

# Tensile Behaviour and Morphology of Polypropylene/Polycarbonate/Polypropylene-graft-maleic Anhydride Blends

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**Abstract.** This work investigates the effect of blending polycarbonate (PC) into polypropylene (PP) matrix polymer on mechanical tensile properties and morphology. The blends, containing 5% to 35% of polycarbonate and 5% compatibilizer, were compounded using twin-screw extruder and fabricated into standard tests samples using injection molding. The compatibilizer used was polypropylene-graft-maleic anhydride (PP-g-MA). The values of tensile strengths and moduli for PP/PC/PP-g-MA blends were lower than that of pure PP. Tensile strength of pure PP was 37.74 MPa, whereas the highest tensile strength among the blends was 32.60 MPa at 70/25/5 composition. The pattern for the blends is non-linear, where the optimum amount of PC for tensile strength was 25%. Addition of PP-g-MA imparts positive effect towards the blends, shown by higher value for both tensile strength and tensile modulus compared to the noncompatibilized blend. Microscopy analysis showed PC reinforcement phase existed as particulates dispersed in PP matrix phase. PC particulates size depends on its fraction and compatibilizer content. As PC content in compatibilized blends increases, its particulate size also increases.

## 1 Introduction

Polymer blend is a mixture of two or more polymers, which typically possesses the combination of the polymers' properties. It can produce materials with desired properties at low cost, stretching engineering resin's performance by blending it with less expensive polymer, and improving certain properties of polymers [1]. Wide application of polymer blends can be found in areas such as transportation, electronic, appliances and packaging [2], but at the same it time brings challenges to produce and design usable and working blends. Polypropylene (PP) is a low-cost commodity polymer and from earlier researches, blending of PP with Polycarbonate (PC) was attempted to get PP-based material that has considerably good impact strength with sufficient stiffness. Since then, research on PP/PC blends had moved beyond the impact strength and stiffness, as thermal properties of the blends were also studied. PP is well-known for having low thermal stability or low heat distortion temperature. Thermal properties of PP/PC blends had been the subject of few studies and improvement in PP thermal stability was reported [3-5]. Upon the positive outcomes in the thermal area of PP/PC blends, more research especially in mechanical properties area is needed to ensure the blend is mechanically sound and usable.

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Over the years, several works on PP/PC blends were reported [6-7]. PP and PC are immiscible with each other because of the differences in polarity and solubility parameters [8-9]. Immiscibility of constituent polymers will result in segregated phases between the polymers, with high interfacial tension and weak interfacial adhesion. Therefore, the dispersion of minor phase will be limited, and contact area between the phases will be relatively small. These morphology attributes contribute to low strength of the blend. When load is applied to the blend, the phases of the blend will not be able to transfer and withstand the stress efficiently. However, the immiscibility allows the constituent polymers to preserve their features into their blends, and reinforcing effect that the minor phase has towards the matrix phase makes it desirable. The key to obtain mechanically usable material is to enhance the morphology and interfaces of phases in polymer blend, and this is when compatibilizer is required.

Dai and Ye [10] tried out of several compatibilizers for PP/PC blends. In PP/PC/PP-grafted-2-terbutyl-6-(3-tertbutyl-2-hydroxy-5-methylbenzyl)-4-methylphenyl acrylic ester (PP-g-BPA) blends, tensile strength went up to 37 MPa in 70/15/15 formulation. It was shown that the tensile strength was increasing with increasing PP-g-BPA content. Similar trend was also observed with impact strength. However, the increase in tensile strength was encountered by reduction in toughness compared to the pure PP. Ternary blend of PP/PC/ styrene-ethylene-butylene-styrene (SEBS) on the other hand showed toughness modification, but drop in tensile strength. The compatibility of SEBS with both PP and PC was translated into the improvement of charpy impact strength. It was concluded that PP-g-BPA provided the best compatibilizing effect among the group since it had the similar group-benzene ring with PC and this was suggested by the declining and much more homogeneous size of dispersed PC. In another work, PP/PC blended with PP-g-GMA showed good compatibilization, and resulted in an increase in tensile strength, young's modulus, and izod impact strength compared to noncompatibilized PP/PC blends [11-12]. The improvement was particularly obvious at 50/30/20 composition, and was attributed to interfacial agent role by PP-g-GMA. Tensile strength is the direct indication of the interfacial adhesion in polymer composites [13]. A good tensile strength reflects a strong interfacial adhesion. Ning and Ko [14] 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 blends has an impact on the blends' mechanical properties. Previous works had shown that optimum mechanical properties such as tensile strength and young's modulus were achieved at 50% – 80% PP, 20% – 30% PC, and with 5% – 20% compatibilizer content [10], [11], [15]. Amount of compatibilizer also plays a big role towards a blend's morphology. Zhihui and co-workers [11] found that PC particles size decreased when amount of PP-g-GMA increased from 2.5 to 20% in 70/30 system of PP/PC blends. The increase in fineness of particles led to higher tensile strength and modulus [3]. In comparison, compatibilization effect has a stronger influence towards polymer blend morphology than a process variation or rheological conditions with physical blends [16]. Besides compatibilization, some works reported studies on PP/PC blends integrated with other substance. Binary blend of PP/liquid-crystalline polymer (LCP) was found to result in an improvement of tensile modulus, but reduction in tensile strength [17]. The addition of PP-g-MA did not help in increasing tensile strength. Only when PC was introduced into the system, the ternary blend portrayed significant improvement in tensile properties. In the meanwhile, ternary blend of PC/PP/attapulgite (AT) was found to have good balanced toughness and stiffness [18].

To summarize, mechanical properties of immiscible polymer blend such as PP/PC will always be an issue because immiscible blend often produces material with poor mechanical properties. Subsequently, this work is aimed to characterize the morphology and mechanical properties, namely tensile strength and young's modulus of PP/PC/PP-g-MA polymer blends of various compositions. PP-g-MA as compatibilizer was suspected to provide interfacial adhesion in PP/PC blends, and is intended in this work to see the effect of it towards mechanical tensile properties.

## **2 Methodology**

## 2.1 Materials

PP used was Propelinas G425, produced by Polypropylene Malaysia (PETRONAS), and has melt volume-flow rate (MVR) of 11.0 cm<sup>3</sup>/10 min, while PC was from the trade name Panlite<sup>®</sup> grade L-1225Y, manufactured by Teijin Kasei America Inc. (Teijin Chemicals), with MVR value of 11.0 cm<sup>3</sup>/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 gel permeation chromatography (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 PC and 5% compatibilizer were compounded by twin-screw extruder at 250°C and 100 rpm before formed into standard shape by injection molding technique. The temperatures of the process were set at 110°C, 230°C, and 220°C for the nozzle, barrel, and hopper, respectively. Injection pressure was fixed at 30 MPa and time taken for cooling was 30 seconds.

## 2.3 Microscopy

Scanning electron microscope (SEM) was used to study the morphology of the blends. Specimens were cryogenically fractured and plated with thin gold layer as preparation.

## 2.4 Mechanical Tensile Test

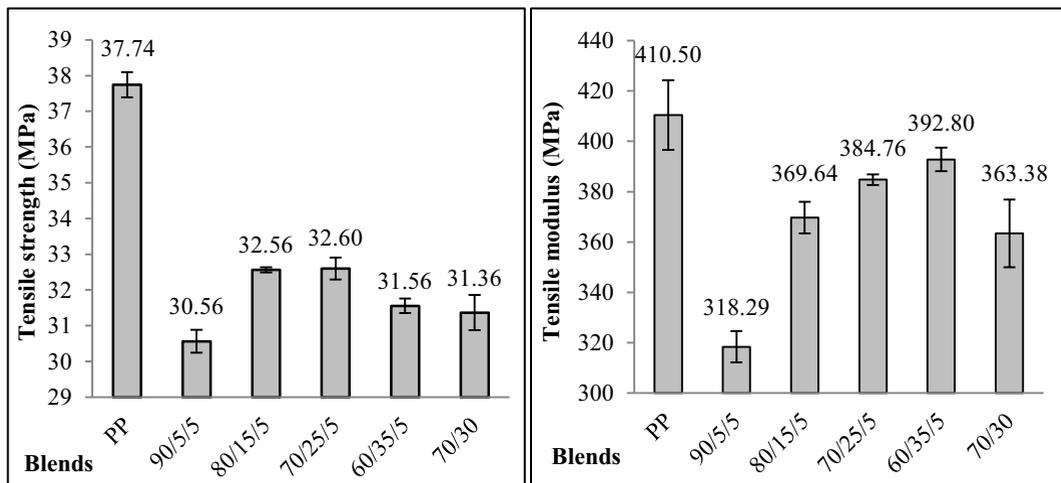
Mechanical tensile test was conducted according to ISO 527-1 [19]. The specimens were in dog-bone shape, having gauge length of 50 mm, 20 mm width and 4 mm thickness. By using universal testing machine (UTM), known loads were applied and recorded at a standard speed of 10 mm/min until the specimens were ruptured. The test was carried out at 23°C and 50% relative humidity and five specimens were tested for each blend composition.

# 3 Results & Discussion

## 3.1 Mechanical Tensile Properties

Tensile strengths and moduli of pure PP, pure PC, and the blends were determined. The tensile strength results are shown in Figure 1. It can be observed that all the blends were showing lower tensile strength and modulus compared to pure PP. Generally, a miscible polymer blends will follow law of mixture where it exhibits mechanical properties proportional to the fraction of the components that made up the polymer composite. On the other hand, immiscible blends such as PP/PC often produce a material with poor mechanical properties. This is mainly due to low interfacial adhesion, high interfacial tension between polymer blend components, and poor dispersion of reinforcement phase in matrix phase. Therefore, the lower tensile strength of the blends than that of pure PP is expected. The highest tensile strength observed among the blends was 32.60 MPa at 70/25/5 composition, followed by 32.56 MPa, 31.56 MPa, 31.36 MPa, and 30.56 MPa at 80/15/5, 60/35/5, 70/30, and 90/5/5 compositions, respectively. The pattern demonstrates decrement in strength when 5% PC is added, but increases as PC content keeps increasing until 25%. After 25%, the strength starts to decrease again. This is similar with the literatures [11], [15], where the highest tensile strength recorded for PP/PC blends was when PC content was around 20% – 30%. Therefore, it can be seen that the blends composition plays the biggest role in determining the tensile properties of the PP/PC blends. In terms of PP-g-MA effect, the only uncompatibilized blend (70/30 composition) had lower

tensile strength than 70/25/5 and 60/35/5 compositions. This suggests that 5% PP-g-MA as compatibilizer has positive effect towards mechanical properties of PP/PC blends.



**Figure 1.** Tensile strength and modulus of PP/PC/PP-g-MA blends.

Similar to tensile strength, the values of tensile moduli for PP/PC/PP-g-MA blends were lower than that of pure PP. Among the blends, tensile modulus of 60/35/5 composition exhibited the highest value, while 90/5/5 composition showed the lowest. As PC content in PP/PC/PP-g-MA increases, so does the tensile modulus. In terms of compatibilizer effect, tensile moduli have shown improvement similar to tensile strength when compatibilized with PP-g-MA.

### 3.2 Morphology

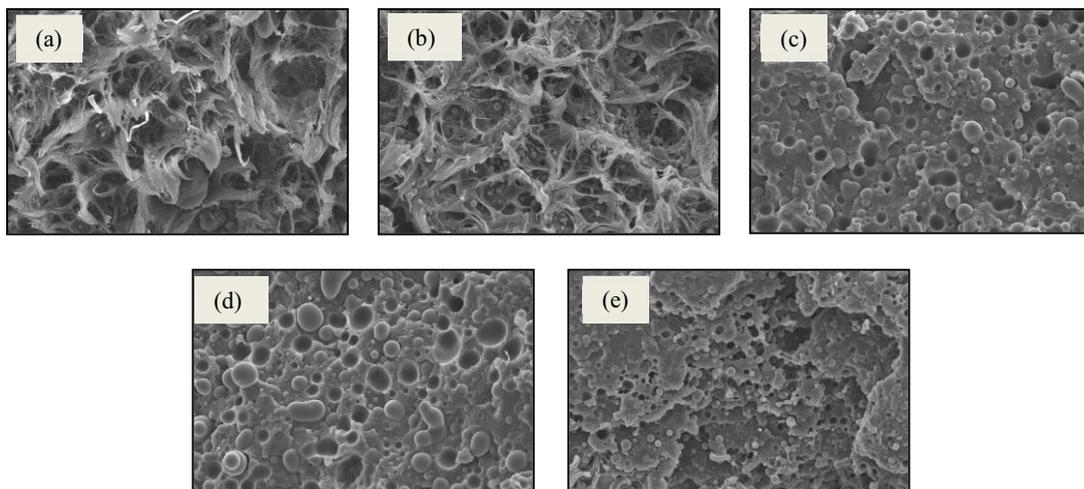
SEM was used to observe the morphology of the tensile test samples. The micrographs at 500x magnification are shown in Figure 2, while the diameters of PC particulates are tabulated in Table 1. The morphologies show that PC existed as particulates, dispersed throughout PP matrix. It was found that the finest PC particulates were present at 90/5/5 composition, and the largest PC particulates appeared at 60/35/5 composition. Generally, as PC content in compatibilized blends increases, the PC particulate size also increases.

**Table 1.** Diameter of PC particulates

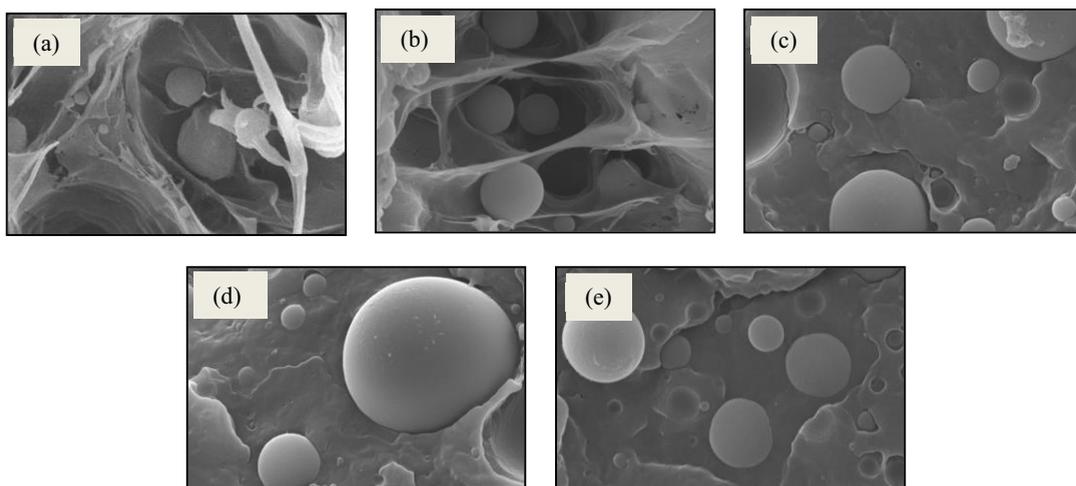
Blends	90/5/5	80/15/5	70/25/5	60/35/5	70/30
PC particulate diameter [ $\mu\text{m}$ ]	5.6 – 7.7	10.0 – 30.7	30.7 – 82.9	75.8 – 263.3	10.0 – 40.1

The intended roles of PP-g-MA in PP/PC blends are to provide interfacial adhesion between matrix and reinforcement phases, and to reduce interfacial tension between the two phases which will result into more uniform dispersion and finer PC phase [20]. The positive impact of PP-g-MA to PP/PC blends were reported in several works [10], [14], where the PP-g-MA contributed to higher dispersion uniformity and finer PC reinforcement particles in PP matrix phase. As particulate size decreases, 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. However, the noncompatibilized blend (70/30 composition) demonstrated lower PC particulates diameter than that of the compatibilized blends of 70/25/5 and 60/35/5 compositions. This is the opposite of what was expected from compatibilizing process. Despite having finer PC particulates, 70/30 composition had lower tensile strength than 70/25/5 and 60/35/5 compositions, indicating PP-g-MA provides a means of interfacial adhesion between PP matrix phase and PC reinforcement phase. Based on the results, the effect of the adhesion towards tensile strength is thought to be stronger than the effect of PC

particulates size. The optimum amount of compatibilizer may need to be investigated, as suggested by Zhihui and co-workers' [11] work that mechanical properties of PP/PC/PP-g-GMA increased with increasing amount of compatibilizer up to 20%. 5000x magnification pictures of PC particulates dispersed in PP matrix are shown in Figure 3. It can be observed that PC particulates and PP matrix existed in two separate phases. It is suspected that there is a little adhesion bond presence when PP-g-GMA is used, based on the tensile strength result. Tensile tests can roughly estimate the interfacial adhesion strength between matrix and reinforcement phases of the PP/PC immiscible blends, as a good tensile strength reflects a strong interfacial adhesion [13].



**Figure 2.** 500x magnification by SEM of: (a) PP/PC/PP-g-GMA (90/5/5), (b) PP/PC/PP-g-GMA (80/15/5), (c) PP/PC/PP-g-GMA (70/25/5), (d) PP/PC/PP-g-GMA (60/35/5) and (e) PP/PC (70/30).



**Figure 3.** 5000x magnification by SEM of: (a) PP/PC/PP-g-GMA (90/5/5), (b) PP/PC/PP-g-GMA (80/15/5), (c) PP/PC/PP-g-GMA (70/25/5), (d) PP/PC/PP-g-GMA (60/35/5) and (e) PP/PC (70/30)

## 4 Conclusions

The blends exhibited lower tensile strength and modulus compared to the pure PP. The pattern is non-linear, whereby more or lesser PC content than 25% would obtain lower strength and the reduction in strength was in the range of 13.6% – 19.0%. In the meanwhile, tensile modulus of the blends

improves as PC content increases. When comparing 70/30 with 70/25/5 composition, the latter showed higher value for both tensile strength and tensile modulus. This suggests PP-g-MA as compatibilizer imparts positive effect towards mechanical properties of PP/PC blend by providing interfacial adhesion between PP and PC phases. From the SEM micrographs, it was observed that PC existed as particulates, dispersed throughout PP matrix. Generally, as PC content in compatibilized blends increases, the PC particulate size also increases. The noncompatibilized blend (70/30) demonstrated lower PC particulates diameter than that of the compatibilized blends of 70/25/5 and 60/35/5 compositions. This is the opposite of what was expected from compatibilizing process. However, 70/30 composition had lower tensile strength than 70/25/5 and 60/35/5 compositions, indicating PP-g-MA provides a means of interfacial adhesion between PP matrix phase and PC reinforcement phase.

## Acknowledgements

This research was made possible through Research Acculturation Grant Scheme (RAGS/1/2014/TK04/UITM//8) by Ministry of Education Malaysia with the help from Faculty of Chemical Engineering of Universiti Teknologi MARA (UiTM) Selangor, and Mechanical Engineering Faculty of Universiti Teknologi PETRONAS, Malaysia.

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