Epoxy resin filled with primary and secondary raw material – useable in agriculture

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Abstract

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Hard inorganic particles in the interaction with polymeric materials increase wear resistance. Also reactoplastics are suitable for filling with micro- and nano-particles for a purpose of some mechanical properties optimization. The paper compares chosen mechanical properties – hardness, wear resistance and tensile characteristics of epoxy resin filled with artificial corundum with various middle particles sizes and their ratio combination. Mentioned systems can be used in a sphere of the agricultural production at renovation of machine parts, they can serve for creating resistant layers on machines, floors and grillages at the same time. The aim of the carried out experiment is to compare the properties of reactoplastics filled with a primary and secondary raw material and to define an optimum ratio of the filler particle size relating to a given mechanical quality. The artificial corundum was chosen as the primary material, the waste corundum from the process of material mechanical treatment was chosen as the secondary one.

Keywords: hardness; tensile strength; waste; wear

In the sphere of animal and plant production many machines are used whose functional areas are exposed to specific types of degradation. An abrasive wear can be ranked among the most widespread types of the wear in the agrocomplex. Functional areas of machines can be renewed by classical way – overlaying. It is also possible to use polymeric particle composites when coating of such materials is fact and inexpensive and it is not necessary to have a special equipment.

Reactoplastics belong to a group of polymers which create chemical bonds among single molecules at a hardening. During the hardening it comes to an interconnection of the macromolecules by transverse covalent bonds which create a reference space grid. The macromolecule setting defines properties of the reactoplastics – it influences permanent deformation in a negative way. Compared with thermoplastics the reactoplastics show higher modulus of elasticity, increased dimensional stability, they are hard and firm. The properties of the reactoplastics e.g. epoxy, polyester, phenolic and other resins are suitable for filling with micro-particles and nano-particles, these resins can serve as matrices of fibre composites at the same time. The epoxy resins are constructional adhesives which can be used at connecting of metals, glass, ceramics and other materials. They excel by good chemical resistance and by mechanical properties.

The micro-particles can improve values of a tensile strength and wear resistance. The example

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can be an experiment of Satapathy et al. (2002) who optimized the tensile strength of the phenolic resins from 10.8 to 16.7 MPa by an inclusion of Al_2O_3 particles of a size 48–100 µm. They set the optimum amount of the filler in matrix as 15% wt. from the tensile strength and the wear resistance points of view. Ku and Wong (2012) reached the tensile strength increase of the epoxy resin by adding 5% wt. of the secondary filler – a glass powder (middle size 11 to 18 µm). Basavarajappa et al. (2010) describe a significant positive influence of SiC micro-particles on the resultant three-body abrasive wear resistance of the polymeric matrices. Filling with the micro-particles is justified at the thermoplastics as well. Panin et al. (2012) observed as much as 18-fold improvement of the abrasion resistance of super high molecular polyethylene filled with Al_2O_3 particles (50 µm) compared with the unfilled material. Mohan et al. (2012) describes the improvement of tribologic properties of the polymeric composites filled with the inorganic filler SiC of the size 20–25 µm. Müller et al. (2011), Müller and Valášek (2012), and Müller and Hrabě (2013) stated possible application areas of the epoxy adhesives filled with Al_2O_3 micro-particles as functional areas of machines, adhesive bonding and cementing of larger units. In the matrix not only particles of the same filler type may be represented. In the work of Meng and Kee (2012) there is described the optimization of the Modulus of elasticity of three-phase composite system with the polymeric matrix where the nanoparticles of the wood powder together with the clay particles are dispersed.

The aim of the carried out experiments is describing basic mechanical properties of the epoxy resin filled with the micro-particles of Al_2O_3 of various sizes and various mutual ratio combinations. The experiment aims at describing these properties at resin filled with the primary corundum, as well as at the resin filled with the waste corundum (the secondary raw material). The waste corundum means the waste from a process of the material surface treatments according to the Catalogue of waste of the Czech Republic (Regulation No. 381/2001) categorized under the catalogue number 12 01 17 (Waste material from grid blasting non-categorized under the number 12 01 16). Splinters after machining of various hardfacing alloys can be used as filler at the same time – when the used methods of machining modernization (no cutting liquid used during machining – dry machining) (Novák 2011, 2012). The mutual comparison of the mechanical properties between the composite with the primary and secondary raw material enables to define substitution possibilities of the primary raw material by the waste. A subsequent defining of application areas enables to increase a ratio of the material recyclation which should be preferred in a modern society. On the basis of references the hypothesis can be pronounced that various sizes of the filler particles influence single mechanical properties in a different way – the carried out experiments aims to verify this hypothesis. The experiment results can specify using these materials not only in the sphere of the agricultural production.

MATERIAL AND METHODS

The ratios among single fractions (F80, F240 and F800; Wista s.r.o, Zlín, Czech Republic) were chosen as follows: 1:2, 2:1, 1:5 and 5:1. The composite systems were cast in the same ratio always with the primary raw material as well as the secondary one (filler). The limit 30% vol. was chosen on the basis of hypothesis pronounced by authors Valášek and Müller (2012) about increasing wear resistance with increasing ratio of hard inorganic particles in the matrix. Higher saturation of the epoxy resin with the filler would deteriorate the mixture applicability (the mixture applicability is influenced by the character and size of used filler but also the matrix). The hardening of these systems was carried out in accordance with the requirements of the producer.

As the filler the waste artificial corundum and primary artificial corundum was used. Inorganic waste particles served for grit blasting of common carbon steels. The mixture of the epoxy resin and inorganic particles was prepared by the mechanical mixing in an ultrasonic tank and consequently the mixture was cast into rubber forms. The porosity (P) was set according to Berthelot (1999) on the basis of differences between the theoretical and real densities, when the real density was calculated on the basis of the mass and volume of testing specimens of sizes 35 × 25 × 9 mm:

$$P = \frac{\rho_{teo} - \rho_{rea}}{\rho_{teo}} \times 100 \qquad (1)$$

where:

P – porosity (%)

ρ_{teo} – theoretical density of system (g/cm^3)

ρ_{rea} – real density of system (g/cm^3)

Table 1. Porosity and agreement probability – tensile strength (t-test)

Material	Porosity (%)		Difference (%)	t-test (p)	
	primary filler	secondary filler		tensile strength	hardness
240:80 1:5	8.26	7.24	–12.4	0.52	0.07
240:80 2:1	9.98	8.04	–19.4	0.87	0.34
240:80 1:2	9.06	7.68	–15.3	0.77	0.14
240:80 5:1	5.14	3.82	–25.7	0.47	0.00
800:80 5:1	8.47	6.02	–28.9	0.12	0.30
800:80 2:1	9.98	9.60	–3.8	0.10	0.02
800:80 1:2	9.66	9.35	–3.2	0.59	0.01
800:80 1:5	6.13	6.32	3.1	0.29	0.95
F80	10.32	11.94	15.7	0.77	0.47
F240	7.14	9.01	26.2	0.25	0.54
F800	8.97	10.54	17.5	0.61	0.74

As guide for the hardness determination of the composite systems the standard CSN EN ISO 2039-1 (1998) was used. The tested specimens dimensions were of 35 × 25 × 9 mm. The ball from hard metal of 10 mm diameter was used. The tested specimens were loaded using the force of 2.452 kN for the duration of 30 s.

The wear resistance testing – the two-body abrasion was carried out on a right circular cylinder with the abrasive cloth P120 and P220 (Carborundum Electrite a.s, Benátky nad Jizerou, Czech Republic) according to the standard CSN 62 1466 (1993). Before the own testing the testing specimens rounding – off was adapted in their bottom – testing part in such way they touch the abrasive cloth by their whole area (the testing specimens height 20.0 ± 0.1 mm, the mean 15.5 ± 0.1 mm). The testing specimen is shifted during the test by means of a motion screw along the abrasive cloth from a left edge of a drum to the right one and it covers a distance 60 m. At one drum turn of 360° it is caused the testing specimen stroke above the abrasive cloth surface by means of a cam. A consequent incidence of the testing specimen simulates the impact. The pressure force is 10 N. During the experimental setting of the wear resistance the temperature in the interface of the testing specimen and the abrasive cloth was measured by means of the infra-red contactless thermometer.

Measured values were statistically processed by means of ANOVA, the probability of the statistical agreement of the mechanical properties data sets among the composites with the primary and secondary filler was evaluated by means of t-test and parameter (P) on the significance level 0.95.

RESULTS

Middle sizes of the filler particles were measured on the stereoscopic microscope (Artray Co., Ltd., Tokyo, Japan) by means of the built-in software (Software Quick Photo Promicra Ltd., Prague, Czech Republic). These sizes corresponded at single fractions of the primary filler to F80: 155 ± 23 μm, F240: 58 ± 15 μm and F800: 6 ± 3 μm. At the secondary filler, smaller middle sizes were measured – this change of the size corresponds to the particles wearing during the grit blasting of the basic material F80: 150 ± 51 μm, F240: 48 ± 13 μm and F800: 5 ± 2 μm.

The composite systems based on the primary and secondary raw materials were hardened according to technologic requirements of the producer. The porosity (P) was set on the testing specimens (Table 1). The negative value of the porosity means smaller porosity of the composites with the secondary raw material compared with the composites with the primary filler. The theoretical density value of the composite systems corresponded to 2.01 g/cm^3 (the resin density stated by the producer is 1.15 g/cm^3).

Mechanical properties comparison

The hardness stated according to Brinell scale (HBV) is shown in Fig. 1. The highest difference among the hardness of the composites with the primary and secondary raw material corresponds to 12.9% (P = 0.005) at the composite 240:80 1:5. The hardness value of the unfilled composite corre-

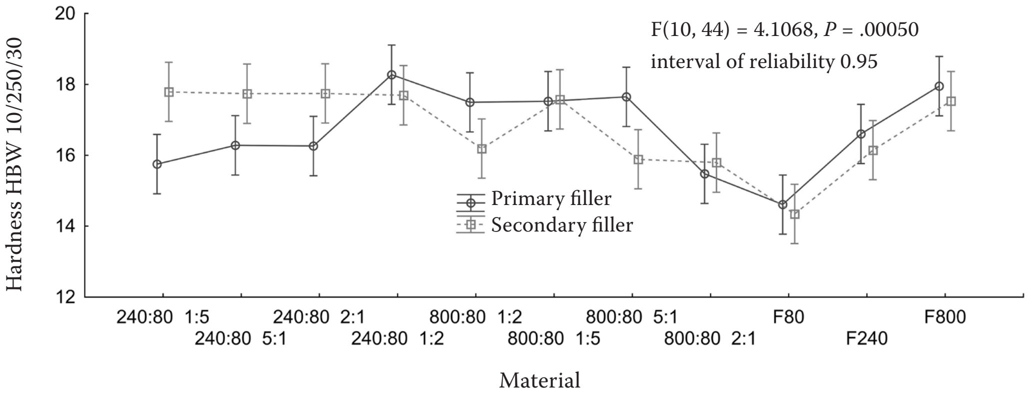

Fig. 1. Hardness

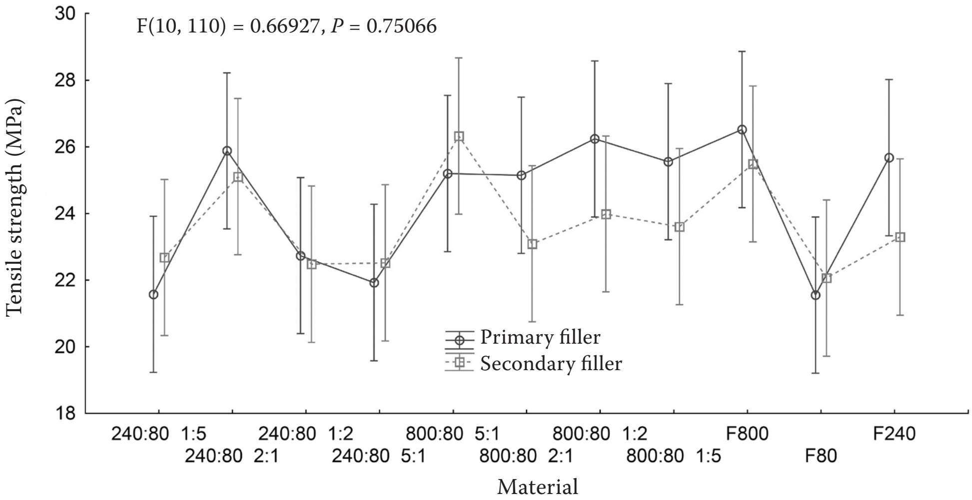

Fig. 2. Tensile strength

sponded to HBW 10.72 ± 1.07. The statistical comparison of the hardness values (the agreement probability *P*) is shown in the Table 1.

The results of the tensile strength are graphically presented in Fig. 2. The highest recorded average tensile strength 26.52 ± 2.21 MPa corresponded to the composite with the primary filler F800. At the composites with the combination of the particles sizes the highest mean value of the tensile strength corresponded to 26.33 ± 3.43 MPa (800:80 5:1 with secondary filler). The tensile strength of the unfilled resin corresponded to 44.11 ± 4.21 MPa.

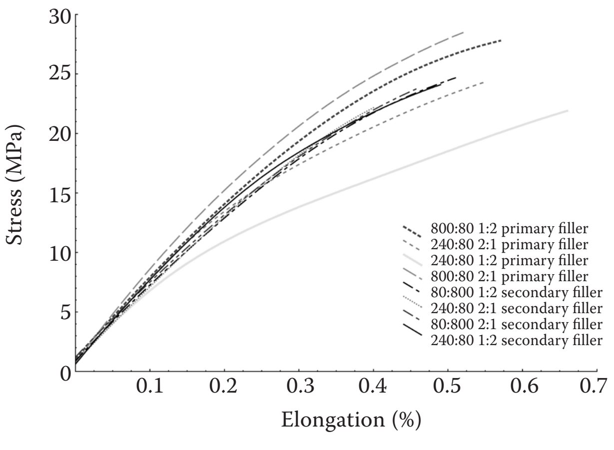

Fig. 3. Tensile curves

The agreement possibility of the statistical data sets among the strength of the composites with the primary and secondary filler is expressed by means of the Table 2. Fig. 3 shows typical tensile curves for single materials.

The comparison of the abrasive wear resistance by means of composite volume losses is presented for the abrasive cloths of granularity P120 and P220 on the Fig 4. The most considerable statistical difference of the data sets among the composites with the primary and secondary filler ($P = 0.00$) was found out at the composites with the fraction F800 at both abrasive cloths and at the composite with the filler F240 ($P = 0.03$) (abrasive cloth P220).

The highest percentage difference among the material based on the waste and the primary raw material was found out at the ratio composites (33.39%, $P = 0.02$) at the composite 240:80 2:1 on the abrasive cloth P220. The second highest difference 29.29% ($P = 0.09$) was recorded at the composite 800:80 1:2 on the cloth P220.

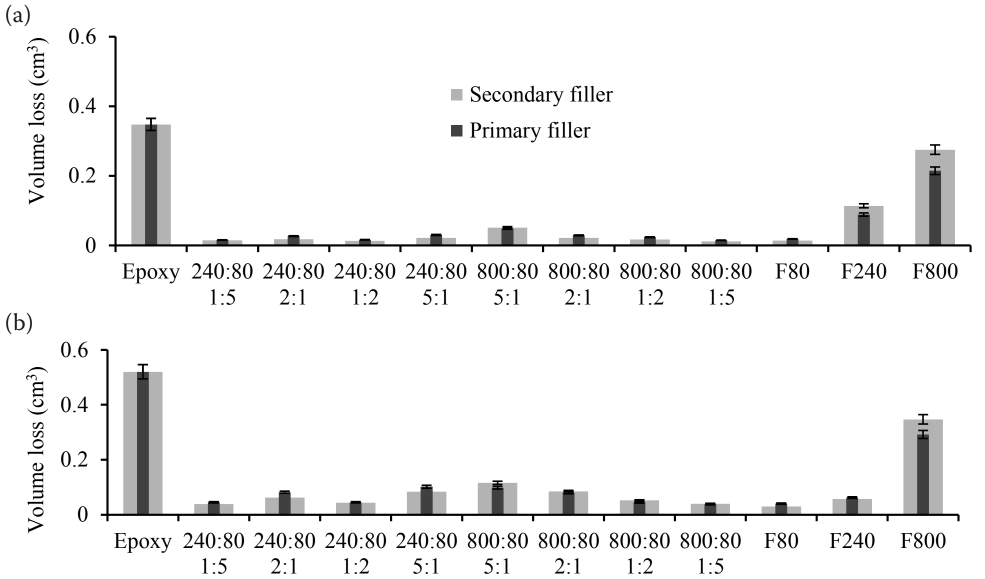

Fig. 4. Volume losses: (a) abrasive cloth P220 and (b) abrasive cloth P120

The smallest volume losses 0.0117 ± 0.0014 cm^3 were reached for the cloth P220 at the composite 800:80 1:5 with the secondary filler (the volume loss for the primary filler was 0.0147 cm^3). For the abrasive cloth P120 the smallest volume loss 0.0302 ± 0.0039 cm^3 was found out at the material with the secondary filler (F80) (the value at the primary filler 0.0402 ± 0.0047).

DISCUSSION

The presence of air bubbles in the cast systems was proved through the porosity. The influence of the secondary fillers on increased porosity (compared with the primary filler) was not proved. The presence of pores and their layout in the matrix influence resultant mechanical properties. The mechanical properties were different in some cases among the composites with the primary and secondary filler from the statistical agreement point of view. These different values of mechanical properties can be attributed on the basis of the carried out experiment to higher values of the porosity and to imperfect distribution of the fillers in the matrix caused by chosen way of the composite preparation than to differences between the primary and secondary fillers. The secondary filler can carry traces of the basic material which was worked by the filler. For this reason, it is always necessary to take into regard a suitability of the secondary raw materials usage as the fillers owing to given properties of this raw material (abundance of contaminants, surface morphology etc.).

The composites preparation process was chosen following to the practice when it is not expected to use mechanical mixers or vacuum. However, according to the results of Wang et al. (2012) the par-

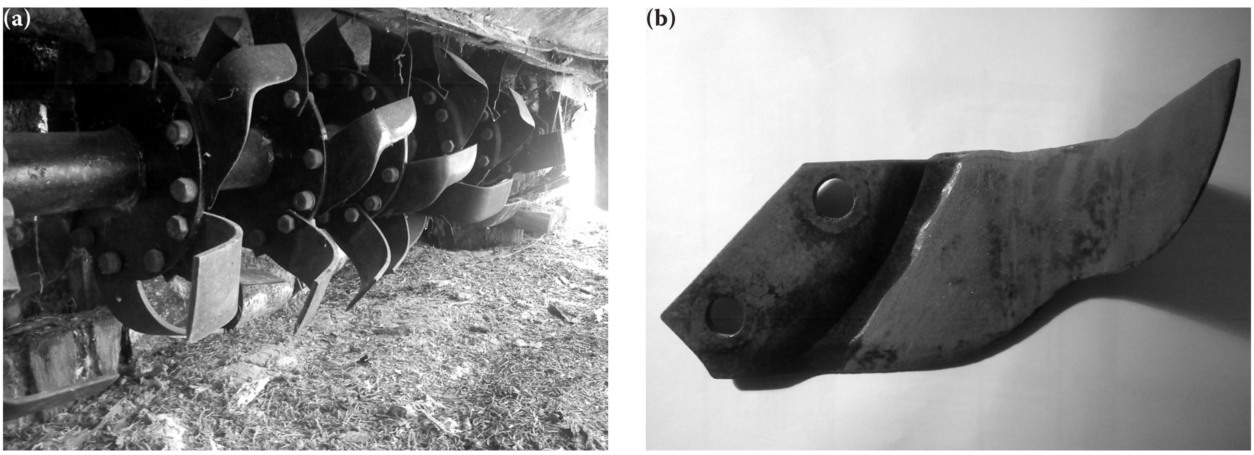

Fig. 5. Application example: (a) rotary tiller blades and (b) blade with composite

ticles dispersion by the ultrasound would increase observed characteristics of percentage units. It is possible to pronounce the hypothesis at the same time that better distribution of the filler particles in the matrix would lead to a decrease of the standard deviations.

From the carried out experiment the presumption of authors (Satapathy, Bijwe 2002; Basavarajappa et al. 2010; Valášek, Müller 2010) was certified that the inclusion of the corundum particles decreased considerably the volume losses of the composites compared with the resin without the filler. The presumption was certified at the same time that systems with smaller filler particle size (F800, F240) will be more prone to the abrasive wearing on used abrasive cloth. Carried out experiment did not certify the hypothesis of Satapathy and Bijwe (2002) about the optimization of the tensile strength of the epoxy adhesives filled with corundum. However, the experiment confirmed the results of authors Ku and Wong (2012) and Wang et al. (2012) who described a considerable fall of the tensile strength of the reactoplastics filled with inorganic micro-particles. The presumption was confirmed that larger particle size (F80) will have more considerable influence on the strength characteristics than smaller particles.

The experiment certified the hypothesis about possible substitution of the primary raw material by the secondary raw material without a significant change of required mechanical properties. This statement opens a space to the mechanical recyclation which is inexpensive and sensitive to environment. Modern society should prefer this waste handling.

Owing to the results the possible application area can be the renovation of functional parts of bodies where increased abrasive wear resistance is required – surfaces of screw conveyers, of chutes, the renovation of cracks and splits etc. A rotary tiller can be also the example of the renovation. As the example of using the composite with the primary filler 240:80 2:1 was applied on a blade of the rotary tiller on 5 ha. Fig. 5 shows the result of the application example on the sandy – clayey soil.

CONCLUSION

Results of the carried out experiment describing the epoxy resin filled with the primary and secondary micro-particles of the corundum with different particle size can be summarized in following points:

- It came as much as to 70% increase of the hardness compared with the resin without the filler (the primary filler 240:80 1:2).
- It came minimum to 40% fall of the tensile strength (the primary filler F800) and maximum to 51% fall (the primary filler F80) compared with the resin without the filler.
- Composite systems (800:80 1:5 secondary filler) was as much as 30-fold more resistant on the abrasive cloth P220 compared with the unfilled resin (on the cloth P120 as much as 14-fold more resistant – F80 secondary filler).
- The substitution of the primary filler by the secondary one – waste does not considerably change resultant mechanical properties.

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