# Effects of ABS-*g*-MAH on Mechanical Properties and Compatibility of ABS/PC Alloy

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*Received 24 February 2000; accepted 17 August 2000*

**ABSTRACT:** The effects of a compatibilizer, namely, an acrylonitrile–butadiene–styrene copolymer (ABS) grafted with maleic anhydrade (MAH) (ABS-*g*-MAH), on the mechanical properties and morphology of an ABS/polycarbonate (PC) alloy were studied The results showed that a small quantity of ABS-*g*-MAH has a very good influence on the notched Izod impact strength of the ABS/PC alloy without compromising other properties such as the tensile strength, flexural strength, and Vicat softening temperature (VST). The impact strength of the ABS/PC alloy, to a great extent, depends on the loading of ABS-*g*-MAH and the degree of grafting (DG) of MAH in the ABS-*g*-MAH. DSC analysis and SEM observation confirmed that ABS-*g*-MAH could significantly improve the compatibility of the ABS/PC alloy. © 2001 John Wiley & Sons, Inc. J Appl Polym Sci 81: 831–836, 2001

**Key words:** compatibility; ABS; PC; ABS-*g*-MAH alloy

## INTRODUCTION

Acrylonitrile–butadiene–styrene copolymer (ABS)/polycarbonate (PC) alloys have become widely applicable in automobile, home appliance, and computer fields due to their relatively good mechanical properties, processibilty, and heat resistance. An ABS/PC alloy can be blessed with a relatively high impact strength when the PC component is rich. To reduce the material cost, an ABS/PC alloy with a high loading of ABS is favorable. Blending PC with high-loading ABS will not apparently compromise the good tensile strength, flexural strength, and high Vicat softening temperature (VST) of a PC/ABS alloy. But the impact strength of an PC/ABS alloy is very low, even lower than that of pure ABS.[1] In general, this unexpected result arises from the poor compatibility of an ABS/PC alloy. Therefore, how to improve the compatibility of an ABS/PC alloy is a problem to be solved and has attracted many researchers in the last decade. Wu et al.[2] successfully toughed an ABS/PC alloy by using ABS with a high rubber content, at a cost of increasing the melt viscosity. Kim et al.[3] improved the interface adhesion of an ABS/PC alloy by adding poly(methyl methacrylate) (PMMA) to change the fracture mechanism and to reduce the notch sensitivity of the alloy. This problem was also of concern in the work of Chiang et al.,[4] who added a small amount of different commercial polymers such as a methacrylate–butadiene–styrene copolymer (MBS), an ethylene–vinyl acetate copolymer (EVA), and a styrene–maleic anhydride copolymer (SMA) to improve the compatibility and notch Izod impact strength of the ABS/PC alloys without affecting other properties.

In recent years, research on multicomponent polymer alloys and blends has focused on the

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Journal of Applied Polymer Science, Vol. 81, 831–836 (2001)

technique of reactive blending of immiscible polymers. In nature, there is one chemical reaction or more between the blending components with reactively functional groups during the blending process at elevated temperature. The reactions can *in situ* generate compatibilizers that act as interfacial agents to reduce interfacial tension and promote interface adhesion.[5–7] This technique should be fast and irreversible because it has been well demonstrated as being effective in some commercialized alloys and blends such as polyamide-6/polyethylene[8] and poly(ethylene terephthalate)/PC.[9] A few publications were concerned with the compatibilzation of ABS/PC by ABS-*g*-MAH.[10] The present work focused on the effect of ABS grafted with maleic anhydride (ABS-*g*-MAH) on the mechanical properties and morphology of ABS/PC alloys in detail.

## EXPERIMENTAL

### Materials

ABS resin (PA-747s) was produced by Qimei Plastics Co. Ltd.; PC (Lexan141) was produced by GE Plastics Co. Ltd.; and ABS-*g*-MAH resins having different degrees of grafting (DG) of MAH were prepared in a twin-screw extruder in our laboratory.

### Reactive Blending and Specimen Preparation

ABS, PC, and ABS-*g*-MAH pellets were dried separately at 80, 90, and 120°C in a vacuum oven for 8 h. The mixture was then extruded in an SHL-35 corotating intermeshing twin-screw extruder with $L/D = 25$. The melt temperature was 220–240°C. The screw speed was 120 rpm and the extrusion speed was about 5 kg/h. Extruded pellets of the alloy were vacuum-dried at 80°C for 10 h and injection-molded to give all the required test specimens with a melt temperature of 250°C and a mold temperature of 120°C.

### Measurements

The IR spectra of ABS-*g*-MAH were obtained in a Perkin–Elmer 1000 FTIR instrument, and the ratio of the stretched vibration absorbency of the carbonyl group at 1780 $cm^{-1}$ (A1780) to that of the nitrile group at about 2200 $cm^{-1}$ (A2200) was linear to the loading of MAH. The DG of the MAH was then calculated from the ratio of A1780/A2200.

The notched Izod impact strength was measured according to the ASTM D256 test method using an impact test machine Model 2500 from the RAY–RAN Co. at room temperature. The dimension of the specimens was $63.5 \times 12.7 \times 3.18$ $mm^3$ with a V-shape notch of 0.25 mm. The swaying velocity of the hammer was 3.5 m/s. Each datum of impact strength represents the average value of impact strengths for a minimum of five specimens.

Tensile and flexural properties were measured according to ASTM D638 and ASTM D790, respectively, by using a tensile machine Instron Model 4465 at room temperature. The crosshead speeds were 50 and 14 mm/min, respectively. The support span was 40 mm for the flexural measurement.

The VST of the ABS/PC alloy was measured according to ASTM D1525 in a VST equipment Model 1700 from the RAY–RAN Co. at heating rate of 50°C/h and 49N load. Each VST datum represents the average value of the VST for a minimum of three specimens. A differential scanning calorimeter (DSC) Model Perkin–Elmer Pyris 1 was used to measure the glass transition temperature ($T_g$) of the ABS/PC alloy at a scanning speed of 10°C /min from 50 to 250°C under a nitrogen atmosphere. The weight of the specimens was about 5 mg.

The specimens of the ABS/PC alloy were frozen in liquid nitrogen for 4 h and broken. The fractured surfaces were exposed to a 30 wt % NaOH aqueous solution for 40 min at 105°C to remove the PC phase and then observed in a Hitachi S-2150 scanning electron microscope (SEM).[11]

## RESULTS AND DISCUSSION

### Izod Impact Strength

The notched Izod impact strength is one of the most important properties for rigid polymers such as the ABS/PC alloy because of their notch sensitivity. Figure 1 shows that ABS-*g*-MAH is a good compatibilizer and tremendously improves the impact strength of the ABS/PC alloy with a PC content 0–80 wt %. The impact strength of the ABS/PC alloy can be greatly enhanced by the addition of 10 wt % ABS-*g*-MAH. The impact strengths of simple ABS/PC alloys without ABS-*g*-MAH are very low, indicating a negative synergistic effect between the ABS and the PC because

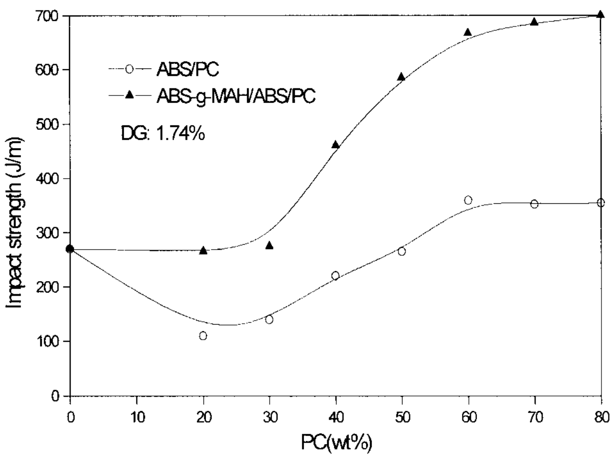



**Figure 1** Notched Izod impact strength of ABS/PC before and after compatibilizing (ABS-*g*-MAH 10 wt %).

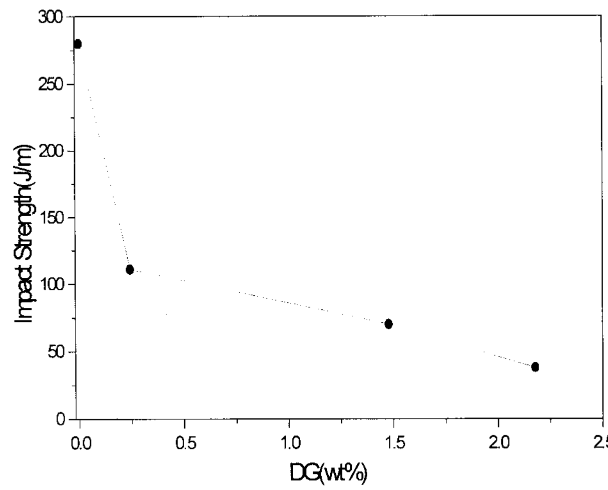



**Figure 3** Effect of the DG of MAH on notched Izod impact strength of ABS-*g*-MAH.

of their poor interfacial interaction in the ABS/PC alloy.

The DG of MAH in ABS-*g*-MAH affects the impact strength of the ABS/PC alloy as shown in Figure 2, where the loadings of ABS-*g*-MAH, ABS, and PC are 10, 60, and 30 phr, respectively. The impact strength increases with an increasing DG to a certain extent, but decreases slowly when the DG is more than 1.74 wt %. An increase in the DG will be beneficial to a possible esterification reaction that takes place between the anhydride groups in ABS-*g*-MAH and the hydroxyl (OH) terminal groups in PC during melt blending. The reaction can *in situ* turn out compatibilizers that act as interfacial agents to improve the interfacial interaction in the ABS/PC alloy.[12] However, there is a limited number of OH terminal groups in PC and a suitable number of anhydride groups in ABS-*g*-MAH should be enough for carrying out the esterification reaction to realize the compatibilizing effect, so that a very high DG is not necessary for the esterification reaction and the impact strength should stay stagnant. Unfortunately, ABS-*g*-MAH is more brittle than is unmodified ABS, so that the impact strength of ABS-*g*-MAH decreases with an increasing DG of MAH as shown in Figure 3. Therefore, a very high DG of MAH in the compatibilizer ABS-*g*-MAH will impair the impact strength of the ABS/PC alloy.

Figure 4 shows that the content of ABS-*g*-MAH

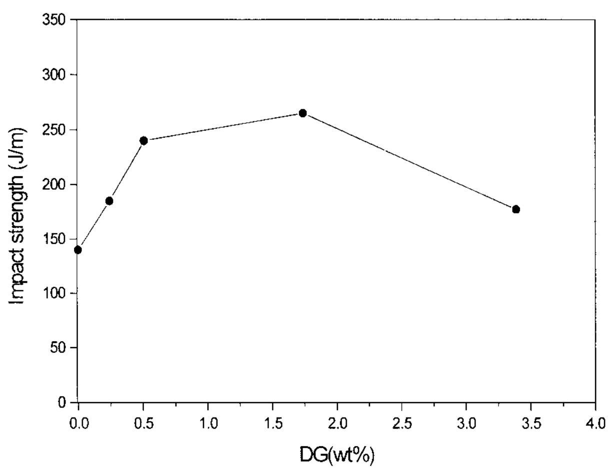



**Figure 2** Effect of the DG of MAH in ABS-*g*-MAH on notched Izod impact strength of 10/60/30 ABS-*g*-MAH/ABS/PC alloys.

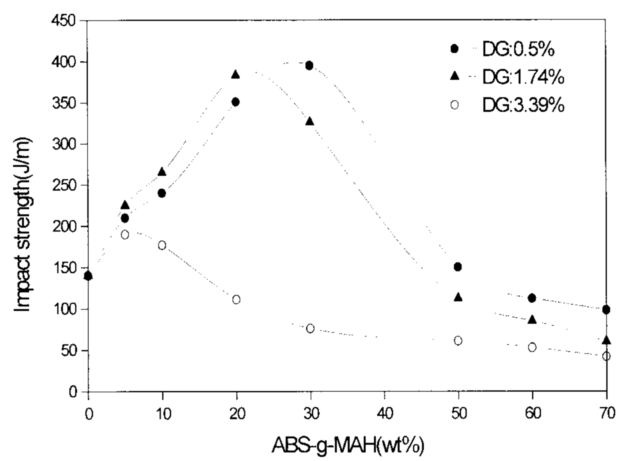



**Figure 4** Effect of ABS-*g*-MAH content on notched Izod impact strength of ABS/PC alloy (PC 30 wt %).

has a great effect on the impact strength of the ABS/PC alloy when the PC content is 30 wt %. When the DG of MAH in ABS-*g*-MAH is 0.5 or 1.74 wt %, the impact strength of the ABS/PC alloy first increases quickly with an increasing ABS-*g*-MAH content and decreases promptly when the ABS-*g*-MAH content is over a given value. It is reasonable to think that the interfacial action of the ABS/PC blend will be improved by increasing the ABS-*g*-MAH content. However, the dicumyl peroxide (DCP) used for the grafting reaction of MAH to ABS could result in the decomposition of ABS easily, which will obviously decrease the impact strength of the ABS/PC alloy when the content of ABS-*g*-MAH is very high. Meanwhile, the brittleness arising from the polar MAH in ABS-*g*-MAH will become also notable with an increasing ABS-*g*-MAH content, therefore greatly deteriorating the impact strength of the alloy.

When the DG of MAH in ABS-*g*-MAH is very high, for example, 3.39%, a small amount of ABS-*g*-MAH improved the impact strength of the alloy to a very small extent, and a high amount of ABS-*g*-MAH had the adverse effect on the impact strength of the alloy. The impact strength of the ABS/PC alloy compatibilized with ABS-*g*-MAH with a high DG is lower than that of the uncompatibilized ABS/PC alloy.

## Tensile Strength

Figure 5 shows the effect of the compatibilizer ABS-*g*-MAH on the tensile strength of the alloy, where the content of ABS-*g*-MAH is 10 wt %. The tensile strength of the ABS/PC alloy is proportional to the PC content. The tensile strengths of the ABS-*g*-MAH/ABS/PC alloys and the ABS/PC alloys are almost the same at a given PC content, which implies that ABS-*g*-MAH has slight effect on the tensile strength.

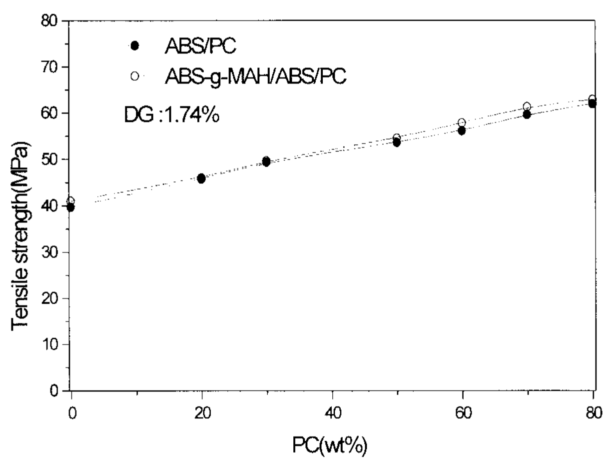



**Figure 5** Tensile strength of ABS/PC alloys before and after compatibilizing (ABS-*g*-MAH 10 wt %).

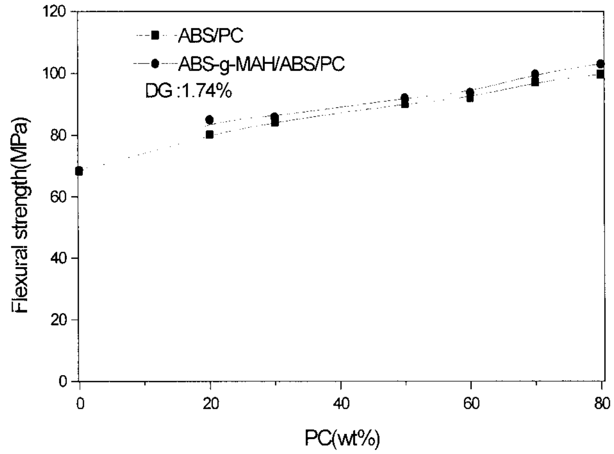



**Figure 6** Flexural strength of ABS/PC alloys before and after compatibilizing (ABS-*g*-MAH 10 wt %).

## Flexural Strength

Figure 6 shows the effect of the compatibilizer ABS-*g*-MAH on the flexural strengths of the alloy, where the ABS-*g*-MAH content is 10 wt %. The flexural strength of the ABS/PC alloy increases proportionally with an increasing PC content. The flexural strength of the ABS-*g*-MAH/ABS/PC alloys is slightly higher than that of the ABS/PC blends at a given PC content, which accounts for the presence of ABS-*g*-MAH.

## VST

Figure 7 shows the effect of the compatibilizer ABS-*g*-MAH on the VST, where the ABS-*g*-MAH content is 10 wt %. The VST of the ABS/PC alloy increases with an increasing PC content. The VST of the ABS-*g*-MAH/ABS/PC alloy is slightly lower than that of the ABS/PC alloy at a given PC content less than 50 wt % and is slightly higher than that of the ABS/PC alloy at a given PC content over 50 wt %. In short, a partial substitution of ABS by ABS-*g*-MAH has little influence on the VST of the ABS/PC alloy.

## DSC Analysis and Morphology Observation

Table I shows the effect of ABS-*g*-MAH on the glass transition temperatures of ABS, PC, and

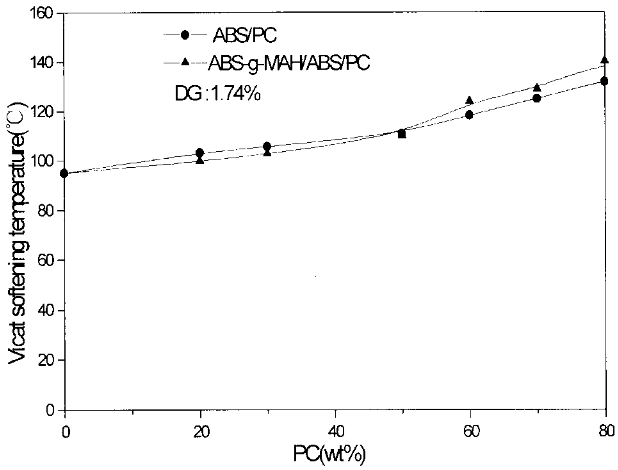
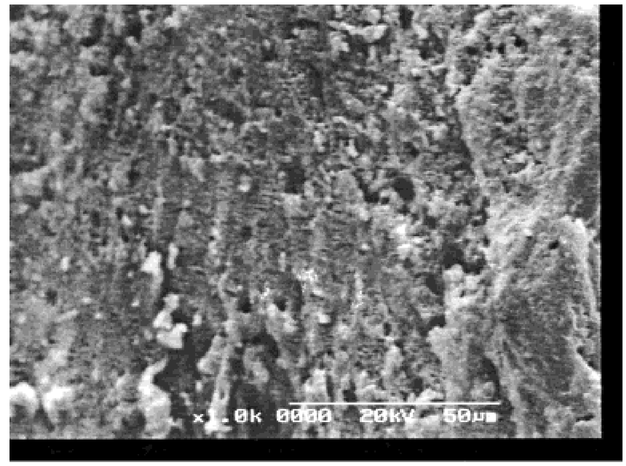
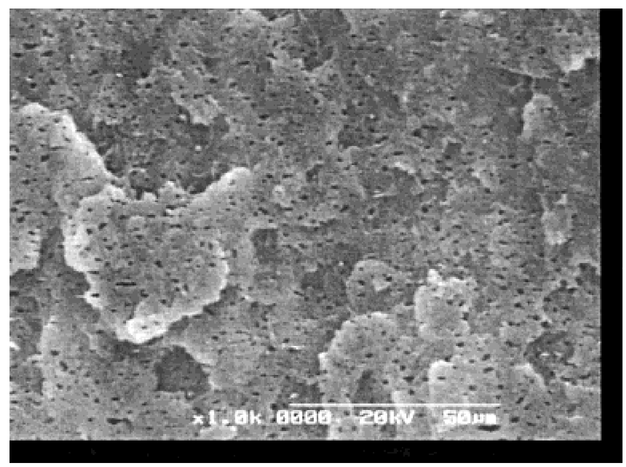



**Figure 7** VST of ABS/PC alloy before and after compatibilizing (ABS-$g$-MAH 10 wt %).




(a) ABS/PC(70/30)




(b) ABS-g-MAH/ABS/PC(10/60/30)

**Figure 8** SEMs of the alkali-etched ABS/PC alloys before and after compatibilizing (DG in ABS-$g$-MAH is 1.74%): (a) ABS/PC (70/30); (b) ABS-$g$-MAH/ABS/PC (10/60/30).

their blends. A $T_g$ of ABS-$g$-MAH is 98.6°C and lower than the corresponding $T_g$ of pure ABS, 101.4°C, which may due to the short flank chain of MAH in the ABS-$g$-MAH resin. In the ABS/PC (70/30) alloy, there are two $T_g$'s, namely, a $T_{g1}$ of 102.1°C for the ABS phase and a $T_{g2}$ of 133.8°C for the PC phase. The $T_{g1}$ is higher than is the $T_g$ of pure ABS, 101.4°C, and the $T_{g2}$ is lower than the $T_g$ of pure PC, 149.0°C, indicating there is a limited compatibility between ABS and PC. Generally speaking, the decrease in the difference of the glass transition temperatures of the two phases implies an improved compatibility in the polymer alloy. The $T_g$ difference ($T_{g2} - T_{g1}$) in the 10/60/30 ABS-$g$-MAH/ABS/PC alloy is lower than that of the 70/30 ABS/PC alloy, which confirms that the ABS-$g$-MAH can enhance the compatibility of the ABS/PC alloy.

Scanning electron micrographs (SEMs) for the alkali-etched surfaces of the 10/60/30 ABS-$g$-MAH/ABS/PC alloy and the 70/30 ABS/PC alloy are shown in Figure 8, where the black holes are the alkali-etched PC phase. The photo of the 10/60/30 ABS-$g$-MAH/ABS/PC alloy shows fine holes proportionally well distributed in the ABS phase, which are typical characteristics of good interfacial interaction, whereas the photo of the 70/30 ABS/PC alloy shows more pockets and bigger holes in the ABS phase, which are characteristics of poor interfacial interaction. These facts, furthermore, prove that ABS-$g$-MAH is a good compatibilizer for the ABS/PC alloy.

**Table I Glass Transition Temperatures of ABS, ABS-$g$-MAH, PC, and Their Alloys**

| Specimens | $T_{g_1}$ | $T_{g_2}$ | $T_{g_2} - T_{g_1}$ |
|---|---|---|---|
| ABS | 101.4 | | |
| ABS-$g$-MAH | 98.6 | | |
| PC | | 149.0 | |
| ABS/PC (70/30) | 102.1 | 133.8 | 31.7 |
| ABS-$g$-MAH/ABS/PC (10/60/30) | 105.5 | 125.6 | 20.1 |

The DG in ABS-$g$-MAH is 1.74 wt %.

## CONCLUSIONS

ABS-$g$-MAH can act as a good compatibilizer for the ABS/PC alloy. A small amount of ABS-$g$-MAH has a notable influence on the notched Izod impact strength of the ABS/PC alloy and a slight effect on the other properties such as the tensile strength, flexural strength, and VST. The impact strength of the ABS/PC alloy increases with an increasing ABS-*g*-MAH content and the DG of the MAH in the ABS-*g*-MAH, but changes, on the contrary, when the DG is very high or the ABS-*g*-MAH content is also very high. The DSC analysis and the SEM photos confirmed that ABS-*g*-MAH could greatly enhance the compatibility of the ABS/PC alloy.

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