

Effect of Styrene–Isopren–Styrene Addition on the Recycled Polycarbonate/Acrylonitrile–Butadiene–Styrene Polymer Blends

Münir Taşdemir,¹ Şener Karatop²

¹Technical Education Faculty, Marmara University, Goztepe 34722, Istanbul, Turkey

²Institute for Graduate Studies in Pure and Applied Science, Marmara University, Goztepe 34722, Istanbul, Turkey

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ABSTRACT: Interfacial agents as compatibilizers have recently been introduced into polymer blends to improve 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 Polycarbonate (PC) and Acrylonitrile Butadiene Styrene (ABS) Copolymer were made compatible by addition of 5, 10, and 20% Styrene–Isopren–Styrene Copolymer (SIS). The mixing operation was conducted 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), Vicat softening point values of polymer alloys of various ratios were determined. It was found that addition of SIS to the structures decreased the tensile strength, yield strength, elastic modulus, and hardness, whereas it increased Izod impact strength and percentage elongation values. © 2006 Wiley Periodicals, Inc. *J Appl Polym Sci* 101: 559–566, 2006

Key words: polymer alloys; compatibilization; mixture; polycarbonate

INTRODUCTION

Polymer alloys and blends are studied extensively in recent years. In a various polymers, it is desired to establish a good balance between hardness and toughness. Hardness of most of the synthetic polymers is characterized with brittleness and crack growth on a sudden loading. Therefore, wide research is being conducted around the world to toughen brittle materials.^{1,2}

Choosing the right polymer blend and compatibilizer and controlling the mixing process are important for the performance of the resultant product. To obtain desired results to toughen the polymers with elastomers, compatibilizer needs to have enough solubility parameter in polymer matrix. However, selecting such a compatibilizer for any rigid polymer is limited.³

PC and ABS are mixed together using different compatibilizers to produce compatible polymer products by various workers. Jin et al. used poly(methyl methacrylate) as a compatibilizer for ABS/PC blends.⁴ Taşdemir used SBS for the ABS/PC blend.⁵ Zhang et al. used ABS-g-maleic anhydride for the ABS/PC

blend.⁶ Pastorini et al. investigated the mechanical and thermal behaviors of the ABS/PC blend with the addition of mica.⁷ Chaudhty et al. investigated the effects of the process conditions on the morphological structures of the PC/ABS polymer.⁸ Another interesting study was done by Tjong et al.; they studied the effects of potassium titanate whiskers on the mechanical and thermal properties of the ABS/PC polymer blend.⁹

As seen from the earlier studies, mechanical and thermal properties and compatibility of PC and ABS polymer could be changed. In this study, incompatible PC and ABS polymers made compatible by the addition of SIS copolymer. The effect of SIS addition on the mechanical and thermal properties of the alloy and the optimum amount of the compatibilizer were determined.

EXPERIMENTAL

Four different polymer alloys were prepared, each with different ratios of PC, ABS, and SIS, in a PC/ABS/SIS system, as shown in Table I.

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

PC used in this study was obtained from GE (USA), with the trade name Lexan and the code number 144 R. MFI value is 19 g/10 min (220°C, 10 kg), vicat softening point is 142°C. ABS is also a GE (USA) product with 750 SW code number. Melting point is 230–260°C. Two types of SIS were used. The first one

Correspondence to: M. Taşdemir (munir@marmara.edu.tr).

TABLE I
Composition of PC/ABS/SIS Polymer Alloys

| Group | PC (%) | ABS (%) | SIS (%) | |
|-------|--------|---------|-----------------|-------------------|
| | | | Type I (D-1107) | Type II (D-KX603) |
| 1 | 70 | 30 | – | – |
| 2 | 65 | 30 | 5 | 5 |
| 3 | 60 | 30 | 10 | 10 |
| 4 | 50 | 30 | 20 | 20 |

is a product of Shell Chemical with the trade name Kraton and D-1107 code number. MFI value is 9 g/10 min (200°C, 5 kg). Its hardness is 37 Shore A and diblock ratio is 17%. The second SIS has the code number D-KX603. Its hardness is 34 Shore A and diblock ratio is 38%. Samples with various proportions of polymer blends were produced between 85–266°C at a pressure of 14–20 bar and a production rate of 305 rpm with a twin screw extruder (Maris-TM40MW; Maris America Corp., Baltimore). Table III outlines the extrusion and injection conditions.

Tensile test samples were prepared according to the ISO 294 standard by using an Arburg brand injection molding machine (Arburg GmbH Co., Lossburg, Germany), as given in Table III. Tensile and impact tests were conducted, respectively, according to ISO 527.2 at a crosshead speed of 50 mm/min and ISO 180 with a Zwick machine (Zwick GmbH, Ulm, Germany). Melt Flow Index (MFI) values were obtained according to ASTM D 1238 with Zwick test equipment. Differential scanning calorimetry (DSC) studies were carried out with a SETERAM DSC 131 (Scientex Pty. Ltd., Victoria, Australia). The heat deflection temperature (HDT) and Vicat softening point of the samples were determined with a CEAST 6505 machine (Ceast SPA, Pian-

TABLE III
The Extrusion and Injection Conditions for Preparing the Polymer Blends

| Property | Extrusion | Injection |
|------------------------|-----------|-----------|
| Temperature (°C) | 85–266 | 210–230 |
| Screw speed (rpm) | 305 | – |
| Pressure (bar) | 14–20 | 1400–1500 |
| Dwell time in mold (s) | – | 15 |
| Cooling water (°C) | 65 | 40 |

ezza, Italy). To investigate the microstructure, the samples were coated with carbon to a thickness of 40 Å on a POLARON SC 502 (Gala Instrumente GmbH, Bad Schwalbach, Germany) and studied with a JSM-5410 LV JOEL scanning electron microscope (Joel, Peabody, MA) operated at 10 kV.

RESULTS AND DISCUSSION

With the increased amount of SIS (type I and type II) in PC/ABS/SIS polymer alloys, yield and tensile strength, hardness, and elasticity modulus of the resultant material decreased, whereas the percentage elongation and Izod impact strength increased. The mechanical properties of the PC/ABS/SIS polymer alloys are given in Tables IV, V and Figure 1.

The thermal properties of the polymer alloys are given in Table VI. As shown in Table VI, the MFI value of the recycled PC/ABS polymer blends is 60.26 g/10 min (300°C, 1.2 kg). With the addition of SIS 1107 and SIS KX 603, increase in MFI values were observed. As seen from the HDT values of type I and type II polymer alloys of recycled PC/ABS/SIS, addition of SIS to the system decreased the HDT values for both type I and II. Similarly, addition of SIS decreased Vicat soft-

TABLE II
Physical and Mechanical Properties of the Polymers

| PROPERTY | PC resin ¹⁰ | ABS resin ¹¹ | SIS resin ¹² | |
|------------------------------------|------------------------|-------------------------|-------------------------|------------------|
| Commercial Name | Lexan | ABS | Kraton | |
| Type | 114R | 750 SW | D-1107 | D-KX603 |
| Density (g/cm ³) | 1.200 | 1.050 | – | – |
| MFI (g/10 min) | 19 (220°C, 10 kg) | – | 9 (200°C, 5 kg) | 16 (200°C, 5 kg) |
| Hardness (Shore A) | – | – | 37 | 34 |
| Tensile strength (MPa) | 63 | 49 | 28 | 17 |
| Tensile modulus (MPa) | 2350 | 2560 | – | – |
| Break strength (MPa) | 90 | 65 | – | – |
| Break modulus (MPa) | – | 2300 | – | – |
| Elongation at break (%) | – | – | 1300 | 1400 |
| Water absorption (24 h) (%) | 0.10 | 0.3 | – | – |
| Vicat softening point (50°C/h-50N) | 142 | 100 | – | – |
| T_m (°C) | – | 230–260 | – | – |
| T_g (°C) | – | 106 | – | – |
| Polystyrene content (%) | – | – | 15 | 15 |
| Diblock content (%) | – | – | 17 | 38 |

T_m , melting temperature; T_g , glass temperature.

TABLE IV
Changes in the Mechanical Properties of the PC/ABS/SIS (Type I) Polymer Alloys

| | PC | ABS | PC/ABS 70-30 | PC/ABS/SIS Type I 65-30-5 | PC/ABS/SIS Type I 60-30-10 | PC/ABS/SIS Type I 50-30-20 |
|---|--------|--------|--------------|---------------------------|----------------------------|----------------------------|
| Elasticity Modulus (MPa) | 597.94 | 497.94 | 673.85 | 591.27 | 517.05 | 374.84 |
| Yield strength (MPa) | 48.96 | 39.90 | 53.65 | 49.51 | 46.66 | 35.38 |
| Tensile strength (MPa) | 49.55 | 41.89 | 55.39 | 51.45 | 48.14 | 36.05 |
| Elongation (%) | 5.25 | 5.36 | 15.26 | 16.95 | 17.07 | 17.70 |
| Hardness (Shore D) | 81.50 | 11.23 | 79.66 | 73.00 | 66.50 | 53.00 |
| Izod impact strength (kJ/m ⁻² , notched) | 4.80 | 77.00 | 34.80 | 44.26 | 48.13 | 60.26 |

TABLE V
Changes in the Mechanical Properties of the PC/ABS/SIS (Type II) Polymer Alloys

| | PC | ABS | PC/ABS 70-30 | PC/ABS/SIS Type II 65-30-5 | PC/ABS/SIS Type II 60-30-10 | PC/ABS/SIS Type II 50-30-20 |
|---|--------|--------|--------------|----------------------------|-----------------------------|-----------------------------|
| Elasticity Modulus (MPa) | 597.94 | 497.94 | 673.85 | 548.39 | 507.97 | 396.89 |
| Yield strength (MPa) | 48.96 | 39.90 | 53.65 | 48.36 | 41.77 | 31.38 |
| Tensile strength (MPa) | 49.55 | 41.89 | 55.39 | 50.22 | 43.20 | 32.45 |
| Elongation (%) | 5.25 | 5.36 | 15.26 | 17.52 | 28.04 | 19.82 |
| Hardness (Shore D) | 81.50 | 11.23 | 79.66 | 72.90 | 63.50 | 49.33 |
| Izod impact strength (kJ/m ⁻² , notched) | 4.80 | 77.00 | 34.80 | 48.20 | 49.33 | 63.50 |

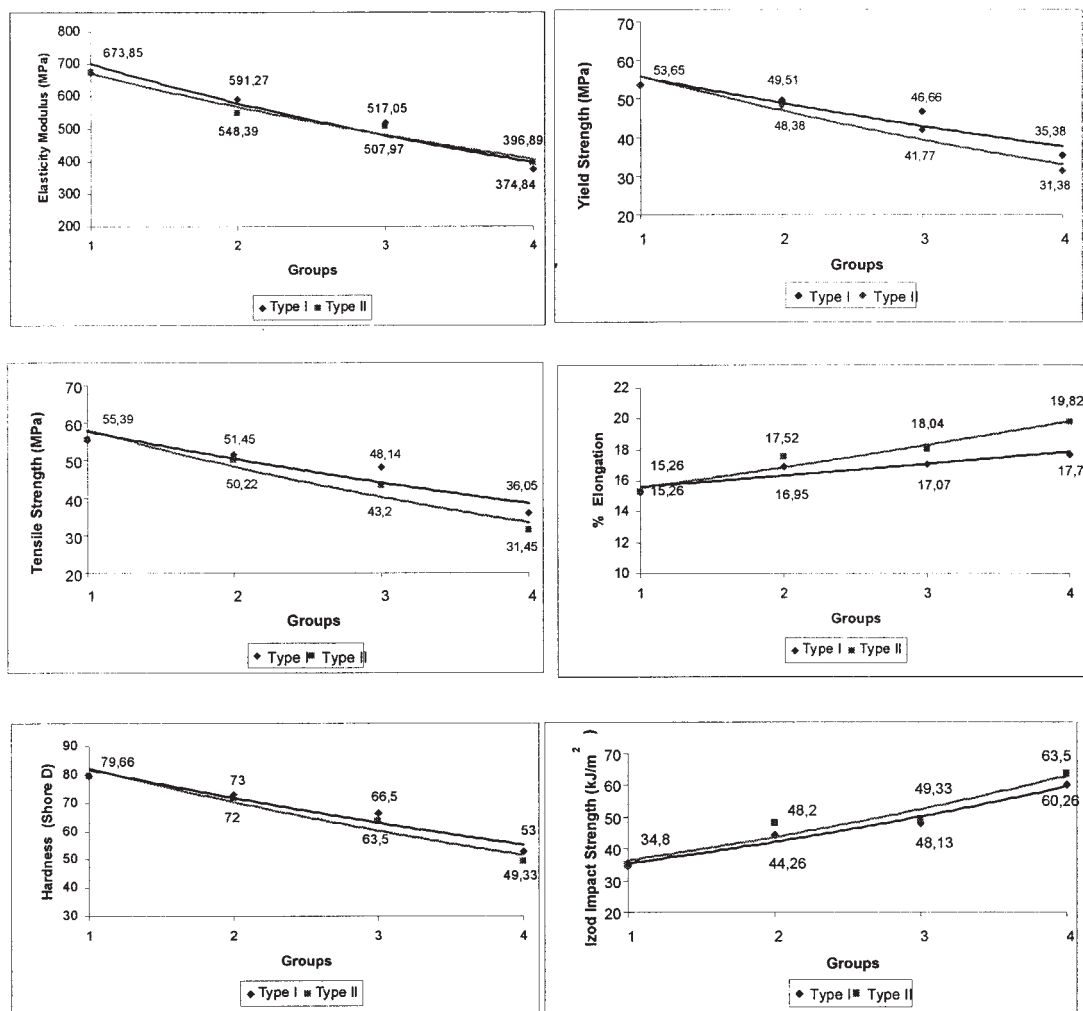
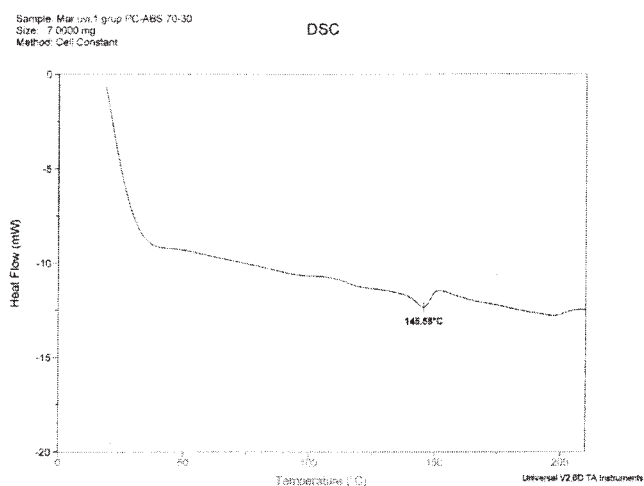


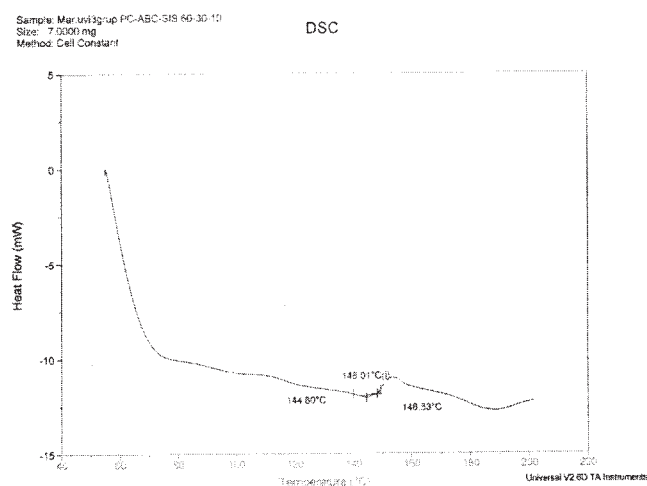
Figure 1 Changes in the mechanical properties of PC/ABS/SIS polymer alloys.

TABLE VI
Thermal Properties of PC/ABS/SIS Polymer Alloys

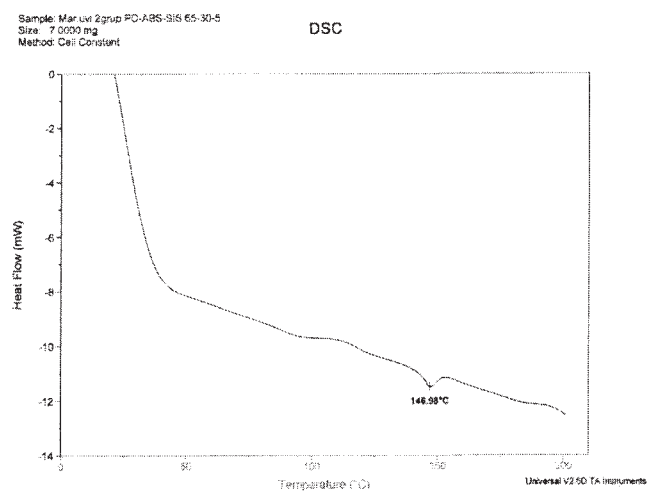
| Thermal properties | Group 1 (70/30) | Group 2 (65/30/5) | Group 3 (60/30/10) | Group 4 (50/30/20) |
|----------------------------------|-----------------|-------------------|--------------------|--------------------|
| Type I (SIS 1107) | | | | |
| MFI (g/10 min) | 60.26 | 68.79 | 75.12 | 80.44 |
| HDT (°C, 1.80 MPa) | 106.20 | 105.30 | 105.08 | 101.30 |
| Vicat softening point (°C, 1 kg) | 114.20 | 114.10 | (03.20) | 102.70 |
| DSC (°C) | | | | |
| PC (T_g) | 145.58 | 146.98 | 148.01 | 145.55 |
| Type II (SIS KX603) | | | | |
| MFI (g/10 min) | 60.26 | 62.68 | 79.29 | 81.20 |
| HDT (°C, 1.80 MPa) | 106.20 | 105.80 | 102.80 | 102.70 |
| Vicat softening point (°C, 1 kg) | 114.20 | 110.50 | 104.20 | 104.20 |
| DSC (°C) | | | | |
| PC (T_g) | 145.58 | 145.00 | 145.40 | 143.07 |



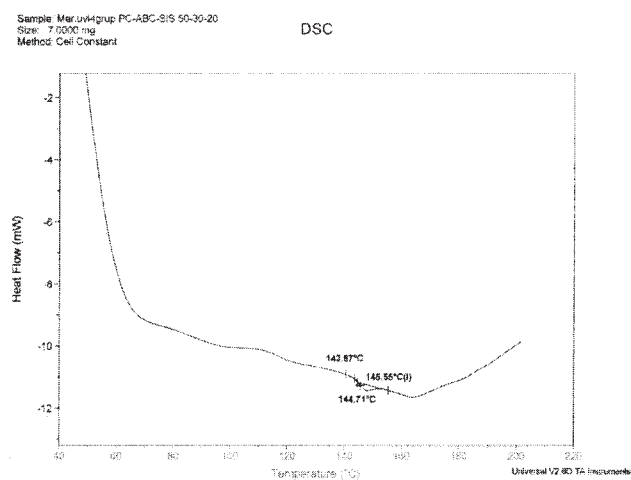
A) Group 1, PC/ABS (70/30)



C) Group 3, PC/ABS/SIS (60/30/10 - Type I)



B) Group 2, PC/ABS/SIS (65/30/5 - Type I)



D) Group 4, PC/ABS/SIS (50/30/20 - Type I)

Figure 2 DSC Curves of the PC/ABS/SIS polymer alloys. (A) Group 1, PC/ABS (70/30); (B) Group 2, PC/ABS/SIS (65/30/5 -Type I); (C) Group 3, PC/ABS/SIS (60/30/10 -Type I); (D) Group 4, PC/ABS/SIS (50/30/20 -Type I); (E) Group 2, PC/ABS/SIS (65/30/5 -Type II); (F) Group 3, PC/ABS/SIS (60/30/10 -Type II); (G) Group 4, PC/ABS/SIS (50/30/20 -Type II).

ening point for both types. However, increases in the percentage of SIS reduced in the decreases for the Vicat softening values. The HDT experiment was started at room temperature with a heating rate of 120°C/h and under a load of 1.8 MPa. DSC curves are presented in Figure 2. On heating, the glass-transition temperature (T_g) of PC in PC/ABS/SIS polymer alloys was observed to be 145.58°C (heating rate = 15°C/min). The addition of SIS did not appear to alter the heating curves to any significant degree.

Microstructure of PC/ABS/SIS type I and II polymer alloys were studied by SEM. The specimens were coated with carbon to 40 Å in thickness under vacuum. Microphotographs were taken at 750×, 2500×, and 5000× magnification and 10 kV potential were used to operate the SEM. By using the microphotographs, structure–property relationship was determined. The fracture surfaces of the PC/ABS/SIS polymer alloys are given in Figures 3–5.

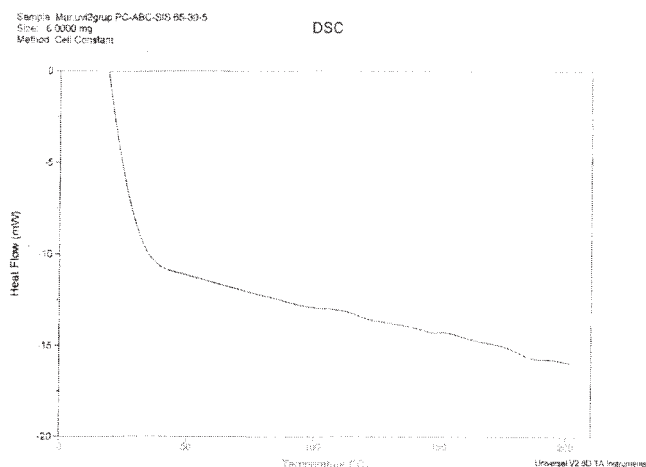
CONCLUSIONS

With increasing amounts of SIS in PC/ABS/SIS (type I and type II), the yield and tensile strengths, hardness, and elasticity modulus of the resultant materials decreased, whereas the percentage elongation and Izod impact strength increased. SIS showed more elastomeric character than the other two materials. Therefore, with the introduction of SIS to the system, the polymer blend was softened, and the Izod impact strength and percentage elongation of the materials increased, whereas the hardness, yield strength, tensile strength, and Young's modulus of the materials decreased. The MFI value of the 70/30 PC/ABS polymer blend was 60.26 g/10 min (300°C, 1.2 kg). When the SIS concentration was increased, the MFI value of the alloy increased. This is because SIS showed more elastomeric character.

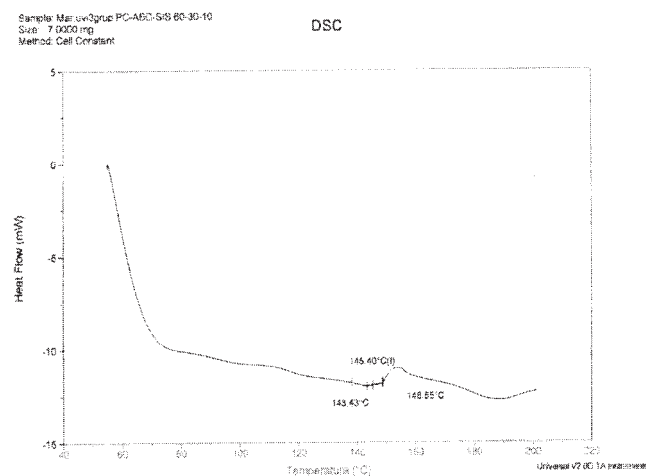
On heating, T_g of PC in the PC/ABS/SIS polymer alloys was observed at 145.58°C (heating rate = 15°C/min). The addition of SIS did not appear to alter the heating curves to any significant degree because SIS showed more elastomeric character than the other two materials.

Measurements of HDT (with the experiment started at room temperature with at a heating rate of 120°C/h and under a load of 1.8 MPa) and the Vicat softening point showed that the addition of SIS to the PC/ABS blend decreased these values.

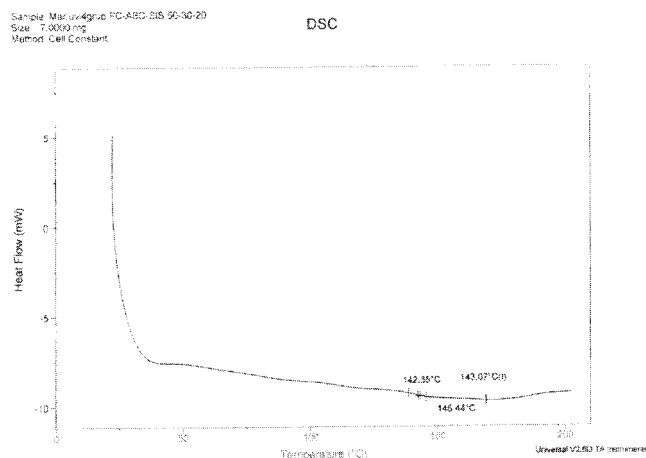
The fracture surfaces of the polymer alloys examined by SEM revealed that in the absence of SIS, the phases present in the blend did not appear to adhere well (Figs. 2E and 2F). However the addition of SIS considerably enhanced the adhesion and distribution of these phases (Figs. 3 and 4). As a result, the group with 5% SIS 1107 provided best values in terms of mechanical, thermal and morphological properties.



E) Group 2, PC/ABS/SIS (65/30/5 - Type II)



F) Group 3, PC/ABS/SIS (60/30/10 - Type II)



G) Group 4, PC/ABS/SIS (50/30/20 - Type II)

Figure 2 (Continued from the previous page)

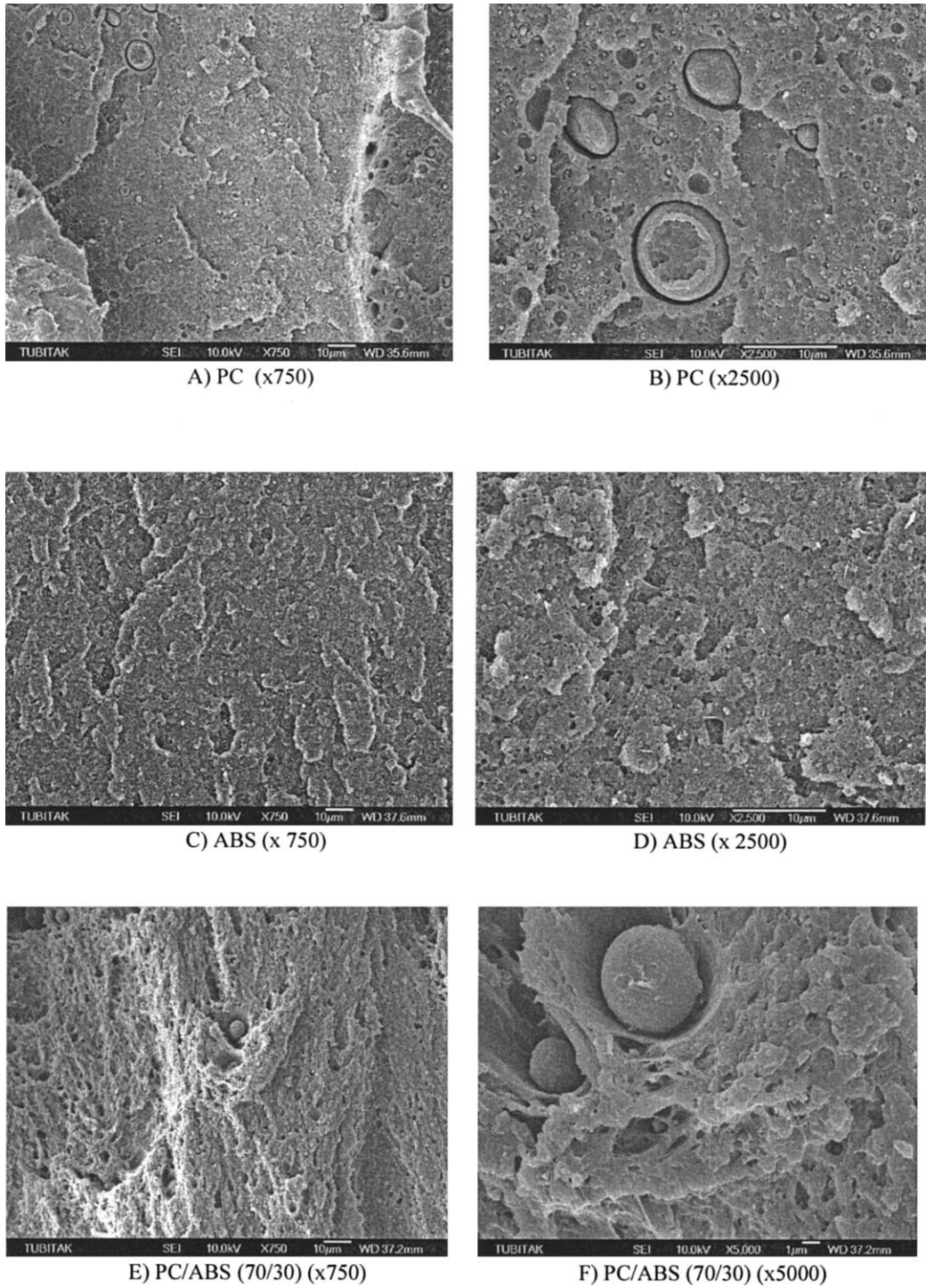


Figure 3 SEM micrographs revealing the appearance of the fracture surfaces of the PC/ABS/SIS polymer alloys. (A) PC ($\times 750$); (B) PC ($\times 2500$); (C) ABS ($\times 750$); (D) ABS ($\times 2500$); (E) PC/ABS (70/30) ($\times 750$); (F) PC/ABS (70/30) ($\times 5000$).

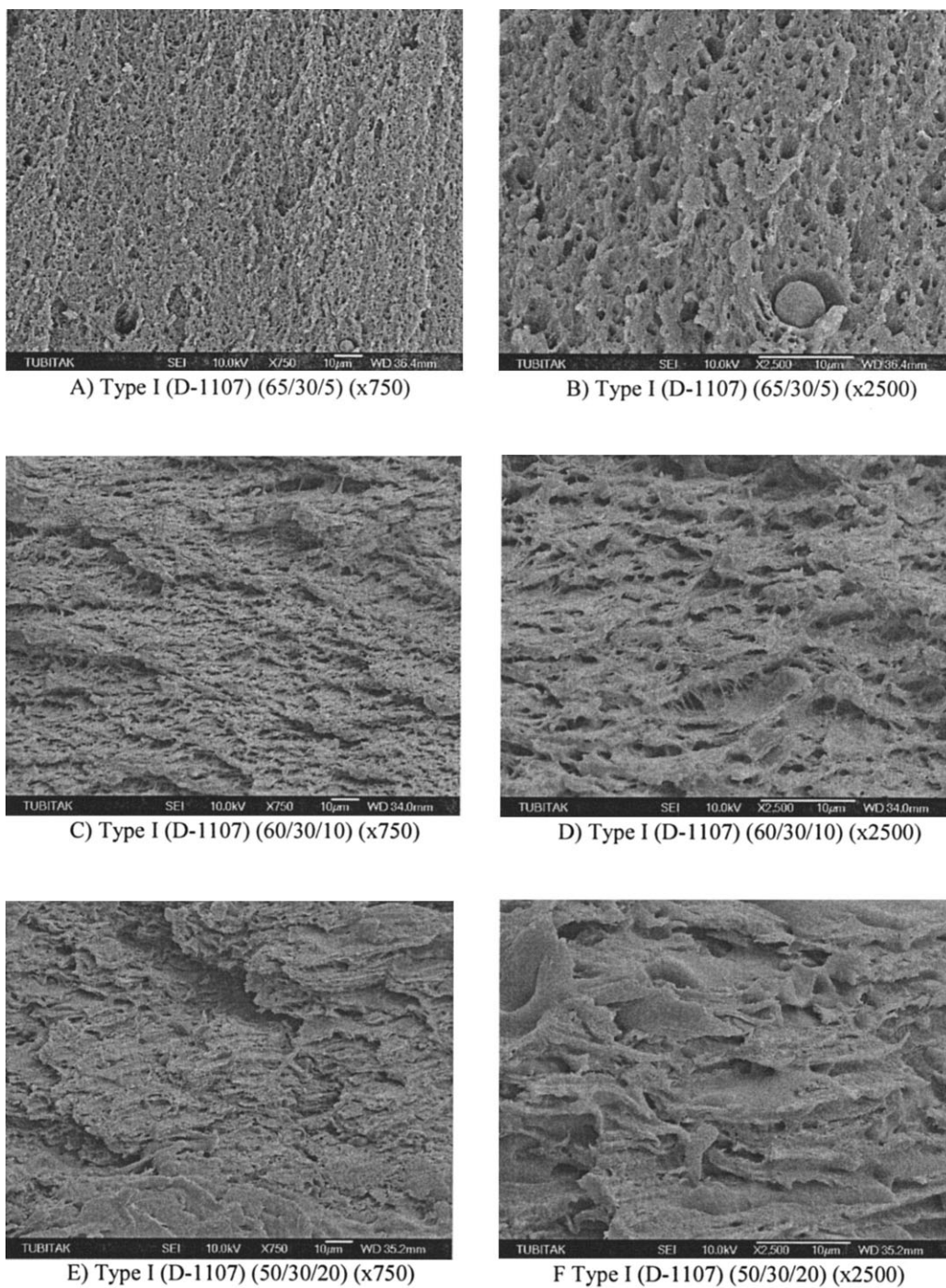


Figure 4 SEM micrographs revealing the appearance of the fracture surfaces of the PC/ABS/SIS polymer alloys. (A) Type I (D-1107) (65/30/5) ($\times 750$); (B) Type I (D-1107) (65/30/5) ($\times 2500$); (C) Type I (D-1107) (60/30/10) ($\times 750$); (D) Type I (D-1107) (60/30/10) ($\times 2500$); (E) Type I (D-1107) (50/30/20) ($\times 750$); (F) Type I (D-1107) (50/30/20) ($\times 2500$).

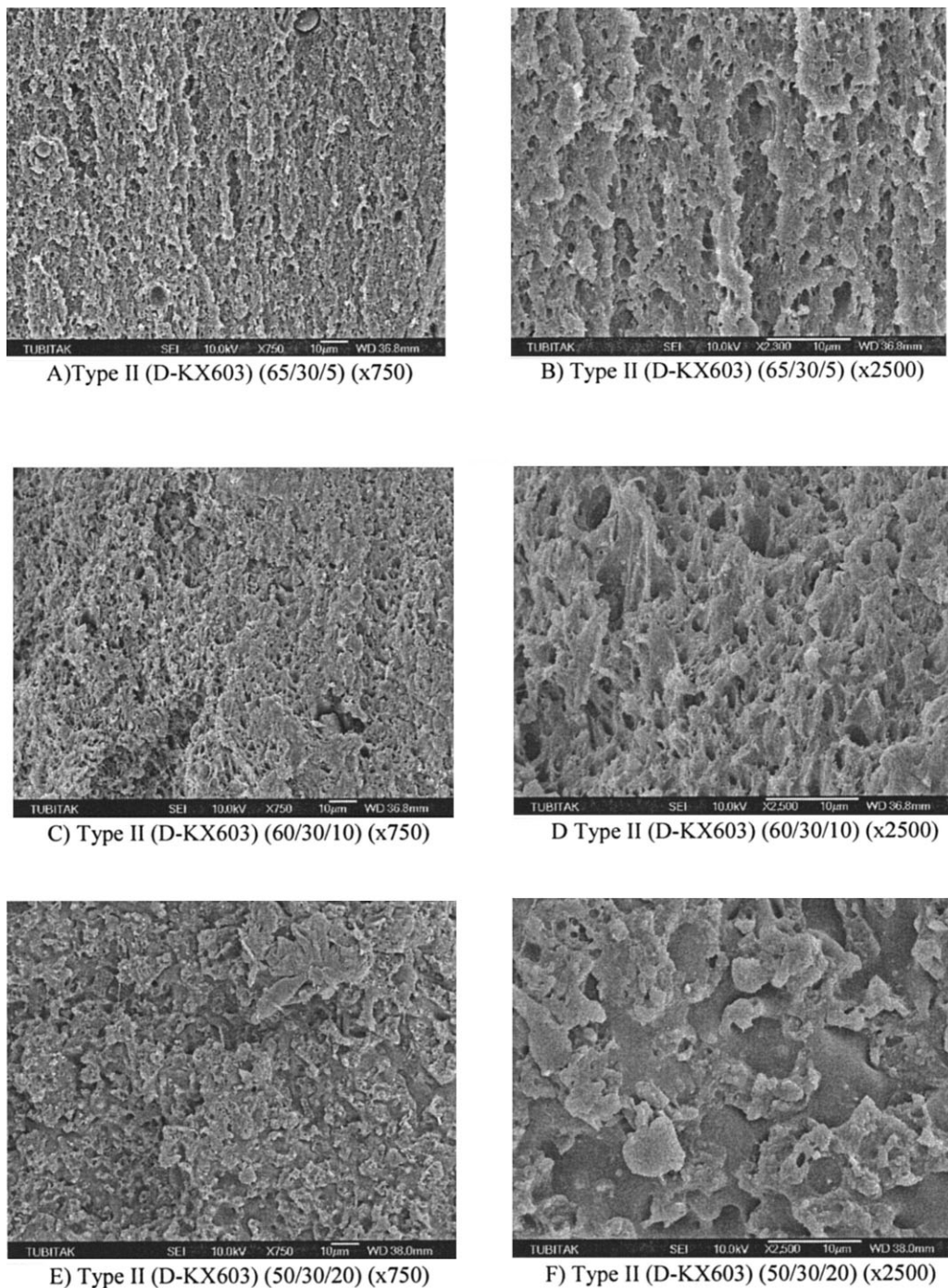


Figure 5 SEM micrographs revealing the appearance of the fracture surfaces of the PC/ABS/SIS polymer alloys. (A) Type II (D-KX603) (65/30/5) ($\times 750$); (B) Type II (D-KX603) (65/30/5) ($\times 2500$); (C) Type II (D-KX603) (60/30/10) ($\times 750$) D Type II (D-KX603) (60/30/10) ($\times 2500$); (E) Type II (D-KX603) (50/30/20) ($\times 750$) (F) Type II (D-KX603) (50/30/20) ($\times 2500$).

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