

Morphological, Thermal, and Mechanical Properties of Polypropylene/Polycarbonate Blend

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ABSTRACT: This work deals with the effect of compatibilizer on the morphological, thermal, rheological, and mechanical properties of polypropylene/polycarbonate (PP/PC) blends. The blends, containing between 0 to 30 vol % of polycarbonate and a compatibilizer, were prepared by means of a twin-screw extruder. The compatibilizer was produced by grafting glycidyl methacrylate (GMA) onto polypropylene in the molten state. Blend morphologies were controlled by adding PP-*g*-GMA as compatibilizer during melt processing, thus changing dispersion and interfacial adhesion of the polycarbonate phase. With PP-*g*-GMA, volume fractions increased from 2.5 to 20, and much finer dispersions of discrete polycarbonate phase with average domain sizes decreased from 35 to 3 μm were obtained. The WAXD spectra showed that the crystal structure of neat PP was different from that in blends. The DSC results suggested that the degree of crystallization of PP in blends decreased as PC content and compatibilizer increased. The mechanical properties significantly changed after addition of PP-*g*-GMA. © 1997 John Wiley & Sons, Inc. *J Appl Polym Sci* **63**: 1857–1863, 1997

Key words: PP; PC; blend; compatibilizer

INTRODUCTION

Blending two or more thermoplastics is a useful way to obtain new materials with desired property combinations. Although most polymers are immiscible and even incompatible with each other, useful blends with good properties are achieved through formation of special morphologies. Effective compatibilization is required to bind the discrete blend components together and to achieve toughness. Reactive extrusion can be used for compatibilizing dissimilar polymers. Functional end groups or specially functionalized polymers react with corresponding reactive groups in

the other polymer, and new covalent bonds are formed during the extrusion process.

Blending polyolefins with engineering polymers such as thermoplastic polyesters is a useful way to upgrade the properties of polyolefins. One major problem that limits the direct blending of polyolefin with engineering polymers is the nonpolar structure of polyolefins. However, reactor-made, olefin-based co- and graft polymers with functional groups are commercially available, and many functionalities can be introduced into the structure of polyolefins through postmodification.^{1–4} Such functionalized polyolefins may act as compatibilizers between polyolefins and high-performance engineering polymers. Physical and chemical interactions across the interface are recognized to be critical in controlling the overall performance in any immiscible polymer blend. Con-

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siderable research effort has focused on methods of reducing interfacial tension and increasing phase adhesion between two immiscible phases. Compatibilizers formed *in situ* based on certain types of reactive copolymers have been of great interest as an alternative to the conventional block or graft copolymers to compatibilize immiscible polymer blends. Research activity on reactive compatibilization has been concentrated mostly on polymer blends between nylon and polyolefins functionalized with maleic anhydride or acrylic acid,^{5–10} with only a few studies on other systems.^{11–14}

Recently, *in situ* compatibilized polymer blends of copolymers containing glycidyl methacrylate (GMA) monomer have attracted great attention because of potentially broad applications. Chung and Carter¹⁵ patented a polymer reported to have excellent low-temperature impact properties, based on polycarbonate (PC), poly(ethylene terephthalate), high butadiene content styrene-acrylonitrile-glycidyl methacrylate (SGA) copolymer. We believe that the presence of SGA functions as an *in situ* compatibilizer between PC and ABS. Akkapeddi and colleagues^{16,17} reported using ethylene-*g*-GMA as a reactive compatibilizer in the blends of PC, PET, and with various polyolefins. Chang and colleagues^{18–20} reported a series of reactive compatibilized blends on GMA-containing copolymers.

The aim of the present work was to study the effect of GMA-containing compatibilizer on the blending of polypropylene/polycarbonate (PP/PC). The mechanical behavior and morphology of PP/PC blends without compatibilizer obtained in an internal mixing chamber and also in a twin-screw extruder have been examined by Favis and coworkers.^{21–23} The morphology of the samples with different compositions and obtained with various processing parameters was estimated on the basis of optical and electron microscopy. The authors found that the size and shape of PC particles dispersed in PP matrix depended significantly on processing conditions as well as on the contribution of particular components. The structure of PP/PC blends has been investigated by wide-angle X-ray scattering.²⁴

EXPERIMENTAL

Materials

PP used in this study was P340 of Pan Jing Petrochemical Co. Ltd. (China) in the form of porous

pellets; its melt flow index was 1.0 (230°C, 2.16 kg load). PC was MS-3000 of Mitsubishi P. Co. Ltd. (Japan). The compatibilizer was PP-*g*-GMA with 0.46 mol % glycidyl methacrylate.

Reactive Blending and Characterization

The polycarbonate was dried for 12 h at 90°C to minimize hydrolytic degradation. Blending was accomplished with a co-rotating twin-screw extruder operating at a constant speed of 100 rpm; the melt temperature was at 250°C. For ternary PP/PC/PP-*g*-GMA blends, the amount of the compatibilizer was kept at 2.5, 5, 10, and 20 vol % of the total blend volume, and the volume relation PC/PP was 10 : 90, 20 : 80, and 30 : 70.

Injection-molded samples were predried 18 h at 90°C before mechanical testing. Izod impact strength tests were made with a XJU-22 impact tester according to the standard ISO/R 180-1961. Measurements of tensile properties of specimens were performed by means of Instron 1121 on ISO/R 527-1966E, at a crosshead speed of 10 mm/min.

A scanning electron microscope JXA-840 was used to observe the morphologies of the blends. Before observation, the examined sections were etched with dichloromethylene for 4 h to increase the contrast.

The thermal behavior of blending samples was determined on a Perkin-Elmer DSC-2. The thermogram was obtained from 80° to 280°C, at a heat rate of 10°C/min. All measurements were performed under nitrogen atmosphere.

Wide-angle X-ray diffraction profiles of PP/PC blends were obtained by using a PW 1700 Philips diffractometer with Cu K α , Ni-filtered radiation. The measurement condition was 40 kV and 30 mA.

RESULTS AND DISCUSSION

Morphology

For evaluation of morphology and mechanical properties, two families of multiphase polypropylenes were prepared by melt blending at 250°C: first, as reference blends of modified polypropylene (PP-*g*-GMA), polypropylene (PP) was blended together with polycarbonate (PC) at different PC content weight fractions; second, in the binary blend 30 vol % PC was blended together with 70 vol % PP, which was partially substituted by 2.5, 5, 10, and 20 vol % of the compatibilizer consisting

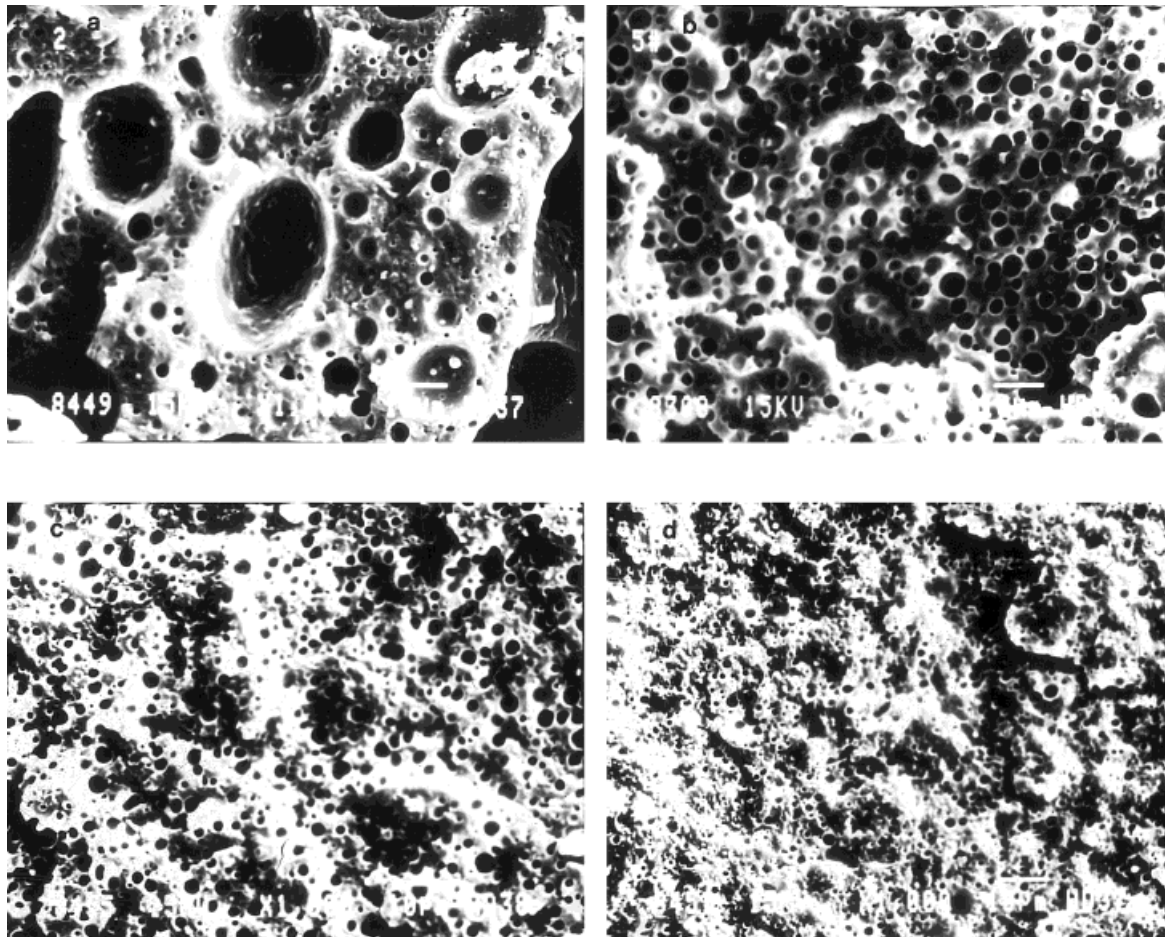


Figure 1 SEM micrographs of PC/PP and PC/PP-g-GMA/PP blends: (a) PC/PP (30/70 vol %); (b) PC/PP-g-GMA/PP (30/2.5/67.5 vol %); (c) PC/PP-g-GMA/PP (30/5/65 vol %); (d) PC/PP-g-GMA/PP (30/10/60 vol %).

of PP-g-GMA. The SEM micrographs of extruded pellet surface of PP/PC and PP/PC/PP-g-GMA blends are shown in Figure 1. As can be seen in Figure 1(a), the binary PP/PC blend exhibits very big spherical-shaped domains, with diameters ranging from 10 to 50 μm , which are uniformly distributed throughout the whole surface, and the spherical holes with smooth walls. These voids have been left by PC domains after the etching process. This can be attributed to the weak adhesion between the two phase. On the other hand, in Figures 1(b), 1(c), and 1(d), we can see that PC domains are very finely dispersed in PP matrix, with diameters ranging from 2 to 5 μm . The particle size distribution is narrow as PC is strongly bonded to the matrix phase. Figure 2 shows the variation of the mean size of PC domains as a function of PP-g-GMA content. Even at low PP-g-GMA content, there is a significant

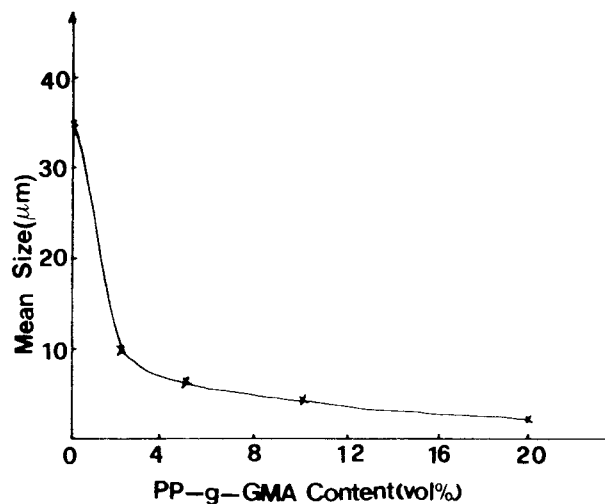


Figure 2 Mean size of PC domains versus PP-g-GMA content.

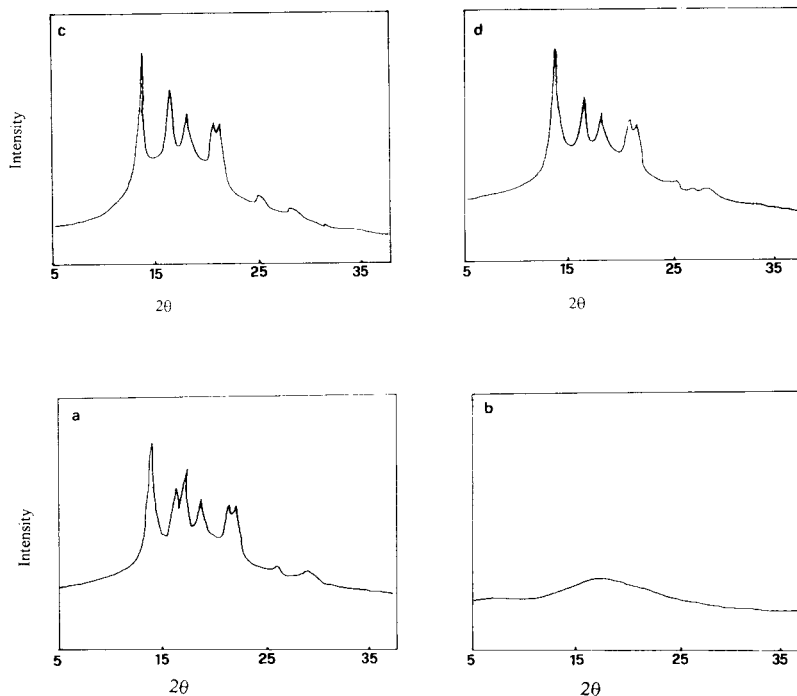


Figure 3 WAXD patterns of (a) PP; (b) PC; (c) PC/PP (30/70 vol %); (d) PC/PP-g-GMA/PP (30/10/60 vol %).

effect of the graft copolymer on the size distribution. These results indicate that PP-g-GMA acts as an interfacial agent, promoting both adhesion and emulsifying effects.

The Crystal Structure of PP in Blends

The WAXD patterns of PP/PC blend are presented in Figure 3. Figures 3(a) and 3(d) show the diffraction pattern of PP and the amorphous PC, respectively. Figures 3(b) and 3(c) are the patterns of PC/PP and PC/PP/PP-g-GMA blends with 30 vol % PC content. For the PP sample, the peak at $2\theta = 15.9$ degree, which corresponds to 300 diffraction plane of the β crystals form (hexagonal phase), disappeared after blending with PC. This suggested that the mixture of α and β crystal forms of the plain PP was replaced by α form in blends. As shown in Figures 3(b) and 3(c), addition of compatibilizer did not affect the crystal structure of PP in blends.

Thermal Properties

The differential scanning calorimetric thermograms of PC/PP are shown in Figure 4. In the binary blend system, the heat of fusion of PP de-

creased as PC increased. As shown in Figure 5, we can also see that the heat of fusion of PP in blends is unaffected by addition of compatibilizer. Perhaps the PC restrains PP crystallization in blends. Figure 5 is the DSC melt curves of PC/PP (30/70) with various PP-g-GMA contents. We can see that the glass transition temperature (T_g) of PC in blends shifted down to lower temperature

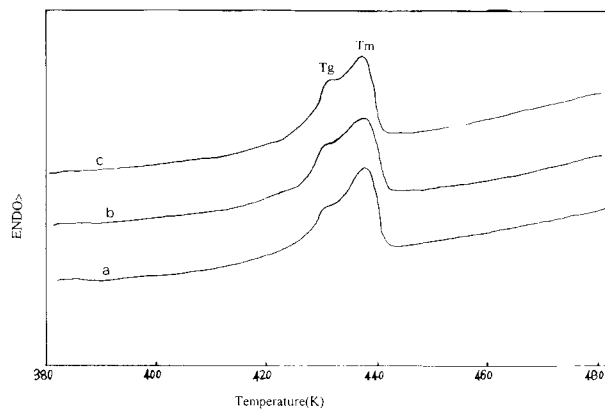


Figure 4 Thermograms of PC/PP blends: (a) PC/PP (10/90 vol %) $\Delta H = 68.96$ J/g; (b) PC/PP (20/80 vol %) $\Delta H = 63.04$ J/g; (c) PC/PP (30/70 vol %) $\Delta H = 57.74$ J/g.

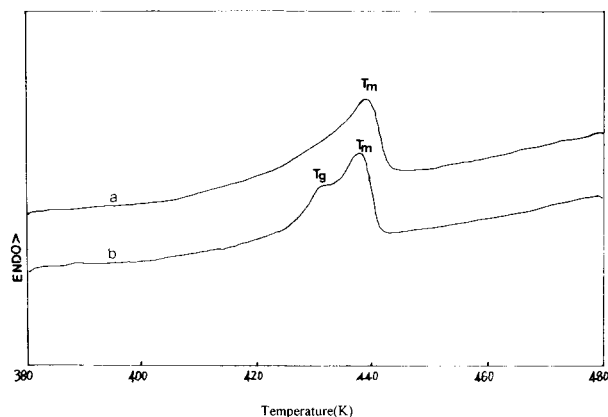


Figure 8 The thermograms of (a) PC/PP (30/70 vol %) and (b) PC/PP-*g*-GMA/PP (30/20/50 vol %) after extraction with dichloromethane for 8 h.

The coupling reactions between the two components made it impossible to extract all the PC phase from the ternary blend.

Mechanical Properties

The mechanical properties of dried PC/PP and PC/PP/PP-*g*-GMA samples are listed in Table I. There is a clear dependence of toughness on the composition. Compared with the binary blends (PC/PP), the Izod impact strength and tensile strength of the ternary blends (PP/PC/PP-*g*-GMA) was significantly improved. Perhaps the adhesion between PC and PP matrix was improved as a result of grafting. As shown in Table I, it can be noted that the impact strength of ternary blends increases as compatibilizer increases. Similar results are observed for E_y , σ_b , and ϵ_b . For

example, Izod impact strength of PC/PP-*g*-GMA/PP (30/20/50) is 31.6 J/m higher than that of PC/PP (30/70). These features can be tentatively explained in that the epoxy groups of PP-*g*-GMA react with end—OH groups of polycarbonate to form polypropylene-block-polycarbonate during reactive blending, providing efficient compatibilizers, reducing surface tension, and improving both PC dispersion and interfacial adhesion between PC and PP. As pointed out by Illing,²⁵ a graft copolymer stays preferentially on surfaces of dispersed domains, acting as an “interfacial agent.” The presence of such an interfacial agent would require less energy for breaking large dispersed particles during melt blending, thus giving domains to adhere to the continuous phase.

CONCLUSIONS

Blends of PC with PP, using various amounts of a grafting copolymer of PP grafted with glycidyl methacrylate as a compatibilizer were investigated. PP-*g*-GMA was expected to react with PC in the molten state to provide interfacial bonding between the two phases. The addition of PP-*g*-GMA significantly changed the morphology and mechanical properties of PC/PP blends. This is attributed to the epoxy group of PP-*g*-GMA reacting with the terminal—OH group of PC to reduce the interfacial tension between the two phases. The mean size of PC particles reduced from 35 μm to 3 μm , and mechanical properties were obviously raised after addition of compatibilizer. The DSC thermograms showed that PP-*g*-GMA acted as a nucleating agent to raise the crystallization temperature of PP in blends.

Table I Mechanical Properties of the PC/PP and PC/PP-*g*-GMA/PP Blends

PP (vol %)	PC (vol %)	PP- <i>g</i> -GMA (vol %)	Young's Modulus E_y (MPa)	Tensile Strength σ_b (MPa)	Elongation at Break (ϵ_b)	Izod Impact (J/m)
90	10	0	702	26.4	122	109.8
80	10	10	844	32.8	197	134.5
80	20	0	674	24.3	31.4	58.3
70	20	10	799	30.7	64.5	67.2
70	30	0	625	22.5	5.7	47.3
67.5	30	2.5	660	27.7	14.8	51.1
65	30	5	725	30.5	32.6	56.3
60	30	10	803	36.2	49.7	67.4
50	30	20	874	42.8	69.4	78.9

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