MECHANICAL PROPERTIES OF EPOXY RESINS WITH ORGANIC FILLER – WOOD FLOUR

Petr Valasek, Petr Chocholous
Czech University of Life Sciences in Prague
valasekp@tf.czu.cz

Abstract. Composite materials can be characterized as a material composed of two or more phases and that phases influence each other synergistically. Those materials have become indispensable in many industrial areas, from the aviation to the agriculture where composite materials replace the conventionally used materials such as steel. However, the composite systems find their application in the field of joining dissimilar materials, in the renovation of machine parts etc. This paper describes themechanical properties of composite systems consisting of two phases – epoxy resin and wood flour. One of the benefits of polymer matrix based on epoxy resins is its excellent resistance to the various degradation environments which are in the contact with composite materials in crop and livestock production. Different mechanical and physical properties of individual phases define the properties of the resulting composite. Adding wood flour into the polymer materials can affect the mentioned properties and the resulting price. It is also a good way for the material recycling that complements conventional ways of recycling wood waste. It is inexpensive and sensitive to the environment. The experiment describes the mechanical properties of polymer composite materials with epoxy matrix such as: hardness, impact strength, tensile strength and resistance to abrasive wear. The resulting composite systems may find their application in the field of agriculture – especially during joining and sealing materials of larger units where high quality connections are not required. The experimental results confirm the hypothesis that the interaction between the epoxy matrix and inorganic filler (wood flour) creates a qualitatively new composite system for usage in agriculture.

Keywords: abrasive wear, hardness, impact strength, wood.

Introduction

The aim of the experiment was evaluation the effect of inclusion of wood flour on the mechanical properties of epoxy resins – hardness, impact strength, tensile strength, shear strength of lap solid adherend and resistance to abrasive wear. Adding wood flour into resin creates composite systems.

Composite systems consist of one or more phases with different mechanical, physical and chemical properties, that are in mutual interaction, influence the resulting characteristics and behavior. The individual phases are usually referred as the filler and the matrix. Ehrenstein [1] defines the term matrix as a material which in case of particle systems transforms in the particular component, so that after the processing is done, a product with a fixed form is created. The filler can improve the value of mechanical properties like resistance to abrasive wear, hardness, impact resistance etc. The fillerpresence in the matrix then influences also a number of other features, such as the characteristics of strength, density and cost [2-6].

All parameters influencing the characteristics of composite materials are related either to their structure, or to the relations between phases. The individual phases influence the resulting characteristics of the material by their own characteristics and by the mutual interaction of the matrix and the filler. And it is the interaction between the fractions that enables us to contribute to materials with new qualities [3; 7].

Wood flour is generated by wood processing or its own mining, where bark, branches, sawdust and wood chips are collected and subsequently processed into wood flour. A common way for the recycling wood is chipboard manufacture or burning. Another, less conventional method of recycling wood - material use, is interaction wood flour with different types of polymer materials, such as polyolefins (high density polyethylene).

Kumar et al. [8] in their research summarize the positive properties of polymers filled with wood flour. They stated the low density, availability and biodegradability of organic fillers. The application area of polymers filled with wood flour can be broad: e.g., construction and automotive industries. Wood flour is one of the most accessible organic fillers. Suitable materials for adding wood flour are mainly high-density and low-density polyethylene, linear low-density polyethylene, and polypropylene. The interaction of the filler and polymer under optimum conditions and composition lead to improve the mechanical, chemical and thermal properties of reinforced polymer [9]. Al

Maadeed et al. [10] in their research fulfill recycled polypropylene (RPP) by wood flour and glass fibers. The presence of wood flour increased the tensile strength and elasticity modulus of the composite. These properties were improved by adding another phase – glass fibers. Ou et al. [11] replaced the glass fibers by kevlar fibers, which had a similar positive effect on high-density polyethylene composites filled with wood flour.

Improvement of the modulus of elasticity and flexural strength increase (polypropylene) are also recorded by Ndiaye et al. [12] Similar results - an increased modulus of elasticity for PP filled with wood flour observed Perez et al. [13]. Mosiewicki et al. [14] in his work mentions reducing creep deformation of Oil-Based Polyester thermosets filled by wood flour.

Materials and methods

For carried out experiments the two-component epoxy resin ECO-EPOXY 1200/324 with the curing agent P11 was chosen. The curing time of this resin is 24 hours at 23 ºC. The total curing occurs after 7 days. Epoxy resins are widely used in agriculture [15; 16]. As filler, wood flour was used. Specifically, there were spruce wood particles smaller than 100 µm. Composite systems were prepared with filler volume percentage of 5, 10, 15 and 20 %. The formulation of the filler part by volume eliminates the influence of the different density between the matrix (1.15 $g \cdot cm^{-3}$) and the filler (0.50 $g \cdot cm^{-3}$). The tested samples were casted into forms from two-component silicone rubber. A rise of air bubbles during the mechanical preparation of the mixture (mixing) was eliminated in an ultrasonic vat. Hardening was carried out according to the technological requirements of the resin producer.

As guide for the hardness determination of the composite systems the standard CSN EN ISO 2039-1 was used. The tested specimen dimensions were of 35 x 25 x 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 two body abrasion was tested on a rotating cylindrical drum device with the abrasive cloth of the grain size P220 (Al_2O_3 grains) according to the standard CSN 62 1466. 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 mowing screw along the abrasive cloth from the left edge of the drum to the right one. The testing specimen is in contact with the abrasive cloth and it covers the distance of 60 m. During one drum turn of 360º it is provoked that the testing specimen is 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 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 on 0.1 mg. The volume decreases were calculated on the basis of the found out volume and the density of the composite systems.

For the lap-shear strength description in the boundary adherend – composite system 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 90º. In this way the average surface roughness of Ra = 1.79 ± 0.24 µm was reached. Then the surface was cleaned and degreased using perchlorethylene and prepared to the composite mixture application.

According to the standard CSN EN ISO 527 (Determination of tensile properties) the destructive tests were carried out.

The impact strength was evaluated based on the norm CSN 64 0611. In these destructive tests, the Dynstat device nr. 283 stated the impact strength, which expresses the kinetic energy of the hammer needed to crush the tested object without notches in relation to the surface of its diagonal cut.

The representation of the fracture surface and adhesive layers was carried out using a stereoscopic microscope (owing to the chips shape irregularity expressed in 2D flat surface).

A statistical evaluation of the results was carried out by means of a program Statistica – one factor ANOVA, reliability level $\alpha = 0.05$. For statistical comparison the Tukey's HSD test was used. Statistical matching of the data sets is indicated in the column.

Results and discussion

Wood flour reduced the density of the composite system and its inclusion did not change Brinell hardness significantly according to the values obtained from the resin without fillers, see Tab 1. Table 1 stated the theoretical density of the composite system. Actual density of the composite system can be different according to this value due to the occurrence of air bubbles in the material structure.

Table 1

Density, hardness of composite systems

Filler, %	ρ_{teo}, g·cm^{-3}	HBW10/250/30
0	1.15	11.21 ± 0.53
5	1.12	11.53 ± 0.20
10	1.08	11.89 ± 0.41
15	1.05	12.36 ± 0.44
20	1.01	11.75 ± 0.16

Abrasive wear resistance of the composite systems showed a slight increase of the volume and weight losses compared to resin without fillers, see Fig. 1.

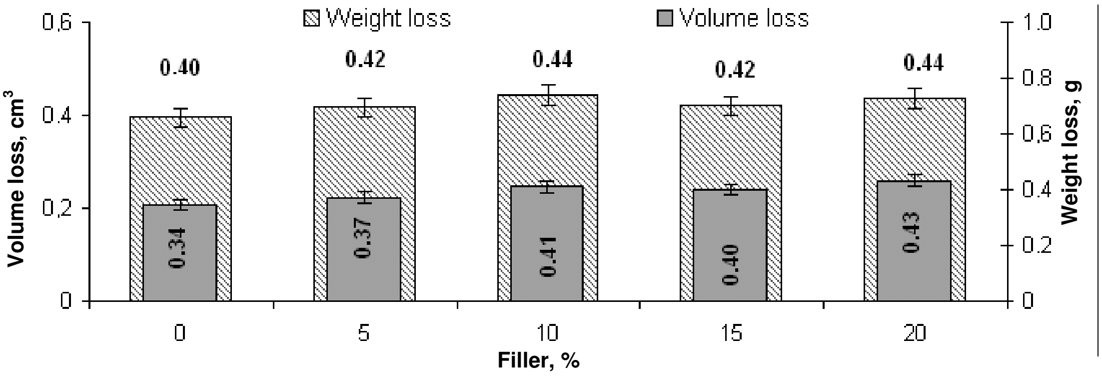

Fig. 1. **Volume and weight losses**

The values of the impact strength of the composites decreased significantly in comparison with the unfilled resin (5.22 ± 0.91 kJ·m^{-2}), see Fig. 1 – statistically comparable with the values of the resin were only composite systems with 5% of filler in the matrix (4.11 ± 1.08 kJ·m^{-2}), see Fig. 1. The measurements were affected by significant errors, which are shown graphically by standard deviations (Fig. 2). The coefficient of variation reached up to 30 %.

%	Mean, kJ·m^{-2}	Agreement		
20	2.547347	*		
15	2.965573	*	*	
10	3.357244	*	*	
5	4.117490		*	*
0	5.217385			*

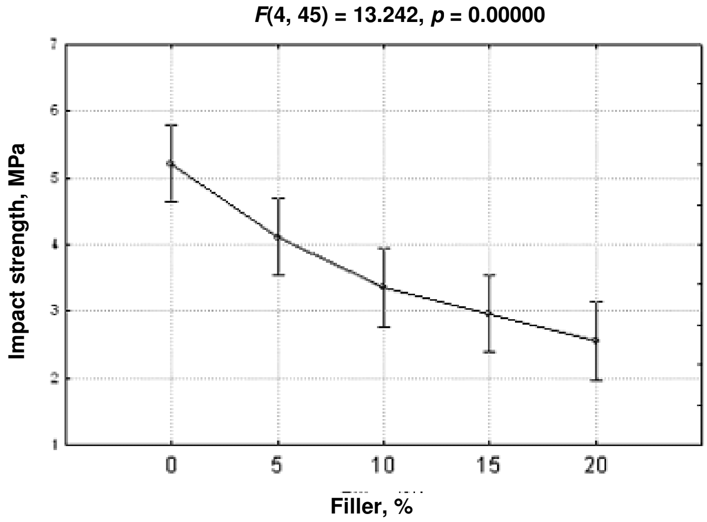

Fig. 2. **Impact strength, Tukey's HSD test (left)**

On Fig. 3 the comparison of the shear strength of rigid adherend is shown. The shear strength of the composite systems was statistically identical in the range 5-20 %. The shear strength of epoxy resin without fillers was always higher (11.48 ± 0.42 MPa).

%	Mean, MPa	Agreement	
20	8.42236		*
15	9.33297		*
10	9.50055		*
5	9.80589		*
0	11.48167	*	

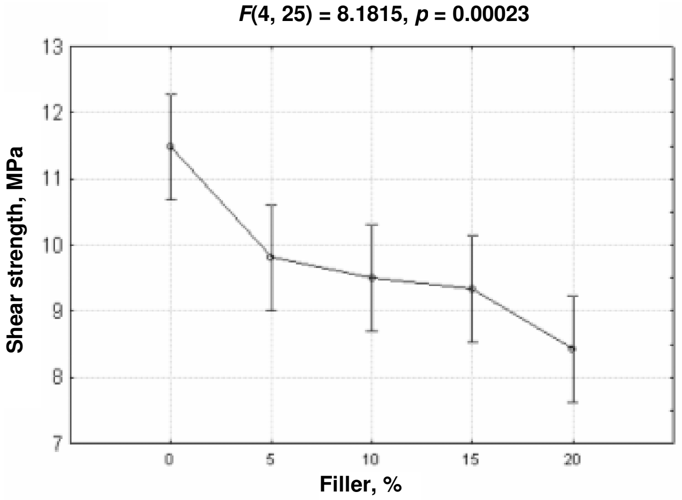

Fig. 3. **Lap-shear tensile strength, Tukey's HSD test (left)**

The fracture surfaces of lap joints were evaluated and these surfaces showed signs of adhesion failure. Due to increasing the proportion of fillers in the matrix bigger gaps between adherend occurred. The mean value of the gap width for the composite systems with 5 % filler matches 0.20 mm, for 20 % 0.7 mm (values measured on stereoscopic microscope, see Fig. 4).

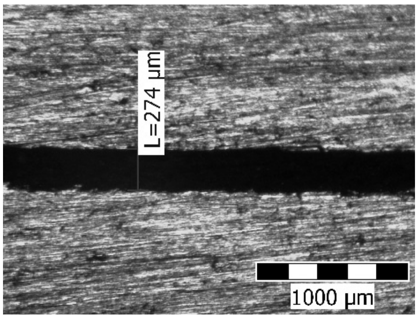

Fig. 4. **Gap width (20%)**

The tensile strength of the specimen representative cohesive characteristics of the composite systems and epoxy resin is shown in Fig. 5.

%	Mean, MPa	Agreement	
20	18.26667		*
15	20.53433		*
10	20.77000		*
5	21.64833		*
0	42.93333	*	

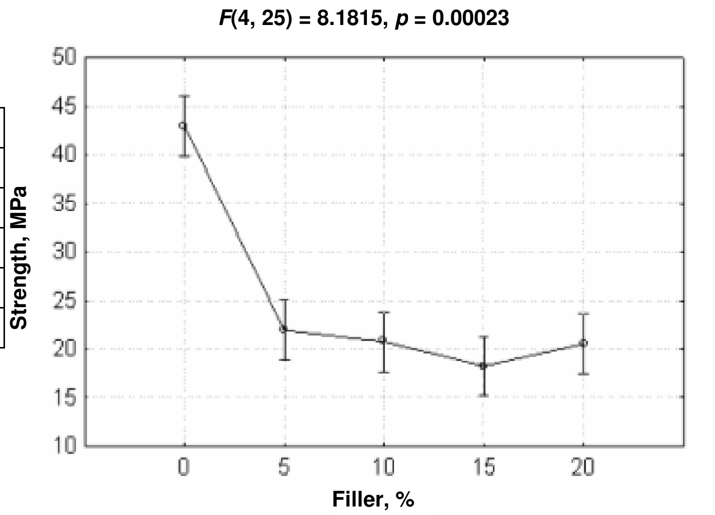

Fig. 5. **Tensile strenght, Tukey's HSD test**

From the Tukey's test it is clear that in the range 5-20 % there are no changes in the values of tensile strength, but also it is clear that all composite systems have significantly lower values of tensile strength than unfilled resin (42.93 ± 1.68 MPa). A typical tensile diagram for the composite system (5 %) and resin without filler is shown in Fig. 6.

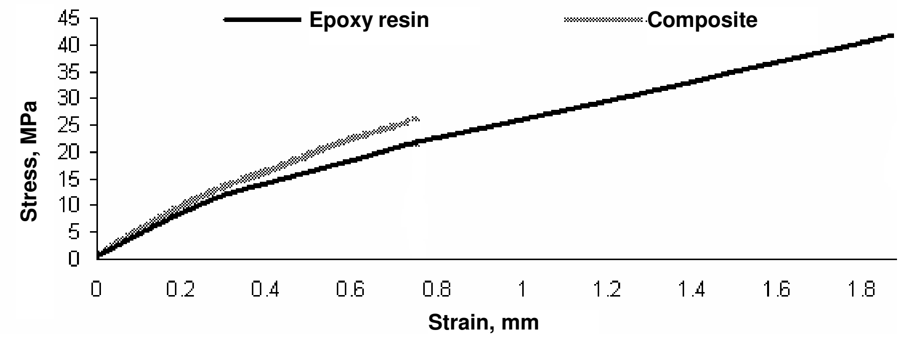

Fig. 6. **Tensile strength diagram**

Conclusion

The experiment did not verify the hypothesis of the authors [8-13], who fill the thermoplastic materials by wood flour. Inclusion of wood flour decreased the impact resistance of the composites compared to the resin without fillers up to 51 %, tensile strength of lap adherend by 27 %, tensile strength representing cohesive characteristics up to 57 %. In the area of hardness and abrasive wear in the interval 5-20 % filler in the matrix significant changes have not occurred compared to resin without filler. The benefits can include reduced cost of composites, i.e., at 20 % of filler 1 $EUR \cdot kg^{-1}$. The assumed price per kilogram epoxy resin is 10 EUR.

Based on the experiment these composite systems can be used in agrocomplex for sealing and bonding larger units that do not require high quality connections, i.e., where the reached mechanical properties of the composite systems are sufficient.

Acknowledgement

This paper has been done when solving the grant IGA TF.

References

1. Ehrenstein G. W. Polymer composite materials. First edition. Prague: Scientia, 2009. 351 p.
2. Kim B.C., Park S.W., Lee D.G. Fracture toughness of the nano-particle reinforced epoxy composite. Composite Structures, Vol. 86, 2008 Elsevier, pp. 69-77.
3. Agarwal D., Broutman J. Fiber Composites. Prague: SNTL, 1987. 294 p.
4. Müller M., Valášek P. Abrasive wear effect on Polyethylene, Polyamide 6 and polymeric particle composites, Manufacturing Technology, Vol. 12, 2012, pp. 55-59.
5. Valášek P., Müller M. Polymeric particle composites with filler saturated matrix. Manufacturing Technology, Vol. 12, Nr. 13, 2012, pp. 272-276.
6. Valášek P., Müller M. Impact strength of polymer particle composites with filler on the basis of corundum waste. In 11th International scientific conference engineering for rural development. Jelgava: LUA, 2012, pp. 304-308.
7. Müller M. Polymeric composites based on Al_2O_3 reinforcing particles. In 10th International scientific conference engineering for rural development. Jelgava: LUA, 2011, pp. 423-427.
8. Kumar V., Tyagi L., Sinha S. Wood flour-reinforced plastic composites: a review. Reviews in chemical engineering, Vol. 27, No. 5-6, 2011, pp. 253-264.
9. Ghahri S., Najafi S.K. et al. Impact strength improvement of wood flour-recycled polypropylene composites. Journal of applied polymer science. Vol. 124, No. 2, 2012, pp. 1074-1080.
10. Al Maadeed M. A., Kahraman R., et al. Date palm wood flour/glass fibre reinforced hybrid composites of recycled polypropylene: Mechanical and thermal properties. Materials & Design, Vol. 42, 2012, pp. 289-294.
11. Ou R., Zhao H., et al.: Reinforcing effects of Kevlar fiber on the mechanical properties of wood-flour/high-density-polyethylene composites. Composites part A-applied science and manufacturing, Vol. 41, No. 9, 2010, pp. 1272-1278.

12. Ndiaye D., Matuana LM. et al. Journal of applied polymer science. Vol. 119, No. 6, 2011, pp. 3321-3328.
13. Perez E., Fama L., et al. Tensile and fracture behaviour of PP/wood flour composites. Composites part B-engineering. Vol. 43, No. 7, Special Issue, 2012, pp. 2795-2800.
14. Mosiewicki M.A., Marcovich N.E., Aranguren M.I. Creep Behavior of Wood Flour Composites Made from Linseed Oil-Based Polyester Thermosets. Journal of applied polymer science Vol. 121, No. 5, 2011, pp. 2626-2633.
15. Müller M. Influence of surface integrity on bonding process. Research in Agricultural Engineering, Vol. 57, No. 4, 2011, pp. 153-162.
16. Müller M., Herák D. Dimensioning of the bonded lap joint. Research in Agricultural Engineering, Vol. 56, No. 2, 2010, pp. 59-68.