POLYMERIC COMPOSITE BASED ON GLASS POWDER – USAGE POSSIBILITIES IN AGROCOMPLEX*

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Polymeric composites can simply enlarge utility properties of adhesives – resins, and not only in the agrocomplex. The paper focuses on the composite system whose matrix was created from a two-component epoxy resin and glass powder was used as the filler. The composite system shows the increase of the abrasive wear resistance at preserving adhesive and cohesive characteristics and so it is predetermined for the application in the sphere of cementing and adhesive bonding of large units where the machine strength and given wear resistance at good resistence against various types of degradation agents are required. From this point of view such composite systems are suitable for cementing and easy renovation in the sphere of the agrocomplex both in plant and animal production. The filler inclusion into the epoxy resin did not decrease the adhesive and cohesive characteristics, it increased wear resistance up to 38% and hardness up to 56%, but it reduced impact strength about 70%. For statistical evaluation, STATISTICA software package (one-factor ANOVA) was used, reliability level $\alpha = 0.05$.

abrasive wear; composite systems; hardness; impact strength

INTRODUCTION

Adhesive bonding strengthens its position in a number of industrial branches. In agriculture, for instance, the cooperation of the companies Henkel and New Holland can be mentioned. Material recyclation is a generally preferred form of using waste. Glass powder is a product of processing glass cullets from the sorted collection of packing glass. One of possibilities of glass powder exploitation is its mutual interaction with various types of polymeric materials which simply enlarge utility properties of adhesives.

The aim of the carried out experiments is to verify a hypothesis that application of the anorganic filler (glass powder) improves some mechanical qualities of resin while preserving cohesive and adhesive characteristics. Lap-shear strength of bonded assemblies was chosen for determination of the adhesive and cohesive characteristics of the system. Mechanical qualities were characterized by porosity, hardness, abrasive wear resistance (two-body abrasion), and impact strength. The hypothesis of preserving cohesive and adhesive qualities e.g. at the increased hardness and wear resistance of the composite opens the door for its application in the agrocomplex, where bonding, cementing, and surface renovation of materials by means of filled resins have already been used. Müller et al. (2011), among others, mentioned the possibility to replace common renovation procedures by these systems in the sphere of functional parts of harvesters and other agricultural equipments (e.g. plow systems, screw conveyors etc.). They saw possible application in the technology of sugar-beet growing and harvesting. According to these authors, in the sphere of sugar-beet growing technology, namely composite systems with the polymeric matrix and fillers on the basis of Al_2O_3 microparticles (corundum) can be used. The epoxy resins are able to resist many degradation agents which is a suitable property for the use in agrocomplex sphere (Ducháček, 2006).

Using glass waste is based on the sorted collection. The glass powder production technology uses sorted glass cullets of mainly packing glass which is not contaminated and does not influence by its properties the required quality of the arising product. For milling the glass, e.g. a ball mill can be used, a separation of undesirable admixtures is carried out on rotary screens. The glass powder can be also gained by milling the glass fibres. A secondary raw material arises by these technological procedures which puts across, owing to its mechanical and chemical-physical properties, in many industrial spheres – production of foam glass, roof coverings, colours. The glass powder is suitable not last for filling the polymeric materials. Just mutual interaction of the polymeric matrix and the filler in the form of the glass powder specifies the resulting properties.

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K u et al. (2010) and K u (2012) tested the epoxy and phenolic resin filled with the glass powder for the purpose of optimizing the composite tensile and bending strength. The epoxy resin can be also filled with the glass beads hundreds of micrometers in size. V a l á š e k (2011) stated that the presence of the glass beads sizing 119 μm in the epoxy resin did not decrease the lap-shear tensile strength of overlapped adherents. According to K i m et al. (2008) and P a r k et al. (2006), the polymeric materials filled with microparticles of anorganic types of fillers can also exhibit increased abrasive wear resistance.

MATERIAL AND METHODS

The Refaglass glass powder of particles smaller than 90 μm was used in the described experiment. Table 1 shows the composition given by the producer (Recifa a.s., Prague, Czech Republic), with organic dirt admixture not exceeding 1%.

The two-component epoxy resin Eco-Epoxy 1200/324 (DCH Sincolor, a.s., Karlovy Vary, Czech Republic) played the matrix function. The tested samples were prepared with variable volume percentages (concentration) of the filler in the matrix (5–40%). The 40 vol.% of the glass powder used in the epoxy resin was limiting from the viewpoint of possible application of the mixture (high saturation of the resin by the filler). The tested samples were casted into forms made of two-component silicone rubber. Formation of air bubbles during the mechanical preparation of the mixture (mixing) was eliminated in an ultrasonic vat. Hardening was carried out according to technological requirements of the resin producer.

Theoretical density of the composite systems was calculated on the basis of the physical relationships, the actual density was determined on the basis of the ratio of weight and volume of the trial objects (B e r t h e l o t , 1998). An important first-class quality factor of the composite system – porosity (P) – was ılculated 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 ($g \cdot cm^{-3}$)
ρ_{Rea} = real composite density ($g \cdot cm^{-3}$)

Hardness of the composite systems was determined according to the CSN EN ISO 2039-1 (2000) standard. The size of the tested specimens was 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 30 s.

The two-body abrasion was tested on a rotating cylindrical drum device with the abrasive cloth of the grain size P120, P220, P400 (Al_2O_3 grains) according to the C S N I S O 6 2 1 4 6 6 (1985) standard. 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. The testing specimen is in the contact with the abrasive cloth and it covers the distance of 60 m. During a single 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 thickness of the testing specimens was 15.5 ± 0.1 mm and their height was 20.0 ± 0.1 mm. The mass decreases were measured on analytic scales weighing with the accuracy of 0.1 mg. The volume decreases were calculated on the basis of the found out volume and the density of the composite systems.

Table 1. Chemical composition

SiO_2	Al_2O_3	CaO	MgO	Na_2CO_3	K_2O
71%	1.7–2%	9–11%	0.5–1.5%	14–15%	0.5%

For the lap-shear strength description at the adherent – composite system boundary 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 90°. In this way the average surface roughness (Ra) of 1.79 ± 0.24 μm was reached. Then the surface was cleaned and degreased using perchlorethylene and prepared for the composite mixture application.

The impact strength was evaluated according to C S N 6 4 0 6 1 1 (1968) standard. In these destructive tests, the impact strength was determined on the basis of the Dynstat device nr. 283, which expresses a kinetic energy of the hammer needed to crush the tested object without notches in relation to the surface of its diagonal cut.

The appearance of fracture surface and adhesive layers was carried out using a stereoscopic microscope (Arsenal, Ltd., Prague, Czech Republic) (owing to the chips shape irregularity expressed in 2D flat surface).

The results were statistically evaluated using STATISTICA software package (one-factor ANOVA; reliability level $\alpha = 0.05$).

RESULTS

The composite system quality is defined by means of the porosity P. The porosity is caused by the presence of air bubbles in the composite matrix. Also an imperfect wetting of the particle surface or a bad

Table 2. Density, hardness, porosity of composite systems

Filler (%)	ρ_{teo} (g·cm^{-3})	P (%)	Hardness HBW10/250/30
5	1.21	4.3	13.39 ± 0.52
10	1.28	3.6	14.05 ± 0.05
15	1.35	8.6	14.12 ± 0.23
20	1.42	7.9	14.58 ± 0.47
25	1.49	4.7	15.63 ± 0.69
30	1.56	6.3	16.07 ± 0.59
35	1.63	5.5	15.93 ± 0.28
40	1.70	12.4	16.47 ± 0.16

homogeneity can be reflected in the porosity values. The excessive presence of incompactness influences the resulting mechanical properties of the material and it can lead to the initiation of cracks and to a general failure. Table 2 gives the values of porosity, theoretical density, and hardness of the composites (resin density 1.15 g·cm^{-3}, glass powder density 2.5 g·cm^{-3}). Hardness of the resin without the filler corresponded to the value of 10.48 ± 0.60 HBW 10/250/30. Increasing portion of the filler in the matrix raised the hardness values of the composite systems.

Fig. 1 shows the results of lap-shear strength. The tensile strength of overlapped tested samples bonded with the composite systems did not differ statistically significantly in all cases from the tensile strength of the samples bonded with the resin without the filler ($F(8, 45) = 1.078$, $P = 0.395$).

A layer thickness was defined only by the composite system, distance wires were not used. From this reason the layer thickness was increased with the increasing portion of the filler in the matrix owing to the increasing viscosity (from 0.29 ± 0.06 mm (5%) to 0.40 ± 0.14 mm (40%)). Fig. 2 shows the adhesive bond cut. The bond failure was always associated with the composite system failure. Here it was the adhesive failure, i.e. in the interface of the adherent and the composite system. Only the composite systems with 40% of the filler in the matrix showed the combined failure (OSC) in the proportion of ca. 75 AF (Adhesive Failure)+ 25% CF (Cohesive Failure). The example of the combined failure is shown in Fig. 3 where undesirable pores – air bubbles are also visible.

A volume loss of the tested samples – composite systems was calculated on the basis of their theoretical density and the real mass loss. An expression of the wear resistance by means of the volume losses makes it possible to compare materials with various densities. The volume loss of the resin without the filler was 0.53 ± 0.01 cm^3 for the abrasive cloth P120, 0.34 ± 0.02 cm^3 for P220, and 0.21 ± 0.01 cm^3 for P400. Mean values of the volume losses of the composite systems are presented in Table 3 by means of Tukey's HSD test which compares mean values of statistical data sets. Sets of data which are regarded as the same are designated by asterisks. Compared with the resin without the filler, the inclusion of the glass powder decreases in all cases the volume losses of the composite materials, which is visible from the values given in Table 3. In the interval of 5–40 vol.% of the filler in the matrix a clear dependency between the filler amount in the matrix and the volume losses intensity was not proved, see a graphical expression for the abrasive cloth P220 (Fig. 4). Only at the abrasive cloth P120 the mean values of data sets can be regarded the same in the observed interval (a constant course). The temperature at the interface of the tested sample and the abrasive cloth was measured by an infra-red contactless thermometer (Testo 845, Testo, Ltd., Prague, Czech Republic) during the experimental testing of the abrasive wear resistance of the composite systems. The temperature went up proportionally to the increasing grain size of the abrasive cloth: it corresponded to 30.3 ± 0.3 °C for the abrasive cloth P400, 33.7 ± 0.9 °C for the cloth P220, and 36.5 ± 0.3 °C for the cloth

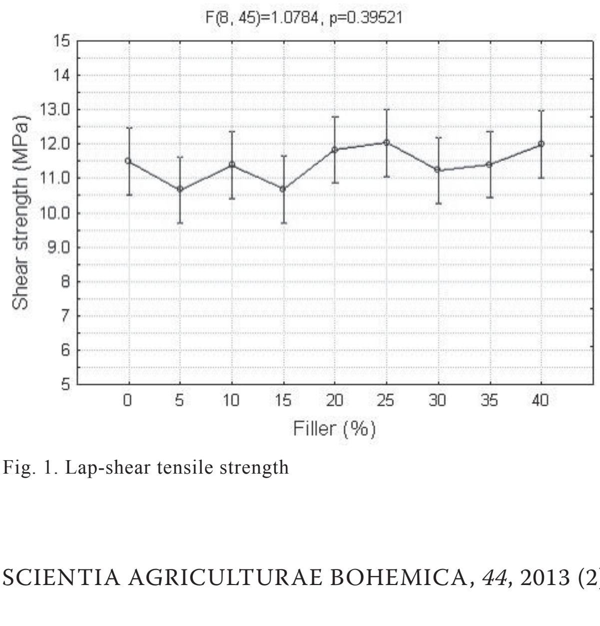

Fig. 1. Lap-shear tensile strength

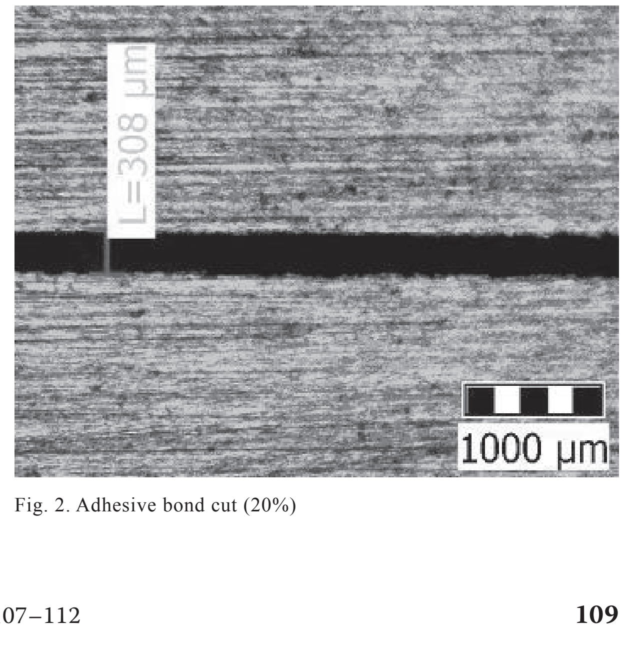

Fig. 2. Adhesive bond cut (20%)

Table 3. Anova - Tukey´s HSD test - volume losses

Cloth P120				Cloth P220						Cloth P400					
%	mean (cm^3)	agreement		%	mean (cm^3)	agreement				%	mean (cm^3)	agreement			
40	0.397515	*		30	0.247516			*		40	0.131313		*		
15	0.402662	*		10	0.262526	*		*		35	0.134927		*	*	
25	0.414772	*		20	0.271952	*	*	*		20	0.141810	*	*	*	
35	0.418868	*		25	0.273607	*	*	*		10	0.143854	*	*	*	
20	0.419976	*		5	0.284848	*	*			25	0.145548	*	*	*	
10	0.420417	*		40	0.285798	*	*			30	0.152397	*		*	
30	0.423551	*		15	0.294055	*	*			15	0.154776	*			
5	0.434601	*		35	0.306417		*			5	0.158959	*			
0	0.527167		*	0	0.347100				*	0	0.218047				*

P120. The mentioned values are the average values from all measurements at each abrasive cloth.

Table 4 presents mean values of statistical data sets of the impact strength indicating that the filler presence in the polymeric matrix deteriorates the resulted impact strength. The impact strength value of the resin without the filler corresponded to 5.22 ± 0.91 $kJ \cdot m^{-2}$. The lowest recorded impact strength equalled to 1.59 ± 0.43 $kJ \cdot m^{-2}$ for the composite with 40 vol.% of the filler. Fig. 5 gives the graphical presentation of the impact strength course.

From the presented results clear decrease of the impact strength with increasing concentration of the filler in the matrix is obvious. In the observed interval of the 5–40% concentration of the filler in the matrix the decreasing trend can be described by the linear function $y = -0.2387x + 3.7665$ ($R^2 = 0.85$). Fig. 6 presents a typical example of the failure area of the tested sample after the destructive testing (impact strength) with visible air bubbles.

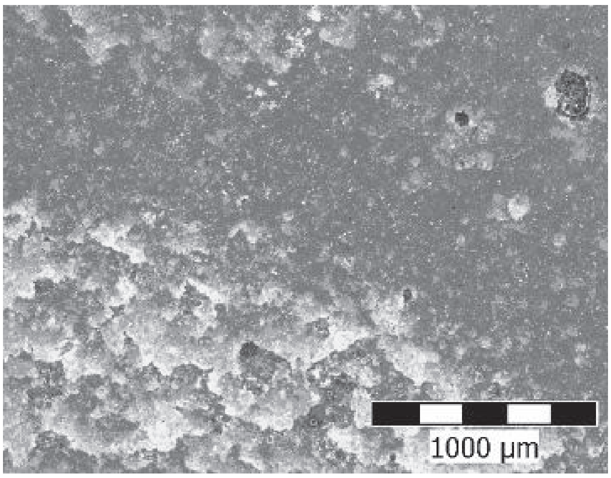

Fig. 3. Combined failure AF+CF (40%)

DISCUSSION

Based on the present experiments, in accord with K i m et al. (2008), it may be concluded that the inclusion of the anorganic particles into the epoxy resins leads to changes in the resin's mechanical properties and qualitatively entirely new materials thus come into being. K i m et al. (2008) ascribe this fact to the mutual interaction among appurtenant items – phases. L e e et al. (2002) encompass namely the interface properties and geometrical and mechanical qualities of the reinforcement into the critical factors which influence the properties (namely the wear resistance) of composite systems with hard anorganic particles. These factors are key also as concerns other mechanical qualities. The chosen procedure of the composites preparation (without using vacuum) reflects the requirement for cheap, easy, and economically acceptable application in the sphere of agrocomplex. The average porosity of the systems corresponded to 6.7%. According to B e r t h e l o t (1998), this porosity is significantly higher than required for high-quality composite systems. The resulting properties of the composite systems can be negatively influenced by the increased values

Table 4. Anova - Tukey´s HSD test - impact strength

%	Mean($kJ \cdot m^{-2}$)	Agreement				
40	1.59				*	
35	1.59				*	
30	2.20	*			*	
25	2.42	*	*			
10	2.62	*	*	*		
20	2.83	*	*	*		
15	3.11		*	*		
5	3.27			*		
0	5.22					*

of porosity but for application in the agrocomplex they are not limiting – the results of the observed characteristics were satisfying.

Cohesive and adhesive characteristics expressed by means of the shear tensile strength of bonded assemblies exhibited no statistically significant change of values at systems with given filler proportion in the matrix as compared to the filler-free resin. Similar results were reached also Valášek et al. (2012) when filling the epoxy resin with glass microballs (106–154 μm in diameter) on the basis of waste. The abrasive resistance of the composite systems was always significantly higher than at the filler-free resin. The volume losses compared with the resin without the filler were reduced by 25% at the abrasive cloth P120, by 30% at P220, and by 38% at the abrasive cloth P400. At the same time, HBW 10/250/30 hardness went up by 56%. Our results confirm the presumptions of Jia, Ling (2005) and Satapathy, Bijwe (2002) using anorganic corundum microparticles for increasing the wear resistance in their experiments. However, when using the glass powder the wear resistance increase is not so considerable as at the artificial corundum, but adhesive and cohesive qualities of the systems are not cut down at once as described by Valášek, Müller (2011) and Valášek et al. (2012) e.g. by the corundum-filled systems. The impact strength values decreased proportionally with the increasing portion of the filler in the matrix, namely of that about 70% compared with the resin without the filler. On the basis of the carried out experiment using other, e.g., polyurethane matrices may be possible.

CONCLUSION

The interaction of the glass powder and the epoxy resin represents an interesting way of the material recyclation which is sensitive to the environment and should be preferred from the Czech legislation point of view. Owing to the above described mechanical qualities and good resistance against degradation agents, the agrocomplex can be one of possible application spheres. Characteristic properties of the composite system based on the glass powder can be summarized as follows:

- increased hardness, abrasive wear resistance at preserving cohesive and adhesive qualities
- decreased impact strength
- acceptable costs, available and easy application.

In the agrocomplex, these materials can assert at renovation of screw conveyors, fan vanes, at cementing and bonding scuttle, cracks in machine boxes, they can serve for planishing welding seams, reparation of small cracks, caulking cracks in tanks, filling splits and microsplits and imperfections, and not last for bonding materials.

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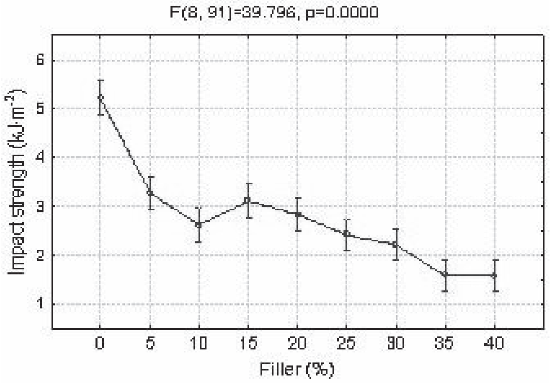

Fig. 5. Course of impact strength values

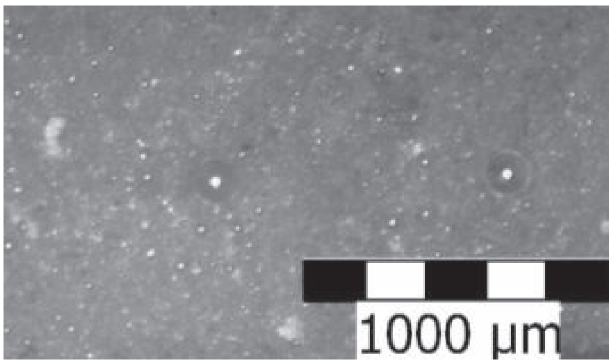

Fig. 6. Failure area (40%)

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