ASIAN JOURNAL OF CHEMISTRY

Morphology and Mechanical Properties of Polystyrene: Blending with Low, Medium and High Molecular Mass Elastomers

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Rubber toughened polystyrene (RTPS) materials were prepared by blending polystyrene with three types of thermoplastic elastomer (SEPS) which include low molar mass, medium molar mass and high molar mass with the same styrene content. The effect of particle morphology, varying molar mass and percentage thermoplastic elastomer content on the mechanical properties were evaluated. The results obtained show that rubber toughened polystyrene blends of low and medium molar mass rubber have superior stress and strain characteristics when compared with rubber toughened polystyrene blend of high molar mass rubber. Study of phase morphology revealed that 30-40L/M blends exhibit more even dispersion of rubber particles in contrast to that of 30-40H blends which exhibit a broader size distribution of rubber particles.

Key Words: Polystyrene, Morphology, Elastomers, Mechanical properties, Rubber blends.

INTRODUCTION

During the last few decades, increasing activities have been directed towards modification of existing polymers to produce new materials with desirable properties. Due to the possibility of attaining a wide range of properties through blending of two or more polymers, it has been known as one of the most applicable methods for modification of polymers. Thermoplastic elastomers (TPEs) form an important class of materials combining elastomeric behaviour with thermoplastic properties. Commonly these are ABA type triblock copolymers that combine a soft central block with glassy end blocks. These blocks should be immiscible and should phase separate with formation of thermoplastic microdomains, which act as physical cross-links for the soft matrix. Polymer blending are widely used in many diverse industries and form the basis for engineering plastics, structural adhesives and materials for fibre-composite materials. Although a considerable number of works have been published on the polystyrene-polybutadiene-polystyrene (SBS) blends, there is little work in the relationship between morphology and mechanical properties of polystyrene-ethylene propylene-polystyrene (SEPS) blends[1-15]. Therefore, the objective of this work is to study the effect of adding thermoplastic elastomers (SEPS) with various molar mass and the influence of the amount of SEPS on the morphology and the mechanical properties of PS/SEPS blends.

EXPERIMENTAL

The thermoplastic elastomers [(styrene-ethylene-propylene-styrene (SEPS)] were produced by Kuraray Chemical company Ltd. of Japan (Table-1). In SEPS the central block consists of the rubber like polymer (70 %) and the terminals are formed from PS segments (30 %).

TABLE-1 DETAILS OF THE THERMOPLASTIC ELASTOMERS			
Details	Septon 2007 Low relative molar mass	Septon 4033 Medium molar mass	Septon (4055) High molar mass
Composition	SEPS	SEPS	SEPS
Predominant architecture	Triblock	Triblock	Triblock
Structure	Linear	Linear	Linear
Glass transition temperature of rubber block	$\approx$ -50 ºC	$\approx$ -50 ºC	$\approx$ -50 ºC
$M_n \times 10^3$	60.49	78.51	147.48
$M_w \times 10^3$	77.88	92.48	222.34
M_w/M_n	1.228	1.178	1.508

Polystyrene used was Atactic polystyrene, Dow styrene 678E GPPS; $M_n = 72.5 \times 10^3$, $M_w = 220 \times 10^3$, $M_w/M_n = 3.05$.

Compounding: The blends produced were of PS with SEPS 2007, 4033 and 4055. Thermoplastic contents were var-

ied from 10 to 40 % by weight. Batches were prepared by Betol BT530 twin-screw extruder with intensive mixing profile, with the zone temperature of 140/145/155/155/165 ºC and at 80 rpm. The dispersion of rubber particles in the blends were carried out under fixed conditions in which screw speed for the blends and the rate feed into the extruder was kept unaltered throughout. The laces of material on existing the die, were quenched in a water bath and passed through a strand cutter to be granulated ready for injection moulding.

Injection moulding: The blends were injection moulded on a Boy 15S injection moulding machine with the barrel temperature of 175-190 ºC (190 ºC at nozzle) at screw speed 230 rpm, to produce tensile test pieces of dimensions 150 mm × 10 mm × 4 mm. The blends were all moulded under identical conditions.

Tensile testing: A Hounsfield universal tensometer was used (according to BS 2782:320:C) to determine tensile strength, modulus of elasticity and elongation at break for each test piece and mean values of five test pieces were calculated. The strain rate was applied in two stages: 2 mm/min to a strain of 0.5 % to obtain modulus data, then a strain rate of 25 mm/min to obtain ultimate tensile properties.

Optical microscopy: Thin specimens (5 µm) were microtomed from rubber toughened polystyrene (RTPS) blends containing 10 to 40 % of the various elastomers. The specimens were imaged using phase optical microscope (Olympus, Vanox-T), for the study of multiphase polymers. Specimens were mounted in glycerol for the study of phase morphology.

RESULTS AND DISCUSSION

The increasing rubber content for a given blend at constant screw speed and feed rate, led to an increase in energy consumption during compounding of the blends due to the viscosity of rubber being higher than polystyrene. The compounding energy also shows an increase as the average molar mass of the rubber increased. This is due to the increase in the viscosity of the elastomer as molar mass increased. To assess the work being done under these fixed conditions the following equation was used:

$$SEI = \frac{MN}{r} \; amps/kg$$

where SEI is apparent specific energy input, M is motor load (amps), N is screw speed (rpm) and r is rate of feed (kg/h). The apparent specific energy input for the blends during extrusion compounding is shown in Table-2.

TABLE-2
APPARENT SPECIFIC ENERGY INPUT OF THE BLENDS

Blend	SEI (amps/g)
GPPS	30.76
Septon* 2007	
10L	9.62
20L	9.65
30L	10.00
40L	12.30
Septon* 4033	
10M	10.00
20M	12.00
30M	13.33
40M	16.00
Septon* 4055	
10H	12.97
20H	13.33
30H	15.55
40H	17.35

*First two digits denote the mass percent and the letter, L, M and H denote the low molar mass, medium molar mass and high molar mass elastomer, respectively.

Tensile results: The stress and strain results for the blends of various elastomer content extruded under identical conditions is tabulated in Table-3.

It can be observed from Table-3 that the toughening particles induced large scale yielding in the matrix PS as rubber content increased. This yielding led to much greater strains at failure and greatly increased the energy required to cause fracture. In this respect the blend containing 30 % medium molar mass rubber is significantly more ductile than 30 % low and high molar mass rubber blends. The blends containing 40 % low and medium molar mass rubber are significantly more ductile than 40 % high molar mass rubber blend. For each type of blend, young's modulus and yield stress of the rubber toughened polystyrene (RTPS) decreased with increasing rubber content. The rubber particles promote multiple crazing, allowing the materials to reach high elongation before fracture.

TABLE-3
MEAN STRESS AND STRAIN VALUES OF VARIOUS BLENDS (± CONFIDENCE LIMITS)

Blend	Modulus (MPa)	Yield		Break (MPa)	Elongation (%)
		(MPa)	(%)		
GPPS	3509 ± 105	47.50 ± 1.50	2.30 ± 0.23	47.50 ± 0.3	2.56 ± 0.42
Septon 10L	2881 ± 83	42.80 ± 0.10	2.44 ± 0.09	41.80 ± 0.1	4.62 ± 0.47
Septon 20L	2474 ± 46	38.20 ± 0.20	2.36 ± 0.09	37.00 ± 0.3	4.40 ± 0.66
Septon 30L	1950 ± 79	32.30 ± 0.10	2.16 ± 0.18	29.70 ± 0.6	10.44 ± 2.57
Septon 40L	1569 ± 106	25.70 ± 0.10	2.28 ± 0.11	23.00 ± 0.5	25.50 ± 7.10
Septon 10M	2767 ± 164	42.80 ± 0.30	2.64 ± 0.15	41.60 ± 0.4	4.84 ± 0.78
Septon 20M	2451 ± 131	37.80 ± 0.10	2.40 ± 0.07	34.40 ± 0.4	11.70 ± 1.89
Septon 30M	1999 ± 94	30.60 ± 0.20	2.04 ± 0.05	27.20 ± 0.3	20.10 ± 1.20
Septon 40M	1580 ± 54	23.50 ± 0.30	2.16 ± 0.13	21.60 ± 0.6	28.50 ± 4.20
Septon 10H	2860 ± 170	38.50 ± 0.30	2.96 ± 0.15	38.50 ± 0.3	3.98 ± 0.26
Septon 20H	2040 ± 278	30.40 ± 0.10	3.22 ± 0.35	30.30 ± 0.2	6.16 ± 1.11
Septon 30H	1794 ± 98	23.90 ± 0.10	7.20 ± 1.67	23.80 ± 0.1	10.64 ± 1.68
Septon 40H	1229 ± 25	18.11 ± 0.13	19.36 ± 2.12	17.90 ± 0.2	22.70 ± 2.80

In all the blends, this effect is more marked as the volume fraction of rubber increased. However, RTPS blends of low and medium molar mass rubber have superior stress and strain characteristics when compared with RTPS blend of high molar mass rubber. These improvements in the RTPS blends when compared against base polymer (GPPS) are however, accompanied by the loss of clarity, optical properties and a decrease in tensile strength and modulus of elasticity.

Morphology of the blends: Optical microscopy was used to study the phase structure of RTPS blends. The optical micrographs of RTPS blends taken at a magnification of 60x are shown in Figs. 1-3. These reveal details of phase structure with the dispersed rubber phase, appearing as light feature against a dark PS continuous phase. The 30-40L/M blends show even dispersion of rubber particles (1-3 µm) in contrast to that of 30-40H blends which exhibit a broader size distribution of rubber particles (5-10 µm).
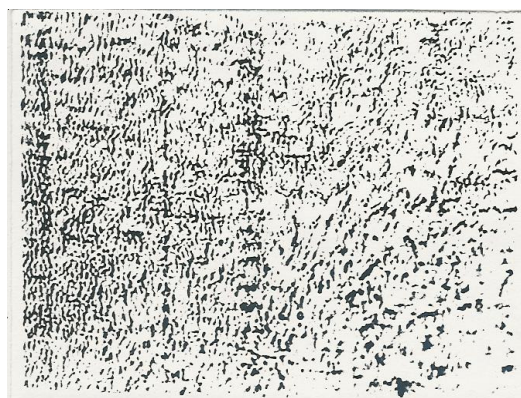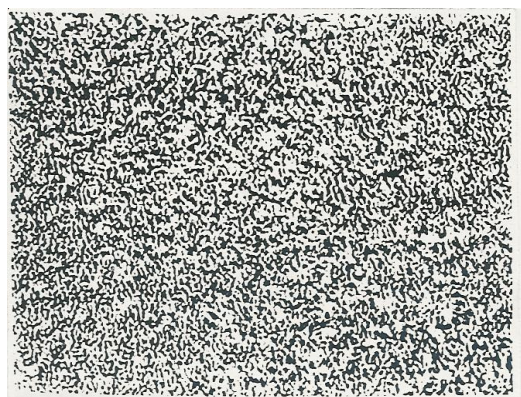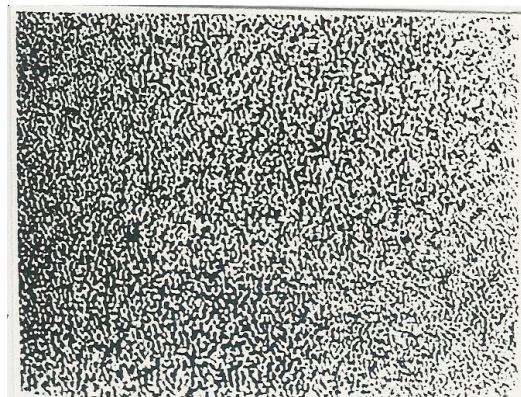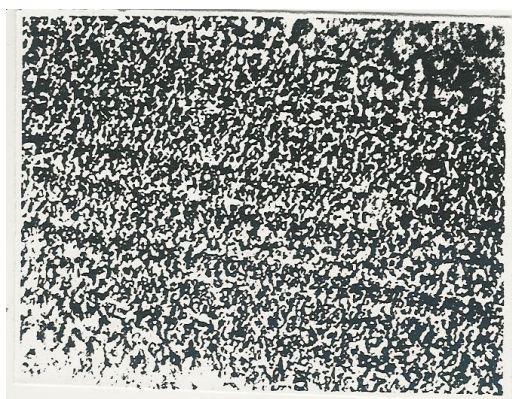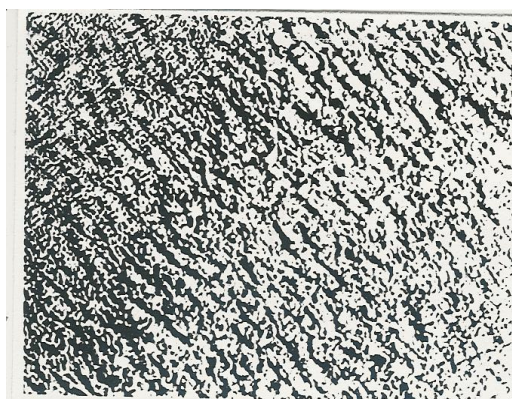

(D)

Fig. 1. Shows optical micrograph of (A) 10L blend, (B) 20L blend, (C) 30L blend and (D) 40L blend (—— 0.01 mm)

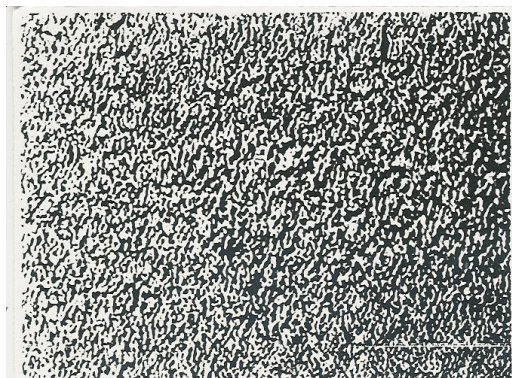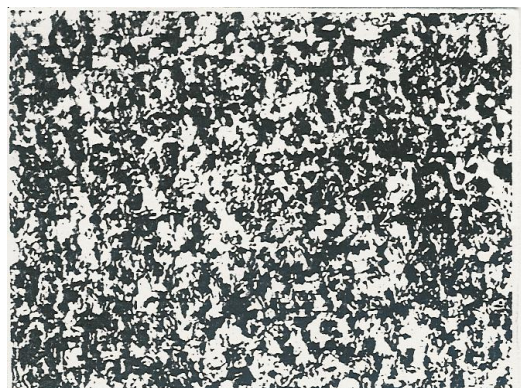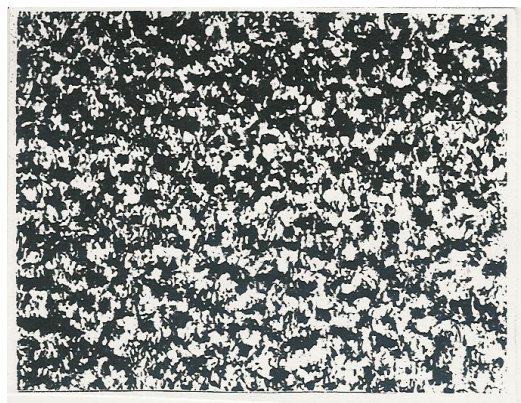(A)

(B)

(C)

(A)

(B)

(C)

(D)

Fig. 2. Shows optical micrograph of (A) 10M blend, (B) 20M blend, (C) 30M blend and (D) 40M blend (——— 0.01 mm)
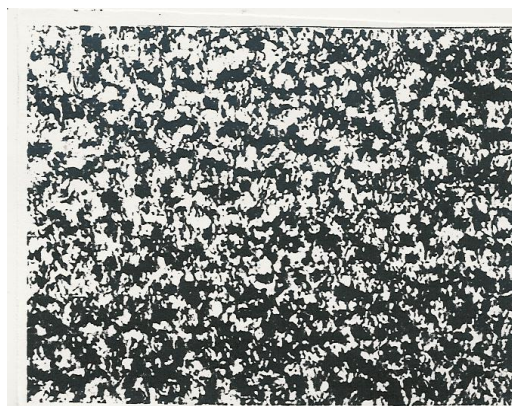

(A)

(B)

(C)

(D)

Fig. 3. Shows optical micrograph of (A) 10H blend, (B) 20H blend, (C) 30H blend and (D) 40H blend (——— 0.01 mm)

Conclusion

(1) The incorporation of thermoplastic elastomers (SEPS) with varying molar mass and rubber content into polystyrene resulted in reduction of young's modulus and yield stress of the rubber toughened polystyrene (RTPS) with increasing rubber content. (2) The toughening rubber particles induced large scale yielding in the matrix PS as rubber content increased which led to much greater strains at failure and greatly increased the energy required to cause fracture. (3) The phase morphology of blends containing 10-40 % low and medium molar mass rubber showed even dispersion of rubber particles (1-3 μm) than blends containing 10-40 % high molar mass rubber with a broader size distribution of rubber particles (5-10 μm).

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