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Morphological and mechanical properties of polyamide 6/linear low density polyethylene blend compatibilized by electron-beam initiated mediation process

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HIGHLIGHTS

- PA6/LLDPE blend was compatibilized by the electron-beam initiated mediation process.
- Interfacial adhesion was significantly enhanced by the radiation initiated cross-copolymerization.
- The elongation at break of blend irradiated at 100 kGy was 4 times higher than PA6.
- The GMA as a mediator played a key role in the electron-beam initiated mediation process.

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ABSTRACT

The aim of this study was to compatibilize immiscible polyamide 6 (PA6)/linear low density polyethylene (LLDPE) blend by using electron-beam initiated mediation process. Glycidyl methacrylate (GMA) was chosen as a mediator for cross-copolymerization at the interface between PA6 and LLDPE. The exposure process was carried out to initiate cross-copolymerization by the medium of GMA at the interface between PA and LLDPE. The mixture of the PA6/LLDPE/GMA was prepared by using a twin-screw extruder, and then the mixture was exposed to electron-beam radiation at various doses at room temperature. To investigate the results of this compatibilization strategy, the morphological and mechanical properties of the blend were analyzed. Morphology study revealed that the diameters of the dispersion particles decreased and the interfacial adhesion increased with respect to irradiation doses. The elongation at break of the blends increases significantly with increasing irradiation dose up to 100 kGy while the tensile strength and the modulus increased nonlinearly with increasing irradiation dose. The reaction mechanisms of the mediation process with the GMA mediator at the interface between PA6 and LLDPE were estimated.

1. Introduction

Polyamide 6 (PA6) and linear low density polyethylene (LLDPE) are large volume commodity polymers that possess unique properties individually (Li and Zhang, 1997). PA6 has good mechanical and thermal properties while LLDPE has good low temperature flexibility and good resistance to moisture permeation. Therefore, PA6 and LLDPE blending has been attempted to achieve a favorable balance of physical properties (Spadaro et al., 1996; Park et al., 1997; Valdes et al., 1998; Utracki, 2002; Barrón et al., 2007; Pino and Feitosa, 2007; Hassan, 2008; Sinthavathavorn et al., 2008).

It is well known that polymer blending is an excellent strategy for modifying the drawbacks of polymers. Unfortunately, most polymer pairs are thermodynamically immiscible. Therefore, the most important point in preparing polymer blends is assigning good dispersion and compatibility to the immiscible polymer blends (Deanin and Manion, 1999; Baker et al., 2001; Clapper and Guymon, 2006). The strategies for compatibilization are well known in many literatures (Konig et al., 1998; Utracki, 2002).

Among the various compatibilization strategies, exposure of polymers or polymer blends to high-energy radiation at room temperature has been relatively newly introduced to modify their properties by changing the molecular structure of polymers or to improve the compatibility of blends (Woods and Pikaev, 1994; Dong et al., 2001; Singh, 2001; Cleland et al., 2003; Singh and Bahari, 2003; Żenkiewicz et al., 2008; Komada et al., 2007; Khan et al., 2012; Shin and Han, 2013). Though the high-energy radiation has several advantages; such as continuous operation, minimum time requirement, less atmospheric pollution curing at ambient temperature, and increased design flexibility through process control (Khan et al., 2012; Porubská et al., 2012), researches on the irradiation of blends seems to have been rather limited in comparison with the common way of

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the addition of a polymeric compatibilizer or reactive compatibilization (Singh, 2001). Some researches for the effects of irradiation on the properties of polyamide blends are published in recent years (Spadaro et al., 1996; Dong et al., 2001; Adem et al., 2005; Pino and Feitosa, 2007; Hassan, 2008). Most are carried out expecting cross-copolymerization at the interface between the continuous and dispersion phases or morphology fixation by taking advantage of the radiation crosslinking characteristics of the mutual polymers to improve physical properties of blends (Evoke et al., 2002; Pan et al., 2002; Dadbin et al., 2005; Pramanik et al., 2009; Porubská et al., 2012). Hassan (2008), Spadaro et al. (1996), and Pino and Feitosa (2007) reported that little difference was found in morphologies and mechanical properties between the blends unirradiated and irradiated at relatively lower dose indicating little improvement of compatibility. Though there was an increase in mechanical properties and interfacial adhesion of the blends irradiated at higher dose, those might not be caused by crosslinking at the interface but the gelation of the each polymer (Pino and Feitosa, 2007; Dong et al., 2001). Adem et al. (2005) studied the effect of irradiation by blending radiation oxidized polypropylene (PP) and pre-irradiated PP/maleic anhydride (MA) to PA6 and they found a little improvement in compatibility.

However, we can suppose that the possibility of radiation crosslinking at the interface may be very low because radiation process is usually performed at room temperature and, what is more, the immiscible blends have a big gap between matrix and dispersions. Therefore, a mediator to lead radiation initiated cross-copolymerization at the interface seems to be needed (Shin and Han, 2013). To our best knowledge no investigation has reported PA6/LDPE blend compatibilized by electron beam irradiation with a mediator for cross-copolymerization at the interface.

In this study, we studied the compatibility of the immiscible PA6/LLDPE blend, which was compatibilized by the electron-beam irradiation strategy with a mediator for cross-copolymerization. The GMA was chosen as a cross-copolymerization mediator because GMA has two reactive sites, which are an epoxy functional group and a double bond. The epoxy group can react with other functional groups in polymers during melt mixing and the double bond can be easily opened by a radical and then cross-copolymerization takes place at the interface. Besides that, GMA is a low molecular weight material, which can easily diffuse toward the interface during melt mixing (Konig et al., 1998). If the mediator has multiple reactive sites, more than two, the blends can have a higher three dimensional network, which no longer melts above its normal melting point and does not dissolve in its usual solvent completely (Dadbin et al., 2005). The polymers containing higher three dimensional network are difficult to apply to the various industrial applications through conventional manufacturing methods of plastics such as injection molding, extrusion, blow molding, etc. compared to thermoplastic polymers. The morphological and mechanical properties were analyzed to observe the effects of this compatibilization strategy on the compatibility of the blend. We also proposed electron-beam initiated reaction mechanisms, which were believed to have occurred at the interface by the medium of the GMA. In addition, we carried out FTIR analysis to support the evidence of the reaction at the interface.

2. Experimental

2.1. Materials

Polyamide 6 (KOPA® KN136) with a density of 1.14 g/cm^3 and water absorption of 1.8% (23 °C, 60% RH) was obtained from KOLON PLASTICS, INC. Low density polyethylene (HANWHA LLDPE3126) with a density of 0.921 g/cm^3 was obtained from Hanwha Chemical. Glycidyl methacrylate (GMA) and m-xylene were provided by Sigma-Aldrich (WI, USA).

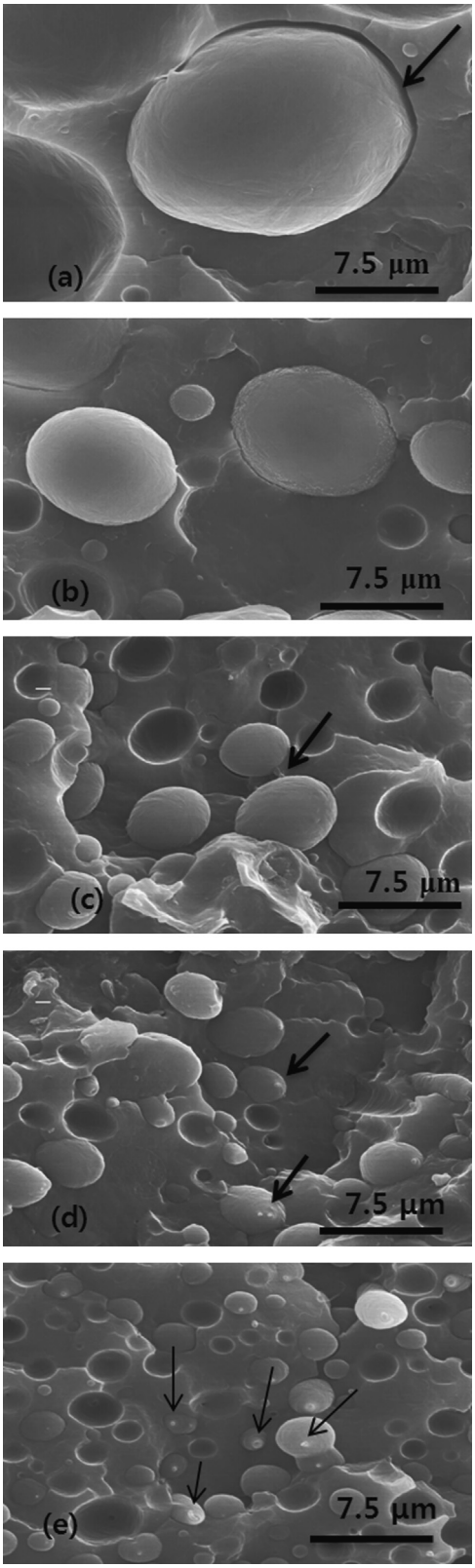

Fig. 1. SEM images of cryofracture surfaces of the blends irradiated at 0 (a), 5 (b), 20 (c), 50 (d), and 100 kGy (e).

2.2. Melt mixing of PA6/LLDPE and GMA

The blend ratio of PA6 and LLDPE was chosen to be 80/20 in weight percent and the amount of GMA content was fixed at 3 parts per hundred rubber (phr) based on the total mass of PA6