



Morphology, Mechanical and Thermal Behavior of Compatibilized Polypropylene/ Poly(Ethylene Terephthalate) Blends

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ABSTRACT

Binary blends of polypropylene (PP)/polyethylene terephthalate (PET) and ternary blends of PP/PET (80/20 w/w) compatibilized with various amounts (3-7 wt%) of ethylene-glycidyl methacrylate copolymer (EGMA) as the compatibilizer were prepared using a twin-screw extruder. The effect of the addition of EGMA on the morphology, mechanical and thermal properties of the blends was investigated. Scanning electron microscopy (SEM) results showed that the blends compatibilized with EGMA showed more refined (i.e., smaller) droplets at EGMA content (5 wt%), the system changed from biphasic towards monophasic morphology. The mechanical properties of the resulting compatibilized blends were studied through tensile and impact tests, and thermal behavior by HDT (Heat deflection temperature). The addition of PP/PET blend compatibilized with 5 wt% EGMA showed an enhancement of about 22% - 31% in tensile properties, 32% - 35% in flexural properties and 13°C in HDT as compared with those of the PP/PET. The inclusion of EGMA to the PP/PET blends was found to improve the blend toughness as well as developing the compatibility between PP and PET. The maximum strain at break was obtained for the PP/PET blends at 80/20 (w/w) composition with EGMA content of 5 wt%.

Keywords: PP, PET, compatibilizer, polymer blend, mechanical properties

1. Introduction

Polymer blends are presently very important in outcome new high-performance organic materials without synthesizing new polymers. Polymer blending is a useful technique to generate materials with specific enhanced properties. The blending of polyolefin's with engineering plastics is a method to progress the mechanical properties of polymeric materials. It is a broadly used marketable practice, since the initial properties can be adjusted to achieve specific needs rapidly and low cost by changing the chemical structure of the components, the composition of the blend and the processing conditions (Shamiri et al., 2014). However, most polymer couples are immiscible. Blending of two or more polymers generally results in a multiphase blend, instead of a homogeneous material (Huang et al., 2020). The morphology and interfaces between microphases are predominant influences in determining ultimate properties of these multiphase blends (Anbinder et al., 2020). Therefore, for effective blending, these factors must be under control in order to acquire reproducibly in the properties of the blend. Reducing interfacial tension and improving adhesion between two phases generally attains satisfactory performance in immiscible blends. Compatibilizers are added to the blends to stimulate mixing of incompatible polymers, which leads to decrease in interfacial tension, delay of coalescence of the dispersed phase, and reduction in the average droplet size (Vamegh et al., 2019; Zaman et al., 2012; Zuo et al., 2020).

Polypropylene (PP), is one of the most important type of linear semicrystalline thermoplastic that is extensively used in packaging and fiber because of its attractive properties such as low price, light weight, good processability, high heat distortion temperature (HDT), excellent barrier properties and relatively higher impact strength than PET. The tensile strength of PP is enough for technical applications and common textile. The main shortcomings of PP are its low elastic modulus and reposition properties. These boundary its practice in applications such as technical Fibers and garments. World making exceeds 35 million tons and approximations display that this volume will escalation in the forthcoming (Odián, 2004). Hereafter, several studies have been carried out to reinforce PP, enhancement its mechanical properties. Reinforcements comprise natural fibers (Zaman and Khan, 2019), organoclays (Zaman et al.,

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2014a) and glass fibers (Khan et al., 2010). Polyethylene terephthalate (PET), on the other hand, is a semicrystalline commodity thermoplastic polymer resin that novelties extensive uses in domestic packaging (Ao et al., 2020), containers for beverage, films, synthetic fibers, electronics and industrial purpose. For example a thermoplastic material, PET can easily be treated by extrusion and injection molding processes. In the latter period, PET has been broadly used in various performances because of its high-strength and high-modulus (stiffness), superior chemical resistance, thermal resistance, fatigue resistance, and availability of resin. PET is accomplished both of chemical reactions with polar polymers and polar interfaces resembling hydrogen bonding because of the ester group (Dimitrova et al., 2000). The polarity of these ester groups will progress the interchain reaction of PET following in good mechanical properties. Despite these advantages, however, PET has shortcomings of very low impact strength, low crystallization rate and moisture absorption that have imperfect its use in positive applications (Wang et al., 2006). To overcome these shortcomings, the blending of PP with engineering thermoplastics has been an effective method to progress the properties of PP. For example, PP/polyamide blends are intensively examined in the literature (Kol et al., 2020). There has been, however, very inadequate research apprehensive with blends of PP with PET. Bataille et al. (Bataille et al., 1987) stated that PP/PET blends without compatibilizer revealed weak interactions due to their different chemical natures and polarities between the two phases, and, hereafter, the mechanical properties were inferior than both for virgin PP and for PET. More recently, Fereshteh Mirjalili et al. (Mirjalili et al., 2011) found that the adding of PP grafted with maleic anhydride (MAH) to PET/PP blends ensued in finely dispersed phases, showing the grafted PPs were competent to compatibilize these blends. In this article, ternary blends of PP/PET compatibilized with various contents of ethylene-glycidyl methacrylate copolymer (EGMA) was developed by using the direct melt blending performance. The aim of this work was studying the effects of selected compatibilizer on morphology, mechanical and thermal properties of PP/PET blends (80/20 w/w) were preferred for the compatibilization studies based on consistent with the study done by Youji and Kancheng (Tao and Mai, 2007). To the best of our knowledge, no study has been conveyed on the effect of EGMA on the morphology, mechanical and thermal properties of PP/PET blends with the concentration range of 3–7 wt%.

2. Experimental

2.1. Raw materials

The PP (major phase, matrix) used in this study was a copolymer grade SM240 with density of 0.9 g/cm³ and a melt flow index of 25 g/10 min (2.16 kg at 230°C) supplied by Titan chemicals. PET as the minor (dispersed) phase was a commercial grade of textile polyester with the intrinsic viscosity of 0.65 ml/g, and also supplied in pellets by Shanghai (China) Lianji Co., Ltd. The Lotader AX8840 type of ethylene glycidyl methacrylate (EGMA) with a melt index of 5 g/10 min (190°C, 2.16 kg) and a glycidyl methacrylate content of 8% was used as compatibilizing agent.

2.2. Blends preparation and characterization

Prior to melt blending, PP and EGMA were dried in a vacuum oven at 80°C for 24 h. PET was dried in a vacuum oven at 140°C for 12 h. The compatibilization was carried out for PP/PET (80/20 w/w) blend with compatibilizer loading level of 3, 5 and 7 wt%. Blends were achieved in a twin-screw extruder (Brabender Plastocorder, model: PLE-331), using a temperature profile of 260-270°C in the die. A screw speed of 60 rpm and a mixing time of 10 minutes were used. In all samples 0.2% of antioxidant (IB215-CIBA) was used to prevent degradation of the PP during the mixture method. Films and specimens were obtained by compression molding, heating the polymer up to 280°C, and maintaining this temperature for 5 min to obtain the complete melt of the pellets. After that, a pressure of 7 MPa was applied for 5 min. The sample was then cooled to room temperature at a cooling rate of around 20°C/min. Similar conditions were used to obtain thicker samples using decompression/compression for the elimination of air bubbles.

Lastly, composites plates were cut into the tensile samples according to ASTM standard D638-03 (type I) on a screw-driven universal testing machine (Instron 4466) equipped with a 10 kN electronic load cell and mechanical grips. Crosshead speed was 30 mm/min. The scanning electron microscopy (SEM) experiments were performed in a Vega Tescan microscope to examine the shape and size of the disperse phase. The observed surfaces were obtained by cryogenic fracture of the films in liquid nitrogen, and the resultant broken surfaces were gold-coated prior to observation.

The SEM micrographs were examined by means of image-processing software. The number-average (D_n), and volume-average (D_v) diameters were calculated with the following equations (Entezam et al., 2012):

$$D_n = \frac{\sum n_i D_i}{\sum n_i} \quad \text{and} \quad D_v = \frac{\sum n_i D_i^4}{\sum n_i D_i^3}$$

where n_i is the number of domains with diameter D_i . The measurement results for at least 150 dispersed domains are summarized in Table 1. HDT was achieved in a CEAST HDT Vicat tester.

Table-1: Surface study of compatibilized PP/PET

Sample	D_n (μm)	D_v (μm)
PP/PET	4.1	4.5
PPTE3	5.4	5.7
PPTE5	3.2	3.6
PPTE7	1.8	2.1

3. Results and discussion

3.1. Scanning electron micrographs

SEM micrographs of PP/PET (80/20 w/w) blends with various contents (0, 3, 5 and 7 wt%) of compatibilizer (EGMA) are presented in Figure 1. The fractured surface of an uncompatibilized PP/PET blends is shown in Figure 1a. In this sample, the PET appeared as dispersed phase with uneven shapes and sizes, and even a large fraction of the domains. The PET domain sizes are strongly dependent upon the amount of compatibilizer used. The SEM micrographs of PP/PET blends compatibilized with various contents of EGMA are shown in Figure 1 (b-d). It can be seen that the particle size reduces and adherence between the two phases is flourished by increasing EGMA content. In the sample containing 5 wt% of EGMA, the droplet sizes are noticeably reduced, the morphology is relatively homogeneous (uniform), and nearly phase-separated domains are not observable. These outcomes reveal the effectiveness of the EGMA in improving the interfacial adhesion between PET and PP. It is widely accepted that a compatibilizer has two main roles in the control of morphology of a blend, that is, prohibition of coalescence and reduction of interfacial tension [8]. The uniformity of shape and size of the PET domains caused by addition of compatibilizer is assumed to be the outcome of reduction of coalescence because of the chemical interactions that seemingly result from the reactions occurred between both EGMA and PET functional groups. However, the compatibility of the blends with 7 wt% is inferior to that of blend with 5 wt% as observed in SEM images. This indicates that a higher content of EGMA may generate the crosslinking of PP and deteriorate the blend properties (Asgari and Masoomi, 2012). Hence, it can be concluded that the content of compatibilizer used should have an optimal restriction between 5 and 7 wt% in this performance.

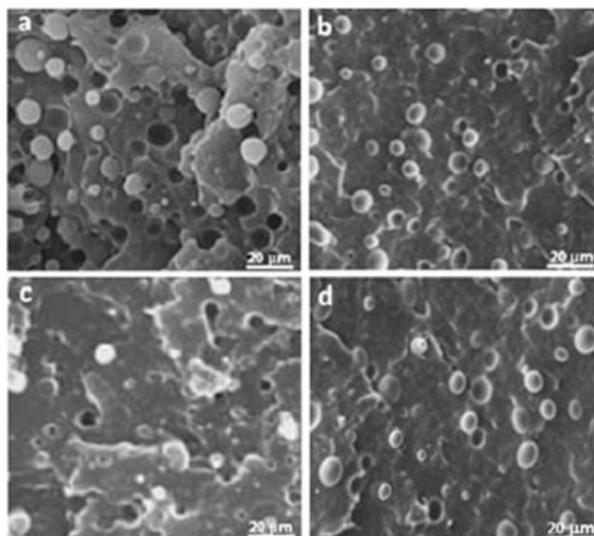


Fig. 1- SEM micrographs of PP/PET (80/20 wt%) blends with (a) 0, (b) 3, (c) 5 and (d) 7 wt % EGMA.

3.2. Effect of compatibilizer concentrations on tensile and flexural properties

Usually, the mechanical properties of immiscible blends without compatibilization are poor because of the weak interfacial adhesion between the components. For uncompatibilized PP/PET blends, the mechanical (tensile and flexural) properties are usually inferior to the arithmetic averages of the two component polymers (Li et al., 2009). Addition of compatibilizers will improve the properties if they adhere well to both immiscible components (Zaman et al., 2014b). The tensile and flexural properties of PP/PET (80/20 w/w) blends compatibilized with various EGMA concentration (0, 3, 5, and 7 wt%) are depicted in Figure 2 and Figure 3, respectively. At lower concentrations of PET/PP blends with EGMA showed increasing tensile strength (TS), tensile modulus (TM) and strain at break, SB (%) up to 5 wt% and then decreased. In this blend, TS increased by 22%, TM increased by 31%, and SB increased by 26%, as compared to the PP/PET blend. The blends with EGMA show a positive blending effect and have a good interfacial adhesion between the phases in the solid state resulting in the increase in tensile properties. However, after the optimum composition at 5 wt% of EGMA, tensile properties started to decrease. This indicated the excess amount of compatibilizer tends to form agglomeration leading to poor adhesion between the compatibilizer and matrix, thus decreased the tensile properties (Figure 2). The flexural properties of PET/PP blends with EGMA shows a similar trend to the tensile strength mentioned above. Figure 3 shows the flexural properties (flexural strength, FS and flexural modulus, FM) started to increase from 44.7 MPa and 1.7 GPa, respectively and reached a maximum value at 5 wt% loading of EGMA which is 32% and 35% higher than uncompatibilized (PP/PET) blend. This optimum improvement in mechanical properties may be due to the strong interactions between the polar PET and non-polar PP component developed by EGMA compatibilizer, as observed by SEM micrograph. The amount of EGMA limit in this polymer blend system was 5 wt%. When EGMA content is 7 wt%, the tensile and flexural properties of the blend are decreased. This was due to the formation of small EGMA droplets by an excess of compatibilizer, which tends to co-exist with large PP domains. The poor intrinsic mechanical properties of EGMA could be another possible reason for the reduced tensile and flexural properties. The compatibilizing role of EGMA for PP/PET blends can be confirmed by the toughening behavior, which implies for SB of blends.

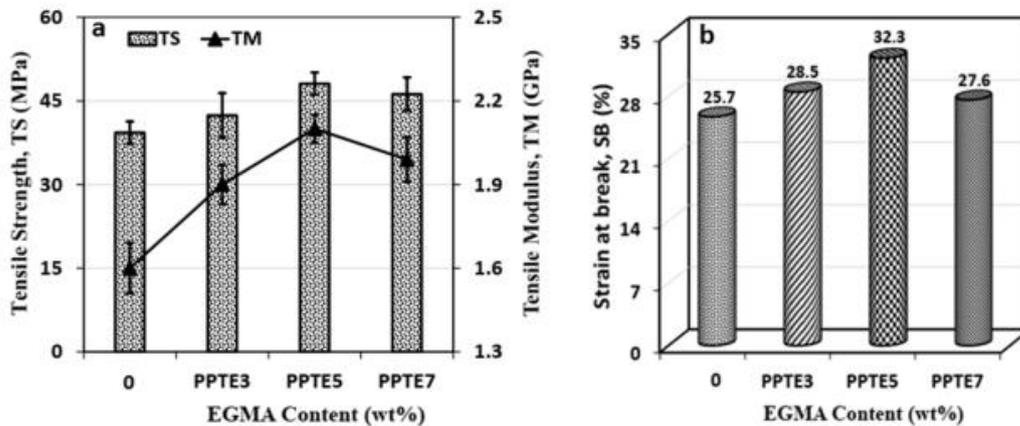


Fig. 2- Tensile properties of PP/PET (80/20 wt%) blends as a function of EGMA content.

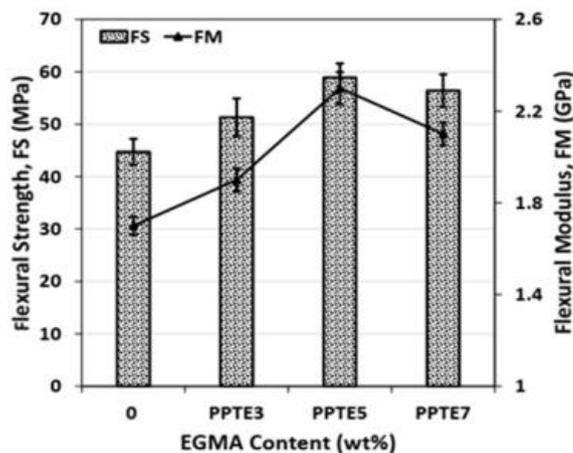


Fig. 3- Flexural properties of PP/PET (80/20 wt%) blends as a function of EGMA content.

3.3. Thermal properties

Figure 4 displays that all compositions had higher heat deflection temperature (HDT) values than the PP/PET blend, representing improved thermal stability developed by the PET dispersed phase. Values of the HDT depend on processing conditions and presence of nucleating agents; the addition of nucleating agents to PP may increase HDT by over 13°C. As observed in literature (Santos and Pezzin, 2003), PET may be act as nucleating agents for PP, which might explain the increase in HDT accomplished in this study.

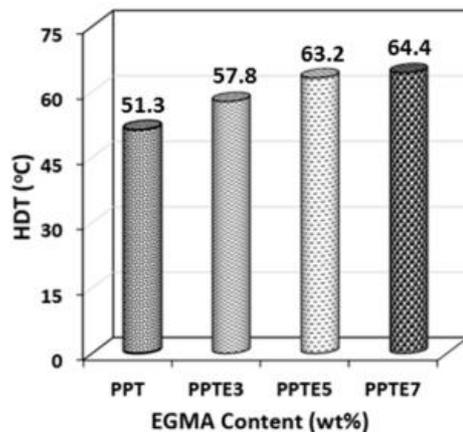


Fig. 4- Heat deflection temperature of PP/PET (80/20 wt%) blends as a function of EGMA content.

4. Conclusions

In this study, the morphology, mechanical and thermal properties of PP/PET (80/20 w/w) blends compatibilized with ethylene-glycidyl methacrylate copolymer (EGMA) as the compatibilizer are examined. The morphological analysis for compatibilized blends showed that when EGMA is added to an incompatible polymer blend of PP and PET, the dispersed phase size decreases for the dispersed phase case and 5 wt% EGMA is the most effective one among them as it produced the finest PET domain size. This morphology, on the other hand, explains the enhancement in the mechanical properties. The EGMA used in this work undoubtedly improved the mechanical properties of the PP/PET blends. The improvement in the tensile and flexural properties of blends also proved that there was a strong interaction between PP and PET in the presence of the EGMA, which strongly induced the interaction between PP and PET. In conclusion, the EGMA used in this work appeared to be a very suitable and useful candidate in the compatibilization with a very obvious improvement in the mechanical properties of the PP and PET blend.

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