Polysulphone and poly(phenylene sulphide) blends: 2. Mechanical behaviour

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This paper reports the mechanical behaviour of injection moulded blends of polysulphone (PSF) and poly(phenylene sulphide) (PPS). The blends prepared by melt-extrusion and subsequent injection moulding are phase separated. Depending on moulding conditions, thermal history, and composition, tensile behaviour ranged from brittle to ductile, with or without cold drawing. Cold drawing was observed in compositions as-moulded with up to 50% by weight PPS. Upon annealing for 2 h at 160°C, ductile failure was maintained for blends containing up to 35% by weight PPS. All other compositions failed in brittle fashion. Flexural strength and modulus, before and after annealing, exhibited negative deviation from the rule of mixtures. All the blends were found to be notch sensitive.

(Keywords: polysulphone; poly(phenylene sulphide); blends; mechanical properties; impact)

INTRODUCTION

The technique of combining two or more polymers to achieve certain desirable properties is a growing technology. Properties of a homopolymer such as ease of processing, chemical resistance, and mechanical response can be modified through blending with other polymers. The mechanical behaviour of compatible polymer blends has been reported[1,2]. Mondragon and Nazabal[3] demonstrated the mechanical behaviour of polyarylate–polycarbonate blends in their transreacted state; these systems show a certain degree of synergistic effect above the simple additive line connecting the two pure components. Blend systems with immiscible phase behaviour may give a positive or negative synergism[4,5]. Mechanical behaviour close to the additive line connecting the two pure components, has also been reported[6].

Polysulphone (PSF) and poly(phenylene sulphide) (PPS) when melt-blended form phase separated polymer blends as reported in the first paper of this series[7]. Other investigators[8,9] using solution mixing procedures also reported similar findings. This paper reports the mechanical behaviour of blends prepared by melt-extrusion and subsequent injection moulding of polysulphone and poly(phenylene sulphide). Both as-moulded and annealed (160°C for 2 h) specimens were investigated.

Conventional test methods such as tensile, flexural, and notched Izod impact tests were employed. The third paper in this series will discuss the rubber toughening of these blend systems.

EXPERIMENTAL

Details about raw materials, blends preparation, injection moulding and dynamic mechanical thermal analysis were given previously[7]. Specimens were annealed at 160°C for 2 h throughout this study.

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Tensile test

A United FM-30 electromechanical testing machine (United Calibration Corp., Garden Grove, CA, USA) was used to test the tensile properties of the blends using ASTM D638 procedure. Type I specimens (injection moulded) were used. A crosshead speed of 50.8 mm/min was used throughout the investigation.

Flexural properties

ASTM method D790M-82 was used. A three-point loading system was employed and data were collected at a deflected strain of 5% for moduli calculation and maximum load for strength calculation. Crosshead speed of 1.27 mm/min and a span of 50.8 mm were used throughout the test.

Notched Izod impact

ASTM method D256 was used. Specimen dimensions were approximately $0.3175 \times 1.27 \times 6.35$ cm.

RESULTS AND DISCUSSION

Figures 1 and *2* show respectively as-moulded and annealed tensile specimens which have been tested under tension. During the tensile test the experiments were stopped when the specimens were observed at the point when a shear band was developed. In some cases, such as specimens a, c and d in *Figure 2*, specimens broke as soon as the shear band was formed.

An injection moulded polysulphone specimen when subjected to a conventional tensile test exhibited necking (single, angled shear band) and cold-drawing (*Figure 1*, specimen a) at ambient temperature. The force–displacement curve revealed a typical yield with a load drop beyond the yield point. A 133% (average of 5 specimens) elongation to break was obtained. Poly(phenylene sulphide) when moulded at a mould temperature set at 21°C gave a 12% elongation to break with a ductile failure.

When both PSF and PPS were annealed for 2 h at 160°C, the failure mode was completely different from

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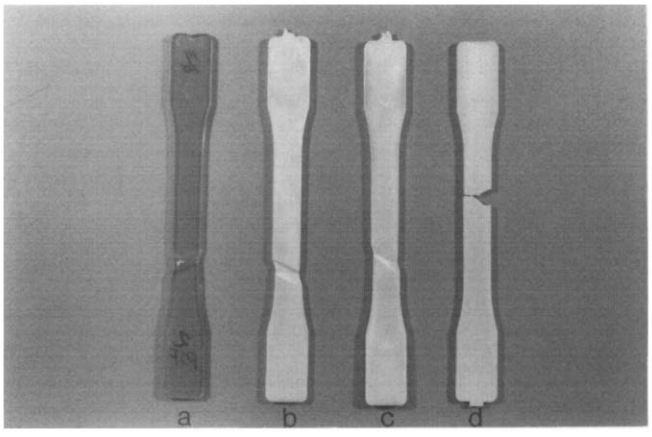

Figure 1 Tensile test results of as-moulded specimens. Experiments were stopped at the point where a shear band was developed except when it was ruptured prematurely. Ratios are PPS/PSF by weight: specimen a, PSF; specimen b, 20/80; specimen c, 50/50; specimen d, 70/30

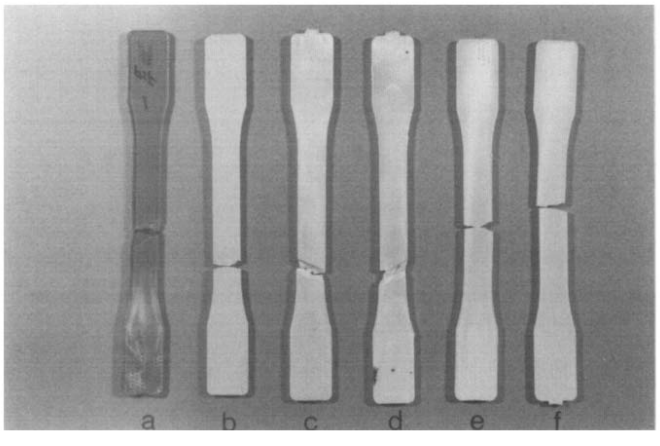

Figure 2 Tensile test results of annealed (160°C, 2 h) specimens. Experiments were stopped at the point when a shear band was developed except when it was ruptured prematurely. Ratios are PPS/PSF by weight: specimen a, PSF; specimen b, PPS; specimen c, 20/80; specimen d, 35/65; specimen e, 50/50; specimen f, 70/30

the as-moulded specimens. PSF under tension fractured immediately after neck formation as shown in *Figure 2*, specimen a. The elongation to break was about 10–15% as compared to 133% before annealing. The poor resistance to embrittlement of PSF under thermal ageing below its glass transition temperature has been reported[10,11]. The same phenomenon was also reported on other glassy polymers such as polycarbonate[12–14]. Annealed PPS also failed brittlely (*Figure 2*, specimen b). Its elongation to break decreased to about 3%. An approximately 10% increase in maximum stress (or stress at break) was observed in both PSF and PPS after annealing for 2 h at 160°C.

Changes in mechanical properties after annealing are an important consideration when possible applications are considered. For automotive body panel applications, parts should be paintable. Paint bake temperatures are typically of the order of 150°C. Hence annealing for 2 h at 160°C is a condition which is representative of possible post-manufacturing conditions.

Figure 3 shows the plot of the yield stress (or stress at break) of the PSF/PPS blends *versus* PPS composition. Data on as-moulded specimens show a slight decrease of maximum stress up to 20% PPS and a gradual increase between 20% and 50% PPS. At and below 50% PPS, all specimens cold-drew when tested at ambient temperature. A single, angled shear band formed first before the cold-drawing process began as shown in *Figure 1*. At 70% PPS, the specimens failed brittlely. An analysis of molecular weight using gas permeation chromatography (g.p.c.) indicated an approximately 37% decrease of weight average molecular weight (M_w) of the PSF fraction after injection moulding (*Table 1*). However, at PPS composition at and below 50% by weight the PSF fraction showed no appreciable change in weight average molecular weight after injection moulding. The change of molecular weight at high PPS concentration after moulding has also been observed in other blend systems with PPS[15]. A possible cause for this is the outgassing of the PPS at elevated temperature which may degrade the other blend component[16,17].

When the blend samples were annealed for 2 h at 160°C, the tensile strength increased over the unannealed specimens and the yield stress (or stress at break, *Figure 3*) reached a maximum value at 35% PPS and then changed drastically towards lower values as the PPS

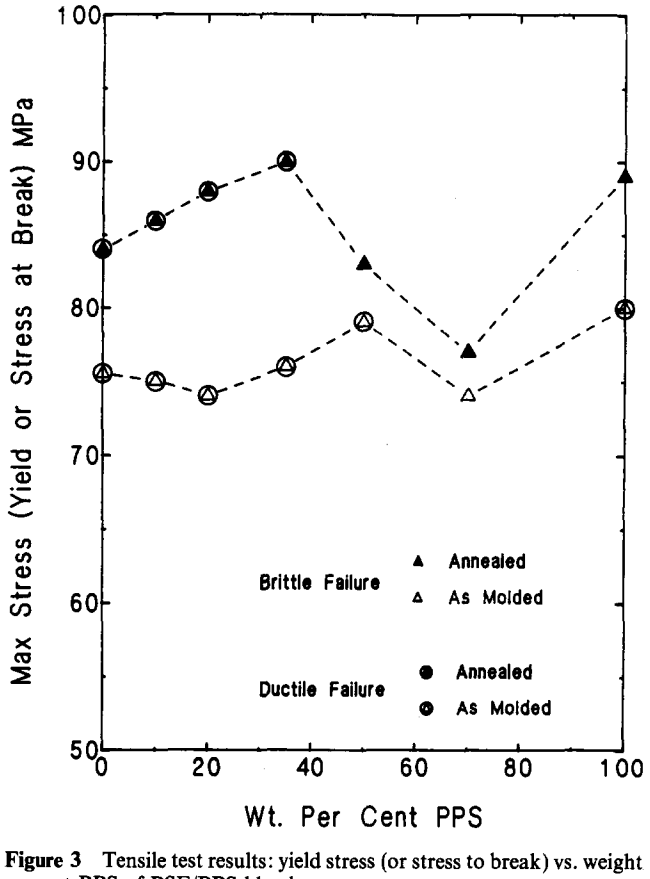

Figure 3 Tensile test results: yield stress (or stress to break) vs. weight percent PPS of PSF/PPS blends

Table 1 Weight average molecular weight of the PSF fraction in injection moulded PSF/PPS blends

Percent PPS	M_w
0	57 000 ± 1100
10	57 700
20	57 300
35	56 400
50	55 600
70	36 400

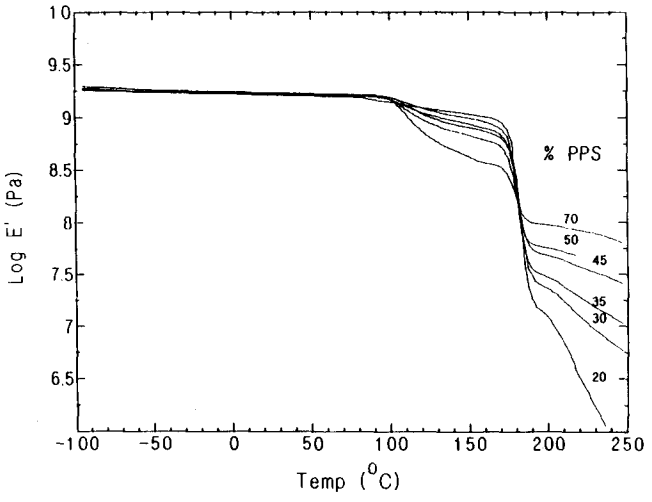

Figure 4 DMTA thermogram at 0.1 Hz of PSF/PPS blends: storage modulus vs. temperature

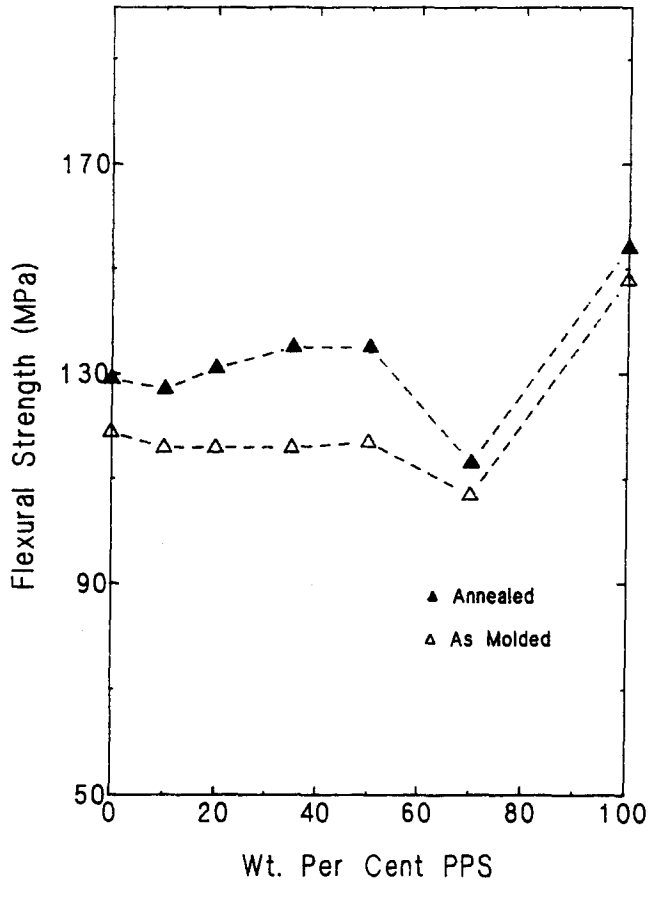

Figure 5 Plot of flexural strength vs. weight percent PPS of PSF/PPS blends

content increased. The overall increase in tensile strength with annealing indicates that the dispersed PPS in the crystalline state can act as reinforcement to the continuous PSF phase. The sharp decrease of strength at 50% and 70% PPS may be due to the PPS becoming the matrix phase and the decrease in M_w of the PSF fraction. A co-continuous morphology was observed at 50% PPS, and at 70% PPS, polysulphone was seen to be dispersed as globules in a PPS matrix[7]. The sharp decrease at 50% PPS may be due to PPS being a matrix-like phase. The blend of 70% PPS which showed brittle behaviour before annealing, remained brittle after annealing. Its low strength is probably caused by the decrease in molecular weight of the PSF.

As homopolymers, both PSF and PPS embrittle upon annealing. It is therefore no surprise that their blends show similar behaviour. During annealing the PPS phase crystallizes further. This is clearly seen in properties such as the temperature dependence of the storage modulus shown in *Figure 4*. A rubbery plateau develops as the PPS content increases.

Figures 5 and *6* show respectively the flexural strength and flexural modulus of the blends both as-moulded as well as annealed. The flexural strength of the blends as-moulded shows large deviation from the simple additive rule of mixtures. Upon annealing, however, the flexural strength exhibited nearly additive response up to 50% by weight of PPS. The flexural modulus of the blends was found to be close to the values of the additive rule of mixtures of the pure materials up to about 50% by weight of PPS before and after annealing.

The notched Izod impact data of the as-moulded blends are listed in *Table 2*. Below 50% by weight of PPS, the Izod impact strengths are close to that of the continuous matrix (PSF), while at 70% PPS, the impact strength is equal to that of the pure PPS. *Figure 7* shows a scanning electron micrograph of the Izod impact

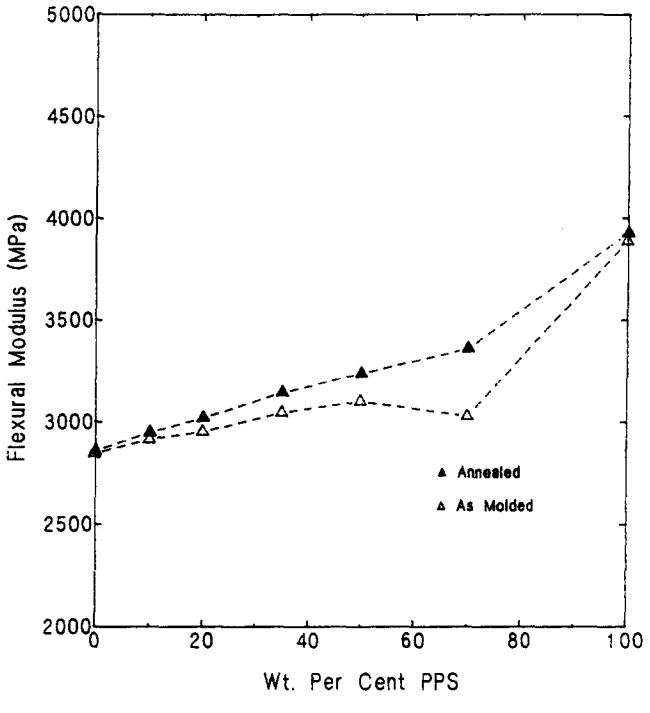

Figure 6 Plot of flexural modulus vs. weight percent PPS of PSF/PPS blends

Table 2 Notched Izod impact data of PSF/PPS blends

Percent PPS	Izod impact strength (J/m)
0	52
10	55
20	56
30	48
35	48
45	37
50	42
70	27
100	27

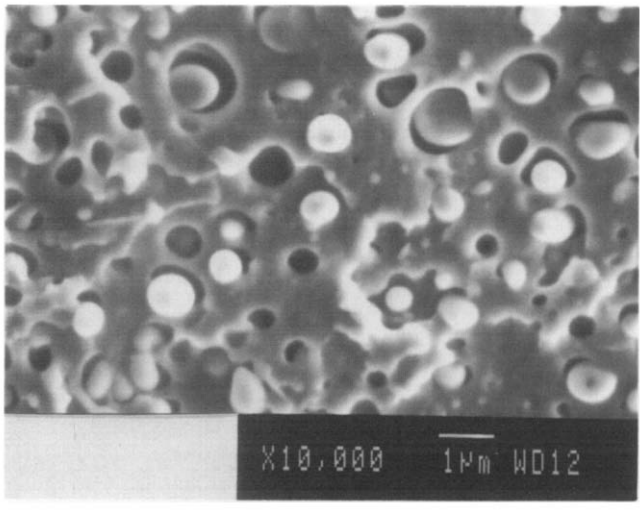

Figure 7 Scanning electron micrograph of Izod impact fracture surface of an as-moulded 20% PPS–80% PSF blend

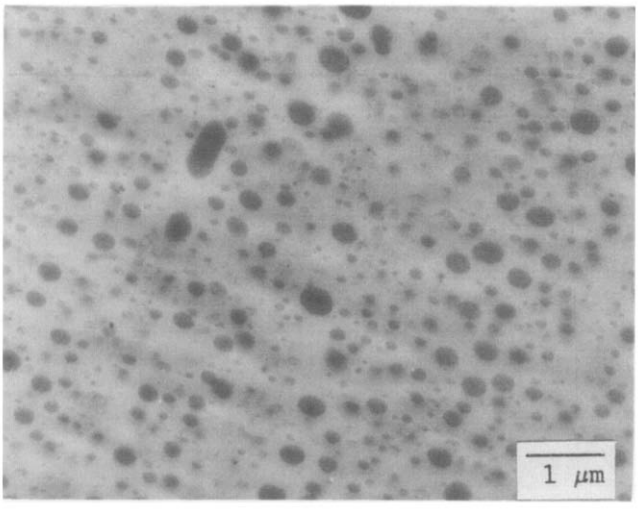

Figure 8 Transmission electron micrograph of an as-moulded 20% PPS–80% PSF blend microtomed underneath the Izod impact fracture surface; dark field: PPS, light field: PSF

fracture surface of a 20% PPS–80% PSF as-moulded blend. The dispersed PPS phase appears as rods as well as spherical particles. Cavitations are observed around the dispersed phase. *Figure 8* shows a transmission electron micrograph of the same specimen cut underneath the fracture surface as viewed perpendicular to the flow direction. No sign of cavities are observed. The energy to break of the notched Izod impact test of PSF/PPS blends are relatively low indicating that the blends are notch sensitive even though they can be cold drawn during tensile test.

The fracture surface shown in *Figure 7* could be interpreted as evidence for poor interfacial adhesion resulting in the rather low toughness obtained in Izod impact test. This would be inconsistent[6] with the tensile stress data obtained as the data indicate a nearly additive response up to 50% PPS by weight. Additionally, the material does not delaminate upon microtome sectioning below the fracture surface (*Figure 8*). The state of stress around an inclusion of PPS in PSF is somewhat complicated. Small particles of PPS remain amorphous even after annealing[7]. Upon cooling to ambient temperature a state of tension should develop in the PPS droplet due to the mismatch of expansion coefficients. One may, therefore, attribute the extensive de-adhesion between the phases as being caused by the release of the interfacial stresses upon passage of the crack itself; the PPS droplets would shrink somewhat and the PSF cavity expand. This is consistent with the tensile test results because the data of the maximum tensile stress show nearly additive response which indicates there is adequate adhesion between the interphase.

In some respects, the results obtained are disappointing. Whatever toughness is achieved, it is lost completely upon annealing. In view of the behaviour of the homopolymers this is not surprising. Nevertheless, if toughness at ambient temperatures can be achieved, these blends would represent an attractive choice of materials with excellent chemical resistance and a high heat distortion temperature, which is retained upon annealing.

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