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Short communication: material behaviour

Orientation induced brittle – Ductile transition in a polyethylene/polyamide 6 blend

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ABSTRACT

Polyamide/polyolefin blends are of scientific and technological interest but, on the other hand, the different chemical nature of the two components makes them incompatible, resulting in unsatisfactory physical properties and making compatibilization necessary. In particular, although the two components are ductile, the binary blends can show brittle behaviour.

It is also known that the effect of the elongational flow (and then of the induced orientation) on polymer blends is a decrease of elongation at break with increase of the degree of orientation.

In this work, the effect of orientation on the mechanical properties of a low density polyethylene/polyamide 6 incompatible blend was investigated.

An unexpected, orientation-induced brittle/ductile transition has been found, and interpreted in terms of microstructural changes, involving the orientation of the matrix macromolecules and of the dispersed phase particles.

1. Introduction

Polyamide/polyolefin blends are particularly interesting and attractive from a scientific and industrial point of view. The different chemical nature of the two components makes these blends incompatible, with unsatisfactory physical properties; this makes compatibilization techniques necessary in order to obtain the desired characteristics [1–8]. Ductility is one of the most penalized properties because, although their two components are very ductile, their binary blends can show brittle behaviour depending on their composition. This is obviously due to the poor adhesion between the two phases, acting as a material defect and giving rise to early breaking of the samples.

Some papers are available dealing with the effect of the elongational flow and then of the induced orientation in polymer blends [9,10]. The observed effect is – like in semicrystalline polymers – a decrease of elongation at break with increase of the degree of orientation.

To our knowledge, no paper has dealt with the comparison between the ductility of the oriented polymer and that of the isotropic state. The aim of this work is, therefore, to make preliminarily investigation of the effect of the orientation on the mechanical properties of a low density polyethylene/polyamide 6 incompatible blend. This blend is known to show significantly different behaviour depending on the polyolefin and polyamide type used, as well as their reciprocal amounts, the processing conditions and the possible presence of additives [11–13].

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An unexpected, orientation-induced brittle/ductile transition has been found, and interpreted in terms of microstructural changes [14].

2. Materials and methods

The polyamide 6 (PA6) used in this work, Radilon S35 100 NAT, was kindly supplied by Radicinova, Italy. It has an intrinsic viscosity (measured in sulphuric acid) of 3.4 dl/g. The low density polyethylene (LDPE) used was a film blowing grade (FC39, Versalis, Italy), melt flow rate = 0.26 g/10 min (at 190 °C, 2.16 kg load). Neither material contains any antioxidant or stabilizer.

Before processing, PA6 was dried for 10 h in a ventilated oven at 90 °C, followed by 16 h under vacuum at 120 °C.

The blend (75wt% LDPE, 25wt% PA6) was then prepared by premixing the materials in the solid state (with the help of a tumble mixer), and then by feeding into an OMC (Italy) corotating twin screw extruder, operating with a thermal profile of 140/160/180/200/220/240 °C and screw of speed 200 rpm.

The film blowing operation was performed with a Brabender (Germany) single screw extruder (D = 19 mm, L/D = 25), with a thermal profile of 180/200/220/240 °C, screw speed 60 rpm, by feeding it with granules of the blends prepared with the twin-screw extruder. The single screw extruder was equipped with a film blowing head and a film blowing unit.

The blow-up ratio (BUR) was about 4 for all of the blown samples, while the draw ratio (DR) was 5 and 10 (film thicknesses were 25 and 50 μm).

Scanning electron (SEM) micrographs were taken on liquid nitrogen fractured samples, using a FEI (USA) Quanta 200F scanning electron microscope.

The micrographs were processed by Leica (Germany) QWin analysis software to analyze the particle size distribution. At least 250 particles per sample were measured.

The particles diameters were averaged by using the following Eqn. 1:

$$D = \frac{\sum_{i=1}^{n} n_i D_i}{\sum_{i=1}^{n} n_i} \quad (1)$$

where D_i is the diameter of the i-th particle, n_i is the number of particles having D_i as diameter.

Mechanical characterization was carried out using samples cut from the films, in both the machine and transverse directions. In order to evaluate the effect of the orientation, tests were also carried out on isotropic samples cut from compression-moulded sheets (10 × 90 × ~0.6 mm) using an Instron (USA) 3365 tensile testing machine according to ISO 527-3. The grip separation was 50 mm and the crosshead speed was 50 mm/min. The reproducibility was satisfactory (±7%).

3. Results and discussion

The values of tensile strength, TS, and elongation at break, EB, of all the investigated samples are reported in Table 1. The compression moulded sheets are unoriented, isotropic samples, while film is oriented and the values of the mechanical properties are measured along both the machine and the transverse direction.

Table 1
Mechanical properties of isotropic and anisotropic samples.

	Tensile strength [MPa]	Elongation at break [%]
Sheet	15 ± 0.7	18 ± 0.8
Film, machine direction, DR = 5	18 ± 1	279 ± 13
Film, machine direction, DR = 10	21 ± 1	164 ± 7
Film, transverse direction, DR = 5	10 ± 0.6	22 ± 1

The blown film of the blend shows tensile strength and elongation at break values which are between those of the two component polymers, reported in Table 2. This is an unexpected result since in the isotropic state (i.e. compression molded sheets), the elongation at break of the blend is well below the values of the two component polymers prepared under the same conditions (Table 2).

The anisotropic samples (i.e. blown films) of this incompatible blend show an almost brittle behavior with very low values of the elongation at break. This is well expected on the basis of the incompatibility between the two components: polyethylene is apolar while the polyamide is a polar polymer. This hypothesis is confirmed by the SEM micrograph reported in Fig. 1.

The blend shows the typical morphology of incompatible blends, with very poor adhesion, presence of voids between the two phases and dispersed particles of about 1–8 μm, with average diameter of about 2.8 μm.

The mechanical properties of the oriented film show unexpected features. Completely unexpected is the behaviour of the elongation at break of these anisotropic films that become ductile after orientation. Indeed, a decrease of the elongation at break with the orientation should be expected [9,10]. The impressive difference between the isotropic and anisotropic sample measured in the machine direction is well evidenced by two typical stress-strain curves reported in Fig. 2. The elongation at break of the isotropic compression moulded sheet is low, and also lower in comparison to other previously published results [15,16] for similar blends. This is of course the result of this type of processing.

The SEM micrograph of an anisotropic sample (Fig. 3) indicates that the dispersed particles of the polyamide phase are deformed (relatively long cylinders and not spherical particles) and preferentially oriented along the machine direction since the elongational flow in this direction is much larger than that in the transverse direction, as also revealed by the SEM micrograph. The calculated average of the cross-section diameters of these cylinders is about 0.63 μm. The contact area between the matrix and

Table 2
Mechanical properties of film and sheet of the two components.

	Tensile strength [MPa]	Elongation at break [%]
PA6 (film)	40 ± 2	210 ± 10
LDPE (film)	17 ± 0.8	410 ± 21
PA6 (sheet)	30 ± 2	40 ± 3
LDPE (sheet)	15 ± 1	480 ± 28