IMPACT STRENGTH OF POLYMER PARTICLE COMPOSITES WITH FILLER ON THE BASIS OF CORUNDUM WASTE

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Abstract. Polymeric particle composites are materials, which utilize the synergic effect of their two phases. In this paper, one phase - matrix - is represented by epoxy, the second phase – filler – is represented by a secondary material, corundum - based waste (Al_2O_3). With the merging of these two different components, a qualitatively new material is created, which also utilizes waste and therefore can be viewed not only with material engineering in mind, but also as a possible sensitive way of recycling. Replacing the filler of primary raw material by a filler of secondary material brings the possibility of economical recycling with regard to the environment and as such should be preferred. At the same time, a qualitatively new material is created, the mechanical properties of which must be described to specify the areas of application. The paper describes the often overlooked mechanical property of these systems – impact strength. The study of impact strength here also considers the potential degrading processes the above mentioned system can encounter during its life cycle. One of the possible areas of application of the waste-based polymeric particle composites is the area of agribusiness. For that reason, the media chosen to represent degrading environments were such, which are common in agribusiness.

Keywords: impact strength, polymer particle composites, waste.

Introduction

Composite systems consist of 2 or more phases with different mechanical, physical and chemical properties, the interaction of which influences the final properties and behavior of the product. The phases are most often known as filler (strengthening phase) and matrix (connected phase). Ehrenstein [1] defines the term matrix as a material, which is in case of particle systems filled with filler (particular component) in such a way, that the product of the process has a stable form. The filler can influence the mechanical properties of the material, such as resistance to abrasive wear, hardness, impact strength etc. The presence of filler in the matrix also has impact on numerous other properties of the material, for example, solidity, density and, of course, its price. All parameters influencing the properties of composite materials relate either to their structure, or to the relationships between the phases. The phases have impact on the resulting properties of the material firstly with their own characteristics, secondly with the matrix-filler interaction. And it is the interaction between the components that makes possible the various properties of the materials [2; 3].

What needs to be specified to describe polymeric particle composites as material systems is, next to the material components and their properties, also the geometry of the framework in relation to the system. This geometry can be described by its form, size and distribution of particles. However, the composite systems can differ from each other even when their particle geometry is identical, for example, by the filler concentration in the matrix and its orientation [3].

Materials and methods

The polymeric particle composites have been cast using forms prepared in advance in laboratory conditions and they have been prepared with the following amount of filler as expressed by the volume percentage (v_p): 5 %, 10 %, 20 %, 25 %, 30 % and 35 %. In the wider view, the only limit of the composite systems is epoxy without filler (in case of polymeric matrices), on the other side stands saturation of the solution (saturation of the epoxy by the particle filler). Misek [4] states that the criterion for categorizing material systems with multiple phases among composites is a 5 % share of filler. The limit 35 % of filler in the matrix is given by the comparatively high saturation of epoxy by the filler.

Image analysis. The used filler on the secondary raw material basis (corundum waste) was put to the image analysis using the stereoscopic microscope (SZP 11 – T) in order to determine concrete shapes and dimensions. The particle sizes of fillers were measured in 2D using the optical microscope at 3.5 x magnification, built in camera and software Quick photo shop industry. The obtained data were statistically evaluated.

Impact strength. The impact strength was evaluated based on the norm ČSN 64 0611 (Determination of the impact resistance of rigid plastics by means of Dynstat apparatus) [5]. In these destructive tests, the Dynstat device Nr. 283 stated the impact strength a_n, which expresses kinetic energy the hammer needed to crush the tested object without notches in relation to the surface of its diagonal cut, as expressed by the following formula (1):

$$a_n = \frac{A_n}{b \cdot h} \tag{1}$$

where a_n – impact strength, kJ·m^{-2};
A_n – energy required to shift the specimen, kJ;
b – width of the test specimen, m;
h – thickness of the test specimen, m.

Degradation process. The objects of degradation processes were test objects with waste-corundum based filler of the F80 fraction with 10 % filler in the matrix. The test objects were prepared in accordance with the abovementioned norm and exposed to the influence of various degradation environments:

- diesel fuel;
- laboratory environment – air temperature 20 – 23 ºC, humidity 60 %;
- water bath with temperature 20 – 23 ºC;
- hydrogen solution of NaCl concentrated 15 %;
- hydrogen solution of the Cererit fertilizer concentrated 15 %.

The test objects were exposed to the influence of these environments for 15, 25, 50 and 75 days. After the set time period, the objects were extracted from their degrading environments, washed, dried and subject to destructive tests.

Results and discussion

Image analysis. Table 1. shows the particle size before the sandblasting process and after it, as well as the angles between the edges of the particles as measured on a stereoscopic microscope. The measurements were conducted 300-times on each fraction of filler.

Table 1

Shape and particle dimension of fillers

Filler	Fraction	Particle dimension before blasting, µm	Particle dimension after blasting, µm	Angle between the edge, degrees
Corundum	F60	282 ± 70	264 ± 90	92 ± 20
Corundum	F80	172 ± 43	147 ± 52	99 ± 20
Corundum	F240	50 ± 17	44 ± 15	96 ± 23
Corundum	F400	17.3 ± 3	17 ± 5	–
Corundum	F800	6.5 ± 1	6 ± 1	–

Impact strength. The impact strength a_n was calculated using the formula 1. The impact strength of epoxy without a filler achieved the value 8.99 ± 1.42 kJ·m^{-2}. An illustrative description of the influence of the size of the filler and its share in the matrix on the resulting impact strength of the composite systems can be seen in the following 3D graph (Fig. 1).

The influence of the filler share in the matrix on the impact strength of the polymeric particle composites with waste-corundum-based filler for the individual fractions is shown in the following graph (Fig. 2), where it is evident that the filler particle size has no significant influence on the final impact strength.

The decreasing trend of the values of the impact strength (a_n) as dependent on the filler share in the matrix (v_p) can be described by following functional equations (2 – 6, see Fig. 2).

$$a_{n\,\mathrm{F}\,60} = -0.077 v_p + 4.6157 \tag{2}$$

$$a_{n\,\mathrm{F}\,80} = -0.0664 v_p + 4.5665 \tag{3}$$

$$a_{n\,F\,240} = -0.0778 v_p + 4.6971 \quad (4)$$

$$a_{n\,F\,400} = -0.0535 v_p + 4.1929 \quad (5)$$

$$a_{n\,F\,800} = -0.0439 v_p + 4.1371 \quad (6)$$

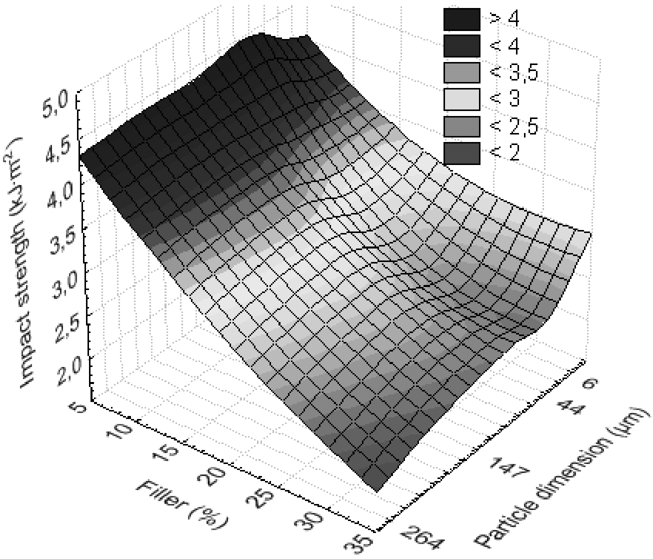

Fig. 1. **Impact strength – 3D Graph**

If the middle the values of the impact strength are evened out (all filler shares from one fraction), the difference between the highest middle value 3.22 kJ·m^{-2} (F800) and the lowest middle value 3.01 kJ·m^{-2} (F60) is 0.21 kJ·m^{-2}. This difference is negligible, taking into account the standard deviation. This confirms the fact that the waste-corundum particle size has no significant influence on the impact strength (even though the impact strength decreases with increasing the particle size). The highest value of the impact strength 4.72 ± 0.98 kJ·m^{-2} was displayed by the composite with the F240 fraction and 5 % of filler in the matrix. However, this value is 4.27 kJ·m^{-2} (53 %) lower than the middle value of the impact strength of filler-less epoxy. The lowest value 2.01 ± 0.60 kJ·m^{-2} was reached by the composite fraction F 60 with 35 % share of filler in the matrix. If we compare the middle values of the impact strength based on the share of filler in the matrix of the concrete fractions, the lowest decrease of 51 % (in comparison to filler-less epoxy) was recorded with composites with 5 % filler in the matrix, the most prominent decrease of 73 % then with composites with 35 % filler in the matrix. From this we can conclude that with increasing the share of waste-corundum-based filler in the composite matrix, the impact strength decreases.

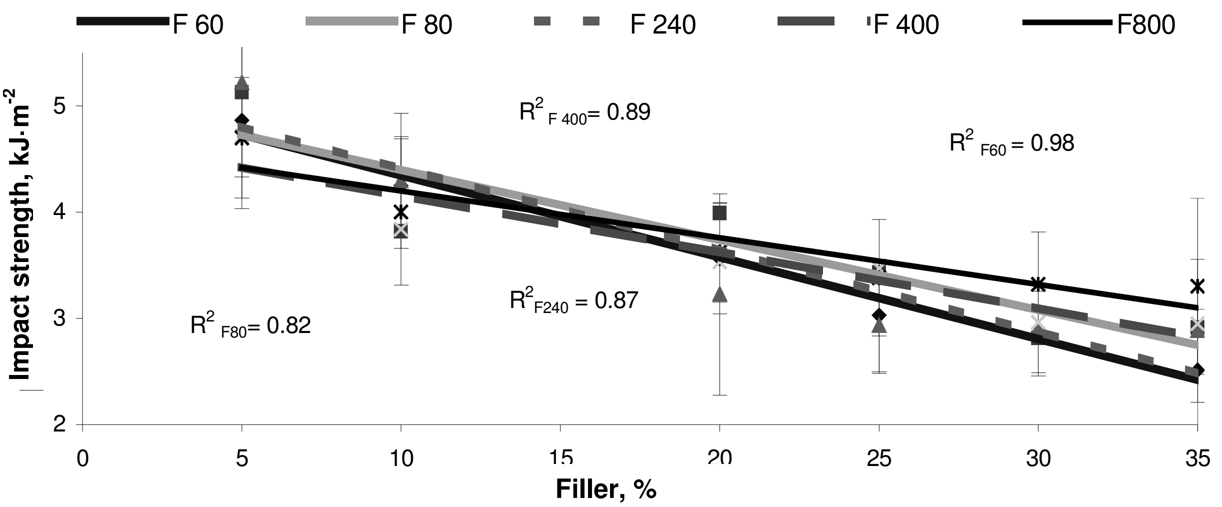

Fig. 2. **Influence of filler share in matrix on impact strength of polymeric particle composites with waste-corundum-based filler**

Degradation process. The values of the impact strength in dependence on the time of degradation in the various degradation media are stated in the following graph of Fig. 3. The values of composite impact strength before the degradation process were 3.32 ± 0.95 kJ·m^{-2}.

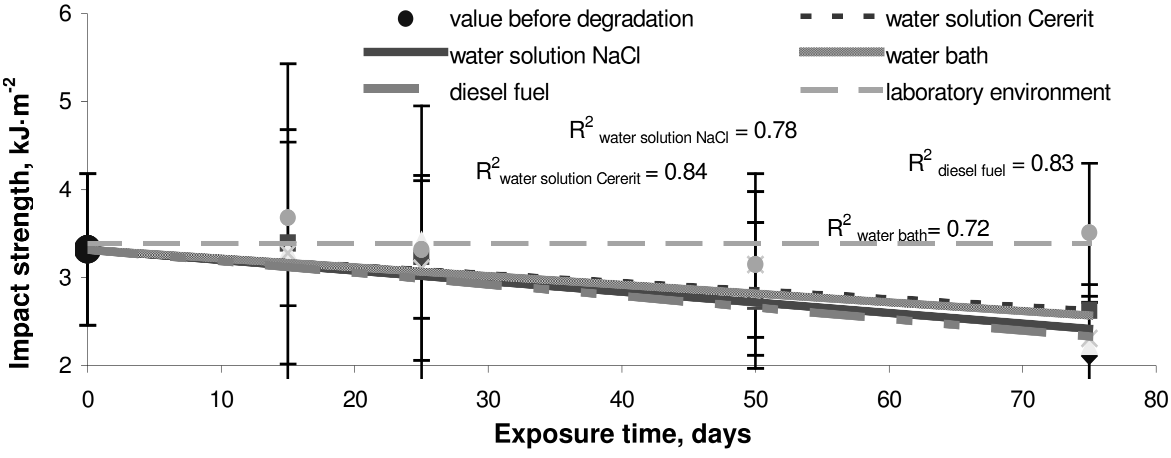

Fig. 3. **Influence of degradation on impact strength**

The influence of the degradation time (d_g) on the impact strength (a_n) in the individual degradation environments (see Fig. 3) can be described by the following functional equations (6 – 9). The middle value of the impact strength where air was the mediator corresponded to the value during the degradation period 3.39 ± 0.19 kJ·m^{-2}.

$$a_{n\ \text{diesel fuel}} = -0.0132d_g + 3.32 \tag{6}$$

$$a_{n\ \text{water solution Cererit}} = -0.0092d_g + 3.32 \tag{7}$$

$$a_{n\ \text{water bath NaCl}} = -0.012d_g + 3.32 \tag{8}$$

$$a_{n\ \text{water bath}} = -0.01d_g + 3.32 \tag{9}$$

As you can see in Fig. 3, all degradation media except air had negative influence on the impact strength, where the decrease of the impact strength values is more or less the same with all these media. The smallest impact strength value was measured by the composites degrading for 75 days in an environment of diesel fuel (decrease 36 %). With the degradation medium water solution NaCl, the decrease in the impact strength after 75 days equalled 33 %, with the water bath 30 % and water solution of the Cererit fertilizer reached a 21 % decrease. The huge standard deviation values could have been caused by different placement of filler in the matrix among the various waste-corundum-based composite systems or by different properties of the filler particles (size, shape, additives) among those composites. At the same time, their size could have been enhanced by the influence of the various degradation processes, which could have disrupted the interaction between the filler and the matrix.

Conclusions

From the experiments conducted it is clear that the impact strength of composite systems with waste-based filler decreases linearly in proportion to the increasing share of waste-based filler in the matrix. Weizhou Jiao [6] states the ability of filler on the basis of Al_2O_3, SiC a SiO_2 to influence the impact strength. However, our experiments have not confirmed this hypothesis. In all cases of adding waste-based epoxy filler into the matrix, the values of the impact strength decreased substantially.

All degrading media with the exception of laboratory conditions had a significant impact on the impact strength which was decreasing linearly with the increasing degradation time. The highest impact was recorded when diesel fuel was used as a medium. Müller and other authors [7; 8] state that one of the significant properties of polymeric particle composites is their high resistance to abrasive wear, but according to the results of our experiments, it is the impact strength that is one of the limiting properties in application of corundum-based polymeric particle composites. This fact needs to be taken into account when looking for areas of application for the products and choose such areas, where the requirements for the impact strength are low.

With the addition of waste-corundum-based filler, materials with new qualities are created, which not only lower the costs, but also save on sources of raw materials. Because of this, these materials should be preferred, where possible. Modern society should choose a direction, in which the environment and considerate use of all materials is the preferred way. One of the possibilities of use for waste corundum is in polymeric particle composites.

Acknowledgements

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

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