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Microparticle composites on the basis of scrap utilizable in the field of agricultural production

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Abstract

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For renovation of functional surfaces of machines and devices for agricultural production it is possible to use, in addition to conventionally used methods, polymers with fillers – composites. The presence of microparticles in the polymeric matrix improves substantially the abrasive wear resistance and hardness. This contribution describes tribological properties of epoxy resin filled with chips of ferrous metals – the change of volume losses increase in dependence on the pressure increase (load) having effect on the worn surface. From the carried out experiments the considerable decrease of filled resin losses is evident compared with the resin without filler. At the same time the exponential increase of volume losses with the increased load was quantified in the course of tribological tests.

Keywords: epoxy resin; hardness; load; wear

Materials used in agricultural production are often exposed to specific wear types and to demanding degradation mediums. In the field of agriculture many various wear types occur, but with regard to its quantity the abrasive wear belongs to the most expressive. Degradation mediums are represented by different sorts of fertilizers, process fluids, weather conditions including enormous temperature fluctuations (Chotěborský et al. 2009). In the case of the limiting wear it is necessary to renovate or to replace the used materials. The use of deposits is the conventional example of metal materials renovation (Brožek 2007, 2009; Müller, Hrabě 2013). In this case the renovated machine part has often better properties than from the original material. Between unconventional methods of renovation it is possible to include the use of composite systems (Müller, Valášek 2012). For the creation of resistant surfaces of materials the polymeric particle composites are often used (Müller 2011). It is a case of polymer filled with various kinds of micro- as well of nanoparticles, which influence mechanical properties in the demanded direction. For the renovation of machine parts and for creation of resistant surfaces of materials above all microparticles of size tens to hundreds micrometers are used. Müller et al. (2011) gives the possibility to utilize the epoxy resin filled with corundum (Al_2O_3) in the field of the sugar beet harvest. His experiments results are confirmed by many authors. Sapathy and Bijwe (2002) used in his experiments corundum of size 40–100 μm for the improvement of wear resis-

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tance (three body abrasion) – it was achieved also by Basavarajappa et al. (2010), who substituted corundum for silicon carbide (SiC). These results were confirmed also by Mohan (2012), who noticed the increase of polymeric composites tribological properties caused by the microparticles presence. Inorganic microparticles can improve not only tribological properties. Abenojar et al. (2009) improved the strength characteristics of epoxy resin by 6–12 % wt. SiC particles of 10 μm size. Lee et al. (2002) includes between critical factors which influence the wear resistance of systems with hard reinforcement the boundary properties and geometrical and mechanical properties of the reinforcement. The increasing hardness of the polymeric matrix caused by the reinforcement inclusion influences the penetration depth of abrasive particles in the polymeric matrix and decreases the quantity of removed material (Suchánek et al. 2007). However, microparticles can initiate the crack creation, which causes the decrease of other mechanical properties – strength and impact resistance.

The aim of the carried out experiment was to quantify the volume losses of the epoxy resin filled with microparticles from ferrous metals chips in dependence on the load, which forces down the test specimen against the abrasive cloth. The principle of abrasion is based on the bonded abrasive particles – it is the case of the two-body abrasion. The determination of the volume losses in dependence on the load makes it possible to define application conditions of the described composite system not only in the field of agriculture. The aim of the experiment is also to confirm the hypothesis of Tenenbaum (1976) about the exponential dependence of the wear (W) on the load (F) according to the Eq. (1) for composites on the basis of ferrous chips:

$$W = k \times F^{n} \tag{1}$$

where:
k – friction coefficient (–)
n – exponent (–)

MATERIAL AND METHODS

As filler the chips from ferrous metals – cast irons – were used. They are excellent to increase abrasive wear resistance. The chips were gained by turning without the use of cutting coolants from 5 different materials (Nos 1–5). For cutting the carbide tips were used. The presented data reflect progressive technologies, where higher cutting speed and minimum use of cutting coolants are preferred. The machining process itself together with the chemical-physical properties of the workpiece influences the formation and movement of the removed material in form of chips (Novák 2011). In accordance with the valid legislation of the Czech Republic the used chips from ferrous metals showed no features of dangerous scrap. The chips of ferrous metals were compared with the classic microparticle filler SiC (F100 – mean size 137.5 μm; Reno-Tech.cz s.r.o., Kaznějov, Czech Republic).

As matrix the two-component epoxy resin ECO Epoxy 1200/324 (DCH Sincolor Plzeň, Plzeň, Czech Republic) (ρ = 1.15 g/cm^3) was used, which was filled with 25 volume percentages of chips from ferrous metals. The concentration 25% was chosen intentionally, because at this concentration owing to the mutual contact of chips the min. sedimentation as result of the gravity force occurs (Valášek et al. 2012). At the lower concentration the unwanted sedimentation would occur, at the higher concentration the demanded cohesion of the system and its applicability would not be kept. The contribution concentrates on the determination of the system max. wear resistance.

The test specimens were casted using moulds from two-component silicone rubber and cured according to the resin producer demands. The porosity (P) of the test specimens was evaluated according to the Eq. (2):

$$P = \frac{\rho_{\mathrm{The}} - \rho_{\mathrm{Rea}}}{\rho_{\mathrm{The}}} \times 100 \tag{2}$$

where
P – porosity (%)
ρ_{The} – theoretical composite density (g/cm^3)
ρ_{Rea} – real composite density (g/cm^3) (Berthelot 1998)

Hardness of the test specimens of 35 × 25 × 9 mm size was measured according to CSN EN ISO 2039-1. Considering the specimen size the ball of 10 mm diameter was used. The specimens were loaded using the force of 2,452 kN for the duration of 30 s (HBW 10/250/30).

As guide for the abrasive wear resistance determination the standard CSN 01 5048 – abrasion using

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Table 1. Size of particles, porosity and hardness of composites

Material	A (mm^2)	v_A (%)	P (%)	Hardness HBW (10/250/30)
No. 1	0.445	74	5.8	19.56
No. 2	0.526	58	10.1	18.04
No. 3	0.640	61	9.4	18.21
No. 4	0.475	40	8.9	16.98
No. 5	0.610	61	9.4	18.30

A – area (2D plane); v_A – variation coefficient; P – porosity; HBW – Brinell Hardness

abrasive cloth fastened to the rotation disk – was used. This method for testing of metallic materials was implemented for polymeric particle composites. The tests were carried out using the abrasive cloth of P120 grit (Alico, s.r.o., Kolín, Czech Republic). By the use of exchangeable weights the specific loads of test specimens were of 0.09, 0.17 and 0.24 N/mm^2, the friction path was 50 m. The tested specimen moved from the edge to the centre of the abrasive cloth. Owing to the decreasing friction path during one revolution the sliding speed decreases from 0.48 to 0.08 m/s. Using the contactless thermometer Testo 845 (Testo s.r.o., Prague, Czech Republic) the temperature on the boundary between the specimen and the abrasive cloth was measured. The volume losses were determined on the basis of the composite theoretical density and the volume losses using the laboratory scales of 0.1 mg responsiveness. The real composite density was calculated using their weight and volume, which was defined by the tested specimen dimensions, measured using the digital calliper (0.01 mm). For the composite system comparison with the steel S235JR the relative wear resistance (ψ) was calculated according to Eq. (3):

$$\psi = \frac{W_{\mathrm{St.}}}{W_{\mathrm{Ts.}}} \tag{3}$$

where:

ψ – relative abrasive wear resistance

$W_{\mathrm{St.}}$ – average volume loss of standard (S235JR) (cm^3)

$W_{\mathrm{Ts.}}$ – average volume loss of the tested specimen (cm^3)

The proportional presence of single phases was determined using a microscope (owing to the chips shape expressed in 2D flat surface). Morphology of chips interaction with polymeric material defines the final properties of composites. For the morphology description of the hard deposit chips the optical analysis was used; using a microscope the chips surface in 2D plane was measured.

RESULTS

By the optical analysis the size of chips was determined as their surface was measured in the 2D plane (A). Table 1 presents the mean value of this size (200 measurements) and the relevant variation coefficient v_A, which demonstrates the large distribution size of used particles. The porosity (P) of composites with ferrous metals chips was determined on the basis of the theoretical density of composites, which was in the range between 2.78 and 2.83 g/cm. The porosity of the composite SiC/Epoxy corresponds to 6.2% at the theoretical density of 1.66 g/cm^3. The

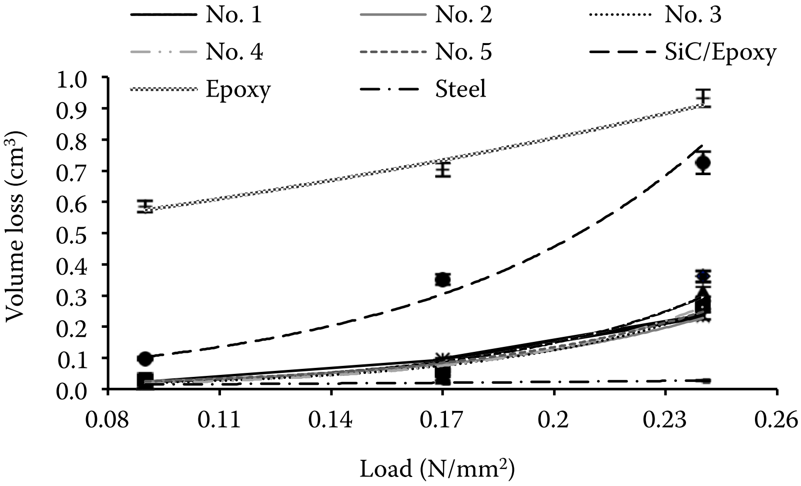

Fig. 1. Relationship between volume loss and load

Table 2. Functional equations

Material	$\psi_{0.09}$	$\psi_{0.17}$	$\psi_{0.24}$	Functional equation	R^2
No. 1	0.56	0.32	0.08	$y = 0.0047e^{17.288x}$	0.94
No. 2	0.53	0.33	0.10	$y = 0.006e^{0.0019x}$	0.96
No. 3	0.63	0.40	0.09	$y = 0.0038e^{0.0022x}$	0.94
No. 4	0.63	0.47	0.08	$y = 0.0032e^{0.0023x}$	0.90
No. 5	0.63	0.21	0.12	$y = 0.0032e^{0.0023x}$	0.99
SiC/Epoxy	0.15	0.06	0.04	$y = 0.0306e^{13.517x}$	0.99
Epoxy	0.03	0.03	0.03	$y = 0.4349e^{3.0806x}$	0.97
Steel	1	1	1	$y = 0.01e^{4.1748x}$	0.99

ψ – relative abrasive wear resistance; R^2 – determination index

hardness of the composites after curing is presented in Table 1. The test specimens for the hardness measurement were made from the same mixture as the specimens determined for the tribological tests. At the hardness measurement the variation coefficient ranges up to 5%.

The volume loss of the resin without filler corresponded to 0.5855 ± 0.0026 cm^3 (at the load 0.09 N/mm^2), 0.7032 ± 0.0076 cm^3 (0.17 N/mm^2) and 0.9321 ± 0.0015 cm^3 (0.24 N/mm^2). At the load of 0.09 N/mm^2 and 0.17 N/mm^2 the min. loss was measured at the composite No. 4 (0.0233 ± 0.0003 cm^3 or 0.0417 ± 0.0005 cm^3), at the load of 0.24 N/mm^2 at the composite No.5 (0.2346 ± 0.0007 cm^3) (Fig. 1). The composite systems filled with chips from ferrous metals showed approximately the same abrasive wear resistance, which was considerably higher than it was determined at the system SiC/Epoxy and at the resin without filler. At the increased load the relative abrasive wear resistance decreased. Compared with the steel the substantial rise of the composite volume losses occurred.

The comparison of the composite systems with the system with steel by means of the relative abrasive wear resistance is evident in Table 2, which presents also the equations of the relation between volume losses and load (using exponential functions according to the Tenenbaum (1976) hypothesis) and the determination index of the mentioned equations.

The worn out surface of the tested specimens at the load of 0.24 N/mm^2 is evident from Fig. 2. On the worn out surface the places are evident, where the microparticles were pulled out by abrasive grains of the abrasive cloth. The evident grooving is visible, too. At the low load the surface of the tested body had no unevenness caused by microparticles grooving and pulling out; microparticles as the more wear resistant phase directed the wear pro-

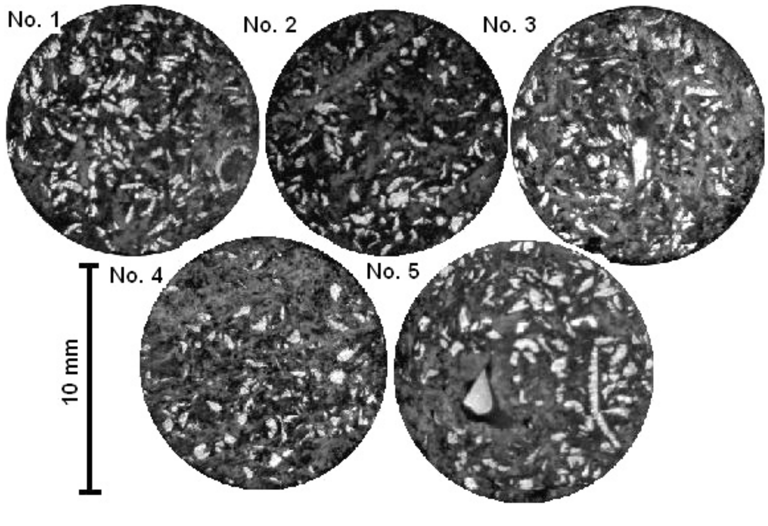

Fig. 2. Surfaces of tested specimens after the tribological test (load 0.24 N/mm^2)

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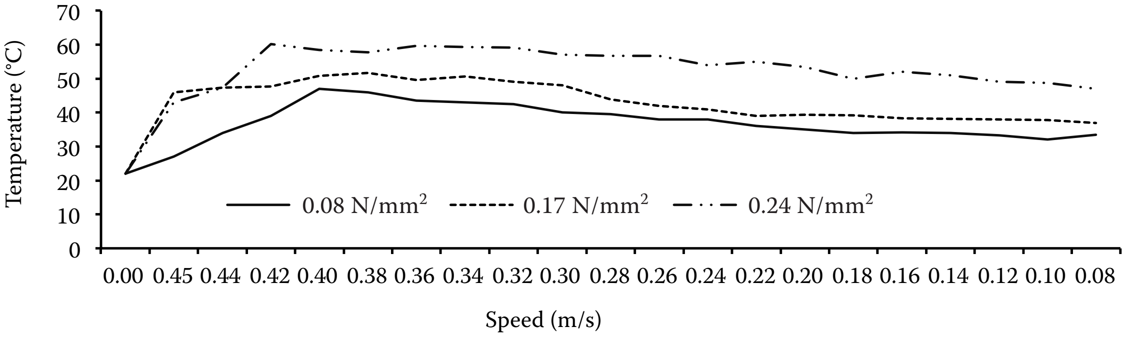

Fig. 3. Influence of load on the temperature on the boundary between the tested specimen and the abrasive cloth

cess. However, at higher load the optimum cohesiveness of phases was no more kept. The decrease of the microparticles presence on the worn out surface was confirmed by the optical analysis of the phases presence, when at the load of 0.24 N/mm^2 the filler amount decreased on average by 6% compared to the lowest load.

The rough estimate of the heat generated in the course of the tribological test is evident from Fig. 3. It shows the concrete thermal curves of the composite No. 5 with chips from ferrous metals at different loads. The dependence between the measured temperature, load and tested specimen speed at all composite systems was clearly proved.

DISCUSSION

The results of the carried out experiments do not indicate the influence of different size of microparticles – chips from ferrous metals – and their different distributional sizes on the final abrasive wear resistance. The experiments proved the increase of the wear resistance caused by the presence of the hard inorganic particles in the polymeric matrix described by authors (Satapathy, Bijwe 2002; Basavarajappa et al. 2010; Müller, Valášek 2012). In composites on the basis of ferrous metals chips the evident influence of load on the volume losses amount was proved – at the load increase from 0.08 to 0.24 N/mm^2, 12.4 fold increase of the volume losses occurred on average. At the SiC/Epoxy composite this increase was 7.5 fold, at the Epoxy resin without filler 1.6 fold and at steel 1.9 fold. In accordance with the Tenenbaum (1976) conclusions it is possible to speak about the exponential dependence. The sharp increase of the volume losses at higher load testifies to a disturbed strength of the boundary polymeric matrix – particle filler – the microparticles breaking out occurs. This fact was confirmed by the optical analysis of the worn out surface. Compared with the resin without filler the composites filled with chips from ferrous metals at the load of 0.08 N/mm^2 have in average 23.5 fold better wear resistance, at the load of 0.24 N/mm^2 it is only 3 fold better. Compared with the used steel at the load of 0.08 N/mm^2 these composites have wear resistance lower of 40%, while at 0.24 N/mm^2 they have it lower of 91% on average. Temperature was measured as one of the factors influencing the tribological properties of polymers. Evident temperature increase was proved with the increasing load. The max. average temperature measured on the boundary between the composite containing chips from ferrous metals and the abrasive cloth was 43°C at the lowest load and 60°C at the max. load (increase of 40%).

CONCLUSION

The described experiment extents the knowledge of authors (Müller et al. 2011; Valášek et al. 2012), as except for the utilization of scrap fillers – chips from ferrous metals – it describes also the behaviour at different loads. This contribution can be used as the basis at the seeking of suitable application mediums not only in the field of agricultural production, e.g. renovation of some parts of ploughs, screw conveyors, vanes, but at making of wear resistant composite layers on floors, grates and machines etc.

- The carried out experiment confirmed the hypothesis of the wear resistance increase using the particle filler on the basis of the ferrous metals chips.

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- The carried out experiments determined the dependence between the composite wear resistance and the load.
- The described utilization of chips from ferrous metals corresponds to the inexpensive material recycling, when chips cannot be utilized in many cases in another way.

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