal of the Series of Scientific Journal of RTU.* https://ortus.rtu.lv/science/en/publications/2277. Accessed 9.9.2014.

Urbane, V. 2004b. The Legislation of Latvian Republic. A Health and a Computer. *Publication in a Scientific Journal of the Series of Scientific Journal of RTU.* https://ortus.rtu.lv/science/en/publications/2276. Accessed 9.9.2014.

Urbane, V. & Velicko, V. 2010. Office Space's Lighting Control System Development. *51. RTU Scientific Conference Proceedings*, Riga, 14.–16. October, 2010. Pp. 76–82. https://ortus.rtu.lv/science/en/publications/10058-Office +Space%E2%80%99s+Lighting+Control+System+Development. Accessed 9.9.2014.

Valancius, R., Jurelionis, A. & Dorosevs, V. 2013. Method for cost-benefit analysis of improved indoor climate conditions and reduced energy consumption in office buildings. *Energies* **6**, 4591–4606.

Wargocki, P., Sundell, J., Bischof, W., Brundrett, G., Fanger, O., Gyntelberg, F., Hanssen, S.O., Harrison, P., Pickering, A., Seppänen, O. & Wouters, P. 2002. Ventilation and health in non-industrial indoor environments. Report from a European multidisciplinary scientific consensus meeting. *Indoor Air* **12**, 113–128.

Waterborne indoor climate systems. 2013. www.swegon.com. Accessed 7.9.2014.

INSTRUCTIONS TO AUTHORS

Papers must be in English (British spelling). English will be revised by a proofreader, but authors are strongly urged to have their manuscripts reviewed linguistically prior to submission. Contributions should be sent electronically. Papers are considered by referees before acceptance. The manuscript should follow the instructions below.

Structure: Title, Authors (initials & surname; an asterisk indicates the corresponding author), Authors' affiliation with postal address (each on a separate line) and e-mail of the corresponding author, Abstract (up to 250 words), Key words (not repeating words in the title), Introduction, Materials and methods, Results and discussion, Conclusions, Acknowledgements (optional), References.

Layout, page size and font

- Use preferably the latest version of **Microsoft Word**, doc., docx. format.
- Set page size to **B5 Envelope or ISO B5 (17.6 x 25 cm)**, all margins at 2 cm.
- Use single line spacing and justify the text. Do not use page numbering. Use indent 0.8 cm (do not use tab or spaces instead).
- Use font Times New Roman, point size for the title of article **14 (Bold)**, author's names 12, core text 11; Abstract, Key words, Acknowledgements, References, tables and figure captions 10.
- Use *italics* for Latin biological names, mathematical variables and statistical terms.
- Use single ('…') instead of double quotation marks ("…").

Tables

- All tables must be referred to in the text (Table 1; Tables 1, 3; Tables 2–3).
- Use font Times New Roman, regular, 10 pt. Insert tables by Word's 'Insert' menu.
- Do not use vertical lines as dividers; only horizontal lines (1/2 pt) are allowed. Primary column and row headings should start with an initial capital.

Figures

- All figures must be referred to in the text (Fig. 1; Fig. 1 A; Figs 1, 3; Figs 1–3). Use only black and white or greyscale for figures. Avoid 3D charts, background shading, gridlines and excessive symbols. Use font **Arial** within the figures. Make sure that thickness of the lines is greater than 0.3 pt.
- Do not put caption in the frame of the figure.
- The preferred graphic format is EPS; for half-tones please use TIFF. MS Office files are also acceptable. Please include these files in your submission.
- Check and double-check spelling in figures and graphs. Proof-readers may not be able to change mistakes in a different program.

References

- **Within the text**

In case of two authors, use '&', if more than two authors, provide first author 'et al.':

Smith & Jones (1996); (Smith & Jones, 1996);
Brown et al. (1997); (Brown et al., 1997)

When referring to more than one publication, arrange them by following keys: 1. year of publication (ascending), 2. alphabetical order for the same year of publication:

(Smith & Jones, 1996; Brown et al., 1997; Adams, 1998; Smith, 1998)

- **For whole books**

Name(s) and initials of the author(s). Year of publication. *Title of the book* (*in italics*). Publisher, place of publication, number of pages.

Shiyatov, S.G. 1986. *Dendrochronology of the upper timberline in the Urals*. Nauka, Moscow, 350 pp. (in Russian).

- **For articles in a journal**

Name(s) and initials of the author(s). Year of publication. Title of the article. *Abbreviated journal title* (*in italic*) volume (in bold), page numbers.

Titles of papers published in languages other than English, German, French, Italian, Spanish, and Portuguese should be replaced by an English translation, with an explanatory note at the end, e.g., (in Russian, English abstr.).

Karube, I. & Tamiyra, M.Y. 1987. Biosensors for environmental control. *Pure Appl. Chem.* **59**, 545–554.

Frey, R. 1958. Zur Kenntnis der Diptera brachycera p.p. der Kapverdischen Inseln. *Commentat.Biol.* **18**(4), 1–61.

Danielyan, S.G. & Nabaldiyan, K.M. 1971. The causal agents of meloids in bees. *Veterinariya* **8**, 64–65 (in Russian).

- **For articles in collections:**

Name(s) and initials of the author(s). Year of publication. Title of the article. Name(s) and initials of the editor(s) (preceded by In:) *Title of the collection (in italics)*, publisher, place of publication, page numbers.

Yurtsev, B.A., Tolmachev, A.I. & Rebristaya, O.V. 1978. The floristic delimitation and subdivisions of the Arctic. In: Yurtsev, B. A. (ed.) *The Arctic Floristic Region*. Nauka, Leningrad, pp. 9–104 (in Russian).

- **For conference proceedings:**

Name(s) and initials of the author(s). Year of publication. Name(s) and initials of the editor(s) (preceded by In:) *Proceedings name (in italics)*, publisher, place of publishing, page numbers.

Ritchie, M.E. & Olff, H. 1999. Herbivore diversity and plant dynamics: compensatory and additive effects. In: Olff, H., Brown, V.K. & Drent R.H. (eds) *Herbivores between plants and predators. Proc. Int. Conf. The 38th Symposium of the British Ecological Society*, Blackwell Science, Oxford, UK, pp. 175–204.

……………………………………………………………………………………………………

Please note

- Use '.' (not ',') for decimal point: 0.6 ± 0.2; Use ',' for thousands – 1,230.4;
- Use '–' (not '-') and without space: pp. 27–36, 1998–2000, 4–6 min, 3–5 kg
- With spaces: 5 h, 5 kg, 5 m, 5°C, C : D = 0.6 ± 0.2; *p* < 0.001
- Without space: 55°, 5% (not 55 °, 5 %)
- Use 'kg ha^{-1}' (not 'kg/ha');
- Use degree sign ' ° ' : 5 °C (not 5 ^{O} C).