COMPOSITE BASED ON HARD-CAST IRONS UTILIZED ON FUNCTIONAL PARTS OF TOOLS IN AGROCOMPLEX*

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The paper describes a two-body abrasion of a polymeric reactoplastic composite filled with microparticles of cast irons which is wear-resistant and suitable for an easy renovation of functional areas of machines and equipments used in agricultural production and elsewhere. The wear process is described by means of two abrasive cloths with bound abrasive grains of different grain sizes. A temperature on an interface of worn material was measured as one of factors influencing the wear process. The polymeric composites with microparticles are suitable for increasing the wear resistance. This presumption was also certified from the carried out experiment when it came to considerable decrease of volume losses of filled materials. Filling the reactoplastics-epoxy resins with cast iron chips got from the process of the material surface treatment by working is one of possibilities of their effective usage.

hardness; polymers; waste; wear

INTRODUCTION

Degradation and wearing processes affecting the functional parts of machines and equipment are coped with both in animal and plant production. A typical example of the wear in the agrocomplex is the abrasive wear. After reaching the limit wear an exchange or renovation of the worn part should follow. Hardfacing is a common way of renovation in agriculture (Kováč et al., 2010; Müller, Hrabě, 2013). In some cases composite materials based on polymers and a particle filler are used. This paper focuses on the description of the polymeric composite with the microparticle filler on the basis of waste (hard-faced chips). The described system can compete with the traditionally used technologies in the same application areas.

From increasing the polymer abrasive wear resistance point of view micro- and nanoparticles are usually used. Suitable size and shape of the filler particles are defined by the application areas. For the renovation of the machine functional areas microparticles of larger size can be used, but e.g. in materials coming into contact with organisms, from tribomechanical qualities point of view, Davaprakasam et al. (2008) prefer silica SiO_2 nanoparticles which have globular surface allowing to form strong inter-phase bonds. The wear resistance testing of composite systems, owing to its representation in many various branches, is of key importance (Nirmal et al., 2011). Methods of abrasive wear testing of particle composites can be basically divided into two-body abrasion (bound abrasive particles) and three-body abrasion (free abrasive particles).

Extruders are used for filling thermoplastics with micro- and nanoparticles. Zhou, Burkhart (2010) used extruder for dispersing nano-silica Aerosil 90 particles of sizes smaller than 1.0 μm which optimized the mechanical qualities of PP (polypropylen) – 5 wt% of particles increased a tensile strength and an elongation in break by 9%. Also organic types of fillers can be used for optimizing the epoxy resins properties which are cast in the composite production. Ji et al. (2009) increased the epoxy resin impact strength by using egg-shells from 9.7 to 16.7 $kJ \cdot m^{-2}$. Large microparticles of the order of hundreds of micrometers are used for strong increasing of the wear resistance. However, microparticles can initiate cracks formation impacting other mechanical qualities – strength and impact strength. Abenojar et al. (2009) describe the increasing of the strength characteristics of SiC/Epoxy composite by using the apparatus for optimizing the microparticle surface. During the experiment the authors observed a considerable increase in wear resistance of a material which was filled with 6–12 wt% of SiC particles sizing 10 μm. Microparticle

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chips of common carbon steel and SiC for increasing the tribological properties were also used by Valášek, Müller (2012), who described primarily the chips sedimentation process during the resin hardening. According to Müller et al. (2011), in the sphere of agriculture the corundum microparticles can be used together with the epoxy resins for renovation of the functional areas at sugar-beet heads harvesting when it is possible to optimize the soil adhesion to the working body through the polymers surface energy.

Satapathy, Bijwe (2002) also used inclusion of microparticles (5 wt%) sizing 48–100 μm for increasing the wear resistance of phenolic resins. Similar results as at SiC are reached by the use of Al_2O_3 particles of similar size (Valášek, Müller, 2012).

From the stated references the presumption results that the microparticles in the form of cast iron chips increase considerably the wear resistance of the reactoplastics – the epoxy resin. The present study aims to confirm this hypothesis and to quantify the wear resistance increase of such filled epoxy resin. In the experiment different roughness (granularity) of abrasive cloths simulating different abrasive conditions was used. Temperature, a typical factor influencing the wear process of polymeric materials, was observed in the interface of the testing sample as well as in the abrasive cloth.

A clear correlation between the material hardness and the wear resistance results from the works of Satapathy, Bijwe (2002). The carried out experiment aims to certify also the hypothesis that different hardness of the hard-faced microparticles (micro-hardness measured by Vickerse) will lead to more considerable increase of wear resistance.

MATERIAL AND METHODS

The epoxy resin Eco Epoxy 1200/324 (DCH Sincolor, a.s., Pilsen, Czech Republic) ($\rho = 1.15$ g·cm^{-3}) was filled with microparticles chips from the material working process. The mixture of the filler and the epoxy resin was prepared by mechanical mixing. The mixture was cast into the silicone rubber forms corresponding in their shape and size to the requirements of the individual standards. Preparation of the compound without vacuum was chosen on purpose and in relation to the sphere of applicability – the agrocomplex (applications with no availability of vacuum in order to reduce expenses are expected). The methodological process of preparation in the ultrasonic tank and hardening of the testing samples in a form made of two-component silicate resin partly eliminates the porosity of composites after hardening. The testing samples were prepared with 25 vol.% of the filler. The filler concentration was set on the basis of the hypothesis that higher concentration will lead to better abrasive wear resistance. However, compared with 25 vol.%, lower concentration of the microparticle filler could improve some mechanical characteristics, but this experiment is focused on the maximum increase of the wear resistance and that is why this concentration was chosen (Valášek, Müller, 2012).

Splinters after machining of various hard-facing alloys were used as the filler. Cutting plates from sintered carbide were applied, no cutting liquid was added during machining (Dry Machining). Described data reflect the progressive technologies where higher cutting speed and minimization of cutting liquids are preferred. The process of machining itself together with chemical and physical properties of the workpiece affect the formation and movement of the taken material in form of splinters (Novák, 2011). Exact chemical composition and metalography description of the used hard-faced chips are not within the scope of this experiment.

Porosity

An important first-class quality of the composite system – porosity (P) was calculated according to the equation (1):

$$P = \frac{\rho_{The} - \rho_{Rea}}{\rho_{The}} \cdot 100 \qquad (1)$$

where:
P = porosity (%)
ρ_{The} = theoretical composite density (g·cm^{-3})
ρ_{Rea} = real composite density (g·cm^{-3}) (Berthelot, 1999).

Abrasive wear

The two body abrasion was tested on a rotating cylindrical drum device with the abrasive cloth of the grain size P60, P120 (Al_2O_3 grains) according to the standard CSN ISO 62 1466 (1985). The testing machine with the abrasive cloth consists of the rotating drum on which the abrasive cloth is affixed by means of a bilateral adhesive tape. The testing specimen is secured in the pulling head and during the test it is shifted by means of a screw moving along the abrasive cloth from the left edge of the drum to the right one. The testing sample is in the contact with the abrasive cloth and it covers the distance of 60 m. During one drum turn of 360° the testing specimen is provoked left above the abrasive cloth surface. Consequent impact of the testing specimen simulates the concussion. The pressure force is 10 N. The mean of the testing samples was 15.5 ± 0.1 mm and their height was 20.0 ± 0.1 mm. The mass decreases were measured on analytic scales (accuracy 0.1 mg). The volume decreases were calculated on the basis of the ascertained volume and the density of the composite systems. The highest temperature value observed in the interface of the testing sample and the abrasive

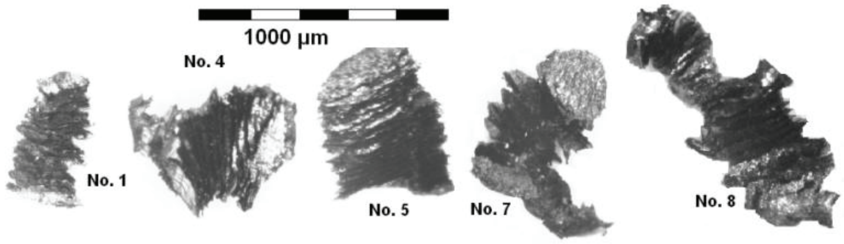


Fig. 1. Morphology of used micro-particles- chip

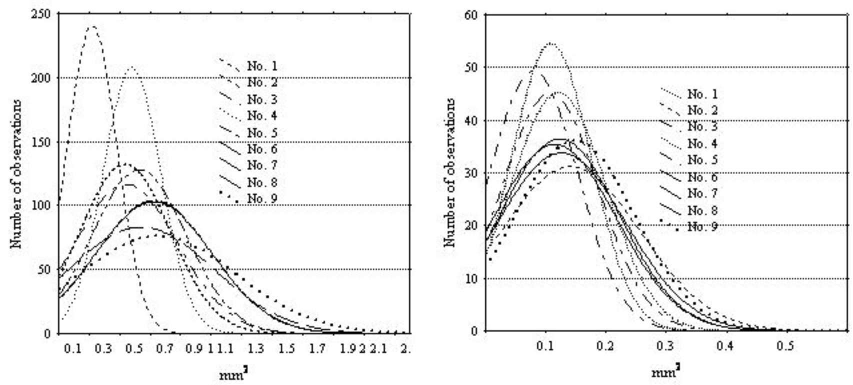


Fig. 2. Histogram - chips size expressed by area in 2D level

cloth was recorded by a contactless thermometer Testo 845 (Testo, s.r.o., Prague, Czech Republic).

Hardness

Hardness determination of the composite systems was based on the standard CSN EN ISO 2039-1 (2000). The tested samples dimensions were 35 × 25 × 9 mm. Because of the size of the filler, a ball of hard metal with the diameter D = 10 mm was used. The tested samples were loaded by the force of 2.452 kN for 30 s.

Hardness of the single phases (matrix and micro-particles – chips) at the testing samples was reviewed simultaneously with microhardness testing according to Vickers (HV 0.2/30). Average values stated in this paper do not contain extremes which would be set aside from the statistical data sets on the basis of normal distribution.

The proportion of single phases and chips dimensions were determined using a stereoscopic microscope (SZP 11-T, Arsenal, Ltd., Prague, Czech Republic) (owing to the chips shape irregularity expressed in 2D flat surface).

The statistical evaluation of the results was carried out through the Analysis of Variance (ANOVA; reliability level $\alpha = 0.05$) of the STATISTICA (Version 9.1, 2010) software package.

RESULTS

The area of chips before casting the composite (A_1) and after tribological tests also the area of chips on the worn area (A_2) were measured using the stereoscopic microscope. Owing to the shape irregularity of single chips the chip area in 2D flat surface (mm^2) was chosen for the size description. Typical morphology of the microparticles – chips is visible in Fig. 1. For the statistical description the normal distribution in the interval of positive values was chosen – see histograms in Fig. 2 – which show the chips size distribution expressed by their area (the histogram on the left defines the particle size before casting the composite, the histogram on the right defines the particle size on the worn area of composites after the tribological tests).

Table 1 presents the mean value of the chips area size (A_1, A_2) together with porosity (P) and real density of the composites. The arrangement of single micro-particles – chips (composite systems) is defined by the size A_1. Except average values of the chips size on the worn area (A_2), the representation of phases (PH) was evaluated expressing the percentage representation of the microparticles on the worn area of the composites (the mean value from all worn areas of composite systems was stated, variation coefficient did not exceed 15%).

Table 1. Density, porosity, size, and representation of phases

Material	ρ_{Rea} (g·cm^{-3})	P(%)	A_1(mm^2)	A_2(mm^2)	PH(%)
No. 1	2.78	8.77	0.218	0.107	36.5
No. 2	2.83	6.00	0.435	0.140	40.7
No. 3	2.80	6.15	0.441	0.106	36.5
No. 4	2.83	2.55	0.478	0.119	36.1
No. 5	2.79	4.96	0.525	0.079	38.7
No. 6	2.81	6.02	0.540	0.122	32.5
No. 7	2.81	2.99	0.622	0.114	32.2
No. 8	2.79	9.04	0.622	0.125	44.2
No. 9	2.78	5.95	0.645	0.148	37.5

ρ_{Rea} = real composite density, P = porosity, A_1 = chips area size 1, A_2 = chips area size 2, PH = representation of phases

Table 2. Hardness

Material	HV (0.2/30)	V_{HV} (%)	HB (250/10/30)	V_{HB} (%)
No. 1	864.23	10.36	18.48	0.01
No. 2	396.00	13.37	18.02	0.12
No. 3	925.77	13.13	17.23	0.01
No. 4	758.18	7.79	17.11	0.10
No. 5	650.38	21.35	20.34	0.05
No. 6	721.67	11.54	20.57	0.02
No. 7	835.75	11.64	19.57	0.04
No. 8	726.00	4.79	19.41	0.03
No. 9	907.60	10.73	17.24	0.07

HV = hardness of microparticles – chips, HB = composite system hardness, V_{HV}, V_{HB} = variation coefficients

Hardness

According to the size of the microparticles, the composite systems hardness was measured using the modified Brinell hardness test. The epoxy resin hardness reached the values of 12.06 ± 1.11 HBW 250/10/30. The microhardness of single phases was measured on the worn area at the same time. The resin hardness reached 8.58 ± 1.65 HV 0.2/30, the values of hardness of the microparticles – chips (HV) and the composite systems hardness (HB) along with variation coefficients (v_{HV}, v_{HB}) are given in Table 2.

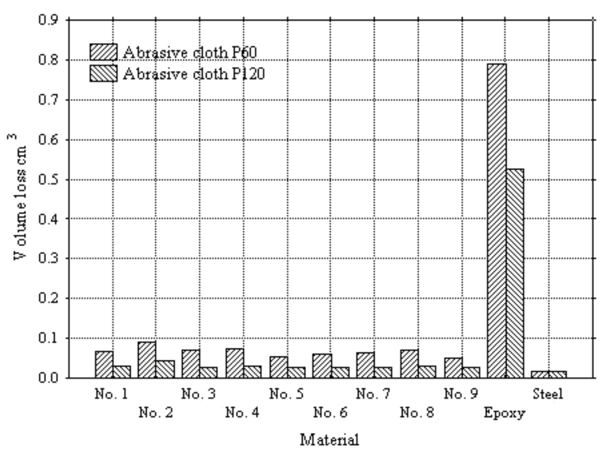
Two-body abrasion

The abrasive wear resistance was evaluated on the cloths of various grain sizes (P60, P120). Fig. 3 (on the left) shows single mean values of the volume losses for both abrasive cloths, in the brackets the variation coefficients of the volume losses for single cloths in the order P60 and P120 are stated. The volume losses of the composites and epoxy resin are for illustration compared with the volume losses of a common carbon steel (210 HV 0.2/30) in the graph. During the experiment the temperature in the interface of the testing samples and the abrasive cloth was measured by the contactless thermometer. Fig 3 (on the right) presents the statistical comparison of the average temperature values measured during the tribological test of the composites for single abrasive cloths. A clear influence of the abrasive cloth grain size on generated temperatures at the composites was proved.

The lowest volume loss of 0.0488 ± 0.0017 cm^3 (P60) and 0.0260 ± 0.0002 cm^3 (P120) was found out at the composite No. 9. On the contrary, the highest volume loss of the composites was recorded at No. 2 – 0.0901 ± 0.0041 cm^3 (P60) and 0.0427 ± 0.0016 cm^3 (P120). The structure of the worn area after the tribological test is visible in Fig. 4.

DISCUSSION

The carried out experiment confirmed the conclusion of A b e n o j a r et al. (2009) who stated the possibility to create wear-resistant composite layers.



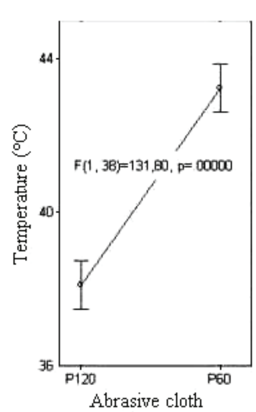


Fig. 3. Two-body abrasion - volume losses (left), temperature (right)

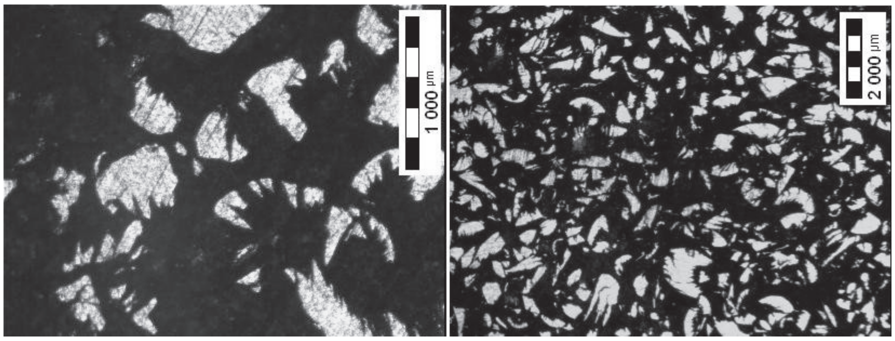


Fig. 4. Typical worn area of composite

Pores in cast systems were proved. It is possible to formulate the hypothesis about lowering the pores occurrence by the change of the production process – using vacuum and mechanical mixers. However, the chosen methodological process reflects the needs of fast and easy renovation of some functional surfaces in the agrocomplex.

Wide distribution size of the microparticles was proved. However, it is not possible to set the clear ratio between the wear resistance and the particle size or the representation of particles (phases) on the worn area.

The phases hardness on the worn area was experimentally determined, however, based on the present experiment the definite dependence between the hardness of the used microparticles and the abrasive wear resistance cannot be set.

The presence of the microparticles – hard-cast irons increased the systems hardness by as much as 70.5% which confirmed the hypothesis of Valášek (2011). However, it is not possible to set a clear correlation between the hardness measured by an imprint of a ball 10 mm in diameter and the two-body abrasion resistance.

The abrasive wear resistance, in accordance with the conclusions of Satapathy, Bijwe (2002) and Müller et al. (2011), grew up by as much as 95% compared with the resin without the filler. Compared with the epoxy resin, all microparticles – hard-cast iron chips analogously increased the abrasive wear resistance, always in the interval of 89–95%. Evaluated composite systems showed smaller wear resistance than common carbon steel.

CONCLUSION

The present experiment confirmed the hypothesis on the substantial increase of wear resistance of reactoplastics containing microparticles. The abrasive wear resistance can be considerably increased by the inclusion of microparticles – hard-cast irons chips. Material recyclation of such type of waste is to be considered. From the carried out experiment it follows that the resulting wear resistance of such a material is a sum of many variables (the hardness of phases and their distribution, the porosity) and its absolute value can be estimated only in a wider interval.

The described materials can be used for easy and fast renovation of functional parts of machines and equipments in the plant as well as animal production: in renovation of some parts of ploughing bodies, screw conveyers, fan vanes or forming resistant composite layers on floors, gratings, and machines to give some examples. However, it is necessary to respect mechanical qualities of these materials in a complex way.

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