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Effect of chain structure on the properties of Glass fibre/polyethylene composites

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ABSTRACT

Three types of polyethylenes (low density: LDPE, medium density: MDPE, and high density: HDPE) were used to investigate the effect of chain branching on the dispersion and adhesion in Glass fibre reinforced polymer composites. The interaction between the polyethylene matrix and the Glass fibres was investigated in terms of differences in mechanical behaviour, morphological characteristics, rheological and thermal properties between the three polymer composites systems. Addition of Glass fibres enhanced the mechanical properties for all systems. The degree of enhancement, however, depended on the branching and crystallinity of each polymer. The long chain branching (LCB) in LDPE resulted in higher increases both in the Elastic (Young's) modulus in the solid state and in the Storage modulus in the melt. The higher crystallinity of HDPE was responsible for higher increase in tensile strength and less fibre pull-out upon addition of Glass fibres. Rheological results also confirm the same observation for LCB. The addition of Glass fibres also resulted in improved thermal stability of the various polyethylene samples.

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1. Introduction

Polymer composites are playing an increasingly significant role in aerospace [1,2], marine [3], automotive [4], construction [5] and other fields due to their unique properties such as high strength to weight ratio and corrosion resistance [6]. In particular, thermoplastic based materials are being used increasingly in many applications in modern life because of their ease of processing and recyclability [7,8]. Polyethylene (PE) is one of the most versatile and widely used thermoplastics in the world because of its toughness, near zero moisture absorption, excellent chemical inertness, low coefficient of friction, ease of processing and unusual electrical properties [9]. Polyethylene is classified into several different categories based mostly on its density. The mechanical properties of PE depend significantly on variables such as the extent and type of branching, the crystal structure and the molecular weight. The main forms of polyethylenes are High Density Polyethylene (HDPE), High-molecular weight HDPE (HMW-HDPE), Ultra High Molecular Weight HDPE (UHMW-HDPE), Low density Polyethylene (LDPE), Linear Low Density Polyethylene (LLDPE), Very low density Polyethylene (VLDPE). These are divided based on density and branching. Commercially, the most important polyethylene grades are HDPE, LDPE, LLDPE and MDPE [10].

LDPE is made through a high pressure polymerisation process and is generally characterised by the long chain branching (LCB) structure. This prevents the molecules form packing as closely together during crystallization which results in low crystallinity. LDPE is more flexible than HDPE, and has lower tensile and compressive strength than HDPE due to its lower crystallinity. Generally LDPE is used in food packaging materials and plastic film applications such as plastic bags and film wraps [10,11]. MDPE is made by the same low pressure process as HDPE but it contains a small amount of short chain branches (SCBs). It is softer than HDPE and never sleek as LDPE together with the common thickness. MDPE is typically used in gas pipes and fittings, sacks, shrink film, packaging film, carrier bags and screw closures [10,11]. HDPE is made of long chains without major branching. It contains less than 1 side chain per 200 carbon atoms in the main chain resulting in long linear chains with high crystallinity and more rigidity. HDPE is used in applications such as milk jugs, detergent bottles, margarine tubs, garbage containers and water pipes [10,11].

These thermoplastics are usually used as matrix materials for making composites. The fibres are used as reinforcements (or fillers) to improve properties such as strength, rigidity, durability and hardness [12] and reduce the cost of material. Many studies are available on polyethylene composites based on both natural [13,14] and synthetic fibres [15,16]. Glass fibres are most used as reinforcements to plastics due to their low cost and fairly good mechanical properties compared to synthetic fibres. Glass fibre reinforced polymers have been widely used in the automotive and aerospace industries for their superior properties like high strength and low weight [17–19].

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In the present work, three types of polyethylene based resins (LDPE, MDPE and HDPE) were used to prepare the Glass fibre reinforced composites. The effects of addition of GF (Glass fibre) on mechanical, thermal and rheological properties were evaluated. The main aim of this study is to investigate the effect of the chain structure (especially branching) on the interaction between the polymer matrix and GF. Also, the effect of the branching on mechanical, rheological and thermal properties of these composites will be described.

2. Experimental details

2.1. Materials

Three types of polyethylene were used in this work as matrix to prepare the composites. LDPE (Low Density Polyethylene) was supplied by Qatar Petrochemical Company (QAPCO). The density of LDPE is 0.920 g/cm^3 and the Melt Flow Index is 0.3 g/10 min. The MDPE (Medium Density Polyethylene) was taken from Qatar Chemical Company (Q Chem). Density of MDPE is 0.938 g/cm^3 and Melt Flow Index is 0.2 g/10 min. HDPE (High Density Polyethylene) was obtained from Qatar Chemical Company (Q Chem). The density and melt flow index of HDPE are 0.946 g/cm^3 and 0.18 g/10 min, respectively. Chopped Glass fibre type E 968A standard reinforcement was purchased from Owens Corning company, UK.

2.2. Methods

2.2.1. Composite preparation

The compounding of LDPE/GF, MDPE/GF and HDPE/GF were carried out in a Brabender twin screw extruder. The processing temperature was in the range of 190–230 °C. The screw speed was set to 60 revolutions per minute. In each system, GF/Polymer ratio was constant at 20/80 by weight. The mixtures were fed into the hopper of the extruder, compounded, cooled and granulated. The compounded samples were prepared as test specimens by PE 5 injection molding machine.

2.2.2. Tensile testing

Tensile tests were performed to measure the tensile properties like tensile strength, tensile modulus and elongation at break of the neat polymer matrix and polymer composite samples. The tensile tests of matrix and composites were measured by using a universal testing machine at a crosshead speed of 10 mm/min. The tensile samples were prepared and tested by according to the ASTM: D638-10. In each case five samples were tested and an average value was reported.

2.2.3. Morphology analysis (Scanning Electron Microscope analysis)

The Morphological analysis was carried out by using a Scanning Electron Microscope type (SEM) of model EDX Philips. Scanning Electron Micrographs were analysed to examine the cross-section of the failure of the samples after tensile test and study the bonding between the fibre and the matrix.

2.2.4. Rheology characterisation

The viscoelastic behaviour of the neat polymers and GF reinforced samples was studied by investigating the melt rheology in an ARES (Advanced Rheometric Expansion System) Rheometer. Samples were moulded into 2 mm thick discs and then rheology measurements were performed to determine the storage modulus (G') in Pa (Pascal), loss modulus (G'') Pa (Pascal) and dynamic viscosity (η^*) in Pa-s (Pascal second). Tests were completed over a frequency sweep range between 0.01 and 100 rad/s at a temperature of 210 °C

2.2.5. Differential Scanning Calorimetry (DSC)

A DSC analysis of the various PE samples and their GF reinforced composites was completed using a Perkin Elmer, Pyris Thermal Analyzer. All measurements were taken under nitrogen atmosphere and at a constant heating and cooling rate of 10 °C/min. The percentage of crystallinity (% X_C) of the samples was calculated according to the following equation [20].

$$X_C\ (\%) = \frac{\Delta H_f}{\Delta H_f^0 w} \times 100 \quad (1)$$

where ΔH_f is the heat of fusion of the sample, ΔH_f is the heat of fusion of a 100% crystalline LDPE (287.6 J/g) [21], MDPE (293.0 J/g) [22] and for HDPE (293.0 J/g) [23] and w is the weight fraction of PE in the composite.

2.2.6. Thermo gravimetric analysis (TGA)

The thermal decomposition of pure polymer matrix and polymer composites were evaluated by thermo gravimetric analysis (TGA). Thermo gravimetric analysis (TGA) measurements were performed in nitrogen atmosphere using Perkin Elmer Thermal instrument at a heating rate of 10 °C/min to yield the onset temperature of decomposition, mass loss and maximum decomposition peak.

3. Results and discussion

3.1. Tensile properties

Figs. 1 and 2 show the tensile strength and modulus, respectively, of the different types of polyethylene and their Glass fibre reinforced composites. These results are consistent with the density values of the samples. Usually higher density translates into higher tensile strength and lower elongation due to higher crystallinity. There is a significant improvement in mechanical properties, both modulus and tensile strength, by addition of Glass fibres.

Similar results have been achieved by Somnuk et al. [24] who studied the adhesion between the Glass fibre and HDPE. They have found that tensile and flexural strength were improved with Glass fibre addition. Ayadi et al. [25] found that mechanical and thermal properties of recycled HDPE were improved by adding short Glass fibre.

The chain structure plays an important role in this improvement. In the case of elastic modulus (E), the increase factor in LDPE after addition of GF is by 5.5, whereas it is only 2.8 times in MDPE and HDPE (Table 1). This is explained in terms of the long chain branching (LCB). LDPE which contains a high concentration of LCB has a strong interaction with Glass fibres through the formation of a network of entanglement between the LCB on the chains

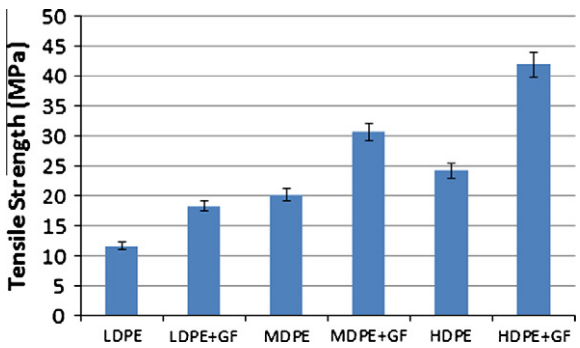

Fig. 1. Effect of polyethylene branching on tensile strength of Glass fibre of neat and reinforced polymers.

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