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TESTING THE TOUGHNESS OF POLYPROPYLENE FILLED WITH GLASS POWDER

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Abstract: The purpose of this paper is to show polymer waste as a raw material or otherwise usable material derived from a partial separation of communal waste. This paper describes the possibilities of polypropylene re-use through recycling with addition of glass powder, from the point of view of toughness caused by impact load. Standard test specimens, made of basic material – polypropylene, with addition of 0%, 5%, 10%, 15%, 20%, 25% and 30% of glass powder with granulation less than 0,5 mm, have been tested through six processing cycles. The measured values gave a possibility of forming patterns for changes of the observed material with different content of additives, through processing cycles, which can be helpful in further research and analysis.
Keywords: recycling, polypropylene, toughness.

1. INTRODUCTION

Due to the concern for the environment, caused primarily by limited resources on the one hand and the accumulation of waste on the other, a need arose for using ecologically acceptable materials and their recycling after product life. In total waste mass, polymer waste plays an important role [1]. Thermoplastic polymers are usually used for their recyclability in comparison to duroplast [2]. In total mass of plastic products, a share of use of polyethylene (PE) and polypropylene (PP) is about 60-70%, of polystyrene (PS) about 10-15%, polyvinylchloride (PVC) 15% and PET 5%.3 [3]. In recent years, the consumption of composites has increased. This refers to mixtures of two or more materials of different composition and shape formed to obtain desired properties. Fibre composites are most often used, with fibres enhancing mechanical properties. Besides the use of artificial fibres, natural fibres are frequently used, such as cannabis, jute, flax, chicken feather or waste paper, cardboard, textile, etc ([4], [5]).

However, the use of multiple materials makes the recycling complicated, since fibres and matrices need to be separated. [6].

The problems of fibre composites production can be overcome with the use of granular composite materials that can be re-used as a whole. The change in toughness of such material is shown in this paper.

Mechanical properties of a material define the characteristics of the product during exploitation. Mechanical properties of polymer materials are defined by their chemical composition, molecular characteristics, structural characteristics, loading time and temperature. They show a reaction of the element exposed to mechanical loads.

They are obtained by mechanical research. First, a body is exposed to some mechanical load, and then the changes on it are being monitored. Research conditions must be constant during the process.

2. RESEARCH SAMPLES

In order to examine the impact, experimental testing was performed. We tested the changes of toughness in the function of changing the cycle of waste polypropylene processing with variable content percentage of glass powder. Glass powder was obtained by grinding the waste glass.

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Waste polypropylene and waste glass were purified from mechanical and other impurities by washing and drying, and prepared for further processing by milling. They were collected by random sampling from the city dump in Banja Luka. Sampling was conducted at multiple locations in the city dump, so it is assumed that polypropylene and glass used in the experiment vary in age and quality.

Performed tests included testing the mechanical properties of mixture of waste polypropylene and waste glass, without chemical and physical properties of composites.

The research objective was to draw conclusions on the possibilities, quality and reliability of re-using waste materials derived from partial separation of components and their multiple uses, i. e. to assess sustainability of mechanical properties through processing cycles with the addition of other material (glass).

Polypropylene powder was used for this experiment, in order to achieve homogeneity when mixing with glass powder. Granulation of the used glass powder is less than 0,5 mm, which is achieved by sieve analysis after milling the glass powder. Mixing is done mechanically – continuously.

Specimens for testing were cast in a specially designed mould. Two kinds of specimens were made – ones of polypropylene as a basic material and the others of polypropylene with mass addition of 5%, 10%, 15%, 20%, 25% and 30% of glass powder.

A number of these specimens that are a mixture of polypropylene with mass addition of 10%, 20% and 30% of glass powder were retained and the rest of them were ground and prepared for reprocessing. The same procedure was repeated six times.

The same preparation procedure was performed for specimens made of basic material and those made of mixture of polypropylene and glass, in six cycles of treatment.

Before use, basic material (polypropylene) and glass powder were heated – dried in order to remove moisture.

The processing temperature was continuous at 230^0C, 220^0C, 210^0C, 200^0C for the first, second, third and the fourth heater respectively. Powdering of material (preparing for re-processing) was performed by industrial mill. The specimen cooling was natural and slowly performed at room temperature, without additional means. For the purposes of planned tests, about 150 specimens were produced.

Cross-section of the produced sample – specimen with addition of 30% of glass powder is shown in a photograph – Figure 1.

3. RESULTS OF IMPACT TESTING

Impact testing is performed in order to assess the behaviour of a material exposed to dynamic loading. It provides conclusions on its brittleness and toughness.

Testing is performed according to standard SRPS G.S2.616 for defining impact toughness of hard plastic masses, according to Charpy.

The impact testing plan is presented in Figure 2.

Figure 1. Cross-section of the specimen with addition of 30% of glass powder

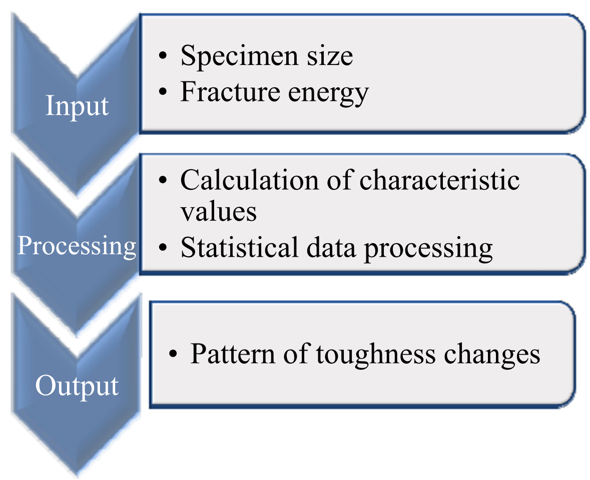

Figure 2.Impact testing plan

Impact test was conducted at the laboratory of the Institute for Materials and Constructions Testing of the Republic of Srpska, Banja Luka, in February 2010.

Tougness is the ability of a material to resist impact loading. It is defined as an energy required to cause a fracture of a specimen with defined geometric shape or as an energy required to cause a fracture of a specimen divided by the cross-sectional area [7].

Typical mechanical values include: fracture energy E_L[J] and material toughness ρ[J/cm^2].

Data on the measuring instrument used for testing the impact loading:

1. Measuring instrument: Instrument for toughness testing – Charpy pendulum impact tester,
2. Manufacturer: VEB WERKSTOFFPRUFMASCHINEN, Leipzig, Germany,
3. Serial number: 403/14.

Dimensions of toughness testing specimens:

1. Specimen length l = 50mm,
2. Specimen width b = 10mm,
3. Specimen thickness s = 4mm.

For one cycle, three specimens were tested. Prepared items for testing were cut out the inner narrower part of the standard specimen (sketches and photographs are shown in Figures 3, 4 and 5). The prepared item has dimensions of a small standard specimen with no groove, and is 10 mm wide. In order to achieve greater impact resistance, the broader part of the specimen cross-section was exposed to impact. Difference in geometry of the fracture area between the specimen made of polypropylene as a basic material and the one made with the addition of 30% of glass powder is shown in Figures 4 and 5.

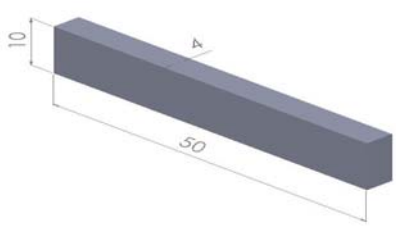

Figure 3.Preparation item for impact testing

The result of testing is fracture energy E_L[J], while material toughness ρ[J/cm^2] is calculated by the formula: $\rho = \frac{E_L}{A}$, where: $A = b \cdot s$ – cross-section area.

4. IMPACT TESTING RESULTS PROCESSING

Toughness mean values, obtained as the arithmetic mean, were used for processing and are shown in Table 1.

In order to facilitate the use of the results obtained by measurement and calculation of composite material with different percentage of mass proportion of glass from the one for which the testing was performed, further processing was carried out by finding the functional dependence between toughness, mass proportion of glass and processing cycles.

Data processing, in this sense, was performed by using the least squares method.

In this case, a change in toughness is expressed depending on the processing cycles and percentage of glass in the basic material.

Finding the functional dependence is carried out in two steps.

The first step includes finding the functional dependence which describes, in the best possible way, a relationship between toughness and percentage of mass proportion of glass for each processing cycle. In doing so, attention was paid to finding one functional relationship that will sufficiently well describe the change in toughness in function of mass proportion of glass for each of the processing cycles.

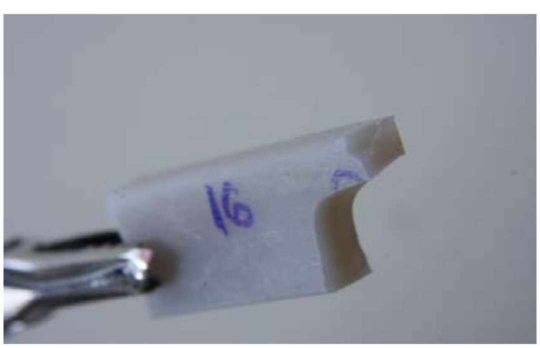

Figure 4. Preparation item after impact testing (pure PP)

Figure 5.Preparation item after impact testing (PP with the addition of 30% of glass powder)

Table 1.Data for processing

Glass percentage	Toughness ρ [J/cm²] – mean value						
	Basic material	I rec.	II rec.	III rec.	IV rec.	V rec.	VI rec.
0%	31.04	30.42	30.62	30.58	31.33	31.46	31.46
5%	25.42						
10%	25	25.83	26.25	26.04	25.83	26.04	25.83
15%	25						
20%	25	25.42	25.83	25.83	25.83	25.83	25.42
25%	25						
30%	25	25.21	25.21	25.21	25	25	25

The analysis shows that the functional relationship is expressed in the following form:

$$y(s,x) = a(s) + b(s) \cdot x^3 + c(s) \cdot e^{-x} \qquad (1)$$

As it follows:

- *y(s,x)* - toughness, [J/cm²],
- x – percentage mass proportion of glass (x = 0,1,...,30),
- *a, b* and *c* – coefficients and
- s - processing cycle (s = 0,1,...,6).

Coefficients a, b and c with variable (x) for each cycle of processing have their values, as it is shown in Table 2. Good agreement between the assumed function of dependence (1) and the averaged values of toughness were confirmed by the values of middle square deviation (σ^2) and curvilinear correlation coefficient (R^2) which are also shown in Table 2.

The second step includes finding the functional relationship between coefficients with variable (x) depending on the processing cycle, and $a(s)$, $b(s)$ and $c(s)$. As it is described in the first step, it was found that the most appropriate functional relationship for this relationship is the following:

$$z(s) = A + B \cdot s + C \cdot s^2 + D \cdot s^3 + E \cdot s^4 + F \cdot s^5 \qquad (3)$$

Where

z (s) – values of coefficients $a(s)$, $b(s)$ and $c(s)$

A, B, C, D, E and F – values of coefficients in equation (3) depending on which coefficient $a(s)$, $b(s)$ and $c(s)$ is being determined.

Values of coefficients A, B, C, D, E and F are shown in Table 3.

Mathematical values given by the previous patterns are shown in Table 4. For recycled materials of polypropylene with 5%, 15% and 25% glass powder supplement there are only mathematical data (experimental measuring was not performed).

The accuracy of the procedure was confirmed through calculated percentage errors for each measurement according to the pattern, which is shown in Table 5.

$$\Delta = \frac{\rho_t - \rho_c}{\rho_t} \cdot 100\%$$

Where:

ρ_t - mean value of toughness obtained by measurement

ρ_c - calculated value obtained using approximate functions (1) and (2).

Maximum error was calculated to be (Δ) = 1,01%, which is considered acceptable.

For more complete visual review of the change, processed data is graphically presented in Figures 5 and 6, as comparative 2D diagrams.

Table 2. Toughness change pattern and coefficients

Processing cycle	**Pattern of changes ρ = f(N,P) (Processing cycle and glass powder percentage)**			**Determination coefficient**	**Middle square deviation**
	a(s)	***b(s)***	***c(s)***	**r^2**	**σ^2**
Basic material	25.119915	-0.0000062536241	5.9234861	0.99684575	0.000432
I rec.	25.741484	-0.000021287192	4.6751913	0.99791938	0.020677
II rec.	26.226454	-0.000038552872	4.3985492	0.99936923	0.067738
III rec.	26.081044	-0.000032222363	4.502286	0.9999733	0.047351

IV rec.	25.96975	-0.000034523003	5.3635756	0.99876931	0.054362
V rec.	26.115164	-0.0000408537	5.3431645	0.99987551	0.076145
VI rec.	25.775599	-0.000029918299	5.682735	0.9991713	0.04086

Table 4.42. Change in coefficient pattern

Change in coefficient pattern *a(s), b(s)* and *c(s)*						
	A	**B**	**C**	**D**	**K**	**F**
a(s)	25.118749	0.14184534	0.97407409	-0.60383613	0.12649488	-0.0088439833
b(s)	$-6.1291427\cdot10^{-6}$	$4.0464616\cdot10^{-6}$	$-3.7260465\cdot10^{-5}$	$2.1442046\cdot10^{-5}$	$-4.4444253\cdot10^{-6}$	$3.1146175\cdot10^{-7}$
c(s)	5.9149555	-1.1162236	-0.47187781	0.50552926	-0.11397742	0.0079687004
	Determination coefficient - r^2			**Middle square deviation - σ^2**		
a(s)	0.9984838			0.010035		
b(s)	0.99316301			$9.5\cdot10^{-12}$		
c(s)	0.96902765			0.109284		

Table 4. Processed data according to glass percentage

Glass percentage	**Toughness ρ [J/cm^2]– processed data**						
	Basic material	I rec.	II rec.	III rec.	IV rec.	V rec.	VI rec.
0%	31.04	30.42	30.62	30.58	31.33	31.46	31.46
5%	25.16	25.77	26.25	26.11	26	26.15	25.81
10%	25. 11	25.72	26.19	26.05	25.94	26.08	25.75
15%	25.10	25.67	26.10	25.97	25.85	25.98	25.68
20%	25.07	25.57	25.92	25.82	25.69	25.79	25.54
25%	25.02	25.41	25.62	25.58	25.43	25.48	25.31
30%	24. 95	25.17	25.19	25.21	25.04	25.01	24.97

Table 5. Percentage error for each measurement

Glass percentage	**Error Δ_ρ [%]**						
	Basic material	I rec.	II rec.	III rec.	IV rec.	V rec.	VI rec.
0%	0.004	0.001	0	0.001	0.001	0.001	0.001
5%	1.01						
10%	0.46	0.44	0.24	0.03	0.39	0.13	0.34
15%	0.4						
20%	0.28	0.61	0.33	0.04	0.54	0.18	0.47
25%	0.09						
30%	0.196	0.16	0.09	0.01	0.15	0.05	0.13

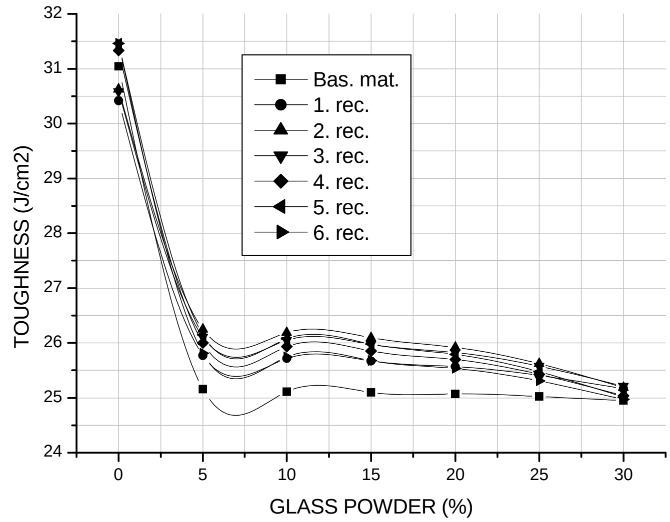

Figure 6. Diagram - 2D presentation of change in toughness of the defined processing cycle in function of glass powder percentage

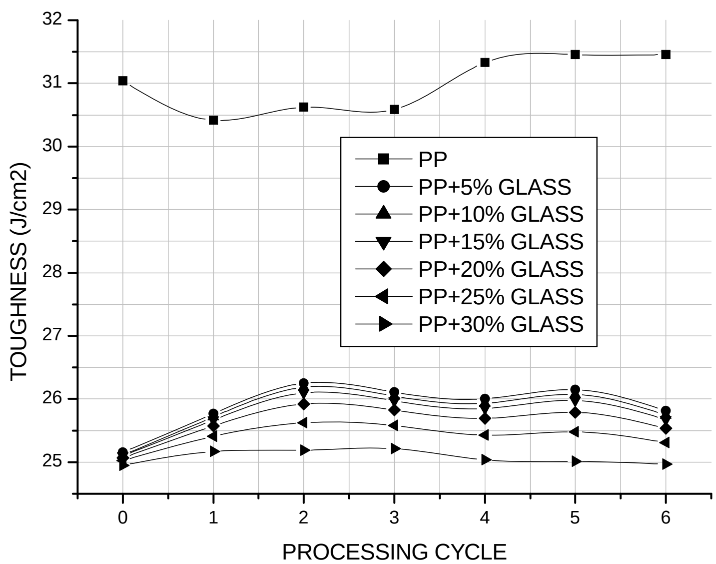

Figure 7. Diagram - 2D presentation of change in toughness of the defined material in function of processing cycle

According to the graphs and tables presented above, it is clear that toughness increases with the first and second recycling cycle (about 2% per cycle), then slightly decreases through further cycles, except for pure polypropylene where it decreases with the first and second cycle, and then slightly increases. It is also evident that toughness rapidly decreases up to 20% with addition of 5% of glass powder to the basic material, therefore, a further trend of decreasing with addition of 30% of glass powder is about 3%. The changes are described by relatively simple mathematical patterns (1) and (2).

In one research, the amount of 0% to 50% of chicken feathers [3] was added to polypropylene matrix, where it was shown that such type of composites (fibre) improves toughness, so that toughness continuously increased with the addition of up to 40% of chicken feathers to polypropylene, and then decreased with the addition of 50%.

5. CONCLUSION

1. Based on the data from literature and conducted experimental research, it can be concluded that waste polypropylene with the addition of different mass proportion (up to 30% of mass proportion of glass powder) of foreign material with granulation less than 0,5 [mm] (granular composite) has a stable change of toughness with the possibility of analytical description of the functional dependence (pattern (1)).

2. Such materials can be recycled without the separation of components up to six cycles, without significantly changing the toughness, thus improving the economic criteria. Through processing cycles, they preserve stable change in toughness.

3. Less than 3,5% of experimental results significantly deviated from the average, and these measurements were repeated. These discrepancies can be attributed to the errors in the structure of the material resulting from production and errors during testing.

4. Analytical patterns, shown in the paper, enable measuring of toughness for any given percentage of glass powder supplement up to 30% at any processing cycle (up to six) with satisfactory correctness.

5. Further research should be aimed at defining maximum percentage of supplement glass and maximum recycling cycle without visible degradation of toughness, i. e. to the upper limit for possibility to use the described material.

6. REFERENCES

[1] Z. Janjuš, *Reliability of the use of recycled thermoplast*, Master thesis, Faculty of Mechanical Engineering, Banja Luka (2006).

[2] S. J. Pickering, *Recycling technologies for thermoset composite materials - current status*, Composites: Part A 37 (2006) 1206–1215.

[3] F. Cavalieri, F. Padella, *Development of composite materials by mechanochemical treatment of post-consumer plastic waste*, Waste Management 22 (2002) 913–916.

[4] T. A. Bullions, D. Hoffman, R. A. Gillespie, J. Price-O Brien, A. C. Loos, *Contributions of feather fibers and various cellulose fibers to the mechanical properties of polypropylene matrix composites*, Composites Science and Technology 66 (2006) 102–114

[5] S. Huda, Y. Yang, *Composites from ground chicken quill and polypropylene*, Composites Science and Technology 68 (2008) 790–798.

[6] B. Alcock, N. O. Cabrera, N. M. Barkoula, Z. Wang, T. Peijs, *The effect of temperature and strain rate on the impact performance of recyclable all-polypropylene composites*, Composites: Part B 39 (2008) 537–547.

[7] R. Lipold, A. Blagojevic, F. Ismailovic, O. Pasic, *Materials in mechanical engineering*, Glas, Banja Luka 1990.

ИСПИТИВАЊЕ ЖИЛАВОСТИ ПОЛИПРОПИЛЕНА ПУЊЕНОГ СТАКЛЕНИМ ПРАХОМ

Сажетак: Сврха рада је да се полимерни отпад прикаже као сировина или на други начин искористљив материјал добијен дјелимичним раздвајањем комуналног отпада. У раду је обрађена могућност поновне употребе полипропилена рециклирањем уз додатак стакленог праха, са становишта жилавости усљед ударног оптерећења. Испитиване су стандардне епрувете, направљене од основног материјала – полипропилена и уз додатак 0%, 5%, 10%, 15%, 20%, 25% и 30% стакленог праха гранулације мање од 0,5 mm, кроз шест циклуса прераде. Измјерене вриједности дале су могућност формирања образаца промјене жилавости посматраног материјала са различитим садржајем страног тијела, кроз циклусе прераде, што може помоћи у даљим истраживањима и анализама.

Кључне ријечи: Рециклажа, полипропилен, жилавост.