Effect of compatibilizers on the mechanical and morphological properties of polycarbonate/poly (acrylonitrile-butadiene-styrene) blends

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Abstract. Blending the existing polymers have an added advantage over the conventional polymers. However, compatibility of the materials is a problem. In this study, metacrylate butadiene styrene (MBS) and polypropylene-graft-maleic anhydride (PP-g-MA) were added as a single compatibilizer on polycarbonate/poly(acrylonitrile-butadiene-styrene) blends (PC/ABS). The effects of the compatibilizer addition on the mechanical and morphological properties were investigated. The PC/ABS blends were prepared in various compositions of 70/30, 60/40, 50/50 with fixed 2 phr MBS or PP-g-MA. PC/ABS blends were prepared by using twin-screw extruder, and test samples by injection molding. Results indicated that MBS exhibited higher tensile strength, hardness, and density, but lower impact strength and elongation compared with PP-g-MA. The tensile strength, elongation, and hardness tended to increase with increasing PC content; however, the impact strength was almost the same. Scanning electron microscopic examination showed that PC/ABS blend compatibilized with PP-g-MA was more porous than the one with MBS. Based on the results, it was found that PP-g-MA was a more effective compatibilizer for the PC/ABS 70/30 blend than MBS. The values of tensile strength, hardness, elongation, density, and impact strength were 602 kg/cm², 79.1 Shore A, 15.3 %, 1.05 g/cm³, and 5.5 kgf/cm respectively.

1. Introduction
Polymer blending technology is one of the major areas of research and development over the past few decades. Blends of the existing polymers have an added advantage over the conventional polymers. Blends can be concluded as compatible or incompatible based on the melt viscosity and mutual solubility of the individual materials [1]. However, compatibility of the materials is a problem. This problem has been solved in many cases by adding a small amount of additives known as compatibilizers. These are generally block and graft copolymers or chemically reactive species which are concentrated at the interface and which act as emulsifiers. The function of the in situ (or in vivo)-formed compatibilizers have been reported to reduce interfacial tension and to improve the size of dispersed phases and the adhesion between two immiscible polymers [2].
Polycarbonate (PC) is a kind of ductile thermoplastic compared to other polymers such as nylon and polyesters. Acrylonitrile butadiene-styrene (ABS) is the largest-volume engineering thermoplastic resin and is considered a bridge between commodity plastics and higher-performance engineering thermoplastics. ABS resins are commonly used in appliance parts (including electrical/electronic) and automotive/transportation applications [3]. Many researchers struggle to trade off the poor part of PC with ABS, and vice versa, with blending these two polymers.

PC/ABS blends are generally considered as an immiscible pair. As a compatibilized system, they can offer improved mechanical and thermal properties due to the PC matrix, whereas the contribution of ABS focuses on the ease of processing, economy, and more reliable impact strength [4]. Chiang et al. [2] reported that three kinds of compatibilizers, methacrylate–butadiene–styrene (MBS), ethylene–vinyl acetate (EVA), and styrene–maleic anhydride (SMA) could be used to improve the flame retardancy phenomenon on the PC/ABS alloy. Tjong and Meng [5] implied that both maleic anhydride (MA)-grafted polypropylene and solid epoxy bisphenol type-A compatibilizers were ineffective to improve the impact toughness of PC/ABS blends containing ABS content ≥40wt%. Farzadifar et al., reported that ABS-g-MA had no significant effect on the tensile strength of the PC/ABS blends while 10 phr of EVA-g-MA decreased the tensile strength. Otherwise, EVA-g-MA could increase the impact strength better than ABS-g-MA in the amount of 5 phr [6]. Triantou and Tarantili [4] successfully improved the intercalation process in organoclay/ABS/PC nanocomposites with ABS-g-MA, while Han et al. used the poly(styrene-co-acrylonitrile)-g-maleic anhydride (SAN-g-MAH) to decrease the droplet size of the ABS on the PC/ABS blends [7]. Polydimethylsiloxane-g-styrene-g-methyl methacrylate copolymer (PSM) in PC/ABS possessed high impact [8] and BS-g-MA performed good compatibilization in various amount of NPCC filler in PC/ABS blends [9]. However, less study were conducted on MBS and PP-g-MA as PC/ABS compatibilizers.

In this paper, two different compatibilizers, MBS and polypropylene graft maleic anhydride (PP-g-MA) were used as PC/ABS compatibilizer. The effect of MBS and PP-g-MA on the mechanical and morphological properties of PC/ABS blends. The crystallinity property was also investigated as supporting data.

2. Experimental method

2.1. Materials

Materials used in this research were PC injection grade resin under the trade name Wonderlite PC-110, ABS injection grade resin under the trade name Toyolac 700 314, methacrylate–butadiene-styrene (MBS) compatibilizer Huaxing ZB-521 ZB-32, PP-g-MA purchased from Sigma Aldrich, and antioxidant under the trade named Irganox 1010 and Irgafos P168.

2.2. PC/ABS blends preparation

The PC and ABS resins were dried at 100 °C and 80 °C for 4 h, respectively, prior to blending. After calculating the necessary quantity accordingly to Table 1, all of the ingredients were mixed in a tumbler mixer for 3 min to form a uniform composition throughout the batch size. The uniformly mixed feed then was prepared using twin-screw extruder and the pellets were made in line with the extruder. The processing temperatures at five zones of the extruder were maintained at 230–240–250–250–250 °C and

| Materials     | Blend 1 | Blend 2 | Blend 3 | Blend 4 |
|---------------|---------|---------|---------|---------|
| PC/ABS        | 50/50   | 60/40   | 70/30   | 70/30   |
| MBS           | 2       | 2       | 2       | -       |
| PP-g-MA       | -       | -       | -       | 2       |
| Irganox       | 0.05    | 0.05    | 0.05    | 0.05    |
| Irgafos       | 0.1     | 0.1     | 0.1     | 0.1     |
the screw speed was kept at 220 rpm, and the feeding speed was 110 rpm. Extrudes from the die were passed through the water bath at 20–25 °C and then ground into pellets. The pelletizer speed was synchronized with the extruder output and screw speed. Extruded pellets were kept for conditioning (in hot air oven at 80 °C for 4 h) to release the thermal stresses and were subsequently dried.

The conditioned pellets were molded to ASTM standard samples using injection molding. During the sample preparation, temperatures in the front, middle and rear positions of the barrel were kept at 260, 260 and 260 °C, respectively, and followed the setting as mentioned in Table 2.

Table 2. Formulation of PC/ABS blends.

|                | Barrel/Inject | Holding Time |
|----------------|---------------|--------------|
|                | End Pos (mm)  | Time (s)     | Flow (%) | Press (%) | Time (s) | Flow (%) | Press (%) |
| 95             | 2             | -            | -        | 3         | 30       | 30       |
| 85             | 2             | 45           | 45       | 3         | 30       | 30       |
| 50             | 2             | 45           | 45       | 3         | 30       | 30       |

2.3. Melt flow index
The Melt Flow Index (MFI) measurements were carried out according to ASTM D 1238 specification (procedure A), in a Tinius Olsen XNR-400B. For each sample 5 measurements were run and the average was obtained. The load and temperature for each sample were given at Table 3.

2.4. Mechanical properties
The density testing was determined with Mirage EW-200SG electro densimeter. The Izod impact tests were carried according to ASTM D256 using Toyoseiki Izod impact tester. The tensile behaviors of the blend specimens were determined using Tinius Olsen H25K universal testing machine, according to ASTM D638.

2.5. Crystallinity properties
X-ray diffraction (XRD) was performed using Shimadzu X-ray diffractometer equipped with XR tubed with the target Cu at the operating voltage and current of 40 kV and 30 mA, respectively and the divergence, scatter, and receiving slits were adjusted at 1 deg, 1 deg, and 0.3 deg respectively. The samples processed as described above were put in the XRD pan where the room temperature was maintained.

2.6. Morphological properties
SEM micrographs were obtained by using Shimadzu SEM with 5K magnification and 10kV. The PC/ABS blends pellets were coated with a thin layer of gold prior to SEM examination.

3. Result and discussion

3.1. Melt flow index
MFI tests have been done to measure the melt viscosity of flow resistance of PC when blended with ABS at a particular shear related to the applied load and temperature. It is also valuable indicator to observe the variations in PC and ABS content in the blends. Table 3 shows that PC/ABS 70/30M blend shows the highest MFI value which means it is the easiest blend to be processed, followed by 70/30P blend. The MFI of the blends is increased gradually with increasing in PC content in the blend. The reason for the increase in MFI value of PC with the addition of ABS may be solvation of the highly entangled structure of molecules of PC due to the presence of ABS molecules. Thus, with increase of shear rate, solvated layers may be sheared away, resulting in an increase in intermolecular interaction and consequent improvement in processability [3].
Table 3. MFI data for PC, ABS, and PC/ABS blends.

| Sample             | Test Condition (°C, kg) | MFI (g/10min) |
|--------------------|-------------------------|---------------|
| PC                 | 270, 2.16               | 7.34          |
| ABS                | 200, 5                  | 2.67          |
| PC/ABS 50/50M      | 230, 3.8                | 2.41          |
| PC/ABS 60/40M      | 230, 3.8                | 3.39          |
| PC/ABS 70/30M      | 230, 3.8                | 6.59          |
| PC/ABS 70/30P      | 230, 3.8                | 5.56          |

3.2. Mechanical properties

Blends with fixed concentrations of 2 phr compatibilizer for the various PC/ABS blends (Table 1) were prepared to investigate the effect of using two different compatibilizers on mechanical properties such as tensile (Figure 1), elongation (Figure 2), and impact strength (Figure 3), as well as on physical properties such as hardness (Figure 4) and density (Figure 5). From the Figure 1, it can be seen that the higher PC content, the higher tensile strength of PC/ABS blends. Each additional 10% PC provides increased tensile strength by about 45%, as expected. Also, the tensile strength decreases as the concentration of ABS increases in the polymer blend, accordingly to the law mixture. Similar results were reported by Triantou & Tarantili [4], who compounded at various compositions of PC/ABS. PC has higher tensile strength than ABS. The virgin PC has a tensile strength about 65 MPa, while ABS only 49 MPa [10]. The optimum blend is obtained at 70/30 PC/ABS blend. It has been reported that PC exhibits high yield strength and ductile behavior. In contrast, ABS shows a brittle characteristic and has low yield strength. Addition of ABS lowers the tensile strength, reduces the cold-down ability of the PC matrix and the consequent elongation at break of the blends [5]. The tensile strength of the blends increases almost linearly with the increase of PC contents.

The tensile strength value of this blend compatibilized with MBS is 62.52 MPa, ± 10% higher than the previous work reported by Liu et al. [11]. MBS give higher value compared with other compatibilizers, such as PP-g-MA (58.99 MPa), EVA-g-MA (± 55 MPa) [6], ABS-g-MA (± 58 MPa) [4], PSM (± 57 MPa), and ABS-g-MA (± 53 MPa) [9]. Incorporation of various compatibilizers phr acts as a bridge between PC and ABS thereby resulting in reducing the interfacial tension between the both polar and non-polar phases [1] and leads to a further increase in tensile ductility [5]. The tensile strength of PP-g-MA compatibilized blend in this study is 58.99 MPa, slightly higher than which had been reported by Tjong & Meng [5]. As reported by Farzadfar et al., there is a chemical reaction between MA groups of the compatibilizers and hydroxyl end groups in PC as can be seen in Figure 4 [6].

![Figure 1](image1.png)

**Figure 1.** Effect of MBS and PP-g-MA on the tensile strength of PC/ABS blends.

![Figure 2](image2.png)

**Figure 2.** Effect of MBS and PP-g-MA on the elongation of PC/ABS blends.
From Figure 2, it can be seen that the addition of ABS reduces the elongation of the blends, as reported before. ABS exhibits very low tensile ductility. This also implies that the stiffness of PC improves considerably with increasing ABS content. The compatibilizers were added at a fixed amount of 2 phr. The elongation at break of PC/ABS blends presents a minimum value at compounds containing 50% ABS. These results suggest limited interfacial interactions taking place in PC/ABS blends, which acquires a minimum when PC and ABS are mixed in equal amounts [4].

The effect of compatibilizers on the elongation of the blends is shown in Figure 2. This result shows that the elongation of PC/ABS blends modified with PP-g-MA is 35% higher than that with MBS, as the tensile strength is lower. And the increasing ABS content, increase the elongation. As expected, blending PP with rubbery polymers like ABS can enhance the elongation properties. However, this value is lower when compared with other compatibilizers, such as EVA-g-MA (around 50%) [6], SMA (around 110%) [11], and MAP (around 90%) [5].

![Figure 3. Effect of MBS and PP-g-MA on the izod impact of PC/ABS blends.](image1)

**Figure 3.** Effect of MBS and PP-g-MA on the izod impact of PC/ABS blends.

![Figure 4.](image2)

**Figure 4.** In this case simply justify the caption so that it is as the same width as the graphic.

Figure 3 shows that the best impact strength of the blends occurs when using PP-g-MA as a compatibilizer, with values of 5.5 kgf.cm. This could be due to the chemical reaction between MA groups of the PP-g-MA and hydroxyl groups in PC as shown in Figure 4. It is worth mentioning that the functional groups of maleic-anhydride is very effective to improve impact properties of PC/ABS 70/30 blend [5]. PP-g-MA acts as a suitable impact modifier for PC/ABS blends by modification of the interface, hence the interface strength between PC and ABS was increased. In contrary, 2 phr of MBS compatibilizer gives very low impact strength in each blend. It indicates that the MBS content must be carefully controlled owing to its brittle nature. Too much compatibilizer added to the blend will lead to a deleterious effect on the impact strength [5]. This result has also been observed by Liu et al., the addition of MBS decreased the tensile strength and elongation of blends a lot, and had no significant effect on the impact strength [11].
Figure 5. Effect of MBS and PP-g-MA on the hardness of PC/ABS blends.

Figure 6. Effect of MBS and PP-g-MA on the density of PC/ABS blends.

Figure 7. Difractogram of (a) PC/ABS 70/30 with ABS, (b) PC/ABS 60/40 with ABS, (c) PC/ABS 50/50 with ABS, (d) PC/ABS 70/30 with PP-g-MA.

Difractogram of PC/ABS blends were performed to observe the crystallinity properties of those blends (Figure 7). Nurhajati et al. reported the diffraction pattern for origin PC displayed typical peak of A-type semi crystalline and broad peak of amorphous ABS. The single strong peaks were found at 2-theta = 16.26° and 2-theta=18.94° for PC and ABS, respectively [9]. The diffractogram of PC/ABS blends...
show single broad peak of A-type amorphous polymers with MBS compatibilizer. The strongest peaks are located around 2-theta=17.46° with intensity of 1423, 2-theta=17.68° with intensity of 1861, and 2-theta=17.02° with intensity of 824 for PC/ABS blends 50/50M, 60/40M and 70/30M respectively. The sharpest shape and highest intensity peak is given by 60/40M PC/ABS blend. It can be seen that the peaks are shifted between the characteristics peaks of origin PC and ABS. PP-g-MA compatibilized blend is found to be more amorphous than MBS, with the broad peak located around 2-theta=17.64° with intensity of 672. Even this blend has amorphous phase, it gives the highest impact strength and comparable tensile strength with MBS blends.

3.4. Morphological properties

![SEM photomicrographs](image)

*Figure 8. SEM photomicrographs (a) PC/ABS 50/50 with ABS, (b) PC/ABS 60/40 with ABS, (c) PC/ABS 70/30 with ABS, (d) PC/ABS 70/30 with PP-g-MA.*

The study of the morphology of surfaces by SEM as an interesting tool for identification of different phases. At 50/50 PC/ABS blends, an even distribution of two polymeric phases is relatively clear (Figure 8(a)). In this blend, the continuous phase is ABS, whereas the dispersed one is PC. But when the amount of PC is greater than ABS, PC becomes the continuous phase, and ABS is the dispersed phase. Figure 8(c) exhibit a relatively smooth surface in comparison to 8(b). This result confirms the tensile behavior of the blends. PC/ABS 70/30 has higher tensile strength than the others. Figure 8(d) shows porous surface of PS/ABS with PP-g-MA as a compatibilizer. Even so porous, this blend has the higher impact strength, it is due to PP-g-MA can enhance the ductile properties of the blend. Based on the results, it was found that PP-g-MA played more effective compatibilization role in the PC/ABS 70/30 blend than MBS compatibilizer.
4. Conclusion
Blends of PC/ABS were prepared with two different compatibilizers and some properties such as MFI, density, hardness, tensile strength, elongation, morphology, and crystallinity were investigated. The results show that the addition of MBS at 2 phr level on the PC/ABS blends led to a significant increase of tensile strength, hardness, and density compared with PP-g-MA, but the impact strength and elongation were lower. The tensile strength, elongation, and hardness tended to increase almost linearly with increasing PC content, however, the impact strength was almost the same. Scanning electron microscopic examination showed that PC/ABS blend compatibilized with PP-g-MA was more porous than the one with MBS. Based on the results, it was found that PP-g-MA played more effective compatibilization role in the PC/ABS 70/30 blend than MBS compatibilizer. Those value of tensile strength, hardness, elongation, density, and impact strength were 602 kg/cm², 79.1 Shore A, 15.3%, 1.05 g/cm³, and 5.5 kgf/cm, respectively.

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