Polymer Bulletin 59, 677–683 (2007)
DOI 10.1007/s00289-007-0812-7

Polymer Bulletin

Mechanical properties of foams comprising virgin and waste polyethylene

Marcelo G. Almeida, Renan Demori, Ademir J. Zattera, Mara Zeni (✉)

Chemistry and Physics Department of University of Caxias do Sul – Francisco Getúlio Vargas, 1130, B. Petrópolis, CEP 95070-560, Caxias do Sul/RS – Brazil
E-mail: mzandrad@ucs.br

Received: 19 April 2007 / Revised version: 15 June 2007 / Accepted: 8 July 2007

Summary

This paper addresses the use of waste polyethylene (p-PE) in low-density polyethylene (LDPE) foams with azodicarbonamide as the blowing agent. The amount of blowing agent was fixed at 5% for all mixtures, with 0.5% cross-linking agent, 1.7% zinc oxide and 1.7% stearic acid, by weight. Proportions of LDPE/p-PE (% wt) tested in foams were: 100/0, 85/15, 70/30, 60/40, 50/50 and 30/70. The components used to obtain the foams were processed in a Banbury mixer at 120°C. The pre-form (non expanded material) was placed in a mold and the foaming was carried out in a hot press at 190°C. The apparent densities of the foams obtained were 60-65 kg.m^{-3}. The mechanical properties (compression set under constant deflection, compressive strength and tear resistance) of LDPE foams containing different proportions of p-PE were compared with the LDPE foam obtained from virgin material only. The mechanical properties of foams with p-PE in their formulation were superior in relation to foams made from LDPE, because p-PE contains high-density polyethylene (HDPE), which is more rigid than LDPE.

Introduction

The United States, European countries and Japan have used plastic foams since 1960. However, only from the 1980s onward did consumption increase with the development of new markets, technologies and applications, such as packaging used as protection against impact and vibration of fragile products. The shoe, civil construction and automotive industries are also potential markets [1].

Zhang *et al*. researched the density and other morphological aspects of high-density polyethylene foams (HDPE), using HDPEs with different molecular weights. Increasing the molecular weight of the HDPE, which may be correlated to increasing viscosity, generates smaller cells. A higher PE viscosity leads to a stronger resistance to blowing [2].

Zhang *et al*., also measured the elastic modulus, and tension and flexion properties of HDPE foams, comparing the data obtained with several models proposed to predict cellular material properties, in order to verify which model best fitted the obtained results. Increasing the HDPE molecular weight changes the behavior of the material tension properties from fragile and brittle to ductile [3-5].

Gendron & Vachon [6] studied the effect of using poly(ethylene-co-octene) with different melt flow indexes, as well as the effect of using different cross-linking agent amounts, on foam density. The use of a cross-linking agent is necessary to maintain the foaming process, and to prevent cell collapse.

Polymers blends have been used to produce cellular materials combining the properties of each polymer in the blend with their respective foams. A high volume commodity polyolefins like polypropylene (PP), HDPE and LDPE are blended and foamed due to their relative easy of processing [7-13].

The compression molding is used to manufacture blended polyethylene foams [14]. A clear effect of polyethylene type on cell size can be observed: when molecular weight is increased there is a higher resistence in the cell growth stage.

Blends of LDPE and poly(ethylene-co-vinylacetate) (EVA) are popular in polymeric foam applications. The noncrosslinked foams made from blends of LDPE anda EVA show an increase of flexibility, toughness, impact resistence and controllable open cell contents [15]. Other blends are commonly used in foams applications such as LDPE/PP, to improve the prolonged use of material when the temperature exceeds 80°C, and LDPE/polystyrene (PS), because the LDPE influences the density and the thermal conductivity of LDPE/PS foams [16-17].

Zattera *et al.* [18] compared molecular, mechanical, morphological, thermal, and mechanical-dynamic properties of post-use polyethylene, derivate from urban waste, in relation to the virgin polymer. They reported that the post-use polyethylene has similar properties to the virgin material.

This study aimed to manufacture low-density polyethylene (LDPE) foams incorporating different proportions of post-use polyethylene (p-PE) and to investigate the effect of the use of different proportions of p-PE on mechanical properties of the foams.

Experimental Methods

Materials and Equipment:

The LDPE used was type SX7012 of Petroquímica Triunfo S.A. (Triunfo – BR) and the p-PE was obtained from a local recycling company (Caxias do Sul – RS).

The formulation components were azodicarbonamide (Planagem CS4M Bayer S.A. – São Paulo - SP), dicumyl peroxide (Retilox Química Especial Ltda. – Santana do Parnaíba - SP), zinc oxide (Global Química Ltda.) and stearic acid (Quimibrás Indústrias Químicas S.A. – Rio de Janeiro - RJ), used as blowing agent, cross-linking agent, activator, and process aid, respectively.

For all the formulations, 50 g were processed using a Banbury mixer (UCS/Eletron), a hot press (Paschal 100 t) and a mold of dimensions 12 x 12 x 5 cm [19].

Preliminary Tests and Analysis:

In a study carried out by Zattera *et al.* [18], the types of PE present in p-PE were analyzed using differential scanning calorimetry (DSC).

The melt flow indexes of LDPE SX7012 and the p-PE were measured using a Dynisco Kayeness Polymer Test System, model D4001 Hv, at a temperature of 190°C and with a weight of 10kg (ASTM D1238).

Mixtures Tested:

The amount of blowing agent was fixed at 5% for all mixtures, with 0.5% cross-linking agent, 1.7% zinc oxide and 1.7% stearic acid, by weight [20]. The proportions of LDPE and p-PE used are given in Table 1.

Table 1 – Proportions of LDPE SX7012 and p-PE (% wt) in the mixtures

Percentage of LDPE	Percentage of p-PE
100	0
85	15
70	30
60	40
50	50
30	70

Preparation of Foams:

The components used to obtain the foams were processed in a Banbury mixer at 120°C for 10 minutes, with progressively increasing speeds from 2 to 10 rpm, aiming at the dispersion of formulation components. The pre-forms (non expanded material with a thickness of a few millimeters – around 3-5 mm) were placed in a mold and the foaming was carried out in a hot press at 190°C for 10 minutes with a 5t ($322x10^5$ $N.m^{-2}$). Molds were cooled in the press through cold-water flow. Expanded sheets of 5 cm thick (corresponding to the size of the mold) were obtained [19].

Analysis and Testing of Foams:

The apparent densities of the foams obtained were determined according to the standard method ASTM D3575 [21].

The mechanical properties of the LDPE foams containing different proportions of p-PE were compared with the LDPE foam obtained from virgin material only. Standard test methods for compression set under constant deflection at 23°C and 70°C (ASTM D3575) [21], compressive strength (ASTM D695) [22] and tear resistance (ASTM D624) [23], were used (five samples for each foam formulation were used in the tests).

Results and Discussion

The characterization of the p-PE, by DSC, indicated that this material was a mixture of HDPE and LDPE, with two melt temperatures (110°C and 125°C).

The LDPE SX7012 and p-PE had melt flow indexes of 1.74 ± 0.16 $g.min^{-1}$ and 0.60 ± 0.01 $g.min^{-1}$, respectively.

The apparent densities of the foams obtained using compression molding are given in Table 2.

Table 2 – Apparent density of LDPE/p-PE foams (ASTM D3575)

LDPE/p-PE (% wt)	Apparent density of foam ($kg.m^{-3}$)*
100/0	61.47 ± 3.89
85/15	61.51 ± 1.99
70/30	62.21 ± 1.81
60/40	65.07 ± 3.09
50/50	64.40 ± 0.14
30/70	63.09 ± 0.38

* Although ASTM D3575 recommends the use of one sample for each foam formulation to measure density, in this study five samples were used, and the density given is the average value followed by the standard deviation.

The standard test method for compression set under constant deflection was performed at 23ºC, according to the standard method ASTM D3575, as mentioned. It consists of using a tool made of two parallel metal plates between which the distance is determined by screws. The foam sample (5x5x2.5 cm), cut from the foamed sheet, is placed between the two metal plates. Once the screws are in place, the sample is subjected to 22 hours of the action of a compressive strength able to reduce by 50% the initial sample thickness. After being left to stand for a further 24 hours, the final sample thickness is measured.

The same test was then performed at 70ºC. The only difference between the two tests is that this one was performed in a furnace. For both cases, 23ºC and 70ºC, results for compression set under constant deflection are expressed as a percentage of the original thickness. The calculation followed the standard method ASTM D3575 [21]:

compression set under constant deflection (%) = [(initial thickness – final thickness)/initial thickness] x 100

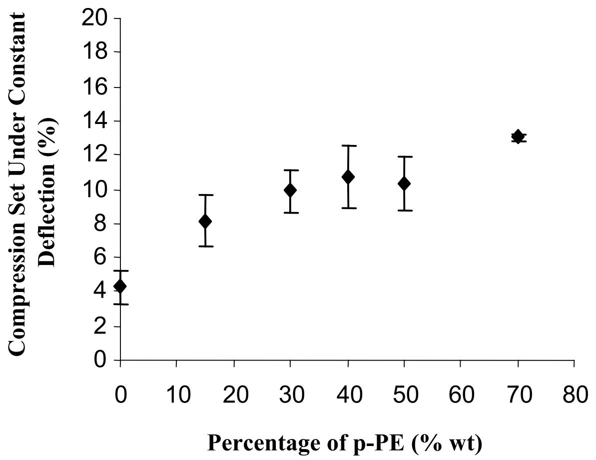
The results of the standard test method for compression set under constant deflection carried out at 23ºC and 70ºC are presented in Figures 1A and 1B, respectively.

At 23°C, the compositions which included p-PE had higher values than the composition with virgin LDPE only. The increase in this property, in relation to foam made from LDPE virgin, was 90% for LDPE/p-PE 85/15 (4.28% to 8.16%) and for LDPE/p-PE 30/70 the value trebled (4.28% to 13.02%) (Figure 1A). These results reflect the fact that the p-PE has HDPE in its composition. As the amount of p-PE in the formulation increased the foam became less flexible.

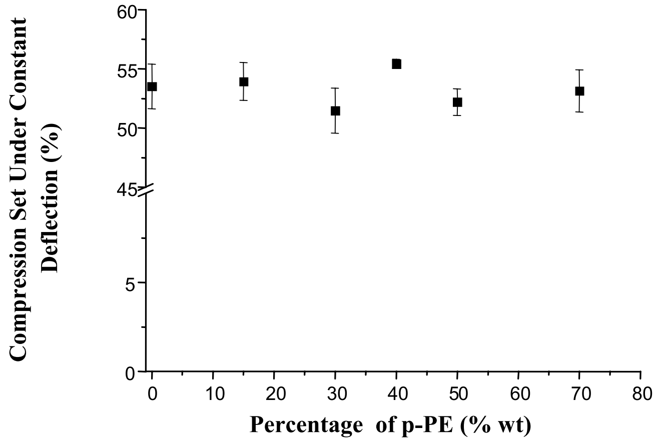
Figure 1B shows that the compression set under constant deflection values at 70°C for the virgin LDPE foam and all compositions which included p-PE were similar. The values were between 50-55% for all compositions, which is higher than those obtained for the test performed at 23°C. These results can be attributed to an increase in the degree of cross-linking, which leads to a more rigid material.

The compressive strength tests were performed using universal testing equipment with a compression speed of 1.3mm.min^{-1}, to determine the force required to reduce the sample thickness to 50% and 75% of its initial thickness, according to the standard method ASTM D695. The results for these tests are shown in Figure 2. The compositions which included p-PE required more strength values than foam obtained from virgin LDPE only, to reduce the thickness by 50% and 75% from de initial thickness. The differences on strength values for the mixtures were 30% higher than those for the foam comprising virgin LDPE only in the case of LDPE/p-PE 85/15, 70/30, 60/40, 50/50 and 80% higher in the case of LDPE/p-PE 30/70. This behavior is due to the fact that p-PE contains HDPE (i.e., the foam becomes more rigid with the increase of the percentage of p-PE).

The tear resistance tests were also performed using universal testing equipment, according to the standard method ASTM D624. This consisted of measuring the strength required to tear the foams at a specific separation speed of 500mm.min^{-1}. The results are shown in Figure 3. The tear resistance increases in foams with over 40% of p-PE incorporated. There was a 25% increase in the value for this property for the composition of LDPE/p-PE 60/40, in relation to foam with virgin LDPE only (tear resistance increased from 2.07 kN.m^{-1} to 2.61 kN.m^{-1}).



A



B

Figure 1 – Compression set under constant deflection at 23ºC (A) and 70°C (B) for foams with varying p-PE compositions.

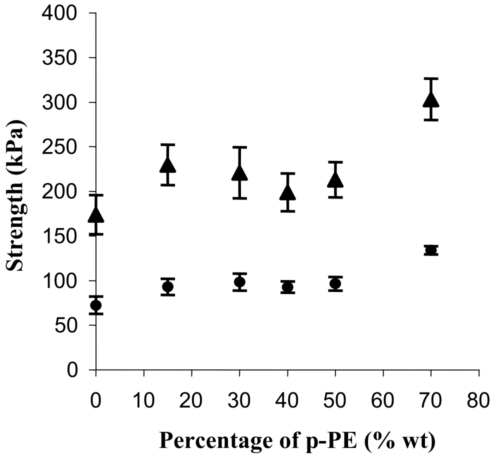


Figure 2 – Strengths required to reduce the thickness of foams with varying PE composition to 50% and 75% of their initial thickness (● 50%; ▲ 75%)

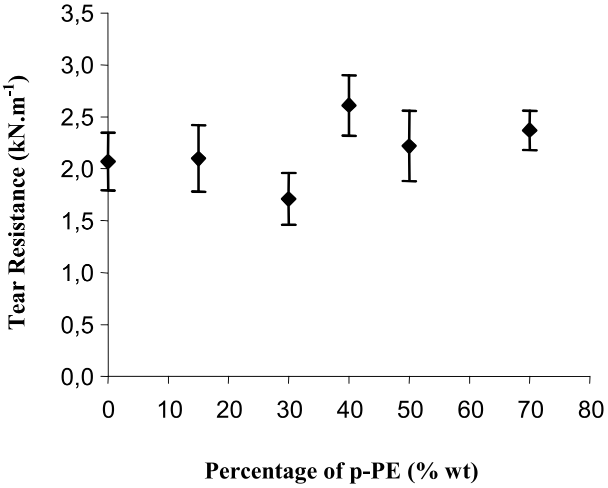


Figure 3 – Tear resistance of PE foams with varying percentages of p-PE incorporated

Conclusions

The mechanical properties of the foams with p-PE in their formulations were superior in relation to foams with virgin LDPE only, since the p-PE contained HDPE, which is more rigid than LDPE. It was possible to verify that there is a relationship between the polymeric matrix and the expanded material properties. The greater the percentage of p-PE in the foam formulation, the more rigid the foam becomes.

From the values obtained for compression set under constant deflection at 23°C, an increase in the reduced thickness (expressed as a percentage of the original thickness) of foams containing p-PE was observed in relation to virgin LDPE foam. Values for LDPE/p-PE 85/15, 70/30, 60/40 and 50/50 were 30% higher, and that for LDPE/p-PE 30/70 was 80% higher, than the value for virgin LDPE foam.

For compression set under constant deflection at 70°C, the reduction in thickness values for the virgin LDPE foam and all foams with p-PE incorporated, were similar, all values being within 50-55%. These values are higher than those obtained in the test performed at 23°C (4-13%), which can be attributed to an increase in the cross-linking degree, which leads to a more rigid material.

In relation to tear resistance, higher values were observed for foams with over 40% of p-PE incorporated, in relation to the virgin LDPE foam. For the composition LDPE/p-PE (% wt) 60/40, there was a 25% increase in this value in relation to the virgin LDPE foams.

The use of recycled material in PE foams is a practical alternative for recycling polymers, providing foams with interesting properties from the technological and market demand points of view.

Acknowledgements. The authors thank UCS, FAPERGS and CNPq for financial support and for supplying materials.

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