# Mechanical, Thermal, and Microstructural Properties of Polypropylene/Polyamide-6/Styrene–Ethylene–Butadiene–Styrene Polymer Alloys

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Received 25 July 2002; accepted 14 January 2003

**ABSTRACT:** Interfacial agents as compatibilizers have recently been introduced into polymer blends to improve the microstructure and mechanical properties of thermoplastics. In this way, it is possible to prepare a mixture of polymeric materials that can have superior mechanical properties over a wide temperature range. In this study, an incompatible blend of polypropylene (PP) and polyamide-6 ($PA_6$) were made compatible by the addition of 10% styrene–ethylene–butadiene–styrene copolymer (SEBS). The mixing operation was conducted by using a twin-screw extruder. The morphology and the compatibility of the mixtures were examined by SEM and DSC techniques. Furthermore, the elastic modulus, tensile and yield strengths, percentage elongation, hardness, melt flow index, Izod impact resistance, heat deflection temperature (HDT), and Vicat softening point values of polymer alloys of various ratios were determined. It was found that the addition of SEBS to the structures decreased the tensile strength, yield strength, elastic modulus, and hardness, whereas it increased the Izod impact strength and percentage elongation values. © 2003 Wiley Periodicals, Inc. J Appl Polym Sci 89: 3485–3491, 2003

**Key words:** polymer alloys; compatibilization; mixture; extrusion; polypropylene (PP)

## INTRODUCTION

Choosing the right polymer blend and compatibilizer and controlling the mixing process are important for the performance of the resultant product.[1]

The increasing trend to develop new polymeric materials with enhanced properties for specific applications by blending can be applied to polyamide (PA)/polypropylene (PP) blends to retain the most desirable properties of both polymers, while avoiding their major drawbacks. For example, polyamide-6 ($PA_6$) polymer is normally mixed with polyolefins to increase the mechanical properties such as Izod impact strength. These two polymers are not compatible and they require the addition of compatibilizer during production.[2]

PP and $PA_6$ are mixed together using different compatibilizers to produce compatible polymer products by various workers. It was shown that Kraton FG-1901 X, used as a compatibilizer in polyamide-6/polypropylene blends, is very effective in compatibilizing the polymers and providing good dispersion in the polymer alloys to improve the adhesion and mechanical properties of the polymer blends. It has been stated that excellent mechanical properties are achieved by compatibilization with Kraton FG-1901 X, at a $PA_6$/PP blend ratio of 2/1. For this composition, the addition of 10% mass Kraton FG-1901 X leads to optimal mechanical properties.[3] Tang et al.[4] mixed PP/$PA_6$ using maleic anhydride (MA) to create functional groups in the PP and investigated the resultant blend in terms of crystallization. Other investigators also used styrene–ethylene–butadiene–styrene (SEBS) copolymer as a compatibilizer in blends, for example, Heino et al.[5] [poly(ethylene terephthalate) (PET)/PP], Radonjic[6] [PP/polystyrene (PS)], Tjong and Xu[7] [PS/high-density polyethylene (HDPE)], and Heino et al.[8] ($PA_6$/PP).

## EXPERIMENTAL

Five different polymer alloys were prepared, with different ratios of $PA_6$ to PP, in a PP/$PA_6$/SEBS system as given in Table I.

Table II below shows the physical and mechanical properties of plastic materials used in the blends.

Samples with various proportions of polymer blends were produced between 85 and 230°C at 20 bar pressure, and a production rate of 300 rpm, with a twin-screw extruder (Maris-TM40MW; Maris America Corp., Baltimore, MD). Table III outlines the extrusion and injection conditions.

Tensile test samples were prepared according to the ISO 294 standard by using an Arburg (Arburg GmbH

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Journal of Applied Polymer Science, Vol. 89, 3485–3491 (2003)

**TABLE I**
**Composition of $PP/PA_6/SEBS$ Polymer Alloys**

| Groups | PP (%) | PA-6 (%) | SEBS (%) |
|---|---|---|---|
| 1 | 80 | 20 | — |
| 2 | 60 | 40 | — |
| 3 | 60 | 30 | 10 |
| 4 | 70 | 20 | 10 |
| 5 | 80 | 10 | 10 |

**TABLE III**
**Extrusion and Injection Conditions to Prepare Polymer Blends**

| Property | Extrusion | Injection |
|---|---|---|
| Temperature (°C) | 180–220 | 210–230 |
| Screw speed (rpm) | 300 | — |
| Pressure (bar) | 20 | 40 |
| Dwell time in mold (s) | — | 10 |
| Cooling water (°C) | 65 | 40 |

Co., Lossburg, Germany) injection-molding machine, as given in Table III. Tensile and impact tests were conducted according to ISO 527.2 at a crosshead speed of 50 mm/min and ISO 180 standards, respectively, by using a Zwich (Zwich GmbH, Ulm, Germany) brand machine. Melt flow index (MFI) values were obtained according to ASTM D 1238 using Zwich test equipment. DSC studies were undertaken by using a Seteram DSC 131 (Scientex Pty. Ltd., Victoria, Australia). Heat deflection temperature (HDT) and Vicat softening point of the samples were determined with Ceast 6505 equipment (Ceast SPA, Pianezza, Italy). To investigate the microstructure, samples were coated with carbon to a thickness of 40 Å on Polaron SC 502 (Gala Instrumente GmbH, Bad Schwalbach, Germany) and studied using a JSM-5410 LV JOEL SEM (JOEL, Peabody, MA) operated at 15 kV, after coating the samples with carbon for conductivity.

## RESULTS AND DISCUSSION

With an increased amount of $PA_6$ in PP, the yield and tensile strengths, hardness, and Izod impact strength of the resultant material were increased, whereas the elastic modulus and percentage elongation were decreased. However, with a decreased amount of $PA_6$ in $PP/PA_6/SEBS$ polymer alloys, for a fixed amount of SEBS, the yield and tensile strengths, elastic modulus, and hardness value were decreased, whereas the Izod impact strength and percentage elongation were increased. The mechanical properties of $PP/PA_6/SEBS$ polymer alloys are given in Table IV and Figure 1.

The thermal properties of the polymer alloys are given in Table V. As seen from the table, the MFI values of $PP/PA_6$ (80/20) and $PP/PA_6$ (60/40) polymer blends were 7.49 and 25.59 g/10 min, respectively. However, the addition of SEBS to the $PP/PA_6$ polymer blend resulted in lower MFI values. Upon heating, the melting temperature of PP in the $PP/PA_6$ polymer blend was observed at 167.1°C.

Upon further heating, the melting temperature of $PA_6$ was found to be 222.7°C. The addition of SEBS did not appear to alter the heating curves to any significant degree. The temperature data obtained from DSC measurements are also shown in Table V and DSC curves are presented in Figure 2.

HDT and Vicat softening point measurements showed that the addition of SEBS to the $PP/PA_6$ blend reduced the HDT and Vicat softening point values, as shown in Table V.

The fracture surfaces of the polymer alloys examined by SEM revealed that, in the absence of SEBS, the phases present in the blend did not appear to adhere well (groups 1 and 2). However, the addition of 10% SEBS considerably enhanced the adhesion and distri-

**TABLE II**
**Physical and Mechanical Properties of the Polymers**

| Property[a] | PP resin[b] | $PA_6$ resin[c] | SEBS resin[d] |
|---|---|---|---|
| Commercial name | Petoplen | Ultramid | Kraton G |
| Type | MH 418 | B 3 S | FG-1901 X |
| Density (g/cm$^3$) | — | 1.130 | — |
| Styrene rate (%) | — | — | 30 |
| MFI (g/10 min) | 4.0–6.0 (230°C, 2.16 kg) | — | 14–28 (230°C, 5 kg) |
| Hardness (Shore A) | — | — | 75 |
| Tensile strength (MPa) | 39 | 100 | 34 |
| Yield strength (MPa) | 31 | 90 | — |
| Maleic anhydride rate (%) | — | — | 2 |
| $T_m$ (°C) | — | 220 | — |
| $T_g$ (°C) | — | 60 | — |

[a] $T_m$, melting temperature; $T_g$, glass-transition temperature.
[b] Ref. 9.
[c] Ref. 10.
[d] Ref. 11.

**TABLE IV**
**Changes in the Mechanical Properties of PP/$PA_6$/SEBS Alloys by Addition of SEBS**

| Mechanical property | Group 1 | Group 2 | Group 3 | Group 4 | Group 5 |
|---|---|---|---|---|---|
| Elasticity modulus (MPa) | 457.30 | 437.57 | 428.06 | 388.22 | 343.69 |
| Yield strength (MPa) | 39.95 | 42.86 | 31.15 | 31.91 | 32.10 |
| Tensile strength (MPa) | 41.66 | 44.52 | 32.10 | 32.60 | 33.16 |
| Elongation (%) | 7.82 | 5.98 | 77.67 | 65.86 | 106.28 |
| Hardness (Shore D) | 64.77 | 66.66 | 61.20 | 60.00 | 59.25 |
| Izod impact strength (kJ/$m^2$, notched) | 3.90 | 5.70 | 14.10 | 14.76 | 15.23 |

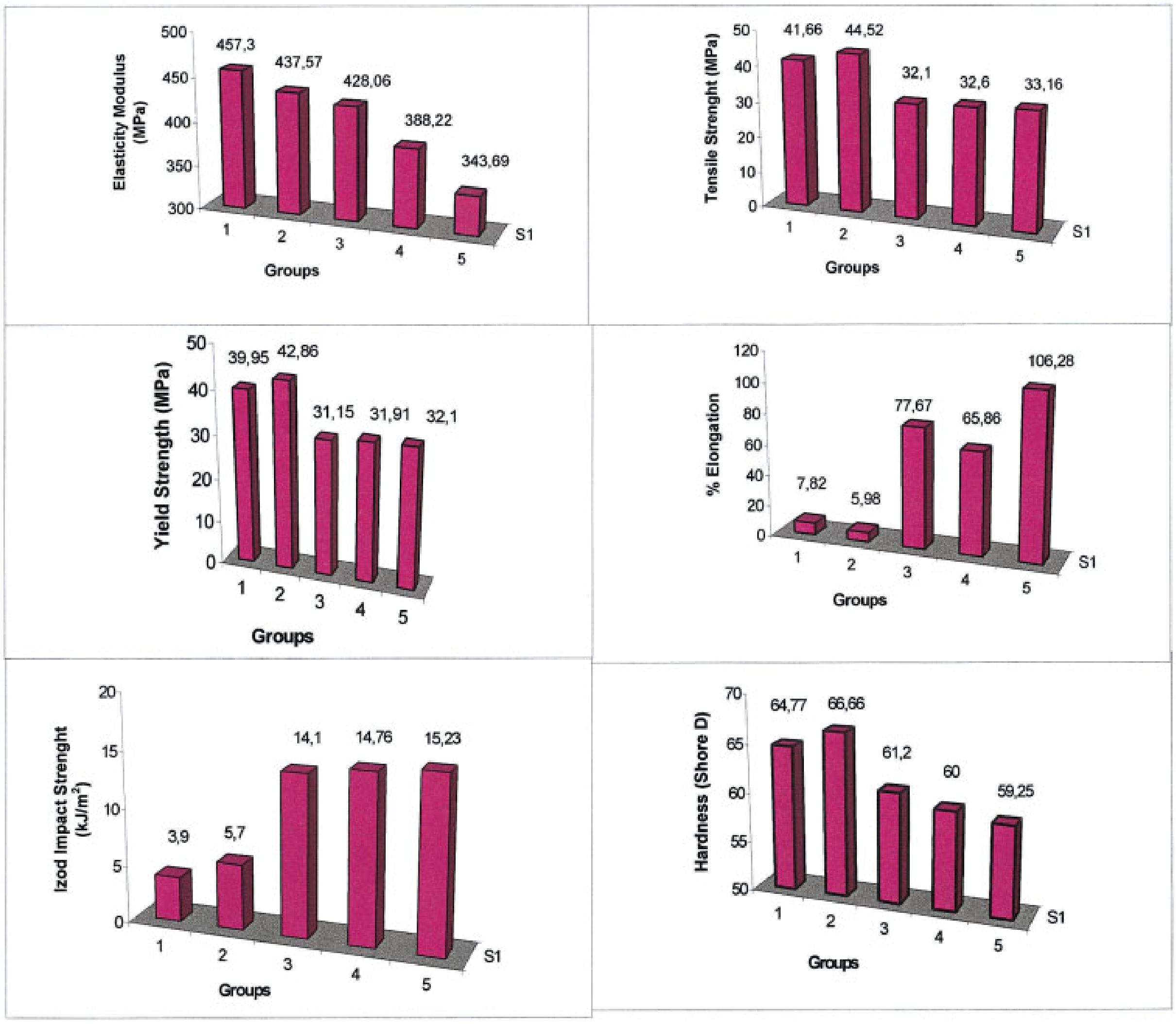
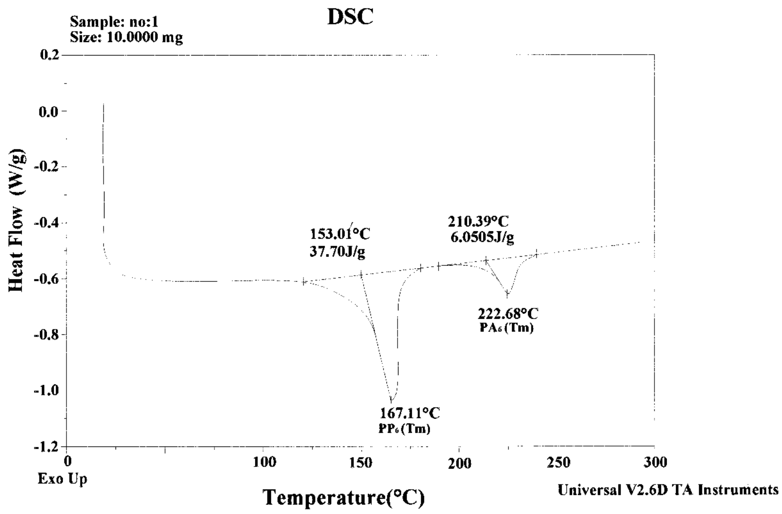


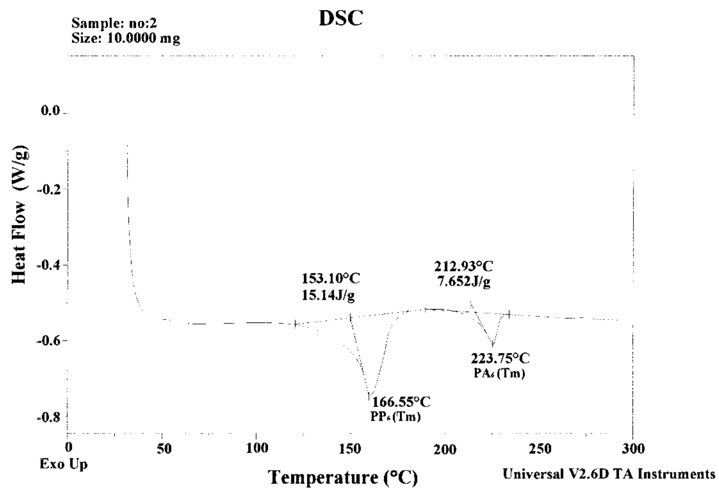

**Figure 1** Changes in mechanical properties of PP/$PA_6$/SEBS alloys by addition of SEBS.

**TABLE V**
**Thermal Properties of PP/$PA_6$/SEBS Polymer Alloys**

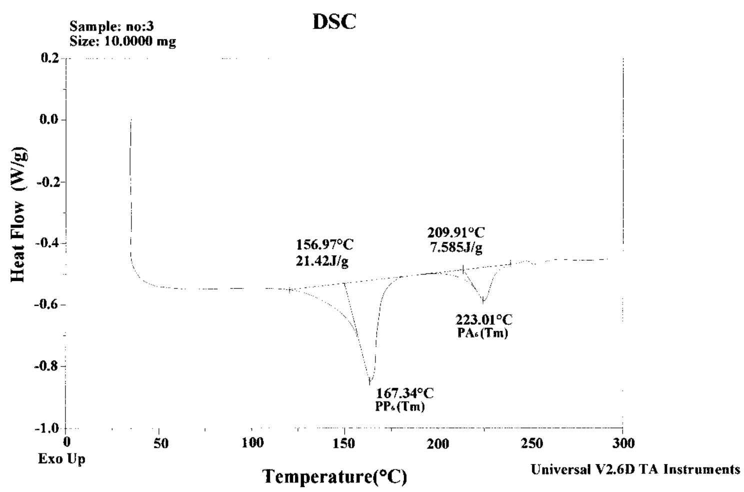
| Property | Group 1 | Group 2 | Group 3 | Group 4 | Group 5 |
|---|---|---|---|---|---|
| Melt flow index (g/10 min 230°C, 2.16 kg) | 7.49 | 25.59 | 1.39 | 1.91 | 2.83 |
| Heat deflection temperature (°C, 180 MPa) | 58.30 | 64.10 | 57.30 | 55.80 | 53.56 |
| Vicat softening point (°C, 1 kg) | 157.16 | 170.3 | 150.1 | 149.4 | 149.1 |
| DSC (°C) | | | | | |
| PP ($T_m$) | 167.1 | 166.6 | 167.3 | 166.3 | 168.0 |
| $PA_6$ ($T_m$) | 222.7 | 223.8 | 223.0 | 222.0 | 222.0 |




A) Group 1

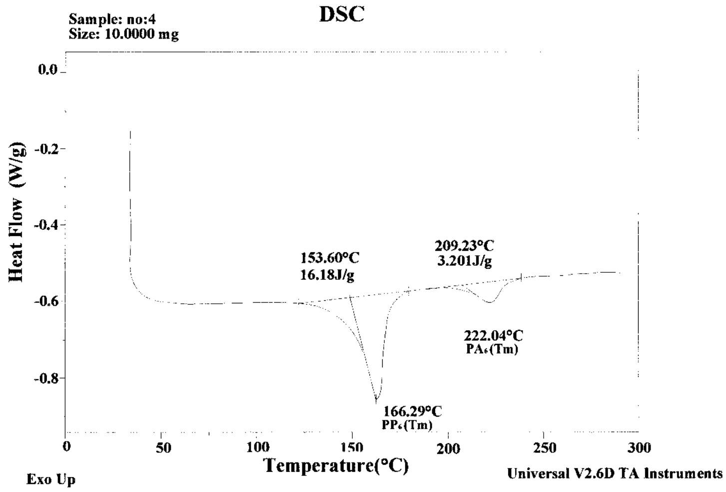



B) Group 2

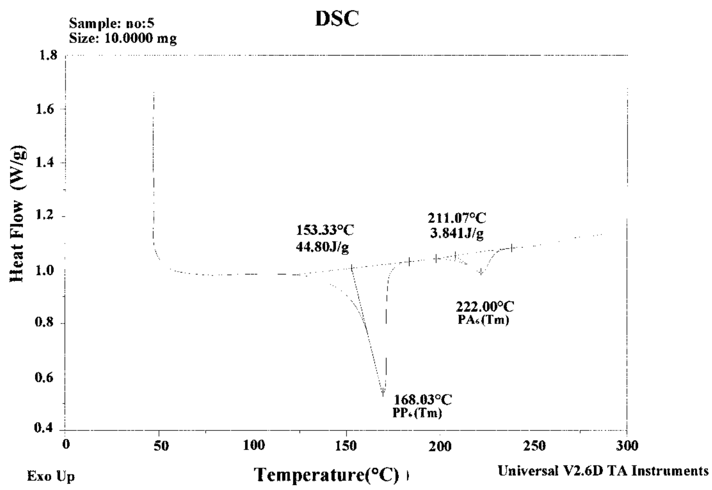



C) Group 3

**Figure 2** DSC curves for PP/$PA_6$/SEBS polymer alloys. (A) Group 1; (B) Group 2; (C) Group 3; (D) Group 4; (E) Group 5.




D) Group 4




E) Group 5

**Figure 2** (*Continued from the previous page*)

bution of the present phases (groups 3–5), as shown in Figure 3.

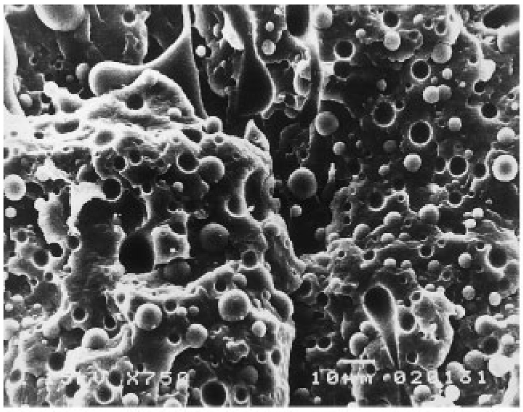
## CONCLUSIONS

By increasing the amount of PA$_6$ in PP, the yield and tensile strengths, hardness, and Izod impact strength of the resultant material were increased, whereas the elastic modulus and percentage elongation were decreased. However, with a decreased amount of PA$_6$ in PP/PA$_6$/SEBS polymer alloys for the fixed amount of SEBS, the yield and tensile strengths, elastic modulus, and hardness value were decreased, whereas the Izod impact strength and percentage elongation were increased. The MFI values of PP/PA$_6$ (80/20) and PP/PA$_6$ (60/40) polymer blends were 7.49 and 25.59 g/10 min, respectively. However, the addition of SEBS to the PP/PA$_6$ polymer blend resulted in lower MFI values.

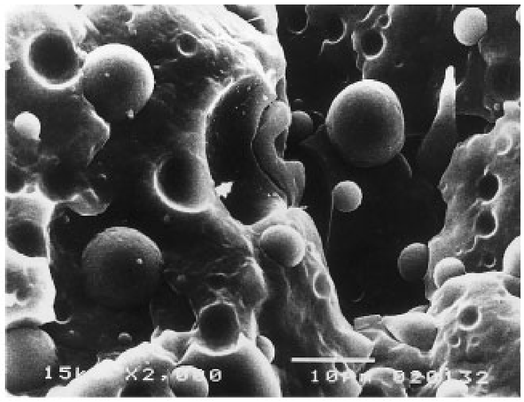
Upon heating, the melting temperature of PP in PP/PA$_6$ polymer blend was observed at 167.1°C. Upon further heating, the melting temperature of PA$_6$ was found to be 222.7°C. The addition of SEBS did not appear to alter the heating curves to any significant degree.

HDT and Vicat softening point measurements showed that addition of SEBS to the PP/PA$_6$ blend decreased their values.

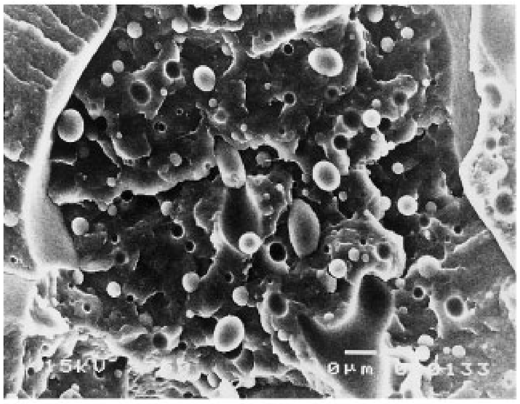
The fracture surfaces of the polymer alloys examined by SEM revealed that, in the absence of SEBS, the present phases in the blend did not appear to adhere well (groups 1 and 2). However, addition of 10% SEBS considerably enhanced the adhesion and distribution of the present phases (groups 3–5).



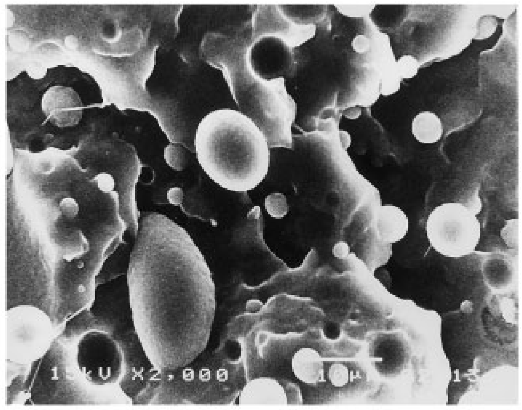

(a-1)




(a-2)



(b-1)

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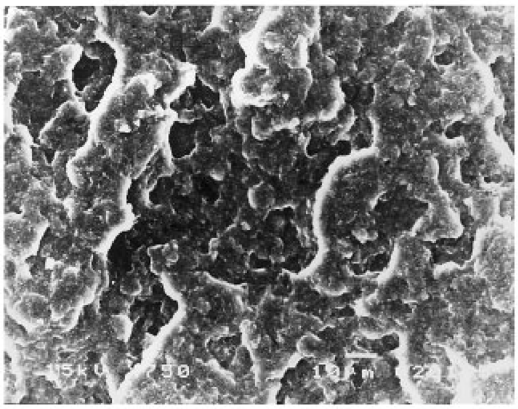
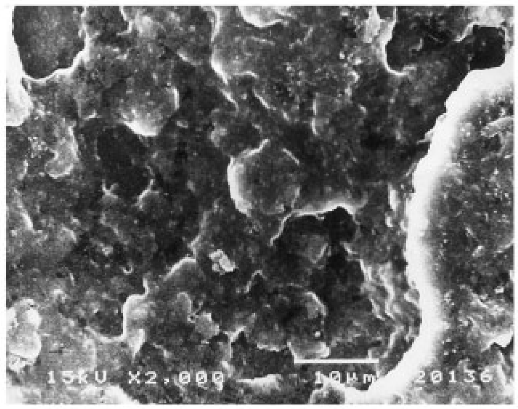


(c-1)

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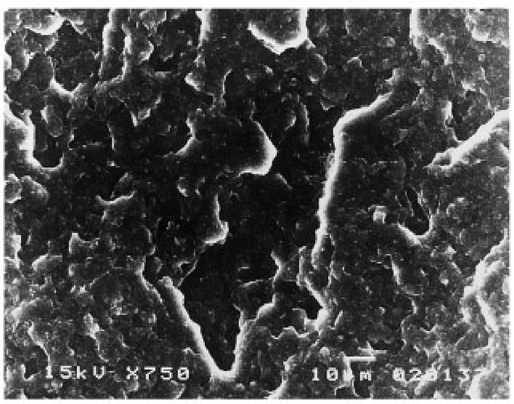
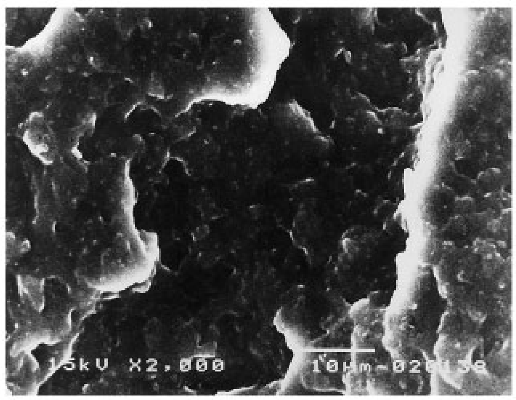
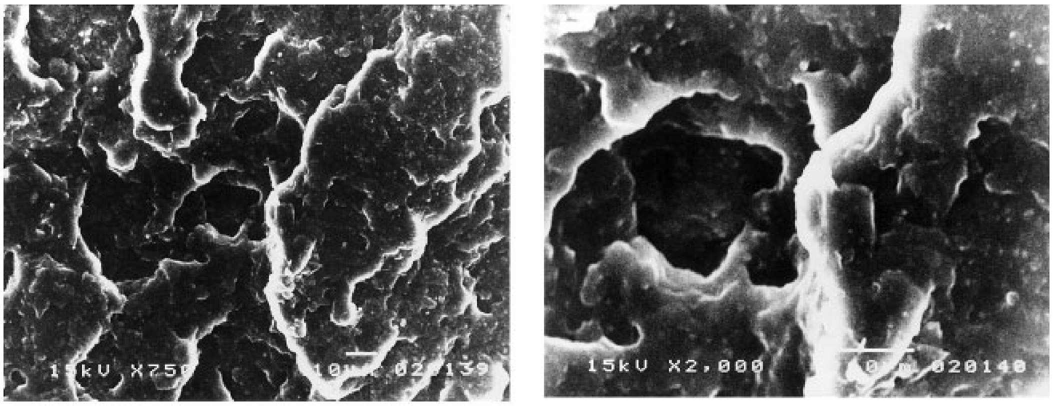



(d-1)




(d-2)

**Figure 3** (*Continued on next page*)




(e-1) (e-2)

**Figure 3** SEM micrographs revealing the appearance of fracture surfaces of the PP/$PA_6$/SEBS polymer alloys (at magnifications of ×750 and ×2000): (A) Group 1; (B) Group 2; (C) Group 3; (D) Group 4; (E) Group 5.

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