Compressive Properties and Morphology of Polypropylene/Polycarbonate Blends

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Abstract. This work investigates the effect of blending polypropylene (PP) with polycarbonate (PC) on morphology and compression properties of the blend. The blends, containing between 5 to 35% of polycarbonate and 5% compatibilizer, were compounded using twin-screw extruder and fabricated into standard tests samples using compression molding. The compatibilizer used was polypropylene-graft-maleic anhydride (PP-g-MA). Microscopy analysis showed minor phase size dependency on compatibilizer content, with irregular shapes of fibers, elliptical, or spherical in certain compositions. As PC content increased, compressive strength also improved. However with PC content of more than 35%, the blend strength decreased. This same relationship was also observed for the blends’ Young’s modulus and stiffness.

Keywords: polymer blend, PP/PC, maleic anhydride, compressive properties.

1. Introduction

In the field of polymer research, over the years there have been several works focusing on blending of PP with PC [1-2]. PP is one of the most used polyolefins in plastic industries because of its attractive properties such as high chemical resistance, low water permeability and relatively low cost. However it is also known to have low heat distortion temperature, on top of low stiffness and impact strength. PC on the other hand is an engineering plastic that has many advantages over conventional material in terms of mechanical and physical properties. From earlier researches, the prime objective of blending PP with other polymer was to improve PP’s disadvantage which is poor impact strength. Blending with PC was attempted to provide a mean to get PP-based material that has considerably good impact strength with sufficient stiffness. Now research on PP/PC blends has moved beyond the impact strength and stiffness, as other properties of the blends are also being studied.

PP and PC are immiscible with each other because of the differences in polarity and solubility parameters [3]. However the blend is still desired because of the reinforcing effect of dispersed PC phase in continuous phase of PP. A compatibilizer can improve interfacial adhesion of separated phases in polymer blend and also reduce interfacial tension of phase boundaries, leading to better dispersion and smaller particulates with higher contact surface area between the two phases. As a result of better phase adhesion and decreased particulate size, any energy or force exerted onto the blend will be more efficiently transferred from one phase to another, hence improving mechanical properties of the blend. A comparison study on compatibilizer was done by Renaut et al [4] who concluded that PP-g-MA was more efficient than the terpolymer ethylene/acrylic ester/maleic anhydride (EBuAMA) in terms of providing better thermomechanical properties of PP/PC blends. Ping and Ko [5] in the meanwhile found out that PP-g-MA was beneficial as a processing agent in improving the processability and mechanical properties of PC by having lower phase separation and melt viscosity compared to only PP/PC blends.
Weight ratio of the constituents in the polymer blend has a big impact on the blends’ properties and morphology. Franzheim et al. [6] have shown that the dispersed particles size of polymer blend was highly-dependent on the blend composition because of the increasing tendency of coalescence with an increasing concentration of the dispersed phase. When PP was more than 50%, PC would become dispersed phase. In terms of shapes for the dispersed phase, PC less than 20% existed as small droplets, while PC fraction of 40% would appear as having irregular shapes such as fibers, elliptical, or spherical [7]. For PP/PC binary blends, co-continuous morphology formed at 40/60 composition [7]. Previous works demonstrated that optimum mechanical properties such as tensile strength and young’s modulus of PP/PC blend were achieved with 70-80% PP, 20-30% PC, and 3-10% compatibilizer content [8-9]. Impact strength in the meanwhile was significantly high at 90/10 system of PP/PC blends (including 3-10% compatibilizer), compared to any other composition.

To date there is still a lack of characterization data on PP/PC blends. It is important to understand and characterize the behaviors of PP/PC blends comprehensively as it could lead to improvement in polymer design and process, thus consequently opening up new areas of application for PP/PC blends.

Compressive behavior is an area of mechanical properties which has been given less attention compared to tensile properties. Compressive behavior is not necessarily be similar to tensile behavior [10], considering the different mechanics of tensile and compression test. In addition, irregular shape of dispersed phase in the morphology of PP/PC blends at certain compositions makes it difficult to predict its mechanical properties. Hence another study has to be conducted to determine compressive mechanics. In selected engineering applications, compressive properties are regarded as more important than tensile properties. For example in the application of subsea pipeline insulation coating using polymer, radial hydrostatic pressure at sea bottom requires high compressive strength and young’s modulus material [11-12]. Besides that, in certain construction’s materials design involving concrete, polymer is added to improve its compressive strength and toughness [13], hence showing the importance of compressive strength in certain application.

Compression behavior and failure of composite is an active research area, but not much work has been published especially for particles reinforced polymer matrix composite (PMC) or polymer blend. A compression test done by Lee and Waas [14] towards carbon and glass fiber reinforced unidirectional PMC demonstrated lower compression strength of carbon fiber composite compared to glass fiber composite, while the stiffness of those two were the opposite. The difference in stiffness was justified by the rule of mixtures while the difference in strength was due to different failure mechanism. The result is proving that compressive behavior of composite is not as straightforward as to the rule of mixture theory. The morphology and failure mode could affect a material’s compressive properties.

Therefore, this research is aimed at characterizing the PP/PC polymer blends for its morphological and compressive properties, namely compressive strength, young’s modulus, and stiffness. Influence of blend composition ratio and the use of compatibilizer on the measured properties are also investigated.

2. Methodology

2.1. Materials

PP was produced by Polypropylene Malaysia (PETRONAS) while PC was from the trade name Panlite® grade L-1225Y and manufactured by Teijin Kasei America Inc. (Teijin Chemicals). The PC has melt volume – flow rate (MVR) 11.0 cm³/10 min (300°C/1.2 kg). The compatibilizer selected was PP-g-MA from the brand Sigma-Aldrich, with molecular weight of 9100 by GPC and maleic anhydride content of 8-10%.

2.2. Sample Fabrication

PC was dried at 95°C for 12 hours prior to compounding to minimize hydrolytic degradation. Pellets of PP, PC and PP-g-MA were mixed according to designated weight fractions. The blends, containing between 0 to 35% of polycarbonate and 5% compatibilizer, were compounded by twin-screw extruder at 250°C and 100 rpm before shaped into standard shapes by compression molding at 220°C for testing.
2.3. Microscopy

Scanning electron microscope (SEM) was used to check the morphology of the blends. Specimens were fractured by liquid nitrogen and plated with thin gold layer as preparation before their morphologies can be displayed by SEM.

2.4. Compression Test

Compression strength was conducted according to ASTM D695 - 08 Standard Test Method for Compressive Properties of Rigid Plastics. The specimens were in cylindrical form, 12.7mm in diameter and 25.4mm in length. Prior to the test, specimens were conditioned at 23 °C and 50 % relative humidity for not less than 40 hour. By using universal testing machine (UTM), known loads were applied and recorded at a standard speed of 1.3 mm/min until the specimen was deformed by 20%. The test was carried out at 23°C and 50% relative humidity and five specimens were tested for each sample.

3. Results and discussions

3.1 Microscopy

The morphological results of the blends are as Figure 1. For PP/PC (70/30) in Figure 1(a), the morphology shows PC particulates size between 4.5 to 11.6 µm dispersed uniformly in PP matrix. In PP/PC/PP-g-MA (90/5/5), PP/PC/PP-g-MA (80/15/5) and PP/PC/PP-g-MA (70/25/5) blends, the PC particulates sizes are 3.1 to 4.9 µm, 2.0 to 4.9 µm, and 3.6 to 6.7 µm respectively. Hence, generally it can be concluded that compatibilized blends has smaller size of PC particulates compared to the non-compatibilized one. This is due to the compatibilizing effect of PP-g-MA which reduces interfacial tension at PP and PC phase boundary. The reduction in interfacial tension makes them less repulsive towards each other, providing better dispersion and thus smaller PC particulates size. Smaller dispersed PC particulate will have higher surface contact with PP matrix. This is desirable in polymer blend as higher surface contact means better force transfer between matrix phase and dispersed phase, resulting in better mechanical properties. However, in all the micrographs shown, voids in crater form that resulted as the PC particulates are detached from the matrix present everywhere, indicating low adhesion between PP and PC phases and this could lower the mechanical properties of the blends. For the blend PP/PC/PP-g-MA (80/15/5), the shape of dispersed PC is a mix of spheres and fibrous. Blend of PP/PC/PP-g-MA (60/35/5) on the other hand shows no definite shape of dispersed PC phase, and the size of it is relatively large.

![Figure 1: Scanning electron micrograph of: (a) PP/PC (70/30), (b) PP/PC/PP-g-MA (90/5/5), (c) PP/PC/PP-g-MA (80/15/5), (d) PP/PC/PP-g-MA (70/25/5) and (e) PP/PC/PP-g-MA (60/35/5).](image)

3.2 Compressive Properties
Result of compression test is summarized in Table 1 and Figure 2. Compressive strength decreases as 5% of PC is added, but increases after that until percentage of PC reaches 25%, which is the highest compression strength recorded for the blend. At PC content of more than 25%, the compressive strength started decreasing once again. Young’s modulus and stiffness also follow the same behavior. This is similar to the patterns observed in literature reviews in which when tensile tests were conducted, the highest tensile strengths were found when PC% was around 25-30% [8-9].

Table 1: Compression properties of PP/PC/PP-g-MA blends

<table>
<thead>
<tr>
<th>Composition</th>
<th>100/0/0</th>
<th>90/5/5</th>
<th>80/15/5</th>
<th>70/25/5</th>
<th>60/35/5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive Strength, MPa</td>
<td>34.4</td>
<td>30.6</td>
<td>31.9</td>
<td>33.6</td>
<td>28.2</td>
</tr>
<tr>
<td>Young’s Modulus, MPa</td>
<td>627.6</td>
<td>648.1</td>
<td>649.0</td>
<td>706.2</td>
<td>601.3</td>
</tr>
</tbody>
</table>

According to the law of mixtures, properties of a composite material are depending upon the fraction of components that made up the composite. However for polymer, the relationship is so often not linear. This is mainly caused by compatibility factor between polymer components, and also uniformity of size, shape, and dispersion of reinforcement phase. Mechanical properties are normally closely related to microscopy. From literature, PC has almost double the value of compression strength than PP. Thus, theoretically the blends are likely to have higher compressive strength than PP. PC reinforcement phase in PP matrix will have compressive stress transferred to it from matrix phase, and since PC has higher compressive strength and larger surface area, it will withstand most the stress. Hence, the bigger PC fraction, the higher compressive strength it will possess. This is with agreement with the result showing compressive strength increases as PC fraction increasing. However, since PP and PC are not compatible with each other, PC reinforcement phase in PP matrix will have large particulate size, low surface area, and low interfacial adhesion. These unfavorable phenomena results in lower mechanical strength. The 60/35/5 blend has lower compressive strength compared to the others. This is because at 60/35/5 composition, the morphology of the blend is suggesting that PC dispersed phase has no definite shape and relatively large in size. The possible explanation for that behavior is that 5% of compatibilizer is not sufficient to keep PC in very small particulate size and to provide strength adhesion between the phases. Zhihui et al [9] in his work used 5, 10, and 20% of PP-g-GMA in 70/30 system of PP/PC blends. The result showed that tensile strength, young’s modulus, and Izod impact strength increase with the increasing amount of compatibilizer. It means even at 70/30 of PP/PC blend system, the compatibilizer amount can reach as high as 20%. Therefore for 65/35 system where interfacial area between PP and PC is larger, it is natural to assume that compatibilizer requirement should be higher than that at 70/30 system. However, this claim needs further work to be confirmed.
4 Conclusion

There is improvement in fineness of dispersed PC phase when PP-g-MA compatibilizer is added. Generally, as PC content increases, the dispersed particulate size also increases. In compression test, the optimum PC content is 25% with 5% compatibilizer, which will obtain the highest compression strength, young’s modulus, and stiffness. More than 25% of PC will obtain lower value of those mentioned properties, suspected to be caused by insufficient compatibilizer amount.

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6 References


