

## Effects of Compatibilizer on Mechanical, Morphological, and Rheological Properties of Polypropylene/Poly(acrylonitrile-butadiene-styrene) Blends

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**Abstract:** The effects of a compatibilizer on polypropylene (PP)/poly(acrylonitrile-butadiene-styrene) (ABS) blends were studied. Blends of the PP/ABS, with PP-g-SAN copolymer as a compatibilizer, were prepared using a twin screw extruder. The flexural and impact strength of the PP/ABS blends with the PP-g-SAN copolymer increased significantly with PP-rich compositions on the addition of the PP-g-SAN copolymer at 3 phr. The increase in the mechanical properties of the PP/ABS/PP-g-SAN blend may have been due to the toughening effects of the ABS in the PP-rich compositions. In the morphology study of the PP/ABS/PP-g-SAN (80/20) blend with the PP-g-SAN copolymer, the minimum droplet size, 5.1  $\mu\text{m}$ , was observed with the addition of 3 phr of the PP-g-SAN copolymer. The complex viscosity of the PP/ABS/PP-g-SAN (80/20) blends increased with the addition of 3 phr of the PP-g-SAN copolymer. From the above mechanical properties, morphology and complex viscosity results for the PP/ABS blends, it is suggested that the compatibility is more increased with the PP-rich composition (PP:ABS = 80/20 wt%) of the PP/ABS blend on the addition of 3 phr of the PP-g-SAN copolymer.

**Keywords:** polymer blends, compatibilizer, mechanical properties, morphology, rheology.

### Introduction

Polymer blends are an alternative way to synthesize new polymeric materials. The properties of the polymer blends are influenced by the properties of the each components and degree of the dispersion of the minor component.<sup>1-26</sup> For example, for the polypropylene (PP)/ethylene-propylene-diene monomer (EPDM) blends, the improvement of the properties can be obtained by the combination of the properties of each components.<sup>2-4</sup> For the PP/EPDM blends, the PP plays the role of the high heat distortion temperature and EPDM plays the role of the toughness.<sup>2-4</sup> Also, for the polycarbonate (PC)/poly(acrylonitrile-butadiene-styrene) (ABS) blends, the PC imparts the mechanical strength and ABS imparts the processibility.<sup>5-11</sup> However, in many cases of the polymer blends, the improvement of the mechanical properties was hardly observed due to the poor dispersion of the minor component.

To improve the properties of the polymer blends, the compatibilizer has been widely used.<sup>16,17</sup> For example, Sundararaj and Macosko have investigated the morphology of the polystyrene (PS)/ethylene-propylene (EP) copolymer blends with and without compatibilizer.<sup>16</sup> From the studies by Sundararaj and Macosko, the coalescence of the dispersed phase (EP) in the PS/EP blends was effectively suppressed by the compatibilizers such as PS-EP diblock and PS-EP-PS triblock copolymers.<sup>16</sup> In our previous work, we reported the decrease of the interfacial tension between the PP and poly(styrene-co-acrylonitrile) (SAN) in the PP/SAN blends using the PP-g-SAN copolymer as compatibilizer.<sup>17</sup> Also, the size of the dispersed phase was found to decrease by the addition of the PP-g-SAN copolymer in the PP/SAN blends.<sup>17</sup>

PP is one of the most widely used commodity polymers with the high heat distortion temperature and economic merits. However, the use of the PP is restricted by the low impact strength at the subambient temperature. On the other hand, the ABS is one of the most widely used rubber-toughened polymers. Therefore, ductile properties of the PP can

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be improved by the blending with the ABS.<sup>18-22</sup> For the PP/ABS blends, Patel *et al.* have used the compatibilizers such as PP-*g*-acrylic acid<sup>21</sup> and PP-*g*-hydroxyethyl methacrylate (PP-*g*-2-HEMA) in order to improve the degree of the dispersion of the minor component (ABS).

In this study, mechanical, rheological, and morphological properties of the PP/ABS blends are reported by the universal testing machine (UTM), Izod impact tester, advanced rheometric expansion system (ARES) and scanning electron microscopy (SEM). In particular, compatibilization effects by the addition of the PP-*g*-SAN copolymer in the PP/ABS blends are investigated.

## Experimental

**Materials.** The polymers used in this study were obtained from commercial sources. The PP was provided by Samsung Total Co. The ABS was provided by LG Chem. Ltd. The graft copolymer PP-*g*-SAN as compatibilizer was supplied from NOF Corporation. The weight fraction of the PP in the PP-*g*-SAN compatibilizer is 0.7. The characteristics of the PP, ABS, and PP-*g*-SAN are summarized in Table I.

**Blend Preparations.** Blends of PP and ABS were prepared using a 11 mm diameter twin screw extruder with a screw ratio of 40:1 length to diameter. For the PP/ABS blends, the ABS with the weight fractions ranged from 0.0 to 1.0 with the increment of 0.1 were mixed with the PP using the extruder. Also, concentrations of the PP-*g*-SAN copolymer, ranged from 0.0 to 5.0 (phr) were added in the PP/ABS blends. The temperatures of the extruder were set at 180 to 200 °C in feeding and barrel zones, respectively. The screw speed of the extruder was set at 90 rpm. Samples were compression molded using a hot press at 200 °C for 5 min. Before preparation of the samples, all the samples were dried under vacuum (< 1 mmHg) at 80 °C for 24 h.

**Mechanical Properties.** The mechanical properties of the PP/ABS/PP-*g*-SAN blends were investigated using an universal testing machine (Instron 4467). Tensile test was performed according to the ASTM D-638. The speed of cross-head movement for tensile test was 5.0 mm/min. Flexural test was performed according to the ASTM D-790. The span length and the speed of cross-head movement was set at 40 mm and 2.8 mm/min, respectively. For tensile and flexural test, 7 specimens were measured and averaged.

Table I. Characteristics of Polymers Used in This Study

Sample	$\overline{M}_n$	$\overline{M}_w$	$T_g$ (°C) <sup>a</sup>	$T_m$ (°C) <sup>a</sup>
PP <sup>b</sup>	41,000	230,000	5	164
ABS <sup>c</sup>	-	160,000	118	
PP- <i>g</i> -SAN <sup>d</sup>	-	-	-5,102	160

<sup>a</sup>Measured in our laboratory by DMTA. <sup>b</sup>Supplied by Samsung Total Co. <sup>c</sup>Supplied by LG Chemical Ltd. (acrylonitrile: 22, butadiene:15, styrene: 63 wt%). <sup>d</sup>Supplied by NOF Corp. (PP-SAN = 70:30 wt%).

**Impact Strength.** The impact strength of the PP/ABS/PP-*g*-SAN blends was measured by notched izod impact strength method (McVan Instruments: ITR-2000). The impact tester was performed according to the ASTM D-256 and 7 specimens were measured and averaged.

**Scanning Electron Microscopy.** The morphology of the PP/ABS/PP-*g*-SAN blends was obtained by scanning electron microscopy (model: Hitachi S-4300) after Pt coating. The samples were fractured with the cryogenic condition.

**Rheology.** Rheological measurements of the PP/ABS blends were carried out on advanced rheometric expansion system in oscillatory shear at 5% strain in the parallel-plate arrangement with 25 mm plate. The frequency sweep from 0.1 to 100 rad/s was performed at 200 °C under dry nitrogen condition. For the ARES measurements, the samples were tested within the linear viscoelastic strain range.

## Results and Discussion

Figure 1 shows the tensile strength of the PP/ABS blends with and without PP-*g*-SAN copolymer (3 phr). From Figure 1, it is observed that the tensile strength of the PP and ABS shows 36.2 and 47.8 MPa, respectively. From Figure 1, it is observed that the values of the tensile strength follow the additive rule with the negative deviation, which may be due to the immiscibility between the PP and ABS. For the PP/ABS/PP-*g*-SAN (3 phr) blends, the values of the tensile strength are increased compared that of the PP/ABS blends without compatibilizer in all the composition ranges.

Figure 2 shows the flexural strength of the PP/ABS blends with and without PP-*g*-SAN copolymer (3 phr). From Figure

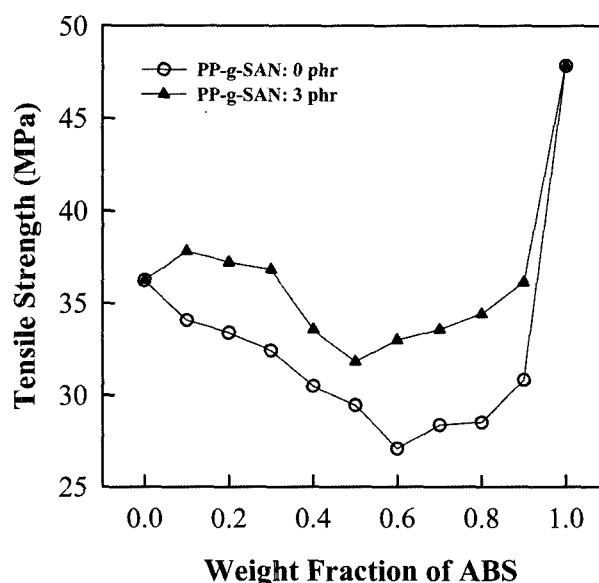
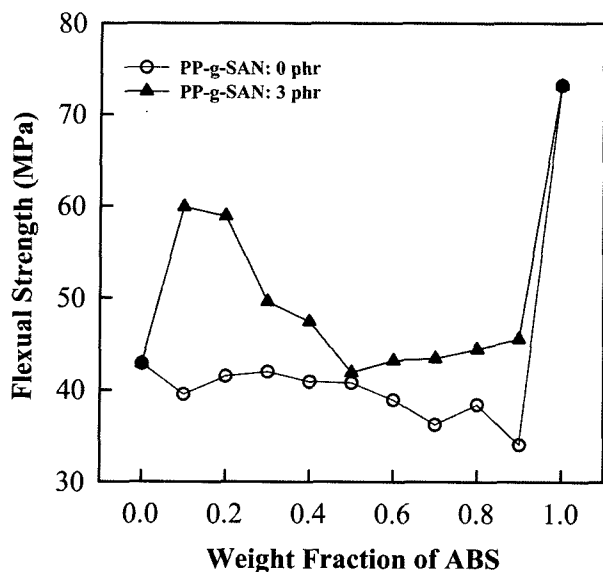
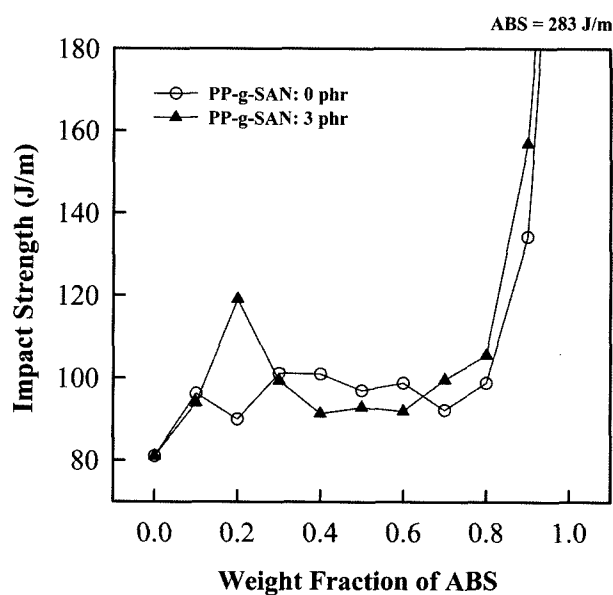


Figure 1. Tensile strength of the PP/ABS blends with and without PP-*g*-SAN copolymer (3 phr): (○) PP/ABS; (▲) PP/ABS/PP-*g*-SAN (3 phr).



**Figure 2.** Flexural strength of the PP/ABS blends with and without PP-g-SAN copolymer (3 phr): (○) PP/ABS; (▲) PP/ABS/PP-g-SAN (3 phr).

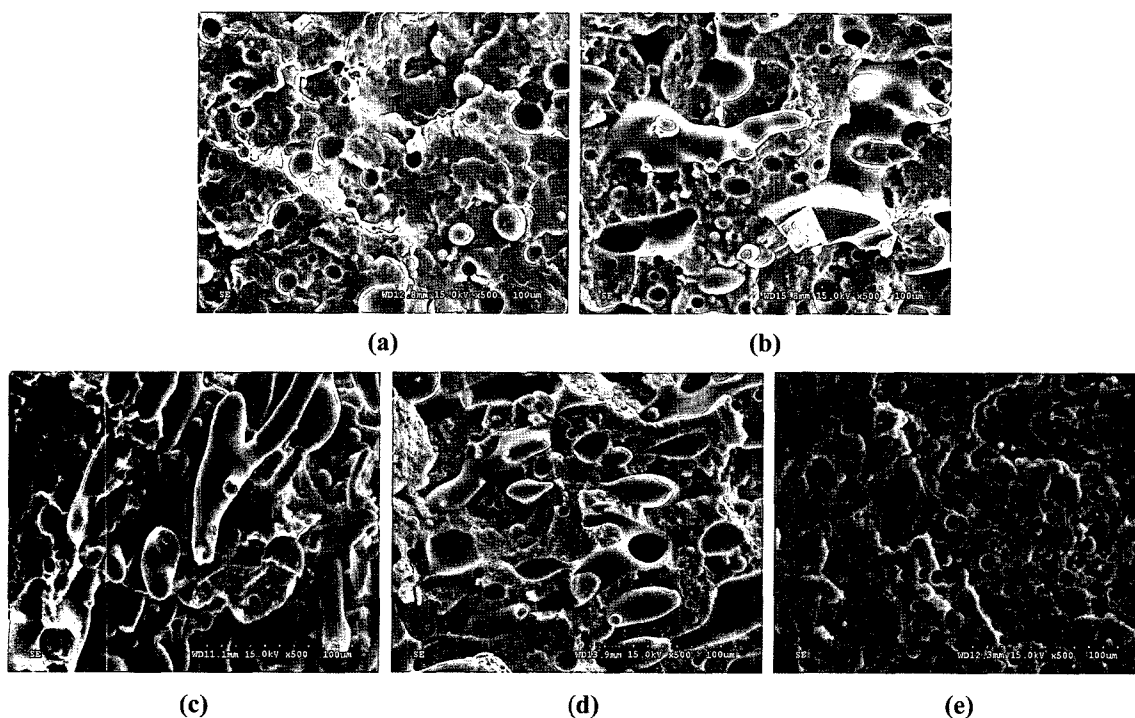
2, it is observed that the values of the flexural strength of the PP/ABS blends are increased by adding the PP-g-SAN copolymer. The increase of the flexural strength is significant in the PP-rich compositions (PP/ABS = 90/10 and 80/20 wt%) than in the ABS-rich compositions. Flexural



**Figure 3.** Impact strength of the PP/ABS blends with and without PP-g-SAN copolymer (3 phr): (○) PP/ABS; (▲) PP/ABS/PP-g-SAN (3 phr).

strength of the PP/ABS (80/20) blend is increased from 41.5 to 58.9 MPa when the PP-g-SAN copolymer is added in the amount of 3 phr.

Figure 3 shows the impact strength of the PP/ABS blends with and without PP-g-SAN copolymer (3 phr). From Figure



**Figure 4.** Scanning electron micrographs of the cryogenically fractured surfaces of the PP/ABS blends: (a) 90/10; (b) 70/30; (c) 50/50; (d) 30/70; (e) 10/90.

3, it is observed that the impact strength of the PP/ABS blends is increased especially in the PP-rich composition (PP/ABS = 80/20 wt%) when the PP-g-SAN copolymer is added in the amount of 3 phr. Impact strength of the PP/ABS (80/20) blend is increased from 90.0 to 119.1 J/m when the PP-g-SAN copolymer is added in the amount of 3 phr. From the results of tensile, flexural, and impact strength of the PP/ABS/PP-g-SAN (3 phr) blends shown in Figures 1-3, it is observed that the mechanical properties are increased especially in the PP-rich region (PP/ABS = 80/20 wt%). The increase of the mechanical properties of the PP/ABS/PP-g-SAN blend in the PP-rich compositions may be due to the toughening effect of the ABS. Similar results were reported by Patel *et al.*<sup>21,22</sup> in the PP/ABS/PP-g-acrylic acid<sup>21</sup> and PP/ABS/PP-g-2-HEMA blends.<sup>22</sup>

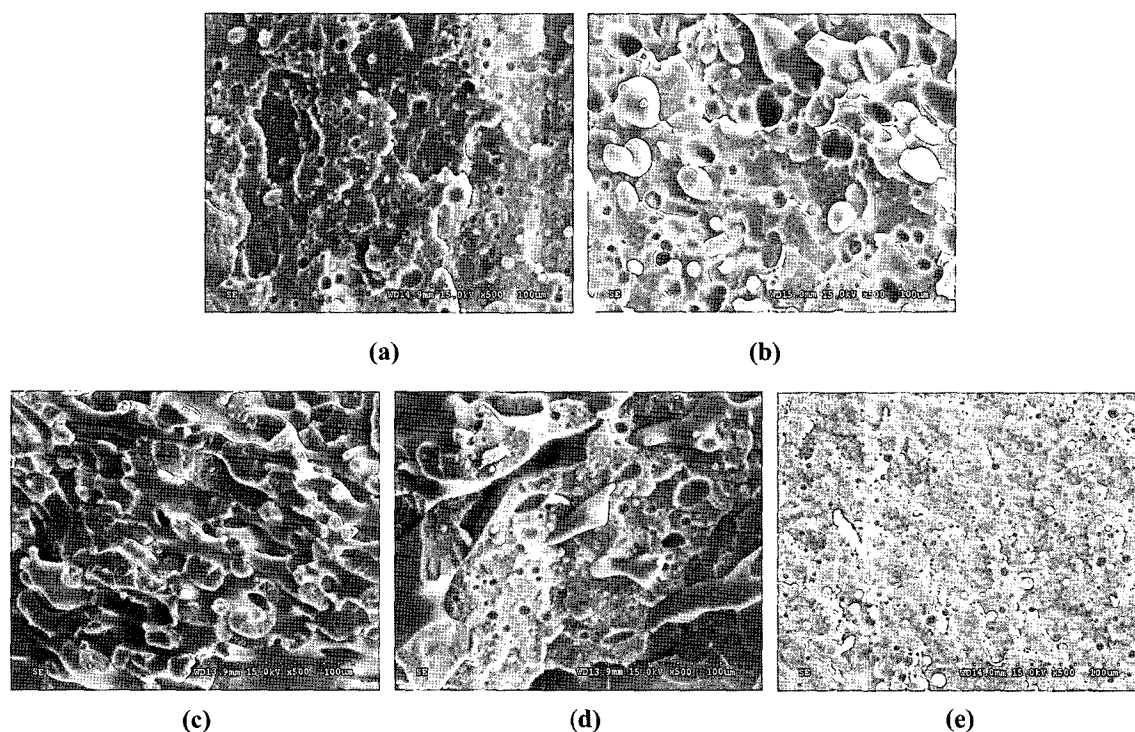
From the results of Figures 2 and 3, it is suggested that the compatibilizing effect of the PP-g-SAN was more pronounced in the PP-rich compositions (PP/ABS = 90/10 and 80/20 wt%) of the PP/ABS blends. This is maybe due to the fact that the small amount of the ABS as well as the addition of the PP-g-SAN was effectively affected to increase of the mechanical properties the PP by the rubber toughening effect of the PP-ABS blends. The microscopic observations of the PP-ABS blends for all the compositions with and without compatibilizer will be shown in Figure 4. Also, the particle size of the ABS of the PP-ABS (80/20) blend with the PP-g-SAN content will be shown in Table II.

**Table II. Impact Strength and Diameter of the Droplet of the PP/ABS (80/20) Blends with PP-g-SAN Copolymer Content**

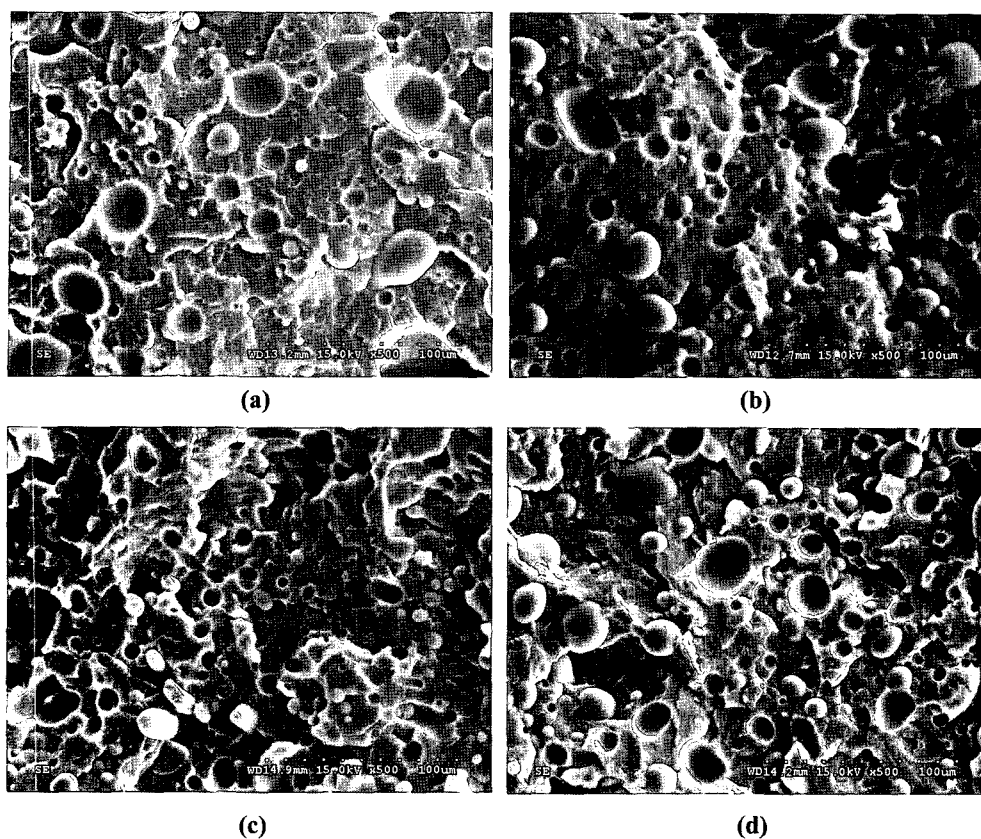
PP-g-SAN (phr)	Impact Strength (J/m)	Diameter ( $\mu\text{m}$ )
0	90.0	7.8
1	109.9	6.5
3	119.1	5.1
5	101.9	8.7

Table II shows the impact strength of the PP/ABS (80/20) blends with the PP-g-SAN copolymer content. From Table II, the impact strength of the PP/ABS (80/20) blends is increased from 90.0 to 119.1 J/m when the PP-g-SAN copolymer is added up to 3 phr. When the PP-g-SAN copolymer is added in the amount of 5 phr, the impact strength is decreased to 101.9 J/m. This results of the impact strength will be compared with the results of the morphology and complex viscosity of the PP/ABS/PP-g-SAN (80/20/3 phr) blend in Figures 5-7.

To see the compatibilization effects of the PP/ABS blend, measurements of the SEM and rheological properties of the PP/ABS blends were performed. Figures 4 and 5 show the SEM images of the cryogenically fractured surfaces of the PP/ABS (90/10, 70/30, 50/50, 30/70, 10/90) blends with and without PP-g-SAN compatibilizer, respectively. From Figures 4 and 5, it is observed that the droplet size of the PP/ABS blends is decreased when the PP-g-SAN (3 phr) is



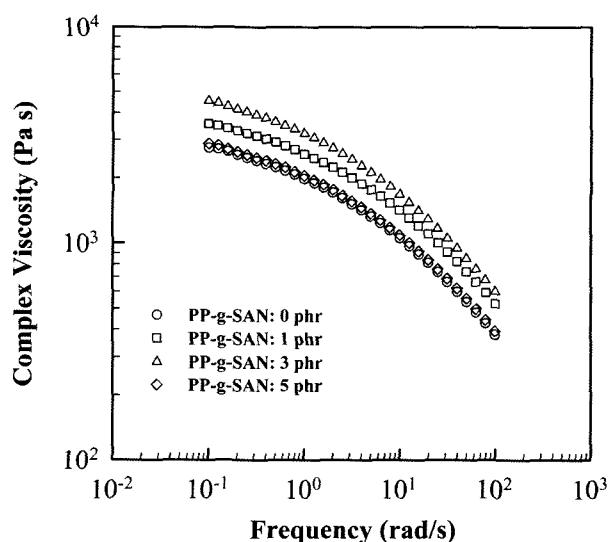
**Figure 5.** Scanning electron micrographs of the cryogenically fractured surfaces of the PP/ABS blends with PP-g-SAN copolymer (3 phr): (a) 90/10; (b) 70/30; (c) 50/50; (d) 30/70; (e) 10/90.



**Figure 6.** Scanning electron micrographs of the cryogenically fractured surfaces of the PP/ABS (80/20) with PP-g-SAN copolymer (0, 1, 3, and 5 phr) blends: (a) 0 phr; (b) 1 phr; (c) 3 phr; (d) 5 phr.

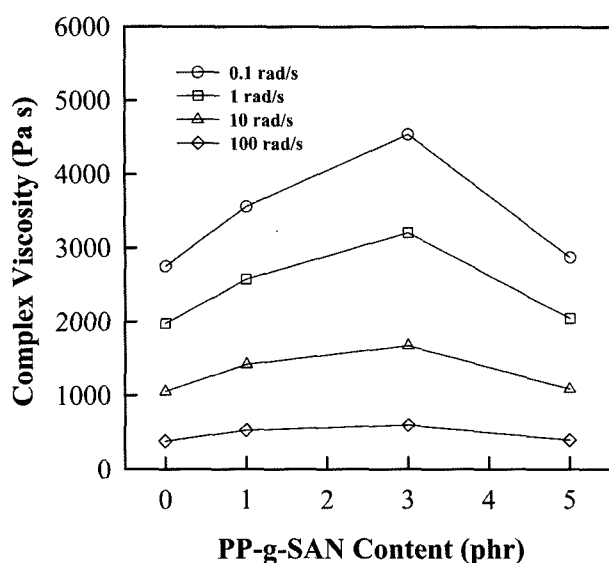
added to the PP/ABS blends. Figures 6(a)-6(d) shows the SEM images of the cryogenically fractured surfaces of the PP/ABS (80/20) blends with the PP-g-SAN copolymer in the amount of 0, 1, 3, and 5 phr, respectively. The droplet size of the PP/ABS (80/20) blend with the PP-g-SAN is shown in Table II. From Table II, when the PP-g-SAN copolymer is added up to 3 phr, the droplet size is decreased from 7.8 to 5.1  $\mu\text{m}$ . From Figure 6 and Table II, the droplet size of the ABS shows minimum (5.1  $\mu\text{m}$ ) when the PP-g-SAN is added in the amount of 3 phr. When the PP-g-SAN is added in the amount of 5 phr, the droplet size is increased to 8.7  $\mu\text{m}$ .

Figure 7 shows the complex viscosity of the PP/ABS (80/20) blends with the PP-g-SAN copolymer. For the PP/ABS (80/20) blends, the complex viscosity shows the highest value when the PP-g-SAN is added in the amount of 3 phr. The increase of the complex viscosity in the PP/ABS/PP-g-SAN (80/20/3 phr) blend may be due to the compatibilizing effect of the PP-g-SAN. The increase of the complex viscosity is consistent with the results of the mechanical properties and morphology, which is that the impact strength is increased and the droplet size is decreased when the PP-g-SAN is added in the amount of 3 phr. When the concentration of the PP-g-SAN is 5 phr, the decrease of the viscosity



**Figure 7.** Complex viscosity of the PP/ABS (80/20) blends with the PP-g-SAN copolymer: (○) 0 phr; (□) 1 phr; (△) 3 phr; (◇) 5 phr.

is maybe due to be the solubilizing effect of the PP-g-SAN or the formation of the separate phase of the PP-g-SAN



**Figure 8.** Complex viscosity of the PP/ABS (80/20) blends with the PP-g-SAN copolymer at different frequencies: (○) 0.1 rad/s; (□) 1 rad/s; (△) 10 rad/s; (◇) 100 rad/s.

copolymer because of the high amount of the PP-g-SAN. The droplet size of the PP/ABS blends was decreased when the PP-g-SAN was added 3 phr. The decrease of the domain size suggests the increase of the compatibility of the PP/ABS blends since the decrease of the domain size is related with the decrease of the interfacial tension of the two polymers. Therefore, the increase of the viscosity is sometimes observed when the compatibility is increased at a certain blend composition.

Figure 8 shows the complex viscosity of the PP/ABS (80/20) blends with the PP-g-SAN copolymer at different frequencies. From Figure 8, the increase of the complex viscosity is more significant at low frequency (0.1 rad/s). This is because that the rheological properties of the complex viscosity at long time relaxation region (low frequency) reflects the interfacial properties of the polymer blends.<sup>17</sup> From the above results of the mechanical properties, morphology, and complex viscosity of the PP/ABS blends, it is suggested that the compatibility is increased more in the PP-rich composition (PP:ABS = 80/20 wt%) of the PP/ABS blend when the PP-g-SAN copolymer is added in the amount of 3 phr.

## Conclusions

In this study, the effects of the PP-g-SAN copolymer on the PP/ABS blends were investigated. In the study of the tensile strength of the PP/ABS blends with the PP-g-SAN copolymer, values of the tensile strength of the PP/ABS/PP-g-SAN (3 phr) blends are increased compared that of the PP/ABS blends without compatibilizer in all the composition ranges. From the results of the flexural and impact

strength of the PP/ABS blends with PP-g-SAN copolymer, the flexural and impact strength increased significantly in the PP-rich compositions when the PP-g-SAN copolymer was added in the amount of 3 phr. From the results of the mechanical properties of the PP/ABS/PP-g-SAN blends, it is concluded that the increase of the mechanical properties of the PP/ABS blend is may be due to toughening effect of the ABS by adding the PP-g-SAN copolymer especially in the PP-rich compositions.

In the study of the morphology of the PP/ABS (80/20) blends with the PP-g-SAN copolymer, droplet size of the ABS showed minimum (5.1  $\mu\text{m}$ ) when the PP-g-SAN was added in the amount of 3 phr. From the results of the complex viscosity and impact strength of the PP/ABS (80/20) blends with the PP-g-SAN copolymer, the complex viscosity and impact strength were increased when the PP-g-SAN copolymer is added in the amount of 3 phr. From the above results of the mechanical properties, morphology, and complex viscosity of the PP/ABS blends, it can be concluded that the compatibility is increased more in the PP-rich composition (PP:ABS = 80/20 wt%) of the PP/ABS blend when the PP-g-SAN copolymer is added in the amount of 3 phr.

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## References

- (1) D. R. Paul and C. B. Bucknall, *Polymer Blends*, John Wiley & Sons, New York, 1999, vol. 1&2.
- (2) W. Jiang, S. C. Tjong, and R. K. Y. Li, *Polymer*, **41**, 3479 (2000).
- (3) L. Huang, Q. Pei, Q. Yuan, H. Li, F. Cheng, J. Ma, S. Jiang, L. An, and W. Jiang, *Polymer*, **43**, 3125 (2003).
- (4) Y. Chen and H. Li, *Polym. Eng. Sci.*, **44**, 1509 (2004).
- (5) G. S. Wildes, T. Harada, H. Keskkula, D. R. Paul, V. Janarthanan, and A. R. Padwa, *Polymer*, **40**, 3069 (1999).
- (6) G. Wildes, H. Keskkula, and D. R. Paul, *Polymer*, **40**, 7089 (1999).
- (7) J. P. F. Inberg and R. J. Gaymans, *Polymer*, **43**, 2425 (2002).
- (8) J. P. F. Inberg, A. Takens, and R. J. Gaymans, *Polymer*, **43**, 2795 (2002).
- (9) S. Balakrishnan, N. R. Neelakantan, D. N. Saheb, and J. P. Jog, *Polymer*, **39**, 5765 (1998).
- (10) F. Elmaghor, L. Zhang, R. Fan, and H. Li, *Polymer*, **45**, 6719 (2004).
- (11) J. I. Sohn, S. T. Lim, S. H. Park, H. J. Choi, and M. S. Jhon, *J. Mater. Sci.*, **38**, 1485 (2003).
- (12) J. H. Park, J. C. Hyun, W. N. Kim, S. R. Kim, and S. C. Ryu, *Macromol. Res.*, **10**, 135 (2002).
- (13) J. Y. Lee and J. Y. Han, *Macromol. Res.*, **12**, 94 (2004).
- (14) J. K. Lee, J. E. Im, and K. H. Lee, *Macromol. Res.*, **12**, 172 (2004).

- (15) S. Park, C. Yim, B. H. Lee, and S. Choe, *Macromol. Res.*, **13**, 243 (2005).
- (16) U. Sundararaj and C. W. Macosko, *Macromolecules*, **28**, 2647 (1995).
- (17) Y. T. Sung, M. S. Han, J. C. Hyun, W. N. Kim, and H. S. Lee, *Polymer*, **44**, 1681 (2003).
- (18) C. Markin and H. L. Williams, *J. Appl. Polym. Sci.*, **25**, 2451 (1980).
- (19) A. K. Gupta, A. K. Jain, and S. N. Maiti, *J. Appl. Polym. Sci.*, **38**, 1699 (1989).
- (20) A. K. Gupta, A. K. Jain, B. K. Ratnam, and S. N. Maiti, *J. Appl. Polym. Sci.*, **39**, 515 (1990).
- (21) A. C. Patel, R. B. Brahmhatt, B. D. Sarawade, and S. Devi, *J. Appl. Polym. Sci.*, **81**, 1731 (2001).
- (22) A. C. Patel, R. B. Brahmhatt, and S. Devi, *J. Appl. Polym. Sci.*, **88**, 72 (2003).
- (23) K. J. Hwang, J. W. Park, I. Kim, C.-S. Ha, and G.-H. Kim, *Macromol. Res.*, **14**, 179 (2006).
- (24) T. Das, A. K. Banthia, B. Adhikari, H. Jeong, C.-S. Ha, and S. Alam, *Macromol. Res.*, **14**, 261 (2006).
- (25) H. S. Park, J. H. Lee, J. D. Nam, S. J. Seo, Y. K. Lee, Y. S. Oh, and H.-C. Jung, *Macromol. Res.*, **14**, 430 (2006).
- (26) C. K. Kum, Y. T. Sung, M. S. Han, W. N. Kim, H. S. Lee, S. J. Lee, and J. Joo, *Macromol. Res.*, **14**, 456 (2006).