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Optimization of fall height setting for drop weight tested polypropylene

Lenka Hylova[1,*], *Miroslav* Manas[1]

[1]Tomas Bata University in Zlin, nam. T. G. Masaryka 5555, 76001 Zlin, Czech Republic

Abstract. This study deals with polypropylene (PP) which was subjected the drop-weight test. PP is a semicrystalline thermoplastic polymer which is commonly used in many indoor applications and also in the automotive industry in the car interiors. The injection moulded PP samples were subjected the penetration test at different fall heights and the results were subsequently evaluated and discussed. It was found out that the fall heights from 100 to 230 J are suitable for PP penetration, but the optimal one is 100 J. Higher heights are not needed because of increasing power consumption of the test device.

1 Introduction

Polypropylene (PP) is a nonpolar thermoplastic semi-crystalline polymer, it is the most consumed polymer globally and has light weight and low density. PP is widely used because of its low cost and being non-toxic and non-hazardous. PP has a great resistance to acids and alkalis, good processing features, electrical insulation, good chemical stability and its bending fatigue resistance is also great. However, PP has low mechanical properties, which is possible to improve by reinforcing with fillers [1, 2].

Siti Rohana Ahmad, Chengzhe Xue and Robert J. Young from United Kingdom dealt with the reinforcement of PP by graphene nanoplatelets (GNP). An average particle diameter of GNP was 15 µm and the average thickness was 6-8 nm. They found out that the blending of GNP to PP led to a huge modification of both mechanical properties and also the microstructure. The thermal stability, the melting temperature and degree of crystallinity were increased. It was found that the Young´s modulus of PP/GNP nanocomposites increased with the loading of GNP [1].

Jia-Horng Lin, Chien-Lin Huang, Chi-Fan Liu, Chih-Kuang Chen, Zheng-Ian Lin and Ching-Wen Lou used as a filler for PP short glass fibres (SGF) and because PP is nonpolar polymer, it was necessary to use a coupling agent for better adhesion between PP and filler. SGF´s average length was 3.2 nm and diameter was 13 µm. This filler was treated with a silane coupling agent. Maleic anhydride grafted polypropylene (PP-g-MA) and maleic anhydride grafted styrene-ethylene-butylene-styrene block copolymer (SEBS-gMA) were used as coupling agents. They blended various amounts of PP, a specified amount of 25 wt% of SGF and 2, 4, 6 or 8 wt% of a coupling agent (PP-g-MA or SEBS-gMA) together to the form different PP/SGF/PP-g-MA blends and PP/SGF/SEBS-g-MA blends and they successfully improved the compatibility between PP and SGF by using previously mentioned coupling agent. The flexural strength, tensile strength, impact strength, compatibility and thermal behaviour were increased. They found out that SGF is a good reinforcing fibre and the connection of 25 wt% of SGF improves the flexural, tensile and impact strengths of PP [2].

Because PP presents low mechanical performance and low impact resistance at temperatures below its glass transition, it is beneficial to create PP blends with elastomeric compounds. The scientists from Mexico dealt with one of these types of blend, namely with PP/EVA (poly[ehtylene-co-(vinyl acetate)]) blend and they studied the effect of compatibilizers on the impact behaviour of this blend. They found out the relationship between the impact resistance and both EVA concentration in the blend and particle size of the dispersed EVA phase. In content of 40 % of EVA in the blend, the impact resistance increased of more than 270 % with the addition of 6.2 phr of compatibilizers at ambient temperature. Moreover, with increasing the compatibilizer content to 10 phr, an additional rise in the impact resistance was obtained [3].

The scientists Lu Wang and Douglas J. Gardner from USA studied the difference between injection moulded PP samples and PP samples created by fused layer modelling (FLM) device. They used two printing process parameters a layer height and extrusion temperature and explored to examine their influence on the Izod impact strength of printed PP samples. The higher proper printing process control, the more similar Izod impact strength to injection moulded PP is. The higher extrusion

* Corresponding author: hylova@utb.cz

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temperature and the smaller layer height, the smaller cell sizes and higher degree of diffusion is [4].

Ying-Guo Zhou, Bei Su, Lih-Sheng Turng investigated PP/LDPE blended parts with a chemical blowing agent (CBA). They fabricated super-ductile PP/LDPE blended parts by conventional injection moulding machine with CBA. They found out that PP/LDPE blend tends to create super-ductile parts using the chemical foaming method. They also found out a close relationship between morphological structures which were influenced by the packing pressure and time, dosage of the blowing agent and ratio of the composition and mechanical properties [5].

The Brazilian scientists studied a lignin as a green primary antioxidant for PP and they found out that lignin showed an appropriate dispersion in PP matrix without heterogeneities of the cryogenic fracture surface of test samples. To obtain this dispersion, it is needed to use a twin-screw extruder. They also realized that it is possible to use lignin as a stabilizer for PP exposed to humid and warm conditions [6].

This study deals with pure PP and its impact behaviour. There is a small number about research concentrated on pure PP mechanical behaviour. It is important to know well the mechanical behaviour of pure PP and then it is possible to improve the properties using some filler or some kind of polymer modification.

2 Experimental

Polypropylene was used as the basic polymer material (TATREN, IM 25-75). An ARBURG Allrounder 470H Advance Injection moulding machine was used for sample preparation, with the processing conditional to comply with polypropylene (PP) 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.

Injection moulded polypropylene samples were tested on drop weight test machine Zwick HIT230F according to ISO 6603-2 at ambient temperature 23 °C. As a main parameter was used fall height, which was optimized. However, for easier explanation in this article is used impact energy, which is calculated from fall height, weight and gravity acceleration constant. 15 samples at each height (30, 50, 100, 150, 200 and 230 J) were tested and then maximum impact force was statisticaly evaluated in program TestExpert II and MiniTab. At the end crack surface after the test of each height was evaluated.

Table 1: Setting of injection moulding machine parameters.

Injection Parameters	Values
Injection Pressure [MPa]	70
Injection velocity [mm.s^{-1}]	50
Holding Pressure [MPa]	60
Cooling Time [s]	20
Mould Temperature [°C]	30
Melt Temperature [°C]	225

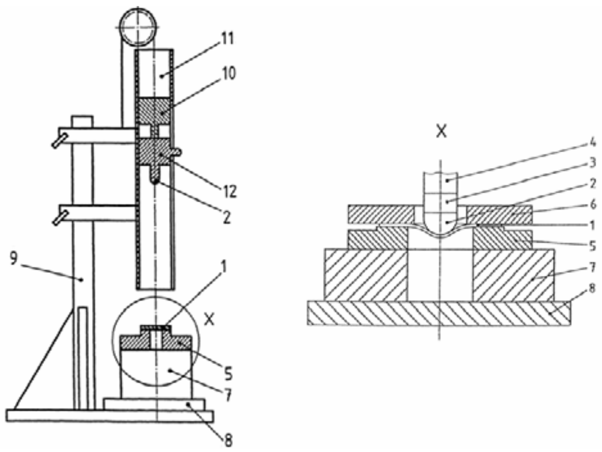

Fig. 1. Falling-dart system.

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.

3 Results and discussion

This study is concentrated on optimization of fall high

Table 2. PP statistical evaluation of the maximum force at the height of the fall.

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	3296	3556	3716	3768	3820	3850
Type error A	1	4	4	8	5	5
Standard deviation	5	13	12	24	16	16
Minimum value	3289	3540	3701	3728	3804	3822
Median	3296	3553	3712	3773	3813	3851
Maximum value	3304	3578	3739	3801	3844	3868
Variation range	14	38	38	73	40	47

during drop weight test of PP. Injection moulded PP samples were penetrated by penetrator with fall heights in the range from 30 to 230 J and the results were subsequently evaluated. The conditions of injection moulding are displayed in Table 1 and PP statistical evaluation of the measurements is shown in Table 2.

3.1. Maximum impact force

The height of fall was set at all measurements differently and the results are then discussed.

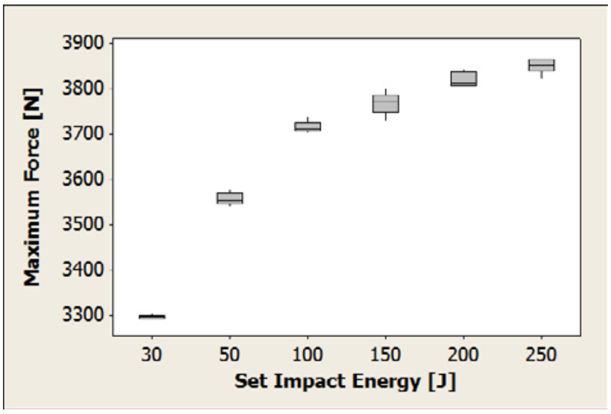

Fig. 2. PP Boxplot graph of maximum force at fall height.

In Figure 2 the maximum force at fall height is displayed. At the height of 30, the sample was not penetrated, there occurs just plastic deformation. It is probably caused by too small fall height for penetration of this material. Penetration occurred at 50 J, but the force is smaller than at the material with the higher fall height what can be caused by the friction of the penetration along the material. Because of that the value 100 J looks like the optimal fall height, because there the penetration occurs and the variation range is small. At the heights from 150 to 230 J the penetrations are also, but it is not needed to use these heights because of increasing power consumption of the test device.

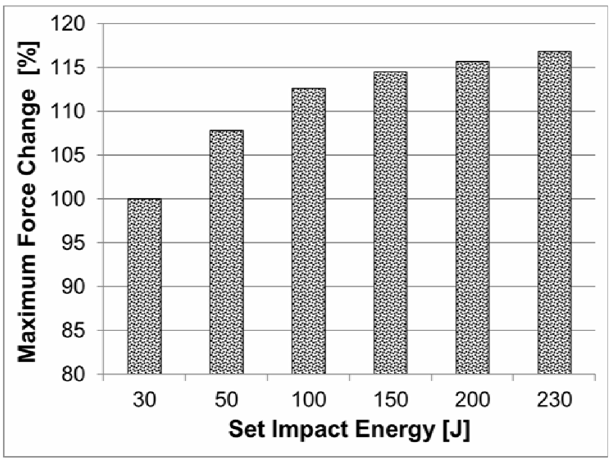

Fig. 3. PP percentage change in maximum force to the prescribed base energy of fall 30 J.

The force change in % during the test can be seen in Figure 3. The changes move in 17 % from the sample with no penetration to last penetrated sample. The sample with the optimal fall height 100 J in comparison with the first penetrated sample at 50 J shows the change around 6 %. The last penetrated sample´s height 230 J increases by 4 % in comparison with the sample with the optimal fall height 100 J. Also in this case it is enough to use the fall height 100 J for the sample penetration.

3.2. Deformation after the test

After the drop weight test the samples were photographed for better idea about the crack growth.

Fig. 4. PP deformation after drop weight test at 30 J.

In Figure 4 it is clearly shown that the material was not penetrated because of too small fall height needed for penetration.

Fig. 5. PP deformation after drop weight test at 50 J.

From Figure 5 to Figure 9 the crack growth at different fall heights can be seen. The crack growth is similar at all samples, because all these fall heights were high enough for this material penetration. However, the fall height 100 J looks like optimal as was already mentioned and explained above.

Fig. 6. PP deformation after drop weight test at 100 J.

Fig. 7. PP deformation after drop weight test at 150 J.

Fig. 8. PP deformation after drop weight test at 200 J.

Fig. 9. PP deformation after drop weight test at 230 J.

4 Summary

In this study the injection moulded PP samples were subjected the test of falling penetrator at different fall heights. The range of fall heights was from 30 to 230 J. At the value of fall height 30 J the sample was not penetrated because of too small fall height. The value 50 J was enough for the sample penetration but was smaller than it was expected which could be caused by the friction of the penetrator along the material during the test. From 50 to 230 J the material was always penetrated, but the values from 150 to 230 J are not needed to use because of increasing power consumption of the test device. The conclusion of this study is that the fall height 100 J is the optimal for the penetration of PP material.

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