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A NOVEL ROUTE FOR OBTAINING HIGH MELT STRENGTH RECYCLED HIGH-DENSITY POLYETHYLENE

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INTRODUCTION

The thermo-mechanical degradation of high-density polyethylene (HDPE), typically occurring during mechanical recycling processes, involves several concurrent phenomena, such as chain scission, branching formation and crosslinking [1], resulting in the achievement of a heterogeneous microstructure. This last, and the consequent poor mechanical properties of recycled HDPE, limit the final application of this material towards low added-value products. Therefore, to effectively accomplish a circular economy model aiming at reuse and recycle the plastic products already in circulation, the degradation-induced microstructural modification should be in some way controlled, in order to drive it towards the achievement of a specific microstructure enabling recycled HDPE utilization in valuable applications. In this work, an effective strategy for obtaining recycled HDPE with increased melt strength, hence improved processability upon elongational flow, was proposed. To this aim, a commercially available additive (Nexamite® R305, NEX) was introduced in a degraded HDPE sample, and the so-obtained material was subjected to further reprocessing. The recycled materials with and without NEX were subjected to non-isothermal elongational flow for obtaining fibers at different draw ratios which were further characterized through tensile tests.

EXPERIMENTAL

Materials

The materials used in this work were:

- ≠ High-density polyethylene (HDPE) Eraclene MS80U supplied by Versalis having a melt flow rate of 27 g/10 min (190 °C/2.16 kg);
- ≠ Nexamite® R305 (NEX) supplied by Nexam Chemical.

Processing

The melt processing (190°C) was carried out by means of a twin-screw extruder Process 11 (Thermo Fisher Scientific) equipped with a screw profile with alternance of conveying and kneading screw elements.

Rheological and physico-chemical characterization

The spectroscopic characterization was carried out on thin films (thickness = 50 µm) by means of attenuated total reflectance infrared spectroscopy, using a Frontier spectrophotometer (Perkin Elmer).

Rheological measurements were performed using a strain-controlled parallel plate rheometer ARES (TA Instrument) at 190°C under nitrogen atmosphere. The melt strength was calculated in non-isothermal elongational flow by using a RheoSpin apparatus and fibers with different draw ratios ($DR = \frac{\text{diameter}_{\text{extrudate}}^2}{\text{diameter}_{\text{fiber}}^2}$), were collected.

The mechanical characterization was performed through tensile tests with an Instron® 5966 machine. The measurement parameters for testing ISO 527-5A specimens were an initial strain rate of 1 mm/min that increased up to 10 mm/min once a deformation of 0.25% was exceeded. The tests on fibers were performed with a crosshead speed of 20 mm/min.

RESULTS AND DISCUSSION

The preliminary tensile characterization of recycled HDPE showed that, due to the thermo-mechanical degradation underwent by the polymer, the tensile modulus slightly decreases as compared to the virgin material, while the elongation at break suffers a drastic reduction passing from HDPE (114 %) to its degraded counterpart (5 %).

The rheological and spectroscopic characterizations demonstrated that the observed dramatic decrease of the material ductility can be ascribed to the heterogeneous microstructure resulting from the different phenomena (namely, chain scission, branching formation, crosslinking) concurrently occurring during the HDPE reprocessing.

Aiming at solving this issue, a commercially available additive (NEX) was introduced in an already degraded HDPE. The obtained results demonstrated that the additive is capable of selectively directing the thermo-mechanical degradation pathway of HDPE towards the achievement of long-chain branching microstructure, as can be inferred from the analysis of the Cole-Cole plot reported in figure 1A. Interestingly, long-chain branched recycled HDPE (containing NEX) exhibits remarkably higher values of melt strength values as compared to recycled HDPE (without NEX), hence allowing the further processing of the so-obtained materials through technologies dominated by the elongational flow.

Finally, fibers based on recycled HDPE containing NEX were collected and characterized through tensile tests, showing a striking increase of the elongational at break as compared to the pristine recycled HDPE fibers (Fig 1B).

In all, this work demonstrates the possibility of obtaining recycled HDPE materials potentially suitable for future applications characterized by high-engineering requirements, opening new perspectives towards an effective upcycling of HDPE-based wastes.

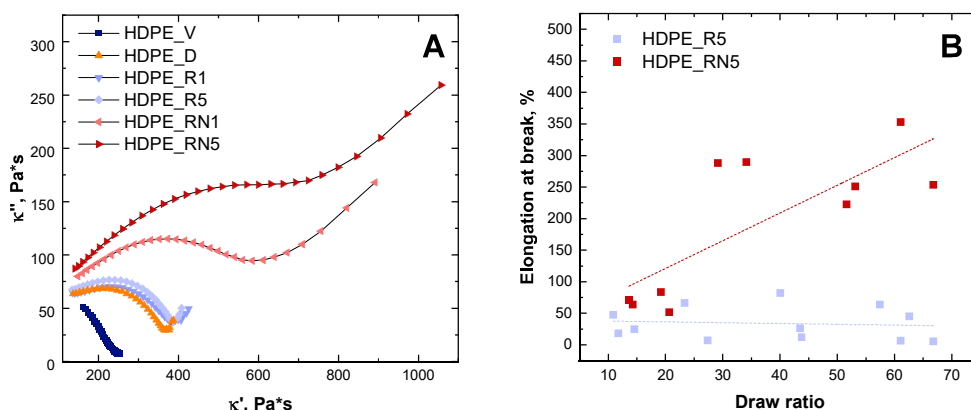


Figure 1. Cole-Cole plot (A) and elongation at break as a function of the DR (B).

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