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Investigation of Mechanical Behaviour of LLDPE Foil

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Abstract. LLDPE foil is commonly used for packing. Since this material allows large plastic deformations, it was suggested to use it as the main part of a new concept of safety systems for the automotive industry. A tensile test and an impact test with a spherical impactor were performed to investigate the mechanical behaviour of the foil. The force-displacement curves of the foil, and deceleration of the impactor and displacement of the foil with the impactor at the bottom dead centre were evaluated to obtain data for the material model.

Introduction

Low-density polyethylene (LDPE) is a frequently used material for packing. This material can be also incorporated with biological materials, such as different starch sources, to obtain partially biodegradable product [1]. The LDPE itself can be recycled and thus reduce the plastic waste [2]. This plastic has been found to be promising e.g. in asphalt mixtures and plastic bonded sand blocks [2, 3].

When comparing low-density polyethylene (LDPE) and linear low-density polyethylene (LLDPE), the strength and the elongation (energy to break a unit volume of material) is higher in the case of LLDPE [4]. Therefore, LLDPE was suggested to use it as the main part of Nanobag system [5] - a new concept of safety systems for the automotive industry. The suitability of the LLDPE foil for the Nanobag safety system should be assessed using numerical simulations of car crashes such as [6].

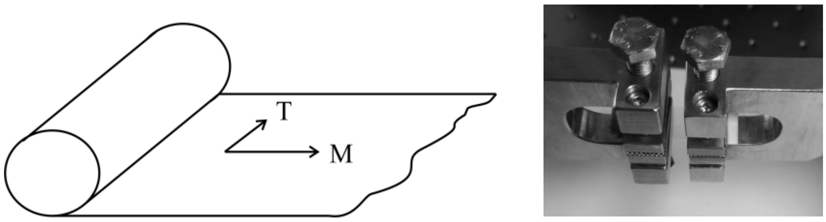
Both LDPE and LLDPE foils are anisotropic. The highest strength is in the longitudinal (machine) direction [4]. The crystallographic deformations were studied in [4] using the scanning electron microscopy and differential scanning calorimetry techniques for lamellar structure and orientation. The LLDPE structure shows more randomly orientated and thicker lamellae than that of the LDPE foil. The result of this structure is a more balanced toughness.

The foil produced by TICHELMANN was used for the study. The thickness was 12 μm, the density was 0.091-0.092 g/cm^3, as provided by the material data-sheet from the producer.

This work aimed to investigate the mechanical behaviour of the LLDPE foil and subsequently to obtain material data for the numerical simulations. The mechanical behaviour was investigated using a tensile test and an impact test.

Tensile test

The 574LE2 TestResources machine was used for the uniaxial tensile test of rectangular samples having the initial length $l_0 = 5$ mm and the width $w = 10$ mm. Tensile samples were cut from the foil in two perpendicular directions (see Fig. 1a), commonly referred to as machine (M) direction and transverse (T) direction, related to the foil manufacturing process [7]. Displacements of mechanical grips Δl (see Fig. 1b) were prescribed and force F was measured. Three loading velocities were applied, namely 0.2 mm/s; 20 mm/s; 100 mm/s. Six samples were tested per each velocity group. The engineering tensile strength and the ultimate elongation were determined from the force-displacement curves. The Mann-Whitney U-test was used to compare the resultant data between velocity groups.



(a) (b)

Fig. 1: a) Material directions, b) a tensile sample in the mechanical grips

Impact test

A drop tower designed by the authors was used to test the foil. The measured foil was n-times ($n = \{8, 9, 10\}$) wrapped in M direction around a specially designed frame imitating the clamping of the foil in the Nanobag safety system (see Fig. 2). A spherical impactor having the diameter of 149 mm and the weight of 10.72 kg dropped from the heights $h_1 = 1$ m and $h_2 = 1.5$ m. The deceleration of the impactor a was measured by KISTLER 8742A5 accelerometer. The displacement of the impactor at the bottom dead centre w_{max} was measured using the Micro-Epsilon optoNCDT 2300-50 laser. The maximum measurable value of the displacement was set to $w_{limit} = 275$ mm, as displacements exceeding this value are not suitable for the Nanobag safety system. The sampling frequency was 26 kHz.

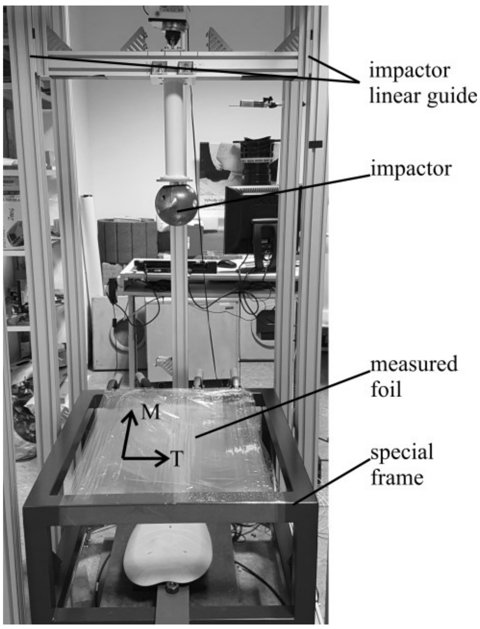
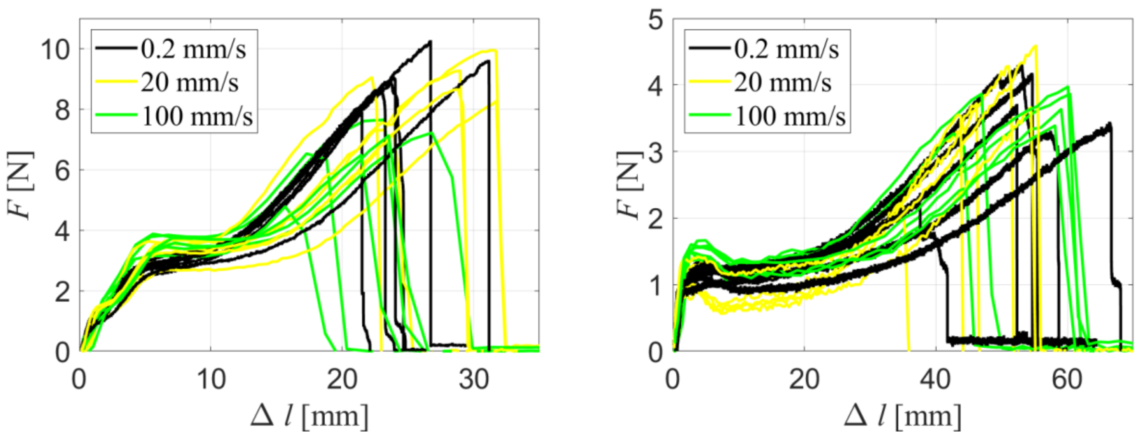


Fig. 2 The impact test

Results

The force-displacement curves of the tensile test are shown in Fig. 3. Evaluated mean values of the engineering tensile strength and ultimate elongation are listed in Table 1 and Table 2. The tensile strength of the foil is approximately two times higher in the M direction than in the T direction. Conversely, the elongation is approximately two times lower in the M direction when compared with the T direction. The influence of the loading velocity on the force-displacement curves was not significant except for the strength in the M direction when the strength was reduced in the case of the fastest velocity (54 MPa at 100 mm/s).



(a) (b)

Fig. 3: The force-displacement curves: a) the M direction, b) the T direction

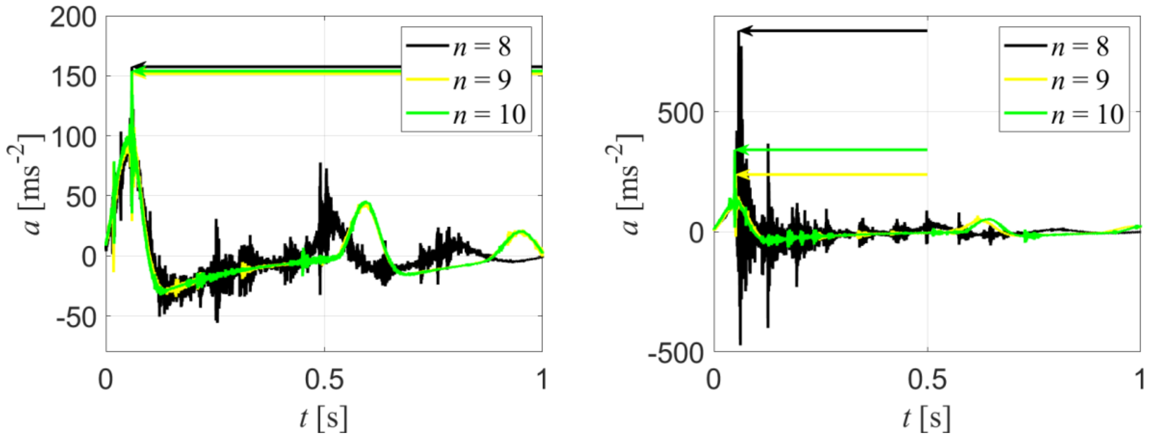
Table 1: The mean values of the engineering ultimate strength

Loading velocity [mm/s]	Strength in M direction [MPa]	Strength in T direction [MPa]
0.2	74.5	28.3
20	72.3	30.0
100	54.0	29.9

Table 2: The mean values of the ultimate elongation

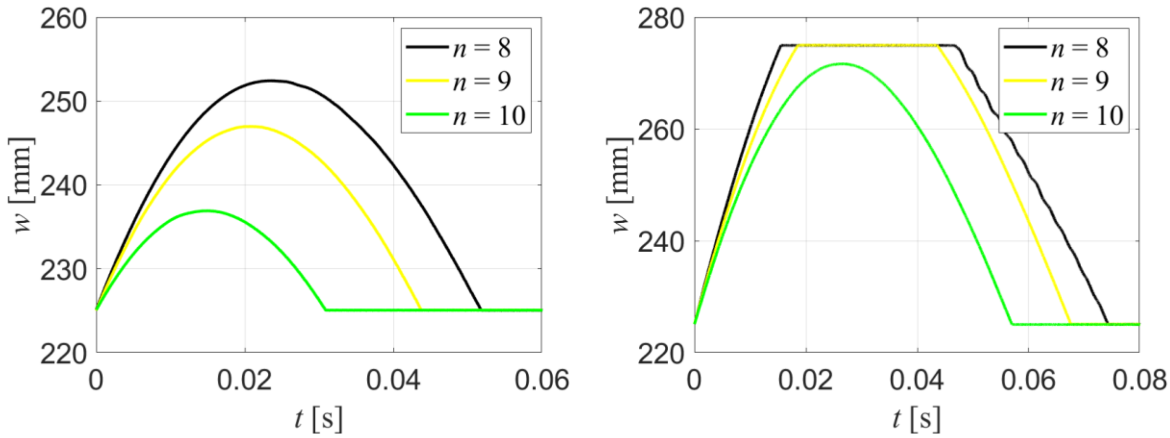
Loading velocity [mm/s]	Elongation in M direction [%]	Elongation in T direction [%]
0.2	499	1065
20	555	950
100	427	1091

The impactor deceleration a and the impactor displacement w in relation to the number of the foil coatings n are shown in Fig. 4 and Fig. 5, respectively. It can be seen that a higher number of the foil coatings n resulted in lower value of the impactor displacement at the bottom dead centre w_{max} (see Table 3). In the case of the drop height h_2: when $n < 10$, the foil did not stop the impactor before the displacement w reached the limit $w_{limit} = 275$ mm and when $n = 8$, the impactor even hit the drop tower frame. Therefore, the maximum deceleration value was 837 ms^{-2}. It follows from the above that the necessary number of the foil coatings was $n = 10$ to comply with the w_{limit} limit for both drop heights. When $n = 10$, maximum deceleration values were 154 ms^{-2} and 342 ms^{-2} for the drop heights $h_1 = 1$ m and $h_2 = 1.5$ m, respectively.



(a) (b)

Fig. 4: The deceleration in time: a) h_1 = 1 m, b) h_2 = 1.5 m



(a) (b)

Fig. 5: The displacement of the impactor in time: a) h_1 = 1 m, b) h_2 = 1.5 m

Table 3: The displacement of the impactor at the bottom dead centre

Number of foil coatings N	w_{max} [mm] with drop height h_1 = 1 m	w_{max} [mm] with drop height h_1 = 1.5 m
8	252.4	over 275
9	247.0	over 275
10	236.9	271.6

Conclusions

The material data suitable for the crash numerical simulations involving LLDPE foil were obtained. The tensile curves in both material directions did not significantly depend on the used loading velocity, except for the strength in the machine direction which was reduced at the fastest velocity. Both tensile and impact tests have shown the promising energy-absorbing properties of the foil. This support the usage of the foil not only for packing but also for further application as the part of Nanobag system, where the energy-absorbing properties are crucial. The ten-times wrapped foil complied with the impactor displacement limit for both tested drop heights.

Acknowledgement

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