The multiaxial behaviour comparison of virgin polypropylene and polypropylene reinforced with 30 % glass fibres

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***Abstract*—**This study is concentrated on the multiaxial behaviour comparison of pure polypropylene to polypropylene reinforced with 30 % of glass fibre (PP30GF), both materials were subjected to the drop-weight test. PP is a semi-crystalline thermoplastic polyolefinic polymer which has a good resistance to the impact load and is commonly used in the wide area of the plastics industry to production of many application. In this study PP samples and PP samples with 30 % glass fibres were injection moulded and subsequently subjected to the penetration test at various potential energies. The results were evaluated and discussed. The results show that reinforced PP has a better behaviour at the multiaxial stress in comparison to the virgin one.

***Keywords*—**Polypropylene, material testing, drop-weight impact test, deformation.

I. Introduction

FOR this study, polypropylene (PP) as a matrix was used. PP belongs to the polyolefin family and it is a thermoplastic which is semi-crystalline. This polymer owns good dielectric and mechanical properties and is used in many areas such as the automotive, electrical industry (electrical insulation etc.) and in the plastics industry [1-4]. PP has a very good mechanical rigidity and resistance because of its higher melting point and crystallinity [5]. To obtain even better mechanical properties it is common to use fiberglass reinforcement as one of many possible modification. For better adhesion of fibreglass and PP is needed to use some compounds such as organofunctional silane with the block or graft polyolefin copolymers.

This kind of compound was twin-screw extruded together with PP. Subsequently quenched in water and cooled in the air at the ambient temperature. Tested samples were injection moulded and then their thermal and mechanical properties tested. The results showed the increase of the tensile modulus, tensile strength, notched impact strength and bending strength in comparison to pure PP. The results showed the higher thermal stability of modified PP compared to pure PP [6].

The scientists created the light-weight high-strength blend which consists PP, short bamboo fibres and hollow glass microspheres. The short bamboo fibres caused the improvement of mechanical properties and hollow glass microspheres controlled the growth of the density of short bamboo fibres addition [7].

The modification of PP using short glass fibres or talc caused the improvement of creep strength in comparison to pure PP [8].

After use multi-walled carbon nanotubes as a filler, it was found out that both shorter and longer nanotubes are able to improve the impact energy of the blend at temperatures above glass transition temperature. In the case of the impact energy, the longer nanotubes had better improvement in comparison to shorter nanotubes. Used nanotubes had the lengths of 1-2 µm and 5-15 µm and similar diameter of 10-30 nm. The content of these particles was at a constant volume of 1 % [9].

Also the addition of polyamide 66, silicon carbide, alumina and molybdenum disulphide to PP was studied. It was found out that these micro-fillers had the hybrid effect on mechanical properties of this mixture, the tensile strain and strength decreased, the flexural strength after addition of micro-fillers increased. Also the hardness and the density increased and the fracture toughness was improved around 188 % [10].

After addition of red phosphorus as a flame retardant to PP reinforced with long glass fibres, the thermos-oxidative aging on mechanical and flame retardant properties was studied. The samples were at the temperature 140 °C for 0-50 days and the longer time the lower mechanical properties, while the thermal stability was influenced by the longer time at 140 °C at least. Also the migration of the flame retardant from the inner structure of the composite was proven [11].

It was proven that after addition of short glass fibres to PP blended with the calcite, the tensile and bending properties were enhanced [12].

The abrasive wear behaviour and mechanical properties of waste sisal/glass, sisal/carbon hybrid fibre reinforced PP composites were analysed and it was found out that the addition of sisal fibres in carbon fibres PP composites

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decreased mechanical properties, while the friction coefficient was improved. The addition of sisal fibres in pure glass fibre reinforced PP composite improved tribological properties and the mechanical ones were comparable [13].

This study deals with the comparison of pure and glass fibres reinforced PP. To obtain the results of the multiaxial behaviour, the drop-weight impact test machine was used.

II. Material and Methods

A. Material Preparation

Virgin and reinforced Polypropylene with 30 % of glass fibre were used as the basic polymer materials (TATREN, IM 25-75 and Scolefin 53 G 10). An ARBURG Allrounder 470H Advance Injection moulding machine was used for sample preparation, with the processing conditional on complying with polypropylene (PP and PP30GF) producer's recommendations, as can be seen in Tab. 1. The samples were in the shape of plates with dimensions 100×100×3 mm according to ISO 6603-2.

Table 1 PP and PP30GF set injection moulding parameters

Injection Parameters	**Values**	
	PP	**PP 30 % GF**
Injection Pressure [MPa]	70	80
Injection velocity [mm.s^{-1}]	40	50
Holding Pressure [MPa]	55	60
Cooling Time [s]	25	20
Mould Temperature [°C]	30	40
Melt Temperature [°C]	215	235

B. Used Methods for the Testing

Injection moulded PP, and PP30GF samples were tested on drop-weight impact test machine Zwick HIT230F according to ISO 6603-2 at the ambient temperature of 23 °C. The scheme of this arrangement is possible to see in Figure 1. As the main parameter was used potential energy, which was set on the testing machine. 15 samples at each set potential energy (30, 50, 100, 150, 200 and 230 J) were tested and then maximum impact force and total consumed energy was statistically evaluated in program TestExpert II, MS Excel 2016 and MiniTab 16. At the end of the test, crack surface was evaluated at each potential energy.

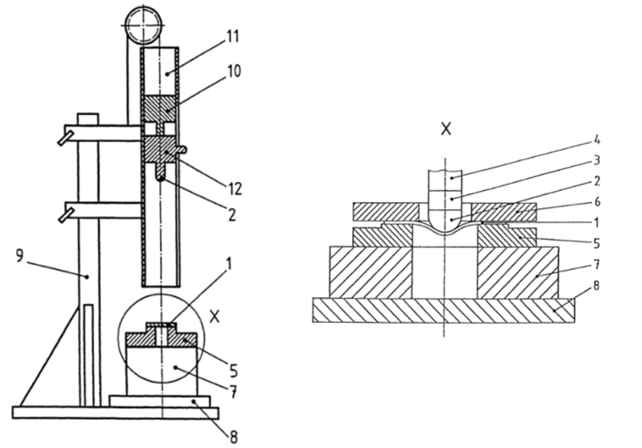

Fig. 1 Drop-weight impact test scheme
1 – Test specimen; 2 – Hemispherical striker tip 10 mm; 3 – Force sensor; 4 – Shaft; 5 – Test specimen support; 6 – Clamping ring (optional); 7 – Base; 8 – Acoustic isolation (optional); 9 – Stand for falling-dart system; 10 – Holding and release system for weighted striker; 11 – Guide shaft for weighted striker; 12 – Weighted striker 23,77 kg.

III. Results and Discussion

This study is concentrated on the multiaxial behaviour of virgin and reinforced polypropylene with 30 % of glass fibre by drop-weight impact test. Injection moulded PP and PP30GF parts were tested on penetration where set potential energy in the range from 30 to 230 J and the results were subsequently evaluated.

A. Maximum impact force

PP30GF statistical evaluation of the measurements is shown in Table 2. This article is continuing of the last study about PP optimization of fall height [14]. Therefore, changes in virgin and reinforced polypropylene can be evaluated by penetration test (multiaxial loading).

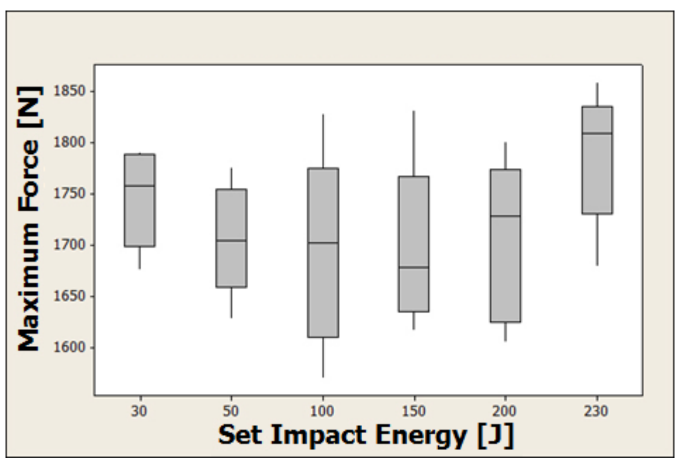

Fig. 2 PP30GF Boxplot graph of maximum force at set potential energy

In Figure 2 the PP30GF maximum force at set potential energy is displayed. Measurements are burdened with a high error because of a non-defined arrangement of glass fibres. Therefore, the median was chosen to compare the maximum force values. The median value of 1758 N at 30 J showed that when the increase of set potential energy of the maximum impact force occurs, the value of the maximum impact force slightly decreased to 150 J. Other increasing of the set potential energy caused the rapid increase of the maximum force on the value of 1808 N at 230 J. The results are still within the error range.

The PP and PP30GF maximum impact force change in % can be seen in Figure 3. The data move about 17 % from the PP sample without penetration to the last penetrated PP sample. The change of maximum impact force for PP30GF is insignificant as was already mentioned. There are two times higher values of maximum impact force for PP in comparison to PP30GF. This can be probably caused by non-defined arrangement of glass fibre, resulting from processing technology – injection moulding.

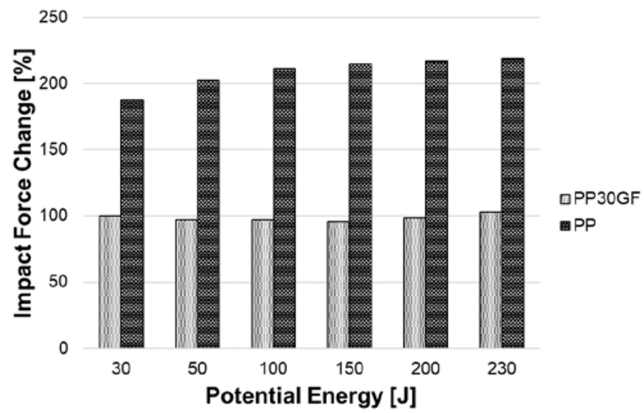

Fig. 3 PP30GF, and PP percentage change in maximum force to the prescribed base potential energy of 30 J

Table 2. PP 30 % GF maximum force statistical evaluation at the set potential energy.

Set energy of fall [J] / **Statistical characteristics [N]**	**30**	**50**	**100**	**150**	**200**	**230**
Number of measurements	15	15	15	15	15	15
Arithmetic mean	1744	1704	1698	1701	1705	1789
Type error A	14	16	29	24	24	19
Standard deviation	44	50	93	75	75	60
Minimum value	1676	1629	1571	1617	1606	1679
Median	1758	1704	1702	1678	1728	1808
Maximum value	1790	1776	1828	1831	1800	1858
Variation range	115	147	257	214	194	179

Table 3. PP 30 % GF total consumed energy statistical evaluation at the set potential energy.

Set energy of fall [J] / **Statistical characteristics [N]**	**30**	**50**	**100**	**150**	**200**	**230**
Number of measurements	15	15	15	15	15	15
Arithmetic mean	6.9	7.9	12.1	9.5	11.6	8.2
Type error A	0.2	0.5	1	0.5	0.8	0.5
Standard deviation	0.5	1.5	3	1.5	2.7	1.6
Minimum value	6.3	5.9	7.4	7.7	7.5	6.1
Median	6.8	7.3	11.4	9	11.9	7.9
Maximum value	7.6	10.2	15.9	12.1	14.6	10.4
Variation range	1.3	4.3	8.5	4.4	7.1	4.3

B. Total consumed energy

Table 3 shows the results of the total consumed energy from which Figure 4 was created. The total consumed energy of the drop-weight test is shown in Figure 4. As can be seen, the biggest change in % is visible at the potential energy 100 J in both cases of pure PP and of the PP filled with 30 % of glass, while the smallest change is at the potential energy of 30 J also in both cases.

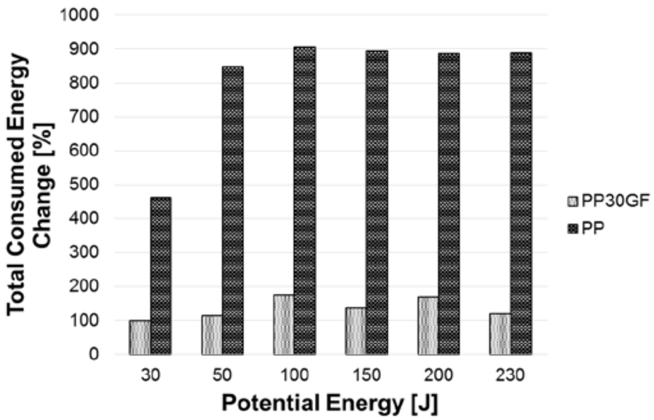

Fig. 4 PP30GF, and PP percentage change in total consumed energy to the prescribed base potential energy of 30 J

C. Deformation after the test

After the drop-weight impact test the tested parts were photographed for better idea about the deformation, and crack growth. The photos of the samples after the penetration tests are displayed in Figures 5-10.

In Figure 5 it is possible to see the deformation of PP30GF sample at 30 J. It is clearly visible that the reinforcement with glass fibres caused the plastic deformation of the sample and as conclude can be said that the energy of 30 J is sufficiently to the penetration of this sample. In the case of pure PP, as can be seen in Figure 6, there no penetration occurs, the pure PP is too tough to be penetrated using so small energy.

Fig. 5 PP30GF deformation after drop-weight impact test at 30 J

Fig. 6 PP deformation after drop-weight impact test at 30 J

The set potential energy of 100 J caused the penetration of both PP30GF and PP as can be seen in Figure 7 and 8. In the case of PP30GF, there the penetration occurs clearly, in the case of pure PP, the beginning of the crack growth is visible.

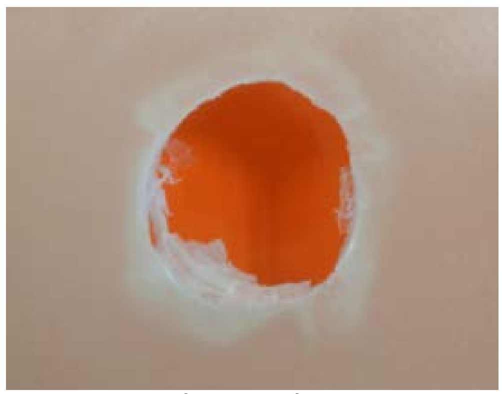

Fig. 7 PP30GF deformation after drop-weight impact test at 100 J

In the case of the set potential energy of 230 J, it is evident that for the PP30GF the energy is enough high, in case of pure PP, the energy caused only the beginning of the crack growth, but the material was not penetrated completely as can be seen in Figure 9 and 10.

Fig. 8 PP deformation after drop-weight impact test at 100 J

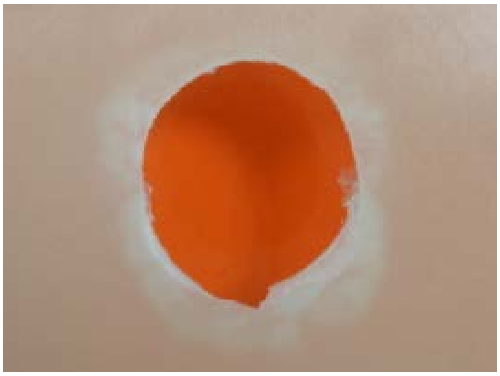

Fig. 9 PP30GF deformation after drop-weight impact test at 230 J

Fig. 10 PP deformation after-drop weight impact test at 230 J

IV. Conclusion

This study dealt with the PP and PP30GF injection moulded samples which were subjected to the drop-weight testing. The set potential energy was in the range of 30 – 230 J. It was found out that the set energy of 100 J is sufficient to penetration of both materials. In case of pure PP the beginning of the crack growth is visible, which is caused by the toughness of this material. The addition of glass fibres caused the easier penetration of the samples.

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