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Influence of dust pollution in the laboratory on the strength of adhesive bond

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Abstract. The main aim of this paper is to evaluate the influence of microclimate conditions on the bond strength in the research laboratory in the Faculty of Engineering at the Czech University of Life Sciences Prague. The main attention is paid especially to the contamination of the working environment with dust particles. In the frame of this research the concentration and size of dust particles in the air was measured by the aerosol monitor DustTRAK II Model 8530 with impactors for measurement of size fractions PM_1, $PM_{2.5}$, PM_4 and PM_{10}. The adhesive bonds were created according to the ISO standards from Duralumin material specimens with different type of two-component epoxy adhesives under different conditions of ventilation (0%, 50% and 100% of ventilation rate). The tensile strength of created specimens was measured by universal testing machine for tensile strength measurement – LABTest 5.50ST. The results of measurement were evaluated by statistical methods and summarized in the conclusions. There is no significant difference in the strength of the bond when applied various performance of ventilation.

Key words: adhesive bond, contamination, dust, ventilation.

INTRODUCTION

Adhesive bonding technology is very important for many structural joints and connections. Different bodies made from different materials can be combined on the contact surfaces with adhesive bonding. There is a better adhesion between the surfaces of liquid and solids than the adhesion between two surfaces of solid substances, and therefore the adhesives (adhesives) are used to bond components. The adhesive penetrates into the inequalities between the bonded materials (adherents) and expels from the micro pores majority of the absorbed gases and vapours.

In this method of adhesive bonding the important terms are the adhesion and cohesion. The glued joint consists of two adherents, two adhesive layers and a one cohesive layer. Adhesion indicates the adhesion of the adhesive to the glued material and indicates cohesion consistency between the particles of adhesive. An equally important factor affecting the quality of the adhesive bonding is wettability that is mainly dependent on the surface tension of both adhesives and adhesive materials (Peterka, 1980).

Currently, the adhesive bonding is used in almost all fields of technology, e.g. automobile industry, aerospace and shipping industries, mechanical engineering, civil engineering, but also in electrical engineering, healthcare and many other branches of industry. This method is suitable for mass production operations. However, the theory still lags behind practice. Many research papers solved the preparation of bonded joints, degrading aspects etc. The area that is currently not properly investigated is an effect of contamination of bonded joints with microparticles such as dust in the air, e.g. from ventilation or halls, workshops, etc.

The research was focused on the evaluation of the impact of contamination by dust microparticles in a two component epoxy adhesive during the hardening process.

Dust is a significant source of the risk in working environment that can be found everywhere in the air. It is a limitation, which cannot be avoided in common practice. In the past many studies on research air quality in various environments have been carried out (Di Giorgio et al., 1996; Jones, 1999), there were also studied problems of special rooms in which the people are working performing various work activities (Bluyssen, 1996; Karwowska, 2003; Kic & Chladek, 2010; Kic & Růžek, 2014), or in agricultural buildings for poultry housing (Karwowska, 2005; Kic et al., 2007; Nimmermark et al., 2009; Kic et al., 2012).

Dust is a common name for solid particles of diameter less than 0.075 mm. It contains human skin cells, a small amount of plant pollen, human and animal hair, textile fibres, paper fibres and many other materials that may be present in the air and which depend on the particular environment (Nou & Viljasoo, 2011).

During the hardening e.g. two-component epoxy adhesives, epoxy resins react with hardeners to form macromolecules (Krofova & Müller, 2015a; Krofova & Müller, 2015b). New methods of bonding and sticking the new adhesives are tested in the laboratory under prescribed conditions. Different chemicals and adhesives containing various chemical components are used during these activities. This creates a very intensive contamination by pollutants that must be removed. The quality of indoor environment must be maintained within the prescribed limits, which are especially the air temperature, humidity, concentration of chemical pollutants and dust environment.

The polymerization process affects the resulting strength of the bonded joint. It can be assumed that the contamination of the bond during the hardening process (polymerization) can cause changes in the chemical process (chain), which depends on polymer properties. This means that the change in the molecular weight of macromolecular substances may result in a reduction or in some cases even in an increase of the resulting adhesive strength (Mleziva, 2008).

The aim of this research was to carry out laboratory experiments on bond strength contaminated by dust during mechanical ventilation in working areas, using information obtained from literature and using recommendations for standard procedures. The results should be used for evaluation of the impact of two-component epoxy adhesive contaminated by dust with microparticles on the bonded joint.

Adhesively bonded single-lap joints are from point of manufacturing view less expensive and in many cases they satisfy strength requirements, while in situations, where there is a requirement of higher strength of adhesively bonded joints, the special construction modifications are applied. These modifications however, require higher expenses and they are more difficult from the technology point of view (Valášek & Müller, 2015).

When the adhesively bonded joints are created, the negative part is a significant consumption of expensive adhesives. One option is adding the filler into the adhesive.

Significant factor for manufacturing expenses is also treatment of surface (Novak, 2012; Hricova, 2013). Nevertheless, recent researches show, that effectiveness of mechanical and chemical treatments is not that principal for strength of adhesively bonded joint (Bockenheimer et al., 2002). The reason is particularly the development of 'new' adhesives.

Adding the filler into reactoplastics matrix on the base of epoxies influences the mechanical properties of resulting composite (Fu et al., 2008; Kim & Khamis, 2001; Kejval & Müller, 2013).

MATERIALS AND METHODS

The research was focused on evaluate the effect of contamination of the environment from ventilation system on the structural joints glued with two-component epoxy adhesives. Used adhesives are showed at the Table 1.

Table 1. Used adhesives

Ozn.	Adhesive	Filler
A	UHU PLUS ENDFEST	-
B	BISON EPOXY METAL	-
C	GLUE EPOX RAPID SINCOLOR	$20\%_{vol}$ of Al microparticles (about 90% of the particles < 45 μm)
D	CHS EPOXY 324 EPOXY 1200	$20\%_{vol}$ of Al microparticles (about 90% of the particles < 45 μm)

The total concentration of air dust was measured by special exact instrument the Dust-Track™ II Aerosol Monitor 8530 (Fig. 1). After installation of different impactors the PM_{10}, PM_4, $PM_{2.5}$ and PM_1 (Fig. 2) size fractions of dust were also measured. There were measured and evaluated 90 data of total dust concentrations, as well as 90 data of each size fraction.

Figure 1. The DustTrak™ II Aerosol Monitor 8530.

Figure 2. Impactors for PM_{10}, PM_4, $PM_{2.5}$, PM_1 measurement.

The failure type according to ISO 10365 was determined at the adhesives bonds. The tensile strength and the elongation test 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}. Tests were performed on normalized testing samples 100 x 25 x 1.5 mm of alloy AlCu4Mg, prepared under standard ČSN EN 1465 by cutting the metallurgical semi-finished product in form of metal sheet. 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 adhesive bonds were hardened at the laboratory temperature 21 ± 2 °C.

The testing samples without mechanical treatment of surface were used for adhesive bonding. Adhesively bonded surface was chemically treated – degreased with Acetone before its own process of adhesive bonding. The untreated samples were used due to minimizing the factors effecting the preparation of bonded surface. This trend is significant particularly in operations, where the automation is implemented.

The roughness parameters Ra and Rz were measured on the adherent's surface designated for adhesive bonding. Roughness parameters were measured with portable profilometer Mitutoyo Surftest 301. Boundary wave length of cut-off was placed to 0.8 mm. Using the profilograph Surftest 301 following values were determined: Ra 0.34 ± 0.07 µm, Rz 2.38 ± 0.38 µm.

Structural epoxy adhesives were used in experiments. There can be added different fractions into the adhesives, with the aim to reduce the final cost of the adhesive (Müller et al., 2015).

- Adhesive A: Design a two-component adhesive Uhu Plus Endfest (transparent),
- Adhesive B: Bison epoxy metal (filled by the manufacturer, unknown filler and concentration),
- Adhesive C: Two-component epoxy adhesive Glue Epoxy Rapid Sincolor and discontinuous phase (reinforcing particles) was in the form of aluminum microparticles (about 90% of the particles are smaller than 45 µm). In this research experiments the filling was 20%vol of aluminium microparticles,
- Adhesive D: Two-component epoxy adhesive ChS Epoxy Epoxy 324 1200 (hardener P11 – Diethylenediamine) and discontinuous phase (reinforcing particles) was in the form of aluminium microparticles (about 90% of the particles are smaller than 45 µm). In this research experiments the filling was 20%vol of aluminium microparticles.

Statistical hypotheses were also tested at measured sets of data by means of the program STATISTICA. A validity of the zero hypothesis (H_0) shows that there is no statistically significant difference ($p > 0.05$) among tested sets of data. On the contrary, the hypothesis H_1 denies the zero hypothesis and it says that there is a statistically significant difference among tested sets of data or dependence among variables ($p < 0.05$).

RESULTS AND DISCUSSION

The bond strength of adhesive C (without filler) was 3.59 ± 0.37 MPa, and the adhesive D (without filler) had the bond strength of 0.20 ± 3.03 MPa. Glued joints C and D without fillers were glued at 0% capacity of air conditioning. By adding the filler in the form of aluminium powder the bonding strength was increased by 14 and 26%.

A substantial change in mechanical properties can be achieved by adding an optimum volume of filler i.e. reinforcement (Ramazan et al., 2008; Miroslav & Valášek, 2012). Optimum utility properties of these composites are limited primarily by risk of cohesive damage caused by improper concentrations and the material of filler.

One example is in research by Ramazan et al. (2008), who found that adding aluminium microparticles increased the bonding strength. Ramazan et al. (2008) used for bonding a composite mixture of aluminium-based microparticles.

Results of experiments showed a positive effect of aluminium microparticles on the increase of the strength of the adhesive (Müller et al., 2015).

Fig. 3 shows the influence of ventilation performance in the hall used for adhesive bonding on the bonding strength. Based on the results of experiments there is not a clear trend of influence of ventilation equipment on the bond strength. Decline and increase of the bond strength, depending on the performance of ventilation equipment moved in the interval from – 9 to 27%. Coefficient of variation ranged from 7 to 25%.

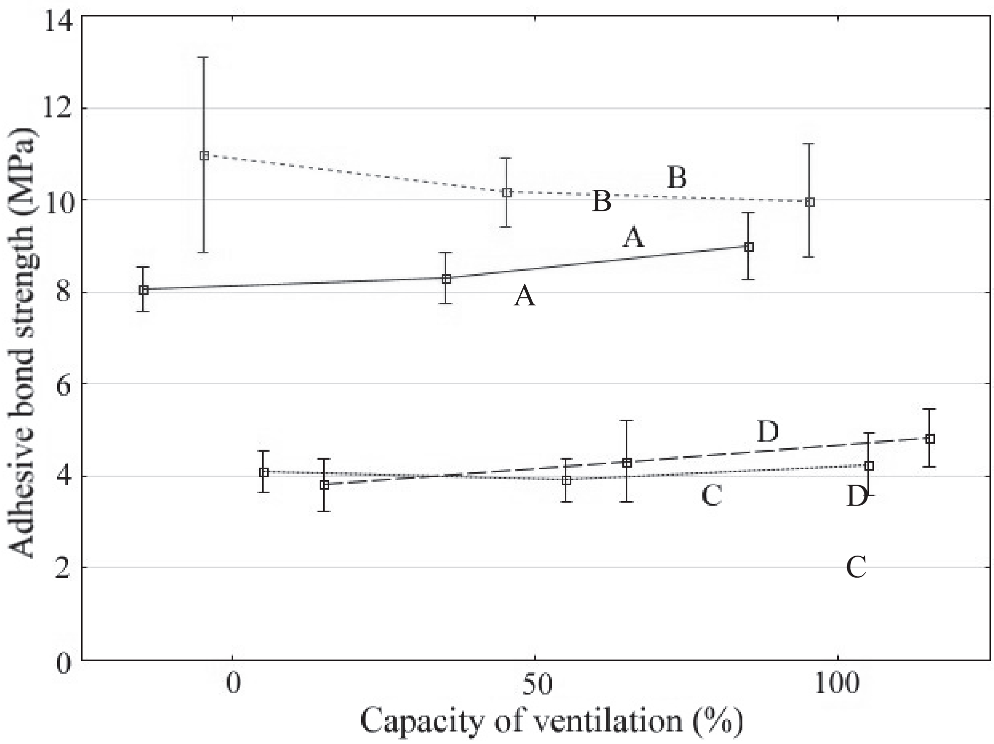

Figure 3. Influence of capacity of ventilation in hall determined for adhesive bonding on adhesive bond strength.

The total concentration and size of dust particles in the laboratory of adhesive bonding measured with a special exact instrument The DustTrak ™ II Aerosol Monitor 8530 are shown in the Fig. 4.

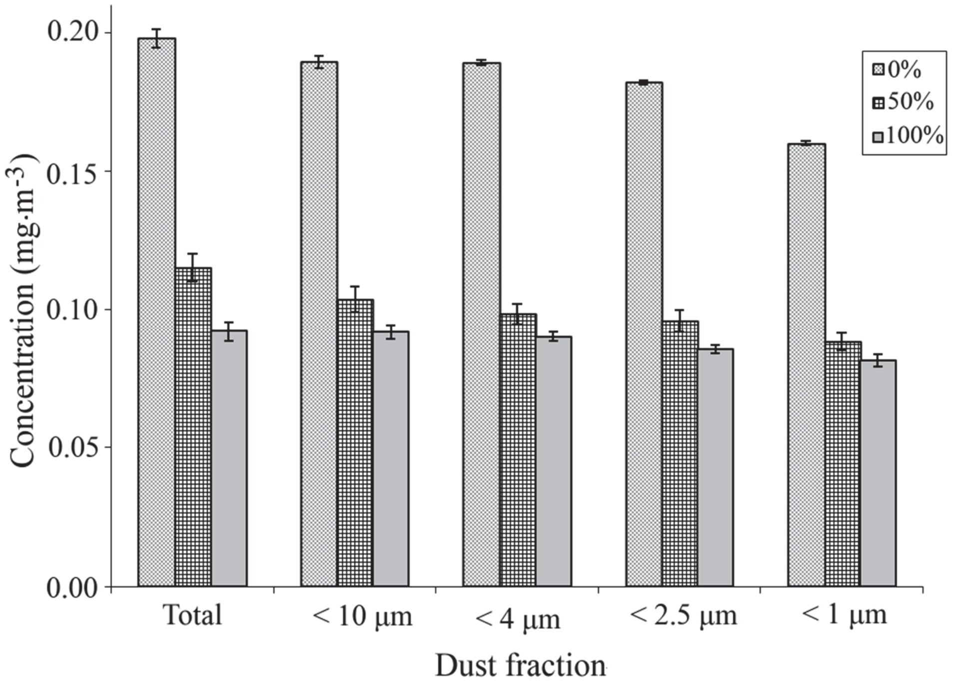

Figure 4. The total concentration and size of dust particles in the laboratory of adhesive bonding.

Based on the statistical analysis of influence of different performance of ventilation on bond strength, it is possible to state that there are statistically homogeneous groups, i.e. there is no difference between the tested adhesives A ($p = 0.0524$), B ($p = 0.5236$), C ($p = 0.6071$) and D ($p = 0.0799$). H_0 hypothesis was confirmed, i.e. there is no difference in the adhesive strength at a significance level of 0.05 between various performance of ventilation, i.e. between 0, 50 and 100%.

Bonded joints A and B showed an adhesive type of fracture surfaces.

Bonded joints C and D showed a special type of cohesive fracture surface. Addition of the filler in the form of microparticles of aluminium not changes breach in comparison with adhesives without filler. Therefore is not possible to agree with the statement of Ramazan et al. (2008) that filled epoxy adhesive has improved adhesion to the glued surface, i.e. there were not cohesive breach of the bond.

Due to different ventilation performance there were not changes of the fracture surface.

Using electron microscopy (SEM) in the frame of the experimental research of the contamination of the adhesive due to the surrounding environment has been confirmed. The back-scattered electrons (BSE) was used in this research analysis. An example of that is a fracture surface of adhesive B on Fig. 5.

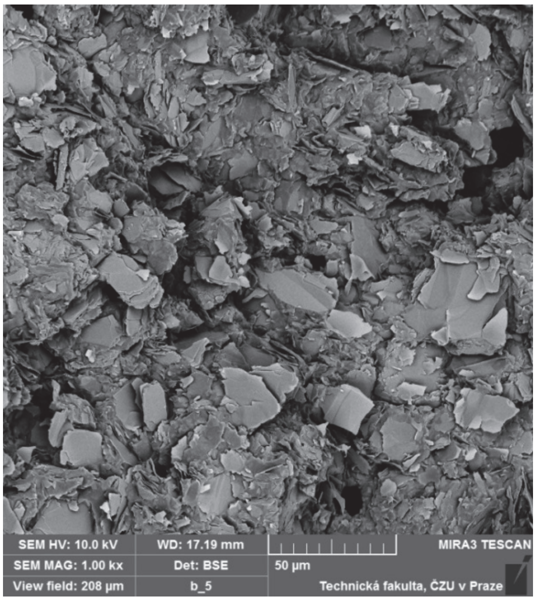

Figure 5. SEM images of fracture surface of sample – Back-scattered electrons (BSE).

CONCLUSIONS

Following conclusions can be deduced from the research focused on the influence of dust pollution in the laboratory on the strength of adhesive bond:

- Bond strength of adhesive C (unfilled) was 3.59 ± 0.37 MPa.
- Bond strength of adhesive D (unfilled) was 3.03 ± 0.20 MPa.
- By addition of filler in the form of aluminium powder was increased bonding strength by 14 and 26%.
- There is no significant difference in the strength of the bond in level of significance 0.05 when applied various performance of ventilation, i.e. 0, 50 and 100%.
- The decline or increase strength of the bond, depending on the performance of ventilation equipment moved in the interval from – 9 to 27%. Coefficient of variation ranged from 7 to 25%.
- The failure area did not change owing to the contamination of the adhesive bond with the dust pollution.

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