MECHANICAL PROPERTIES OF MULTI-COMPONENT POLYMERIC COMPOSITE WITH PARTICLES OF AL_2O_3/SIC*

J. Kejval, M. Müller

*Czech University of Life Sciences Prague, Faculty of Engineering, Prague,
Czech Republic*

Composite materials, due to their specific properties, are widely applicable in many industrial branches. They consist of minimally two components influencing their resulting properties. Properties required for a given application can be reached by a combination of the individual components. During the presented experiment, microparticles of Al_2O_3 and SiC were added into the composite material in order to improve mechanical properties (wear resistance, hardness, and tensile properties) of a suggested composite system. Composite materials were prepared using various ratios of individual components of Al_2O_3 and SiC and various particle sizes with the aim to set an optimum proportion of the components in dependence upon the required mechanical quality. Such composite systems can be utilized e.g. for a renovation of agricultural machines and machine parts. To verify the procedure in practice, a chosen composite system was applied on the knives of a rotary cultivator and their service life was compared with that of standard knives.

Epoxy resin; filler; tensile strength; testing; wear

INTRODUCTION

Composite materials can be defined as heterogeneous materials composed of two or more phases which considerably mutually differ in their mechanical, physical, and chemical properties (Suresha, Ravi Kumar, 2011). There are two phases in the composite material – a matrix and a reinforcement. The discontinuous phase is called a filler and the continuous one is called a matrix. A possibility to create composite layers firmly connected with a basic material belongs among untraditional ways of creating new functional surfaces. A basic presumption for an optimum choice of materials and their prospective combination is the knowledge of their behaviour and mutual interaction (Kučera, Chotěborský, 2013).

E.g. Satapathy, Bijwe (2002) dealt with abrasive wear and tensile strength of various composite systems based on a resin filled with particles of Al_2O_3 with sizes up to 150 μm. They observed an influence of loading, particle sizes, speed of abrasion, and their mutual interactions on the abrasive wear. The wear was most affected by loading whereas speed had minimum influence. A three-body abrasion wear of a polymeric particle composite was dealt with by Basavarajappa et al. (2010) who reached significant improvement at filling with SiC particles.

Galusek et al. (2007) described a combination of micro- and nanoparticles of Al_2O_3/SiC leading to the improvement of both tensile and impact properties of a tested composite system by 8%, however, it did not represent any considerable improvement if compared to using solely Al_2O_3.

The aim of the experiment was to improve mechanical properties of the polymeric composite system by adding the Al_2O_3 and SiC microparticles of various sizes and in various mutual ratio combinations. Mechanical properties such as wear resistance – three-body abrasion, hardness, and tensile properties were investigated. Composite materials were prepared with various ratios of individual components of Al_2O_3 and SiC using various particle sizes with the aim to determine the optimum representation of the individual components in dependence upon the required mechanical properties and their mutual interactions. Composite systems filled with microparticles can be exploited e.g. in renovation of agricultural machines and machine parts or in adhesive bonding and cementing of larger complexes as stated by Müller et al. (2011), Valášek (2011), and Müller, Valášek (2012) and Valášek, Müller (2013). The composite systems can be utilized in the area of renovation as well as an overlaying material (Müller, Hrabě, 2013) and Valášek, Müller (2013).

---

* Supported by the Internal Grant Agency of the Technical Faculty of the Czech University of Life Sciences Prague, Project No. 2013:31140/1312/3107.

doi: 10.7160/sab.2013.440407

The application of the chosen composite system was practically verified on knives of the rotary cultivator the service life of which was compared with that of standard knives.

MATERIAL AND METHODS

A two-component epoxy resin ECO-EPOXY 1200/324 (DCH Sincolor, a.s., Karlovy Vary, Czech Republic) on the basis of bisphenol A hardened with the hardener P11 (DCH Sincolor, a.s., Karlovy Vary, Czech Republic) was used as the matrix for the evaluation of the influence of the particles size and their concentration ratio on mechanical properties of the polymeric particle composite. Al_2O_3 and SiC with the 30% total volume amount of the filler were added into the composite as the reinforcing phase. Ratios between the individual fractions of Al_2O_3 (F80) and SiC (F60, F80, F100, and F240) were chosen as follows: 1 : 5 and 5 : 1 (Al_2O_3 : SiC). The expression of the filler amount in the matrix in the volume % (volume ratio) prevents the influence of a different density of the matrix (the density in the unhardened state stated by the producer is 1.15 $g \cdot cm^{-3}$) and the filler. The particles size of Al_2O_3 of the fraction F80 was 185 *μm* and the size of SiC particles ranged according to the producer and in dependence on the fraction from 260 *μm* for the fraction F60 to 58 *μm* for F240.

The preparation of the composite systems consisted in mixing the epoxy resin and the particle filler which was always done in the same way in order to secure the reproducibility of the results. It came to mechanical mixing of the mixture in a plastic vessel which was placed in an ultrasonic tank where a mechanical waving contributed to a homogeneous dispersion of the filler particles in the matrix and minimized the rise of air bubbles which could negatively influence the required mechanical properties.

Then test samples were cast into prepared forms which corresponded to given standards by their shape and sizes. The forms were made from a material Lukopren N according to prepared steel casting pattern.

A picture analysis carried out by a stereoscopic microscope by means of a built-in camera and Quick Photo Industry software was used for finding out shapes, sizes, and edge angles of the filler particles. Individual sizes and areas of the particles were measured in 2D flat.

Abrasive wear resistance (three-body abrasion) was tested according to the CSN 62 1466 (1993) technical standard on a device with a rotating drum (Fig. 1) on which abrasive cloths of P120 and P220 grain size were gradually placed. The test samples shape was a 20 ± 0.1 mm high cylinder with 15.5 ± 0.1 mm in diameter. The ends of the test samples had been adjusted before the test so that they corresponded to the radius of the test cylinder and thus the test samples touched the cloth by the whole bottom area at the same time. The test samples were pressed to the abrasive cloths by the pressure of 10 N and during the whole time of the test they covered a distance of 60 m on one cloth.

Hardness was experimentally measured using a method of Brinell, in accordance with the CSN EN ISO 2039-1 (2003) technical standard, on samples sizing 35 × 20 × 10 mm loaded by 2.452 kN force for 30 s. A ball 10 mm in diameter made of hard metal was used as a penetrating indentor.

For setting tensile properties according to the CSN EN ISO 527-1 (1997) standard, the test samples of sizes given by the CSN EN ISO 3167 (1997) standard were prepared.

RESULTS

The size of the particles was measured using the picture analysis on an optical microscope by means of

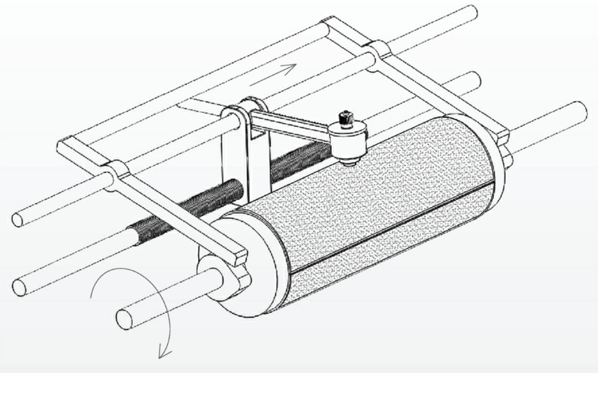


Fig. 1. Device for abrasive testing of polymeric materials

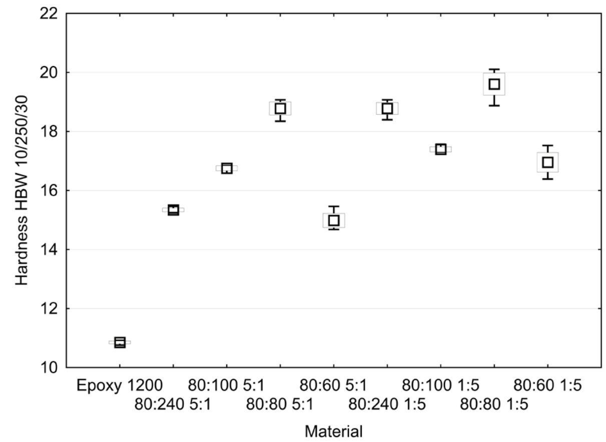


Fig. 2. Hardness

Table 1. Statistical comparison of mean values - Tukey‘s HSD test

Composite	Abrasive cloth	Arithmetical mean (cm^3)	Agreement of measured sets							
			1	2	3	4	5	6	7	8
80:60/5:1*	P 220	0.009933	*							
80:80/5:1	P 220	0.010367	*							
80:100/5:1	P 220	0.013067	*							
80:240/5:1	P 220	0.014967	*	*						
80:80/1:5	P 220	0.016700	*	*						
80:60/1:5	P 220	0.021733	*	*	*					
80:60/1:5	P 120	0.024867	*	*	*	*				
80:80/5:1	P 120	0.034333	*	*	*	*	*			
80:60/5:1	P 120	0.034367	*	*	*	*	*			
80:100/5:1	P 120	0.037333	*	*	*	*	*			
80:240/1:5	P 220	0.043233	*	*	*	*	*			
80:80/1:5	P 120	0.050633		*	*	*	*			
80:240/5:1	P 120	0.055733			*	*	*			
80:100/1:5	P 220	0.061033				*	*			
80:100/1:5	P 120	0.065233					*			
80:240/1:5	P 120	0.134367						*		
Epoxy 1200	P 220	0.346867							*	
Epoxy 1200	P 120	0.522800								*

*Ratios between the individual fractions of Al_2O_3 (F80) and SiC (F60, F80, F100, and F240) were chosen as follows: 1 : 5 and 5 : 1 always in the order Al_2O_3 : SiC.

the built-in camera (SZP 11-T, Arsenal, Ltd., Prague, Czech Republic) equipped with Quick Photo Industry program. The measured size of the Al_2O_3 particles was 145 ± 23 *μm* (fraction F80), while the SiC particles sized 416 ± 78 *μm* (fraction F60), 276 ± 41 *μm* (F80), 252 ± 51 *μm* (F100), and 61 ± 15 *μm* (F240). Porosity of the test samples arising during their preparation was determined, too. It did not exceed 10% at all the prepared composite systems. Theoretical density of the composite systems ranged 1.8–2.0 g·cm^{-3} and the matrix (epoxy resin) density in the unhardened state given by the producer was 1.15 g·cm^{-3}.

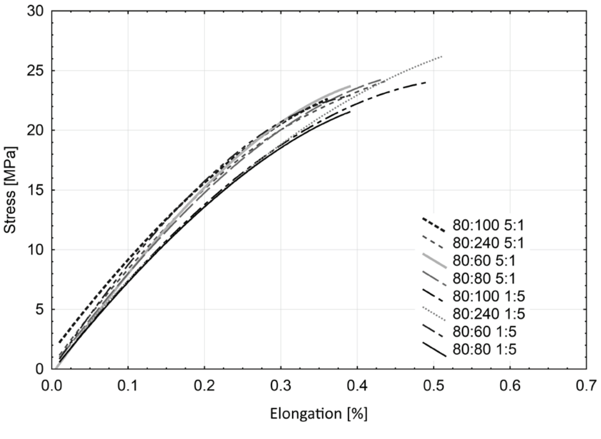


Fig. 3. Tensile strenght

Fig. 2 shows the dependence of the hardness according to Brinell on the concentration and the ratio of the components in the composite systems. The highest measured hardness was at the composite systems with the content of Al_2O_3 of F80 and SiC of F80 in the ratio 1 : 5 which amounted to 18.8 ± 0.31 HBW. Hardness increase was 58% compared with resin without the filler.

Fig. 3 shows the tensile curves from the test of the tensile strength. The highest tensile strength measured (25.48 ± 1.09 MPa) corresponded to the composite systems with the content of Al_2O_3 of F80 and SiC of F240 in the ratio 1 : 5, i.e. with the highest content of the smallest grains of SiC. The lowest average value of tensile strength measured was 19.71 ± 1.21 MPa and the difference between the lowest and the highest values was 23%. Tensile strength of the unfilled epoxy resin was 42.58 ± 1.28 MPa.

Fig. 4 shows the results of measuring the three-body abrasion. The volume losses for the epoxy resin without the filler were 0.3473 ± 0.0017 cm^{-3} for the cloth P220, and 0.5198 ± 0.0021 cm^{-3} for the cloth P120. The smallest volume loss for the cloth P220 was at the composite systems with higher content of Al_2O_3, in the ratio 5 : 1 (Al_2O_3 : SiC) at the composite 80 : 60 (volume loss 0.011 ± 0.0025 cm^{-3}), at the composite

Table 2. Measurement of rotary cultivator knife wear

	Before test		After test	
	with composite	without composite	with composite	without composite
Sizes [mm]	72	70	52	44
Mass [g]	930	900	830	740

80 : 80, 80 : 100, and 80 : 240. The smallest measured volume loss for the cloth P120 was 0.024 ± 0.0025 cm^{-3} at the composite 80 : 60 with the 1 : 5 ratio.

Tukey's HSD test was used for the statistical comparison of the mean values. Table 1 presents the particular means in statistically homogeneous groups. There is not a direct dependence among the tested composite systems from the viewpoint of homogeneity of arithmetical means.

The composites in the ratio 80 : 60/5 : 1, 80 : 80/5 : 1, 80 : 100/5 : 1, 80 : 60/1 : 5, 80 : 80/1 : 5, 80 : 100/1 : 5 at using the abrasive cloths P220 and P120 can be regarded as statistically homogeneous groups. From

Fig. 4. Abrasive wear resistence-volume losses

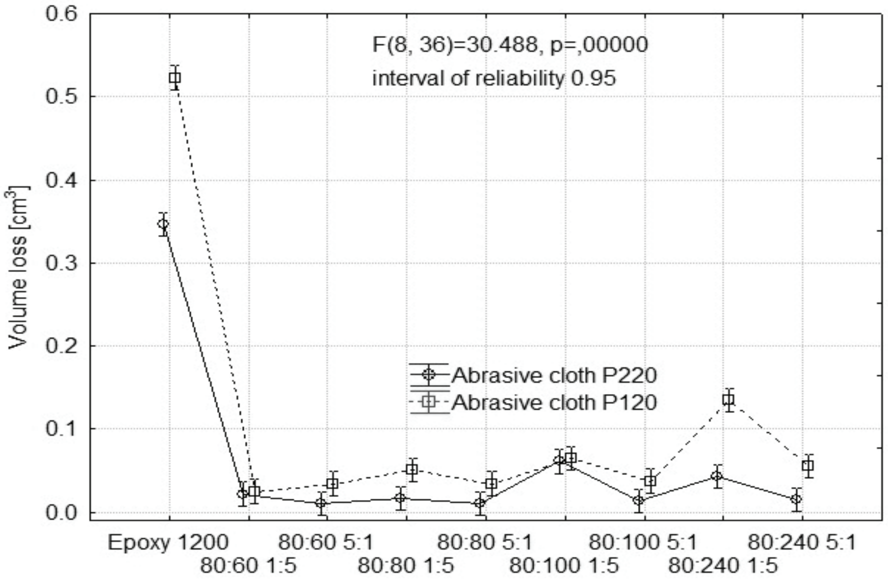
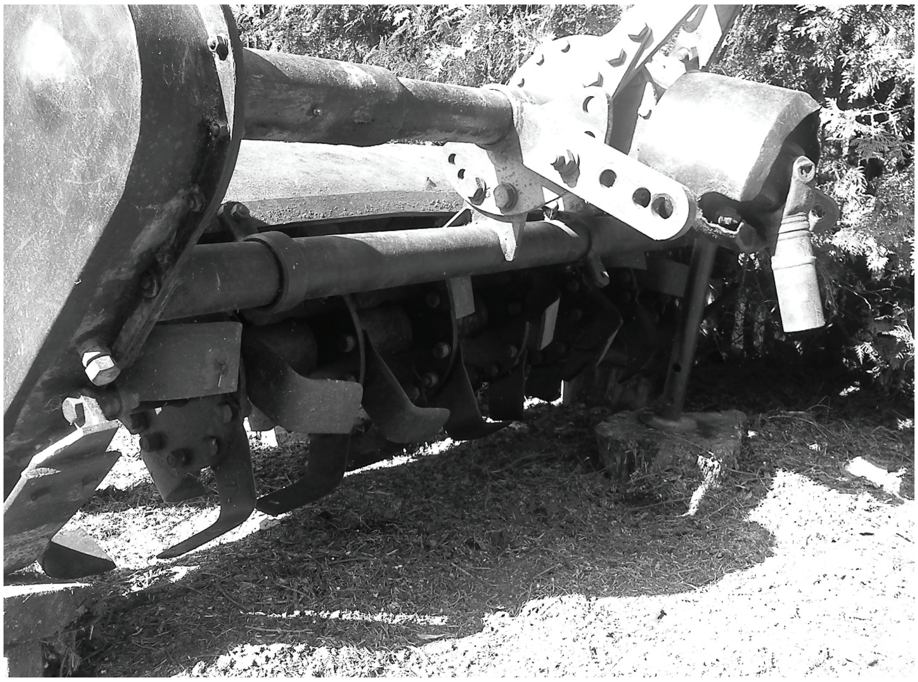


Fig. 5. Applications of particle composite on working part of rotary cultivator



the statistical point of view, there is not a considerable difference among these composites when applying various abrasive cloths (P220 and P120). The epoxy adhesives are considerably different groups exhibiting inhomogeneity as concerns various abrasive cloths.

Functional surfaces of working parts of agricultural machines are suitable for testing the composite systems application. On the basis of the laboratory measurements the composite system showing the best properties (mainly the best abrasive wear resistance significant especially on the working parts in the contact with the soil) was chosen.

To verify the results in practice, the particle composite system with the ratio 1 : 5 of Al_2O_3 of F80 and SiC of F60 was applied on the knives of a rotary cultivator connected to a tractor (Fig. 5). Testing was carried out on a 5 ha area of sandy and clayey soil; for size and mass losses see Table 2. The knives wear was evidently reduced, the mass loss decreased by 8%, and size loss (width of the knives) by 9%.

DISCUSSION

The results of the tensile strength test agreed with the authors' conclusions describing aggravation of the tensile properties at reactoplastics filled with microparticles, where the tensile strength lowered with the increasing size of the particles added to the composite system (Valášek, Müller, 2010).

The measurement results confirmed the presumption of a considerable decrease of the volume losses at the composite systems filled with Al_2O_3 particles previously formulated by Satapathy, Bijwe (2002) and Valášek, Müller (2010).

CONCLUSION

The results of the carried out experiments aimed at mapping the influence of added Al_2O_3 and SiC particles of various sizes and in various mutual ratio combinations into the epoxy resin can be summarized as follows:

- Significant increase of hardness in a majority of the tested composite systems containing larger SiC grains (size 250 μm and more), hardness increase by 58% compared with a matrix without the filler.
- Decrease of tensile strength by 40% at all composite systems, difference among the individual concentration ratios making 23%.
- At the three-body abrasion wear, the systems combining a higher content of Al_2O_3 with SiC were the most resistant – if compared with the unfilled epoxy resin, they exhibited by as much as 98% higher resistance.
- Possible application of the chosen concentrations of the particle composites on the agricultural machines working parts and elongation of their service life was verified.
- At the application on the rotary cultivator knives the wear was decreased by 8%.

REFERENCES

Basavarajappa S, Joshi AG, Arun K, Kumar AP, Kumar MP (2010): Three-body abrasive wear behaviour of polymer matrix composites filled with SiC particles. Polymer-Plastics Technology and Engineering, 14, 8–12. doi: 10.1080/03602550903206407.

CSN 62 1466 (1993): Rubber. Determination of abrasion resistance using a rotating cylindrical drum device. Czech Standard Institute, Prague.

CSN EN ISO 527-1 (1997): Plastics – Determination of tensile properties – Part 1: General principles. Czech Standard Institute, Prague.

CSN EN ISO 3167 (1997): Plastics – Multipurpose test specimens. Czech Standard Institute, Prague.

CSN EN ISO 2039-1 (2003): Plastics – Determination of hardness – Part 1: Ball indentation method. Czech Standard Institute, Prague.

Galusek D, Sedláček J, Riedel R (2007): Al_2O_3-SiC composites prepared by warm pressing and sintering of an organosilicon polymer-coated alumina powder. Journal of the European Ceramic Society, 27, 2385–2392. doi: 10.1016/j.jeurceramsoc.2006.09.007.

Kučera M, Chotěborský R (2013): Analysis of the process of abrasive wear under experimental conditions. Scientia Agriculturae Bohemica, 44, 102-106. doi: 10.7160/sab.2013.440206.

Müller M, Hrabě P (2013): Overlay materials used for increasing lifetime of machine parts working under conditions of intensive abrasion. Research in Agricultural Engineering, 59, 16–22.

Müller M, Valášek P (2012): Abrasive wear effect on polyethylene, polyamide 6 and polymeric particle composites. Manufacturing Technology, 12, 55–59.

Müller M, Valášek P, Novák P, Hrabě P, Paško J (2011): Overlays and composites application in technology of sugar beet cultivation and harvest. Listy cukrovarnické a řepařské, 9, 304–307.

Satapathy BK, Bijwe J (2002): Analysis of simultaneous influence of operating variables on abrasive wear of phenolic composites. Wear, 253, 787–794. doi: 10.1016/S0043-1648(02)00158-8.

Suresha B, Ravi Kumar BN (2011): Two-body abrasive wear behavior of particulate filled polyamide66/polypropylene nanocomposites. Journal of Applied Polymer Science, 119, 2292-2301. doi: 10.1002/app.32909.

Valášek P (2011): Strength characteristics of polymer particle composites with filler on the basis of waste from mechanical surface treatment. In: Proc. 10th Internat. Scientific Conference on Engineering for Rural Development, Jelgava, Latvia, 434–439.

Valášek P, Müller M (2010): Possibilities of use of mechanical surface treatment waste in form of polymeric particle composite fillers. In: Proc. 9th Internat. Scientific Conference on Engineering for Rural Development, Jelgava, Latvia, 267–270.

Valášek P, Müller M (2013): Polymeric composite based on glass powder – usage possibilities in agrocomplex. Scientia Agriculturae Bohemica, 44, 107–112. doi: 10.7160/sab.2013.440207.

Valášek P, Müller M (2013): Composite based on hard-cast irons utilized on functional areas of tools in agrocomplex. Scientia Agriculturae Bohemica, 44, 172–177. doi: 10.7160/sab.2013.440308.

Received for publication on June 28, 2012
Accepted for publication on September 8, 2013

Corresponding Author:

Asc. prof. Ing. Miroslav Müller, Ph.D., Czech University of Life Sciences Prague, Faculty of Engineering, Department of Material Science and Manufacturing Technology, Kamýcká 129, 165 21 Prague 6-Suchdol, Czech Republic, phone: + 420 224 383 261,
e-mail: muller@tf.czu.cz