 DOI: 10.1051/matecconf/201712502050

Impact resistance of high-density polyethylene against falling penetrator with different potential energy

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Abstract. This study deals with high-density polyethylene (HDPE) which was subjected the drop-weight test. HDPE is a semicrystalline thermoplastic polymer which is commonly used in many applications and mainly in the automotive industry because of its properties. The injection moulded HDPE samples were subjected the penetration test at different potential energies and the results were subsequently evaluated and discussed. The samples were tested in the range of potential energies from 30 to 230 J. The first sample penetration occurred at the energy 50 J. It was found out that the potential energy 30 J is too small for penetration of this material, which shows the impact resistance of HDPE.

1 Introduction

Polymers in comparison with small molecules have rare properties that are very often difficult to predict. For dealing with polymeric materials it is desirable to have some knowledge background of the physical chemistry of polymers. For the industrial practice it is important to know the properties such as heat capacity or melt viscosity for establishing polymerization and processing conditions. Polymers are omnipresent and they are used in a huge number of the applications, from consumer products to high-temperature industrial use to medical devices under a wide-range of conditions. Multilayer films, nanomaterials, electronic devices and electro-optical are being developed in modern polymer science for end-use performance evaluation. These applications require much more complex and specialized testing [1].
Polyethylenes are commodity polymers which account for more than 70 % of total plastics consumption and are low cost, easily processable and available. Typical applications of these polymers are packaging, household items, net ropes, medical applications, fishing rods, water pipes, etc. There are many types of polyethylenes, such as linear low density polyethlyene, low density polyethylene, ethyl vinyl acetate copolymer, polyolefinic elastomer, high density polyethylene and more other polyethylenes [2].

In our study is as a material used high density polyethylene (HDPE) because of its material properties such as impermeability to water, chemical resistance, low cost and easy processing, etc. HDPE is a semicrystalline linear thermoplastic polymer which is commonly used for tubing, shrinkable products, electrical insulation, cable jacketing, waterproofing, corrosion protection against corrosion and for many other applications [3].
HDPE is often used in variety of impact strength demanding applications such as pipe protection for oil and gas transportation, load-bearing biomedical implants, liquid food containers, industrial vessels and automotive fuel tanks. HDPE during these applications may be subjected to drop or crash loading. The scientists from Argentina and Austria J.P. Torres, P.M. Frontini, M. Machado and Z. Major proposed and validated a thermomechanical constitutive model that aims to achieve a compromise between formulation simplicity and prediction accuracy. They found out that initial linear elastic response coupled with a temperature-dependent power-law viscoplastic flow element and a non-linear strain-hardening element are appropriate to model biaxial stress scenarios. They provided experimental infrared thermography data connected with digital image correlation to realize temperature development during HDPE deformation at high velocity. A first try was made at modelling HDPE failure using an element effacement technique. A force-time curve and fracture patterns were well predicted. However, they found out that their experimental information obtained in their study is not sufficient and they are going to continue in their study in the future [4].

A.A. Baulin, A.A. Baulin, A.V. Kalandin, N.A. Kudryavtseva from St. Petersburg improved a good stabilization method of HDPE blends during its preparation to obtain significantly increased stress cracking resistance with retention of physicomechanical

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properties of the composites which are of a practical importance. They used 0.15 % each of complex antioxidants and light stabiliser together with a copolymer of ethylene with vinyl acetate and linear low-density polyethylene to achieve the stabilization of HDPE blend [5].

The scientists from Iraq dealt with filling of HDPE with lignocellulose (LC), calcium carbonate (CC) and fibre glass (FG) and they studied their mechanical properties. They used 0, 5, 10, 15, 20 and 25 wt% of filling with all three fillers. It was found that LC filler increases mechanical properties as the tensile strength, impact strength, Shore D hardness, Young modulus and elongation in % of HDPE. The composite consisted of HDPE and this filler is eco-friendly, low density and has high mechanical properties [6].

This study may become a big benefit for the deeper knowledge of HDPE behaviour, which can be consequently applied in practice applications.

2 Experimental

High-density polyethylene (HDPE) was used as the basic polymer material (DOW HDPE 25055E). An ARBURG Allrounder 470H Advance Injection molding machine was used for sample preparation, with the processing conditional to comply with high density polyethylene (HDPE) 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: Setting of injection moulding machine parameters.

Injection Parameters	**Values**
Injection Pressure [MPa]	80
Injection velocity [mm.s^{-1}]	60
Holding Pressure [MPa]	65
Cooling Time [s]	30
Mould Temperature [°C]	30
Melt Temperature [°C]	185

Injection moulded high density polyethylene 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 30, 50, 100, 150, 200 and 230 J potential energy of penetrator with weight. For each potential energy 15 samples 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.

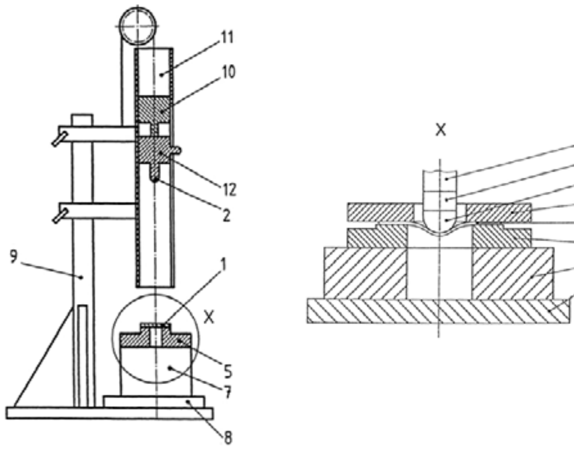

Fig. 1. Falling-dart system.

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 impact resistance of HDPE against penetrator with different potential energies. Injection moulded HDPE samples were penetrated by penetrator with potential energies 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 HDPE statistical evaluation of the measurements is shown in Table 2.

3.1. Maximum impact force

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

Table 2. HDPE statistical evaluation of the maximum force at the energy 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	3554	3675	3780	3840	3754	3890
Type error A	2	3	3	9	18	18
Standard deviation	7	9	10	27	56	55
Minimum value	3543	3655	3761	3768	3657	3786
Median	3553	3675	3783	3853	3767	3918
Maximum value	3564	3688	3792	3899	3851	3929
Variation range	21	33	32	80	194	143

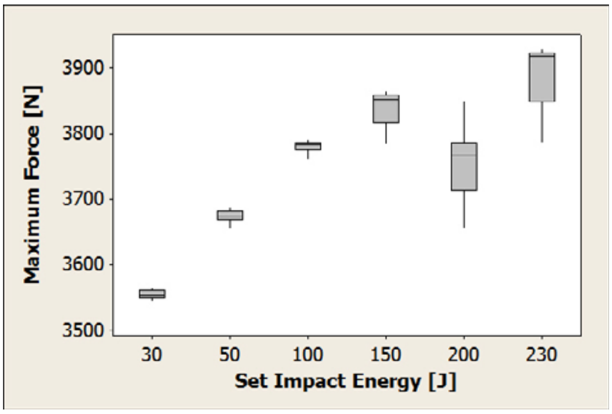

Fig. 2. HDPE Boxplot graph of maximum force at potential energy.

In Figure 2 the maximum force at potential energy is displayed. At the energy of 30, the sample was not penetrated, there occurs just plastic deformation. It is probably caused by too small potential energy for penetration of this material. Penetration occurred at 50 J, but the force is smaller than at the material with the higher impact energy what can be caused by the friction of the penetration along the material. Because of that the value 100 J looks like the optimal potential energy, because there the penetration occurs and the variation range is small. At the energies from 150 to 230 the penetrations are also, but the variation ranges at these measurements are too high.

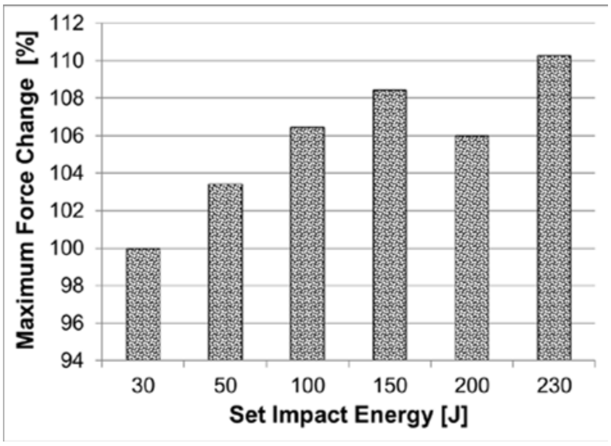

Fig. 3. HDPE percentage change in maximum force to the prescribed base energy of fall 30 J.

The force change in % during the test can be seen in Figure 3. The changes move in 10 % from the sample with no penetration to last penetrated sample. The sample with the optimal impact energy 100 J in comparison with the first penetrated sample at 50 J shows the change around 3 %. The last penetrated sample´s energy 230 J increases by 3 % in comparison with the sample with the optimal potential energy 100 J.

3.2. Deformation after the test

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

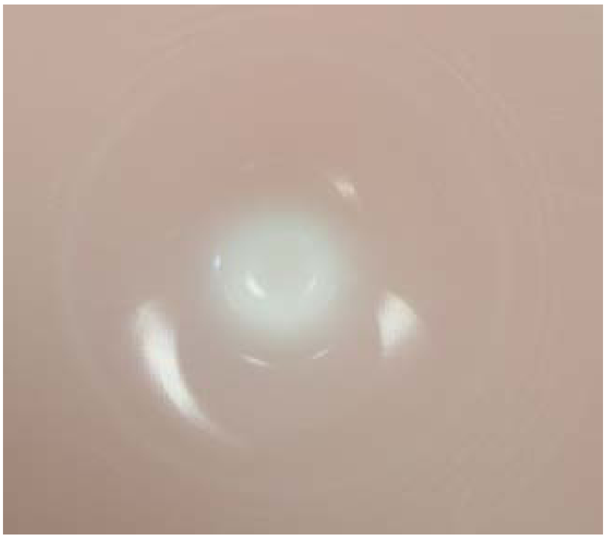

Fig. 4. HDPE deformation after drop weight test at 30 J.

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

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

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

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

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

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

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

4 Summary

In this study the injection moulded HDPE samples were subjected the test of falling penetrator at different potential energies. The range of potential energies was from 30 to 230 J. At the value of potential energy 30 J the sample was not penetrated because of too small energy. 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 had too high variation ranges. The conclusion of this study is that the potential energy 100 J is the optimal for the penetration of HDPE material and the lowest potential energy for penetration is 50 J.

Acknowledgment

This paper is supported by the internal grant of TBU in Zlin No. IGA/FT/2017/010 and funded from the resources of specific university research and by the Ministry of Education, Youth and Sports of the Czech Republic within the National Sustainability Programme project No. LO1303 (MSMT-7778/2014) and also by the European Regional Development Fund under the project CEBIA-Tech No. CZ.1.05/2.1.00/03.0089.

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