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.

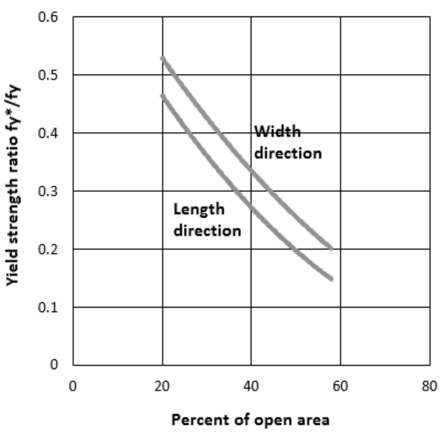


Figure 1. Yield strength ratio depending on percent of perforation (f_y* – yield strength of perforated plate; f_y – yield strength of unperforated plate).

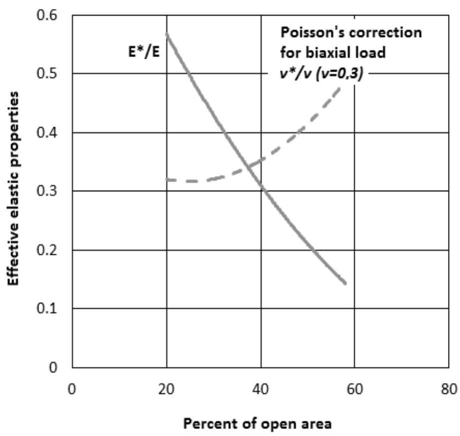


Figure 2. Effective elastic properties depending on the percentage of perforation (E* – elastic modulus of perforated plate; E –elastic modulus of unperforated plate; v* –Poisson's ratio of perforated plate; v –Poisson's ratio of unperforated plate).

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.

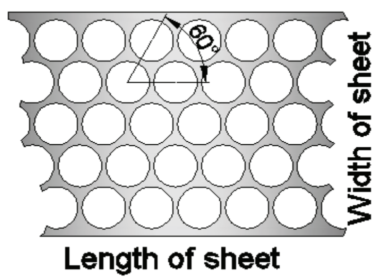
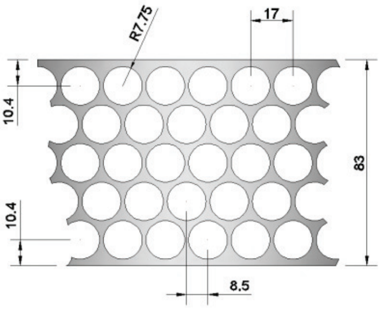


Figure 3. Perforated plate with round holes arranged in 60° angle.

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.

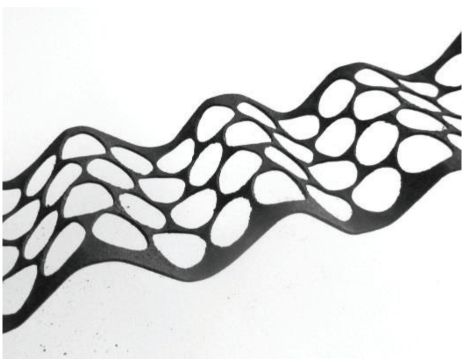


Figure 4. The crosswise profiling of perforated steel tape (width 100 mm, thickness 1.2 mm).

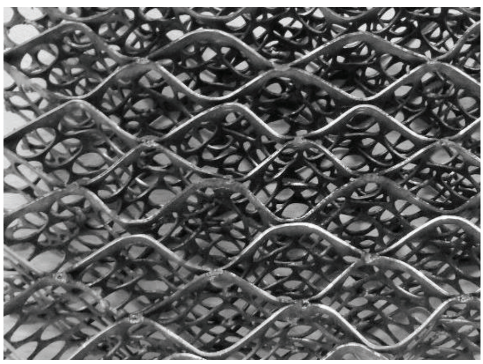


Figure 5. Cellular structure from S235JRG2 perforated tapes produced by RSW.

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.

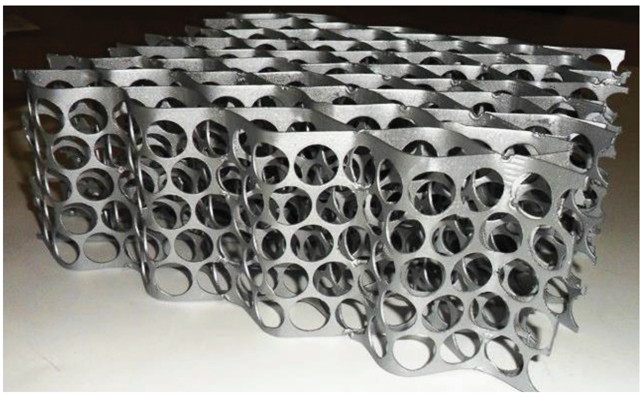


Figure 7. Cellular structure made of perforated bands.

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.

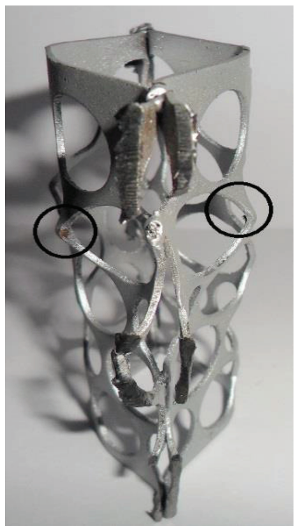
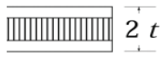
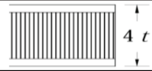


Figure 8. View of deformed basic element of cellular structure and the load bearing capacity local failure places.

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.

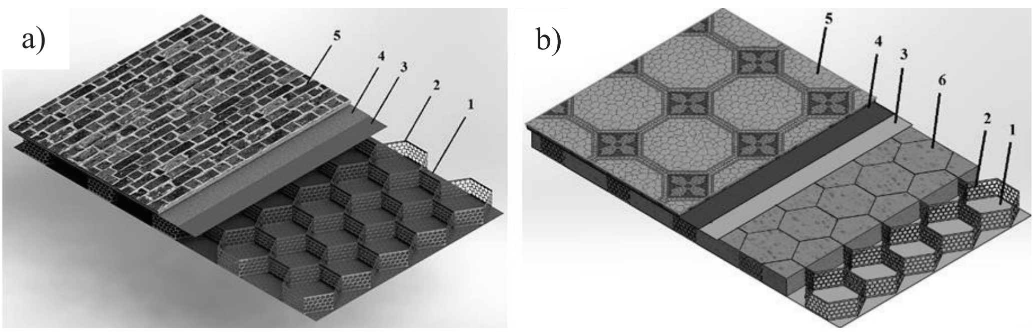


Figure 9. Example of sandwich wall panel based on perforated and profiled metal tape placed upright without an insulation layer (a) and with an insulation layer (b): 1 – lower metallic sheet; 2 – perforated and profiled metal tape; 3 – upper metallic sheet; 4 – layer of glue, 5 – facing (finishing) material;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

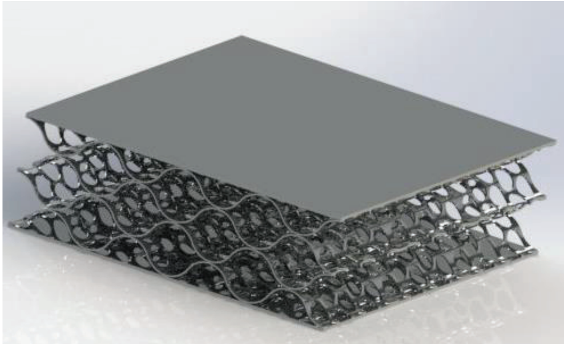


Figure 10. Example of a multilayer sandwich wall panel for absorption of mechanical energy based on perforated and profiled metal tape placed flatwise.

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.