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Short glass fiber-reinforced polyamide 6,6 composites toughened with maleated SEBS

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Abstract

Polyamide 6,6 hybrid composites toughened with maleated styrene–ethylene butylene–styrene (SEBS-g-MA) and reinforced with 5, 10, 15, 20 and 30% short glass fiber (SGF) were prepared by melt blending and subsequent injection molding. The matrix blend of composites consisting of 80 wt.% PA6,6 and 20 wt.% SEBS-g-MA. The mechanical behavior and fracture resistance of the SGF/SEBS-g-MA/PA6,6 hybrid composites were investigated. Tensile test showed that the incorporation of SGF to the PA6,6/SEBS-g-MA 80/20 blend improves both the tensile strength and stiffness substantially at the expense of its tensile ductility. The essential work of fracture (EWF) methodology was used to evaluate the fracture toughness of the hybrids. EWF measurements indicated that the SGF additions are beneficial in enhancing the specific essential work of fracture (w_e) of the hybrids. The specific essential work of fracture appeared to increase with increasing fiber content up to 15%. It then decreased for the hybrids containing SGF content $\geqslant$20%. Overall, the w_e value of hybrids was higher than that of the unreinforced PA6,6/SEBS-g-MA 80/20 blend. The correlation between the microstructure and the fracture resistance of the hybrids is discussed.

Keywords: A. Polymer-matrix composites (PMCs); A. Short-fiber composites; B. Fracture toughness; B. Mechanical properties; D. Scanning electron microscopy (SEM)

1. Introduction

Polyamides (PA) are commonly used in a wide range of engineering applications because of their attractive combination of good mechanical properties and processability. The major deficiencies of polyamides for industrial applications are their high moisture absorption and high notch sensitive characteristics. These deficiencies can be improved by blending with other polymers [1–3] or with the elastomers [4–7]. In the latter case, the impact toughness of polyamides is improved substantially with the incorporation of elastomer particles [4,5]. The cavitation of elastomer particles and associated matrix shear yielding are the main toughening mechanism for the PA/elastomer blends. The blends of polyamides and unfunctionalized elastomers generally exhibit low impact toughness because the rubber particles formed during melt blending process are relatively large. The compatibility between PA and elastomers can be enhanced by the incorporation of compatibilizers. In this aspect, the elastomers are grafted with functional group such as maleic anhydride (MA) prior to blending with PA. The functional group can react with the amine end groups of PA, leading to a finer dispersion of elastomers in the PA matrix. Paul and coworkers reported that PA6,6 can be made super-tough by blending with maleated styrene-ethylene butylenes-styrene (SEBS-g-MA) elastomer alone. This is because the melt blending of SEBS-g-MA with PA6,6 results in the formation of rubber particles within the optimal size range for effective

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toughening [4]. The toughness improvement associated with the addition of elastomers is achieved at the expense of stiffness and strength characteristics. Reinforcement by inorganic fillers [8] or short glass fibers [9–13] can restore the required stiffness and strength of rubber toughened polyamides, leading to the formation of ternary or hybrid composites.

In recent years, the essential work of fracture concept has been increasingly used to evaluate the fracture toughness of ductile polymers and tough composites [14–20]. According to this method, the total energy to fracture a sample (W_f) having a sharp crack can be divided into two parts, i.e., the essential work of fracture (W_e) required to fracture the polymer in its process zone, and non-essential or plastic work (W_p) consumed by various deformation mechanisms in the plastic zone. Thus W_f can be expressed as

$$W_f = W_e + W_p \tag{1}$$

Considering that W_e is surface related, whereas W_p is volume related, W_f can be given by the related specific work terms:

$$W_f = w_e LB + \beta w_p L^2 B \tag{2}$$

$$w_f = \frac{W_f}{LB} = w_e + \beta w_p L \tag{3}$$

where w_f is the specific total fracture work, w_e and w_p are the specific essential fracture work and specific plastic work, respectively; L is the ligament length, B is sample thickness, and β is a shape factor of the plastic zone. βw_p is a measure of the energy used for the plastic deformation around the crack tip. Apparently, EWF concept is a simple method to test the specimens with different ligament lengths, recording the area under the load displacement curve (W_f), plotting the w_f versus L diagram and evaluating the best fit regression line. It should be noted that the specimen must be fully yielded prior to crack initiation, which can be easily evaluated for slow testing of double edge notched tensile specimen. In a recent study [21], we have used the EWF concept to investigate the fracture toughness characteristics of the maleated polypropylene (mPP) hybrid composites reinforced with short glass fiber (SGF) and toughened with SEBS or SEBS-g-MA elastomer. The results showed that a strong interfacial bonding between the SGF and mPP can impair the fracture resistance of ternary SGF/SEBS/mPP and SGF/SEBS-g-MA/mPP hybrid composites. This work attempts to assess the fracture behavior of SEBS-g-MA toughened polyamide 6,6 hybrids reinforced with SGF using the EWF methodology. The SGF content of the hybrids varies from 5 to 30 wt.%. The tensile and impact properties of these PA hybrids are also investigated.

2. Experimental

2.1. Materials

The materials used in this study were polyamide 6,6 (Mitsubishi Engineering Plastics Co., Taiwan), SEBS-g-MA (Kraton FG 1901X; Shell Co.) and SGF with a length of ~4 mm (144A-14C; Owens Corning). The SGF was not treated with coupling agents.

2.2. Blending

PA6,6 pellets and SGF were dried separately in ovens at 100 °C for 48 h. And the SEBS-g-MA was dried at 60 °C for 48 h. The matrix of composites was PA6,6/SEBS-g-MA 80/20 (wt.%) blend and designated as SGF0 in this article. The composites were reinforced with 5, 10, 15, 20 and 30 wt.% SGF respectively (The glass fiber content was based on total mass of polymers). They were designated as SGF5, SGF10, SGF15, SGF 20 and SGF30, respectively. The composites were prepared by melt mixing using a Brabender twin-screw extruder. The dried polymer pellets and SGF were initially loaded into a Brabender with operating temperature profiles of 260–270–270–260 °C. The extruded strands were pelletized and dried. The dried pellets were fed into an injection molder (Cheng Hsong Jetmaster 4 Mark II-C) to plaques of 200×80×3.2 mm. Tensile bars according to ASTM D636 were cut from the plaques.

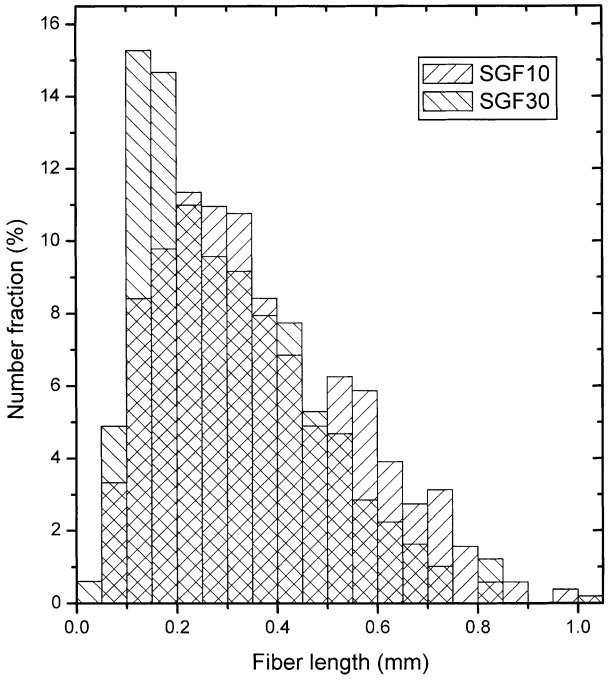

Fig. 1. Number fraction vs fiber length distribution of the SGF10 (▨) and SGF30 (▧) hybrids.