STRENGTH CHARACTERISTICS OF POLYMER PARTICLE COMPOSITES WITH FILLER ON THE BASIS OF WASTE FROM MECHANICAL SURFACE TREATMENT

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Abstract. Particle composites are materials reinforcement of which is formed by non fibrous particles. The particle size is in all directions equal. The properties of polymeric particle composites are defined by the synergic sum of the matrix properties and the filler properties. The polymeric particle composite, the filler of which was the waste in form of sawdust, chips and grit blasted material coming from the surface mechanical treatment processes and the matrix was the two-component epoxy adhesive, was the subject of the carried out experiments. The substitution of the primary raw material by the secondary one offers the possibility of the waste thrifty recycling. This possibility should be preferred because the material produced in this way is more economical and more environmentally friendly. The aim of the experiments was to determine the tensile properties of the composites, concretely the dependence between the filler volume in the matrix, and the tensile strength or the tensile lap-shear strength of bonded assemblies. These materials can be applied mostly in renewal of mechanical parts and in the fields of bonding and puttying. The potential areas of application in agriculture are the renovations of soil processing tools.

Keywords: polymeric particle composites, tensile properties, waste.

Introduction

Polymer particle composites are heterogeneous materials, which combine synergically the matrix and the filler properties. Composites engage the material engineers above all by the great flexibility of relatively simple comprised material structures and with this corresponding wide spectrum of applied properties [1]. When choosing the suitable matrix it is necessary to have regard for the required mechanical properties. Relatively often the definite sort of thermosets holds the function of the matrix, e.g., an epoxy resin. Then we speak about the polymeric matrix. The resin use as the composite matrix extends its usable properties. So, it is the case of a specific sort of a bonded joint.

The epoxy resins character enables their filling with inorganic fillers. At present we find on the market a row of epoxy resins, which differ by the molecule chain length and by the viscosity. These resins are characteristic by a small contractibility of 0.05 to 5 %. They are distinguished by a very good adhesion to a row of adherents [1]. For the carried out experiments the two-component epoxy resin ECO-EPOXY 1200/324 with the curing agent P11 was chosen. By the research it was determined that during its life time this resin is able to resist the various degradation mediums, citations [2; 3]. The curing time of this resin is 24 hours at 23 ºC. The total curing occurs after 7 days. As the filler the waste from the surface working – according to the Czech Republic waste catalogue, group 12 01 01, i.e., abrasive material from shot blasting (synthetic corundum, glass beads) and group 12 01 17, i.e. waste from milling and cutting processes (chips from material cutting, abrasive material from water-jet cutting) were used. These groups are not put in the attachment No. 5 of the Statute book 185/2001 about waste, therefore it is not a case of groups of dangerous waste and their handling is in the Czech Republic in no way legislatively limited [4]. By the application of these secondary materials as composite systems filler the possibility of this waste recycling comes into consideration. It is sensitive to environment and it should be preferred. The used fillers meet the particle character, i.e., they are non- fibrous particles above all of sphere, tetrahedron, lamella or similar shape [1]. The composite system final properties are connected above all with interfacial relations. Single phases influence the material final properties on the one hand by their characteristics, on the other hand by the interaction of the matrix and filler [5]. This interaction of the particle filler and matrix is enabled by the adhesion, i.e., by the Coulomb friction on the boundary filler – matrix. As much as possible adhesion is demanded at the requirement of the composite high strength [1]. The expected particle composite systems application on the basis of waste is the field of puttying and machine parts renovation, where above all the high wear resistance, high hardness at low density and last but not least acceptable price are demanded. Polymer particle composites can also find the use in the agrocomplex field, e.g., at renovation of soil-treatment tools. At these systems use the lowered adhesion to soil and in this way the lowered frictional resistance can be expected. Between wellmarked advantages the low liability to corrosion can be included. This can influence above all the economical indexes at the suitable material choice for the machine parts renovation [2]. At polymeric particle composites application good strength characteristics are necessary. The adhered surface for the composite system application must be prepared so that the optimum adhesion is guaranteed. At the optimum adhered preservation it is necessary to guarantee the definite strength characteristics of polymer particle composites, which will guarantee the adhesive as well as the cohesive compactness of the basic material and the composite. In this paper for the cohesion description of the composite system or more precisely of the interaction between the filler and the matrix the tensile strength test of the composite specimens was chosen. Then the lap-shear strength describes the area of load on the boundary adherent – composite system.

Materials and methods

The polymeric matrix of particle composites was from epoxy resin. These materials are most often produced by the reaction of epichlorhydrine with bisphenol A. For the structure netting of these resins connected with curing the polyamines are used [6]. For the experiments the resin Eco – Epoxy 1200/324 was chosen. In the uncured state such a resin is considered as epoxy one, which has in the molecule two and more epoxy groups. This group of resins is in many respects taken for the very perspective. Modified epoxy adhesives are in the fore of constructional adhesives for metal jointing up to the temperatures about 150 ºC [7].

As the filler the waste from mechanical surface preparations was used: waste abrasive particles from blasting – synthetic corundum of fractions F80 and F240, glass beads of fractions 134 and 159, waste from milling and sawing, chips from material parting and abrasive particles from water-jet cutting.

As the filler the chips from the band saw were taken, the cutting speed was of 40 $m \cdot min^{-1}$. The chip form is influenced by the cutting conditions and it depends above all on the cutting speed [8]. Owing to the irregular filler particles shape for the description of this filler shape their outline area (μm^2) was chosen, for the other fillers their dimensions in µm – see Table 1.

The waste abrasive from blasting was taken from a sand blaster where steel sheets were blasted. The blasted surface was at every waste abrasive about 82500 mm^2, the blasting time was about 120 minutes. The abrasive from the water jet parting was taken at the use of parting with abrasive.

Composite systems were prepared with filler volume percentage of 12.5, 25, 50, 75, 100 and 125 %. The formulation of the filler part by volume eliminates the influence of the different density between the matrix (1.15 $g \cdot cm^{-3}$) and the filler (according to the type 1.63-2.3 $g \cdot cm^{-3}$). At the test specimens casting for the composite systems tensile properties determination the moulds made of the material Lukopren N 1522 were used. It is the silicone rubber paste vulcanizing at the room temperature without the catalyst addition. These moulds show the separation property towards the used resin. The total curing time of the used resin was 7 days at 23 ºC. After this time the cured test specimens were taken out from the moulds and prepared mechanically according to the standard CSN EN ISO 3167 (Plastics – Multipurpose test specimens) [9]. According to the standard CSN EN ISO 527 (Determination of tensile properties) the destructive tests were carried out, when the tensile strength σ_M according to the following equation (1) was written down [10].

$$\sigma_M = \frac{F}{A} \tag{1}$$

where σ_M – tensile strength, MPa;
F – measured force value, N;
A – initial cross-section surface of the test specimen (width thickness x), mm^2.

The tensile lap-shear strength test was carried out according to the standard CSN EN 1465 (Adhesives – Determination of lap-shear strength of bonded assemblies). The assembly consists of two steel sheets of 1.5 mm thickness, the dimensions of which were in accordance with the above mentioned standard. The lap-shear strength of assemblies bonded using the composite system with waste filler (filler volume percentage in the matrix of 12.5, 25, 50, 75, 100 and 125 %) was calculated using the equation (2) [8].

$$\tau = \frac{F}{S} \tag{2}$$

where τ – lap-shear strength, MPa;
F – maximal force, N;
S – bonded joint surface, mm^2.

Results and discussion

The used fillers on the secondary raw material basis were put to the image analysis using the stereoscopic microscope in order to determine concrete shapes and dimensions. The particle sizes of single filler sorts were measured in 2D using the optical microscope at 3.5 x magnification, built in camera and software Quick photo shop industry. The obtained data were statistically evaluated by way of normal distribution in form of the histogram of the particles frequency. The histogram example for the glass beads fraction 159 filler is presented in Fig. 1. The particle dimensions of other fillers are presented in Table 1.

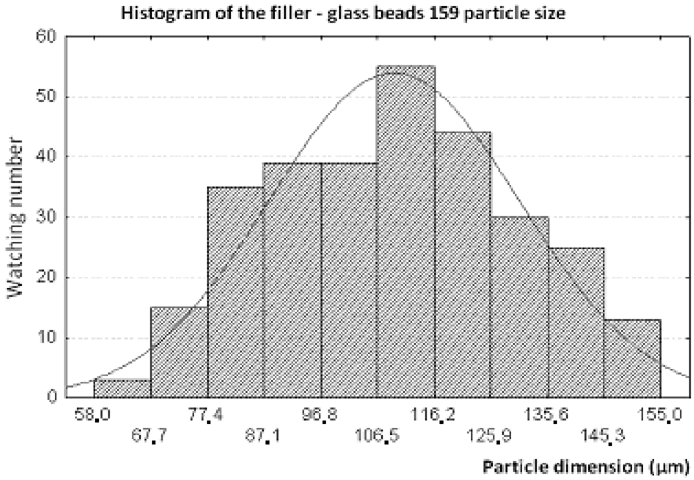

Fig. 1. **Frequency histogram**

For the lap-shear strength description on the boundary adherent – composite system the lap assemblies were made. The surface of 1.5 mm thick steel sheets, onto which the composite system was applied, was at first blasted using the synthetic corundum fraction F80 under the angle of 90º. In this way the average surface roughness of R_a=1.82±0.17 µm was reached. Then the surface was cleaned and degreased using perchlorethylene and prepared to the composite mixture application. The applied composite system thickness, i.e., joint thickness, was defined by the single particle size. The joint thickness was measured using the stereoscopic microscope. The example of the joint thickness depending on the filler sort and its amount in the matrix is presented in Fig. 2.

Table 1

Fraction sizes

Fraction	**Size**	**Unit**
Abrasive for water jet	134±69	µm
Corundum F240	44±15	µm
Corundum F80	147±52	µm
Glass beads 134	109±21	µm
Glass beads 159	119±29	µm
Chips from the cutting	520279±343898	µm^2
Quartz sand	112±46	µm

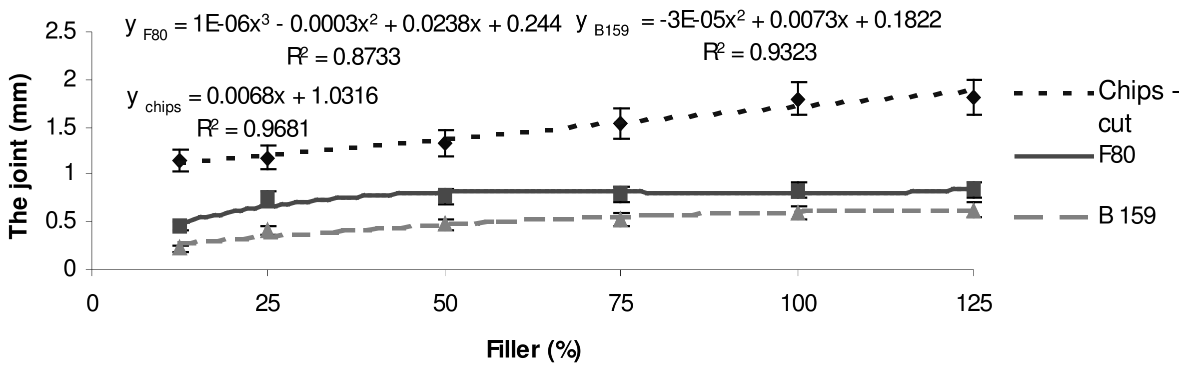

Fig. 2. **Joint thickness**

In this way made lap-shear assemblies were destructive tested. The results (without the filler-chips from the cutting the dimensions of which were measured in μm^2 and the results of this filler are given in the text) are presented in Fig. 3. It is evident that the lap-shear strength was the highest at the mere resin without the filler. At the filler adding the strength decreased proportionally to the filler volume and sort. The minimal strength decrease was recorded at the glass beads (B134, B159) filler. The lap-shear strength values at the glass beads fraction B159 and 100 % concentration increased even slightly to the value of 11.70±0.85 MPa compared with the values of the resin without the filler (11.32±0.93 MPa) – the increase of 3.4 %. On the contrary, the maximum strength decrease to the value of 3.01±0.41 MPa was recorded at the filler from chips – concentration 125 % – decrease of 73.4 %.

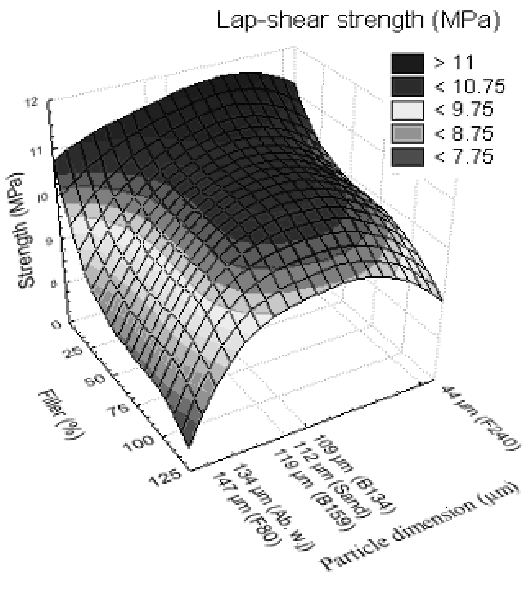

Fig. 3. **Lap-shear strength**

The lap-shear assemblies' strength failure was most often the adhesive failure. It occurred on the boundary in the boundary adherent – composite system. Only the more saturated solutions of 100 and 125 % filler content showed the combined failure (simultaneously the adhesive and cohesive failure). But in such cases the cohesive failure was only on 5-10 % of the bonded surface.

For the strength determination of the interaction between the filler and the matrix the destructive testing of the multipurpose test specimens cast from the concrete composite systems was used. The results evaluation is presented in Fig. 4 (without the filler-chips from the cutting the dimensions of ehich were measured in μm^2).

As at the foregoing case the strength decrease was proportional to the filler volume in the matrix. But compared with the lap-shear assemblies the strength decrease was more considerable. The resin without filler strength value was of 47.67±2.28 MPa. Against this value the least considerable strength decrease of about 61 % was registered at the filler corundum F240, where the composite mixture strength decreased to the value of 18.59±1.18 MPa (125 % filler volume in the matrix). The most considerable strength decrease was reached using the filler B 159, where the strength decrease was of 80.6 % – 9.24±1.27 MPa (125 % filler volume in the matrix).

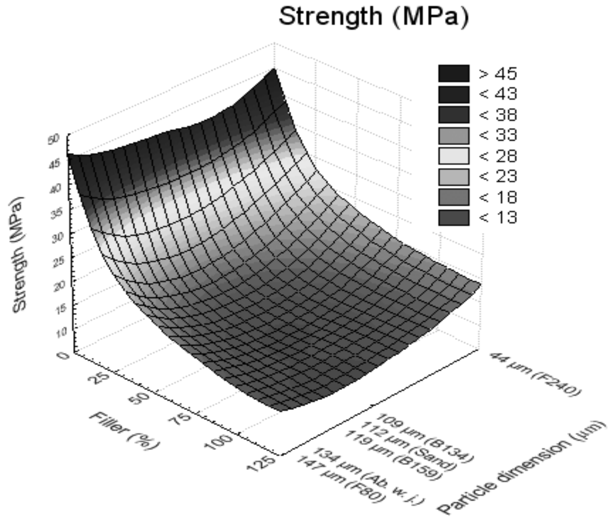

Fig. 4. **Strength of multipurpose specimens**

If we compare the strength of the lap-shear assemblies with the strength of the tested multipurpose specimens we find out that the more considerable strength decrease, proportional to the filler volume in the matrix, equals the level of the lap-shear assemblies. The example of the strength characteristics comparison is offered in Fig. 5. The quick strength decrease of tested multipurpose specimens with the increasing filler volume is evident, which decelerates from about 25 % filler volume in the matrix to the strength of the lap-shear assemblies. The assemblies' lap-shear strength decrease compared to the tested multipurpose specimens strength decrease is negligible.

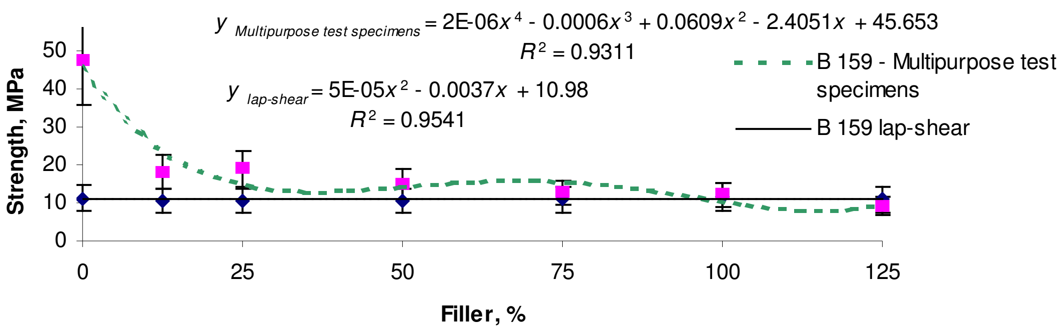

Fig. 5. **Graphical representation of the lap-shear strength and multipurpose specimen strength using the filler B 159**

Conclusions

The expected application field of polymeric particle composites on the waste basis is above all in puttying and renovation of machine parts. In agriculture the application field is open in the field of tools for the soil treatment. As it follows from the works of Muller, Valasek [11] and Qunji [12] the polymeric particle composites are above all abrasive wear resistant, are distinguished by high hardness and the very low density up to 2.5 g·cm^{-3}. But from the carried out experiments it follows that the strength of composite particle systems decreases proportionally to the filler volume in the matrix. With a view to the interaction between the filler and matrix (tests using the multipurpose specimens), the cohesiveness of this boundary decreases already at the minute addition of the above mentioned fillers in the matrix. But the sharp decrease is ceasing in the interval of 25-125 % filler volume in the matrix and descends mostly to the mild decrease. Right now the strength values on the boundary adherent – matrix get nearer to the strength values in the boundary adherent – composite system (lap-shear test).

Just this strength values evenness should result in the stability of the composite particle systems at their application. On the basis of the carried out experiments the use of polymeric particle systems on the waste basis should be in the application field of puttying and renovation, when only a low thickness of the composite system is applied and cohesive strengths are even. The right adherent surface preparation should guarantee good strength on the boundary adherent – composite system, which should correspond to the strength evoked by the interaction of the filler and resin [13]. But it is necessary to be aware that the use of secondary raw materials as fillers causes a row of difficulties. Above all the pollution by various filler particles size and by impurities can influence the cracks initiation and the reduction of the demanded strength [14]. The application of secondary raw materials as fillers offers the possibility of the waste thrifty recycling, which, as seems, can be well founded and utilizable.

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References

1. Machek V., Sodomka J. Polymers and composites with polymeric matrix. Prague: ČVUT, 2008. 86 p.
2. Müller M., Valášek P. Adhesive bonds degradation. In 9th International scientific conference engineering for rural development. Jelgava: LUA, 2010, pp. 49-52.
3. Müller M., Chotěborský R., Hrabě P. Degradation processes influencing bonded joints. Research in Agricultural Engineering, 2009, vol. 55, no. 1, pp. 29-34.
4. Law nr. 185/2001 (Zákon č. 185/2001 SB., o odpadech a o změně některých dalších zákonů) [online] [27.9.2009.]. Available at: http://portal.gov.cz/wps/portal/_s.155/701/.cmd/ad/.c/313/ .ce/10821/ .p/8411?PC_8411_l=185/2001&PC_8411_ps=10
5. Kim B.S., Park S.W., Lee D.G. Fracture toughness of the nano-particle reinforced epoxy composite. Composite Structures, vol. 86, Elsevier, 2008, pp. 69-77.
6. Dalibor V. Materials and their marginal status. Prague: VŠCHT, 2010. 204 p.
7. Peterka J. Bonding of structural materials in engineering. Prague: SNTL, 1980. 788 p.
8. ČSN EN 1465 (Adhesives – Determination of tensile lap-shear strength of bonded assemblies)
9. ČSN EN ISO 3167 (Plastics – Multipurpose test specimens)
10. ČSN EN ISO 527 (Plastic – determination of tensile properties)
11. Valášek P., Müller, M. Possibilities of use of mechanical surface treatment waste in form of polymeric particle composite fillers. In 9th International scientific conference engineering for rural development. Jelgava: LUA, 2010, pp. 267-270
12. Xue Qunji, Wang Qihua., 1997. Wear mechanisms of polyetheretherketone composites filled with various kinds of SiC. Wear, vol. 213, 1997, pp. 54-58.
13. Müller M., Hrabě, P., Chotěborský, R. Optimization of surface treatment paremetrs in adhesive bonding technology. In 7th International scientific conference engineering for rural development. Jelgava: LUA, 2008, pp. 214-219.
14. Brožek M. Cutting Conditions Optimization When Turning Overlays. Journal of Materials Processing Technology. Vol. 168, 2005. Issue 3, pp. 488-495.
15. Brožek M., Nováková A. Briquetting of chips from nonferrous metal. In.: 9th International Scientific Conference „Engineering for Rural Development“. Jelgava, Latvia University of Agriculture, Faculty of Engineering. 2010, pp. 236-241.