Preliminary Investigation of Poly(ether sulfone)/Poly(aryl ether ketone) Containing 1,4-Naphthalene Blends

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ABSTRACT: The blends of poly(ether sulfone) and poly(aryl ether ketone) containing 1,4-naphthalene were prepared by melt mixing in a Brabender-like apparatus. The specimens for measurements were made by compression molding under pressure and then were water-quenched at room temperature. The tensile strength, tensile modulus, elongation at break, thermal analysis, and scanning electron microscopy were each measured. The dependence of tensile strength, tensile modulus, and elongation at break on blend systems was obtained. The effects of composition and miscibility on the mechanical properties are discussed. © 2005 Wiley Periodicals, Inc. J Appl Polym Sci 99: 472–476, 2006

Key words: poly(ether sulfone); poly(aryl ether ketone) containing napthalene (NA-PAEK); blend; miscibility

INTRODUCTION

The modification of polymer properties with the aid of blending has been used increasingly to obtain inexpensive materials with improved characteristics. Polymer blends may be classified into homogeneous (miscible) and heterogeneous (immiscible) blends in general. However, one generally considers that the positive effects can be obtained only by using heterogeneous blends with partial miscibility, except for the system of poly(2,6-dimethyl-*p*-phenyene oxide) and polystyrene.[1] Flory[2] predicted that the driving force for miscibility is provided by specific interactions between the polymers; if the specific interactions were strong enough in the polymer blends, they would be miscible polymer blends. Obviously, obtaining a heterogeneous material with the synergism by improving some properties of polymers is expected.

Poly(ether sulfone) (PES) with good mechanical and electrical properties (Scheme 1) is a high-performance engineering plastic; the high glass transition temperature ($T_g \approx 225°C$) enables the sample to retain its modulus at an elevated temperature. Unfortunately, it has a relatively high melt viscosity and low ultimate elongation. To improve the properties of PES, several blends of PES with other polymers have been made,[3–10] but these investigations mainly focus on the properties of rheology, heat resistance, and chemical resistance of the blends.
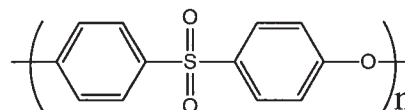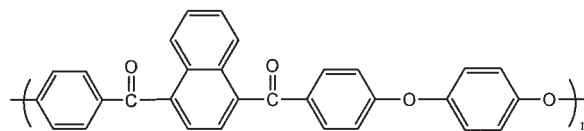

Scheme 1

Poly(aryl ether ketone) containing 1,4-naphthalene (NA-PAEK) with the repeat unit (Scheme 2) is an amorphous polymer with excellent ductility and higher tensile strength and good thermal stability. The NA-PAEK has both higher T_g and solubility. In this article, the main purpose is to improve on the toughness of PES so as to further discuss the effects of the composition on miscibility, density, and dynamic mechanics of PES/NA-PAEK blends.

EXPERIMENTAL

Materials

PES was obtained from the Chemistry Department of Jilin University. The inherent viscosity was 0.36 dL/g ($\bar{M}_n = 24,538$). The NA-PAEK was synthesized in our lab ($\bar{M}_n = 33,814$, $\bar{M}_w = 55,628$). All PES and NA-PAE were dried at 90°C for 12 h in a vacuum oven to remove the absorbed water.

Scheme 2

TABLE I
Comparison of DSC and DMA (tan δ) for Blends

PES/NAPEK (wt/wt)	T_g (°C)			
	PES (DSC)	NA-PAEK (DSC)	PES (DMA)	NA-PAEK (MMA)
100/0	226.42	—	238.36	—
80/20	225.38	196.70	238.03	205.36
70/30	224.64	195.97	237.59	205.55
60/40	224.46	195.85	237.77	207.25
50/50	224.16	195.30	238.41	210.27
40/60	223.89	195.35	238.19	210.02
0/100	—	192.46	—	207.59

Figure 2 Dependence of tensile strength on composition.

Sample preparation

The blends of PES/NA-PAEK with different weight ratios were prepared by melt mixing using a Brabender-like apparatus (Rheocoder XSS-300) at 300°C for 10 min. The blends were dried under vacuum at 110°C for 4 h. The 0.5-mm-thick specimens were obtained by compression molding at 300°C and then were water-quenched at room temperature. The specimens for the dynamic test were made by the same method described above. The tensile specimens were cut with a dumbbell-shaped knife (the effective dimension was $20 \times 4 \times 0.4$ mm).

Methods and instrumentation

The scanning electron microscope (SEM) used was a Shimadzu SSX-550 superscan SEM (Shimadzu, Kyoto, Japan). The SEM was applied to investigate the homogeneity of the phase distribution in the blend of polymers. The sample was fractured in liquid nitrogen and subsequently coated with a gold film. A SEM apparatus was used with an accelerating voltage of 15 kV.
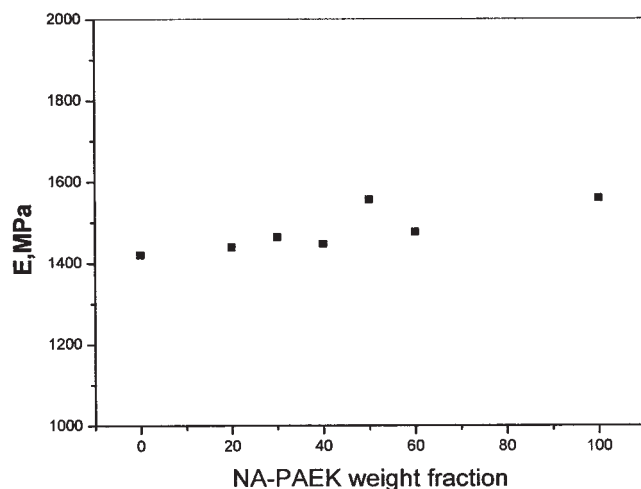
A differential scanning calorimeter (DSC; Mettler Toledo DSC821e) was used. The thermal behaviors of the polymers were characterized by DSC. The measurements were carried out in nitrogen atmosphere and the heating rate was 20°C/min.

Dynamic mechanical analysis (DMA) was carried out with a DMA Q800 (TA Instruments, New Castle, DE). DMA was performed from 100 to 250°C at 2°C/min. The frequency was 3 Hz.

The tensile test was carried out on an Instron tester (AG-I 20KN; Shimadzu Co.). The tensile strength, modulus, and elongation at break were reported as average values for at least 10 samples; the data values of tress–strain cures are near to the average values (Table I).
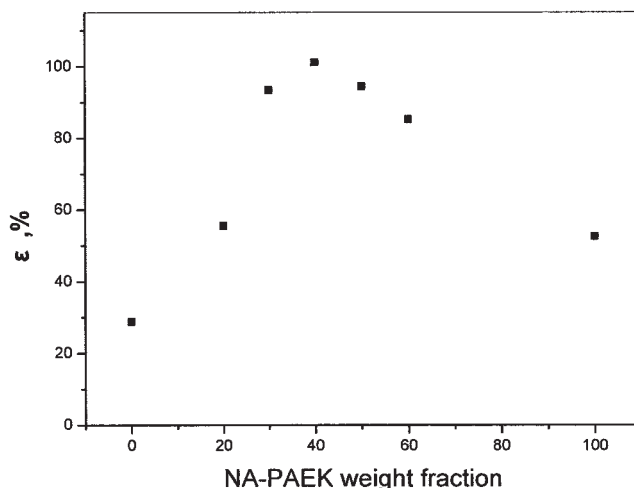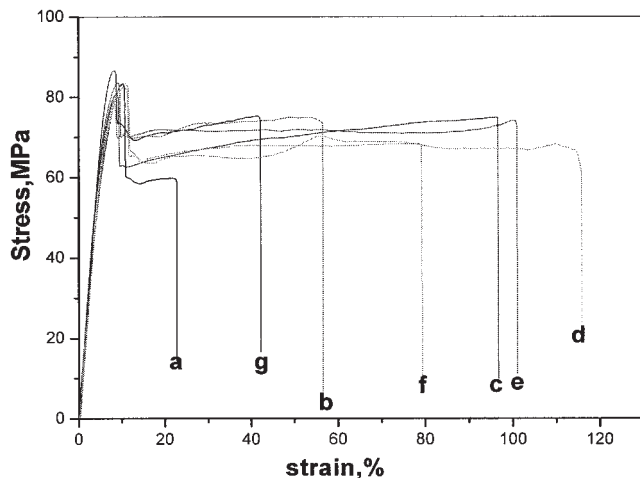
The density was measured by a gravity bottle at 25°C.

Figure 1 Dependence of tensile modulus on composition.

Figure 3 Dependence of elongation at break on composition.

Figure 4 Stress–strain cures of PES/NA-PAEK: (a) 100/0; (b) 80/20; (c) 70/30; (d) 60/40; (e) 50/50; (f) 40/60; (g) 0/100.

Figure 6 Temperature dependence of tan δ in PES/NA-PAEK blends: (a) 0/100; (b) 100/0; (c) 80/20; (d) 70/30; (e) 60/40; (f) 50/50; (g) 40/60.
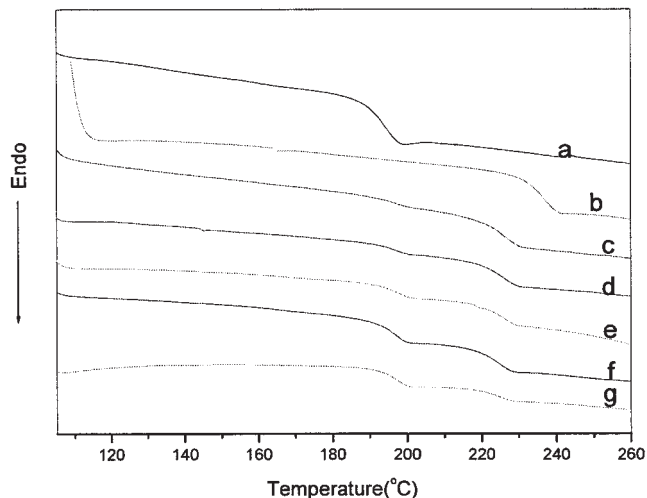
RESULTS AND DISCUSSION

Effects of composition on tensile behavior
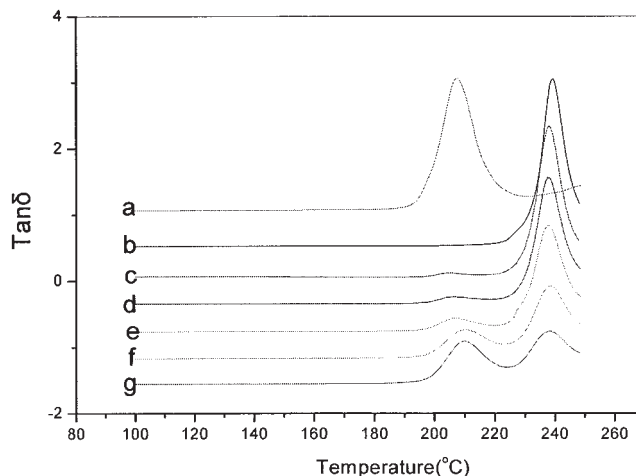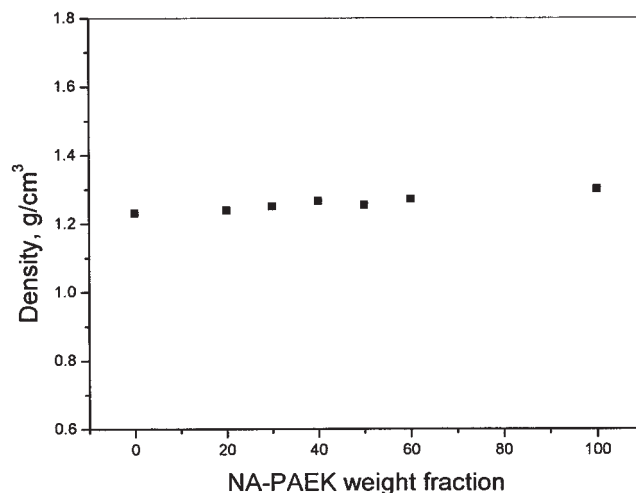
The results of tensile test are shown in Figures 1-4. From these figures, it can be seen that the tensile strength (σ), tensile modulus (E), and elongation at break (ε)of the blend are higher than that of PES. The tensile strength and tensile modulus almost linearly increases with increasing NA-PAEK content, whereas the elongation at break shows a maximum at 40% of NA-PAEK. The nearly additive responses for tensile strength and tensile modulus could be attributed to the two-phase cocontinuous morphology and the partial compatibility between the two components as discussed below.

Compatibility

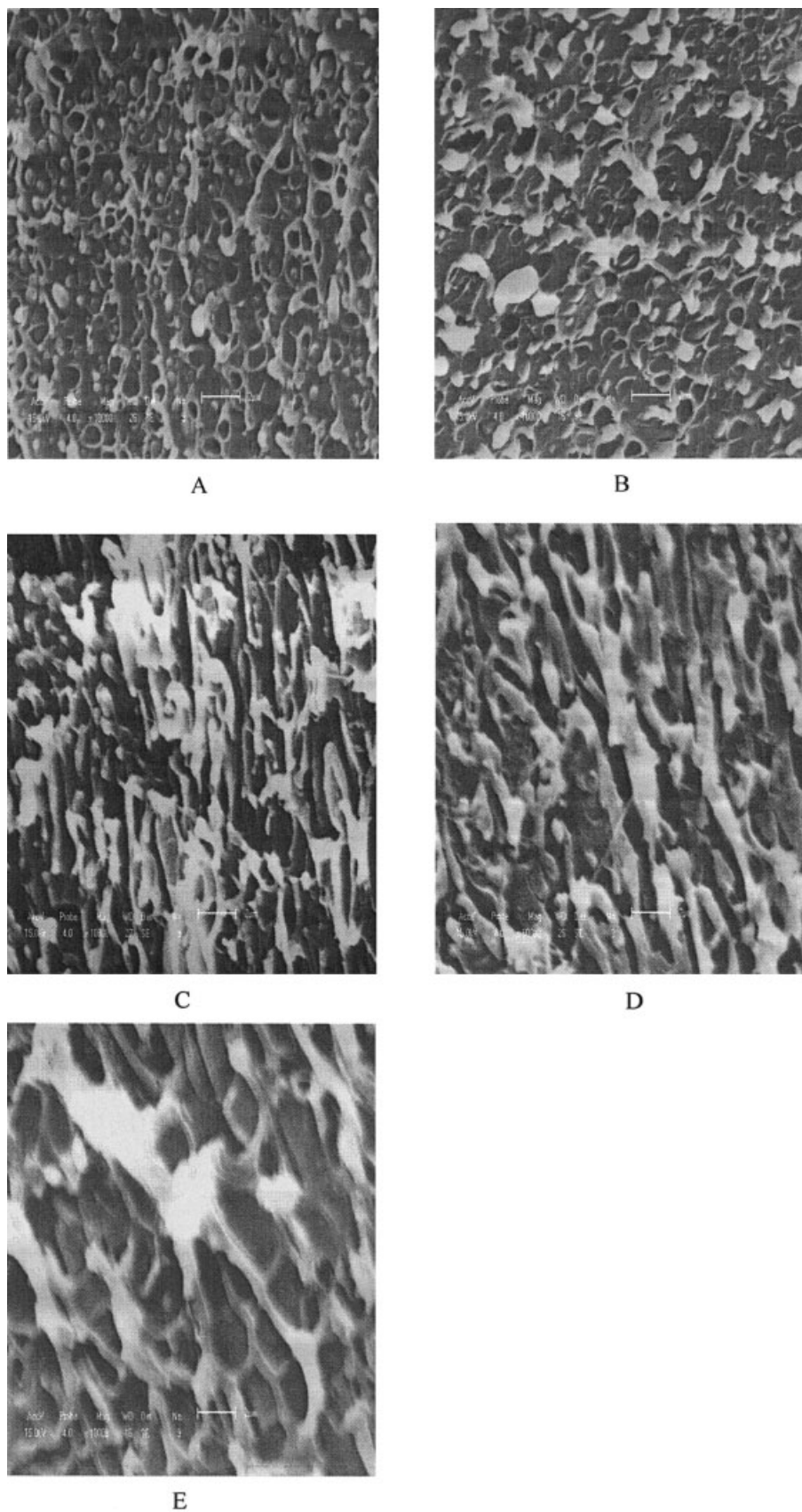From DSC (Fig. 5) thermographs it is found that the PES/NA-PAEK blends show two T_g's corresponding

to that of PES and NA-PAEK, respectively. The T_g of PES (T_{g1}) is a little lower than that of pure PES, whereas the T_g of NA-PAEK (T_{g2}) is a bit higher than that of pure NA-PAEK (i.e., the two T_g's shift inward). This implies that the PES/NA-PAEK blend is a two-phase but partially compatible system. The results obtained from DMA (Fig. 6) and the synergistic density (Fig. 7) confirm this conclusion.

Morphology

The SEM photographs of fractured surface for PES/NA-PAEK blends are shown in Figure 8. From the photographs, it can be seen that PES/NA-PAEK is a two-phase system. The two phases penetrate each other. As a result, an interlocked cocontinued morphology is formed. Such morphology is almost inde-

Figure 5 DSC curves of blend systems: PES/NA-PAEK (a) 0/100; (b) 100/0; (c) 80/20; (d) 70/30; (e) 60/40; (f) 50/50; (g) 40/60.

Figure 7 Dependence of density on composition.

Figure 8 SEM photographs of the (magnification, ×10,000) PES/NA-PAEK blends: A (80/20); B (70/30); C (60/40); D (50/50); E (40/60).

pendent of the composition, but the phase region of NA-PAEK becomes thick as the NA-PAEK weight fraction increases. As a tensile load acts on a specimen with such cocontinued morphology, the two components respond simultaneously. The contribution of each component to tensile behavior (i.e., tensile strength and tensile modulus) depends on its fraction in the two-phase system. The contribution of each component to tensile properties (i.e., tensile strength and tensile modulus) must be proportional to its fraction in the two-phase system.

Because the density of the PES/NA-PAEK blend is nearly the linear addition of the pure components, it may be that there is no volume change after blending. This might be the reason for the additive responses of tensile strength and tensile modulus.

CONCLUSIONS

PES/NA-PAEK blend is a partially compatible system with interlocked morphology of cocontinuous phases.

The tensile strength and modulus are approximately proportional to the weight fraction of NA-PAEK; however, the elongation at break shows a synergistic improvement at 40 wt % NA-PAEK.

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