Thermal and Mechanical Properties of Phenolphthalein Polyethersulfone/Poly(phenylene sulfide) Blends

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SYNOPSIS

The thermal and mechanical properties of phenolphthalein polyethersulfone/poly(phenylene sulfide) (PES-C/PPS) blends were studied using a differential scanning calorimeter, a dynamic mechanical analyzer, and mechanical characterization. The morphologies of fracture surfaces were observed by scanning electron microscopy. The blends are multiphase systems with strong interaction between the two phases. It is of interest that, although the strength and ductility of PPS are lower than those of PES-C, the addition of PPS can improve markedly the impact strength of PES-C without changing its higher strength. The PPS can also act as a flow aid for PES-C. © 1995 John Wiley & Sons, Inc.

INTRODUCTION

Phenolphthalein polyethersulfone (PES-C) is a novel high-performance thermoplastic developed in this institute in 1985.[1] The repeating unit of PES-C is as follows:
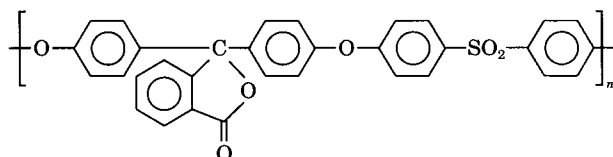
It is an amorphous polymer with good mechanical properties and exceptional thermal resistance. However, this polymer exhibits poor impact resistance together with very high melt viscosity. Its processing temperature is limited to within 340–370°C.

Poly(phenylene sulfide) (PPS) is a semicrystalline high-performance thermoplastic with outstanding chemical resistance, combined with good mechanical properties and high-temperature resistance. Its properties are affected by crystallinity: Crystalline PPS has a lower elongation at break than does glassy PPS.[2]

Blending of polymers has now become an established method of producing thermoplastic materials with an unusual combination of desirable properties. There has been some work reported on blends of PPS with other high-performance thermoplastics, such as PSF[3,4] and PEI.[3] These blends have shown good mechanical properties, including higher impact strength and tensile strength than those of PPS. Also, the elongation at break is greater than each of the pure components at suitable compositions. High-performance polymer blends containing a thermotropic liquid crystalline polymer (LCP) also have received considerable attention in recent years.[5-12] Because of its low melt viscosity, the LCP phase in these blends forms fibers or ribbons or droplets in the matrix, leading to the formation of the so-called self-reinforced or *in situ* composites. The viscosities of those blends are lower than those of the thermoplastic polymer, thereby making processing easier. It is interesting that a small amount of LCP can improve significantly the processibility and mechanical properties of PES-C, such as impact strength[10] and plane strain fracture toughness.[11] As a continuing study on toughening the PES-C matrix, in this report, we discuss the morphology and mechanical properties of PES-C/PPS blends.

EXPERIMENTAL

Materials and Sample Preparation

The PES-C matrix used in this study was offered by Xuzhou Engineering Plastic Co., China. Its re-

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duced viscosity in chloroform at a temperature of 25°C is 0.37 dL/g. The PPS matrix was offered by Zigong Chemical Reagent Factory China.

Powders of PES-C and PPS were mechanically mixed with compositions ranging from 2 to 25 wt % of PPS in the PES-C matrix. The blends were then extruded at 330–350°C in an SHJ-30 twin-screw extruder and pelletized. Test specimens were injection-molded on an JSW-17SA injection-molding machine (Japan) with barrel temperatures of 325–360°C.

Thermal Analysis

The samples were investigated with a Perkin-Elmer DSC-7 differential scanning calorimeter at a heating rate of 20°C per minute. A DuPont 9900 dynamic mechanical analyzer was also used to study the thermal behavior at a heating rate of 3°C per minute.

Mechanical Testing

The tensile and flexural properties were measured with a WD-100E tester according to ASTM D638 and D790, respectively. Reported values were the average of five measurements for each sample at room temperature. The crosshead speeds were 5 and 20 mm/min, respectively. Unnotched Charpy impact strengths were evaluated using an XCJ-4 Impact Tester at room temperature.

Observation of Phase Morphology

The fractured surface morphologies were observed using a scanning electron microscope (SEM) (Model JAX-840). The samples were sputter-coated with gold before viewing under the microscope.

Melt Flow Index (MFI)

The MFI of PES-C/PPS blends were measured at 340°C under a force of 7.12 kg.

RESULTS AND DISCUSSION

Thermal Studies

In this study, the DSC and DMA method were used for analyzing the PES-C/PPS blends. The DSC traces of PES-C/PPS blends are shown in Figure 1. Features of particular interest are the glass transition temperature (T_g) and the melting endotherms. The T_g of the pure PPS is not evident from this figure. The as-received PPS shows a melting endotherm, T_m, at about 279°C. With increasing PPS content in the blends, the T_g of the PES-C phase decreases while the T_m of the PPS phase increases. This can be clearly seen from Table I where the T_g of the PES-C phase and T_m and the heat of fusion (H_f) of the PPS phase of all the blends are listed.

From the observed melting peak, an amorphous fraction can be calculated, using 53.68 J/g as the H_f for 100 wt % PPS, as listed in Table I.

To characterize the blends further, the dynamic mechanical properties were determined and are shown in Figure 2. Similar to the DSC results, with increasing PPS content in the blend, a slight depression of the T_g of the PES-C phase can be ob-
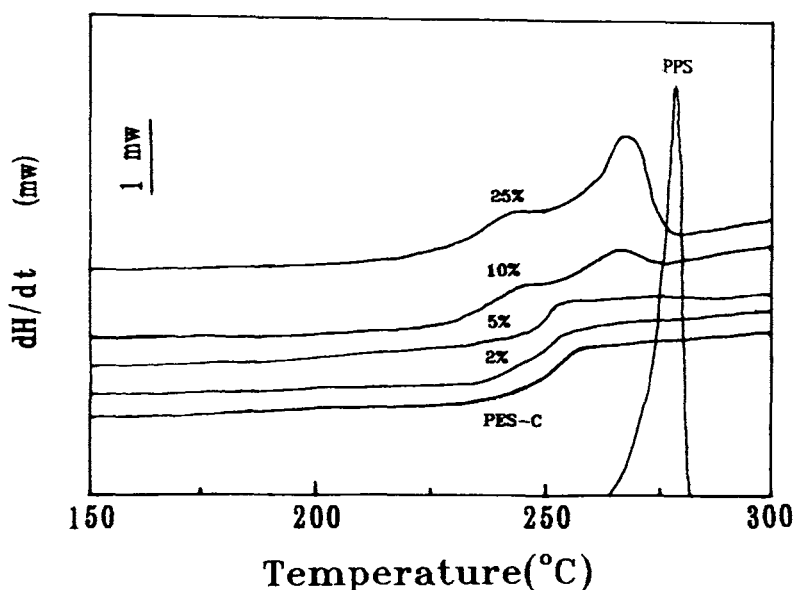
Figure 1 DSC traces of PES-C, PPS, and their blends with different PPS content.

Table I   DSC Results of PES-C/PPS Blends

PPS (%)	T_g (°C)	T_m (°C)	H_f (J/g)	H_f (J/g)[a]
0	245.7			
2	243.0			
5	239.8			
10	237.8	264.1	2.02 (62.4%)[b]	5.37
25	234.5	267.7	6.00 (55.3%)	13.42
100		279.1	53.68	

[a] Calculated value: 53.68 J/g as 100 wt %.
[b] Amorphous fraction.

served. This is different from reported PPS blends with high-performance thermoplastics, such as PEI and PSF.[3] Akhtar and White's studies showed that there was no shift in the melting peak of PPS and the T_g of PEI and PSF.[3] The storage modulus shows an apparent decrease around 110°C followed by a "platform." One may attribute this T_g-type transition to the glass transition of the amorphous phase of crystallized PPS.

According to these results obtained from both DSC and DMA (as shown in Table I), the PES-C/PPS blends, with PPS content less than 25%, contain essentially no crystalline PPS. This indicates that most of the PPS in the blend takes the amorphous form and the PPS blends well mechanically with the PES-C matrix. This is the same as for re-

ported PSF/PPS blends.[4] With PPS < 10%, the blend fails to crystallize even when annealed at 160°C for 2 h.

Mechanical Studies

The tensile strength, flexural modulus, and elongation at break of the PES-C/PPS blends are shown in Figures 3 and 4, respectively. The tensile strength and elongation at break are not much different from those of pure PES-C up to a PPS content of 10%. The blend with a PPS content of 25% shows a marked decrease in both tensile strength and elongation at break. The flexural modulus shows a gradual increase with the addition of PPS and is found to be close to the values using the additive rule of mixtures of the pure materials. These results are quite different from the results of blends containing LCP.[5–10] With increasing LCP content, the tensile strength and modulus of blends with LCP can be improved, but the elongation at break decreases markedly even when the LCP content is as low as 3%, which is the main reason that LCPs have not been used as flow aids in commercial injection-molding formulations.[12] Akhtar and White[3] investigated blends of PPS with PEI and PSF. In their studies, the tensile strength decreases monotonically with increasing PPS content for the PEI/PPS blends and remains unchanged for the PSF/PPS blends. But the elongations at break showed strong maxima at PPS contents of 20 and 50% for PEI/
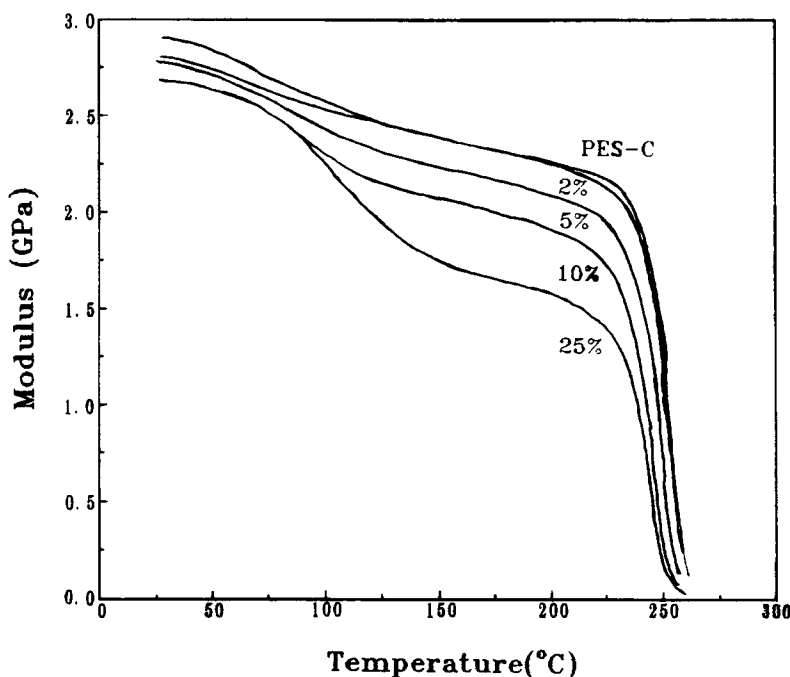
Figure 2   The storage modulus of PES-C/PPS blends with different PPS content.
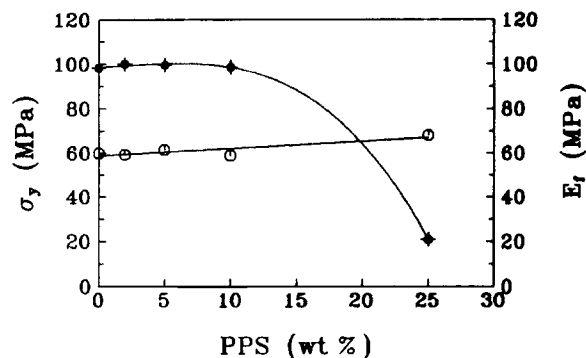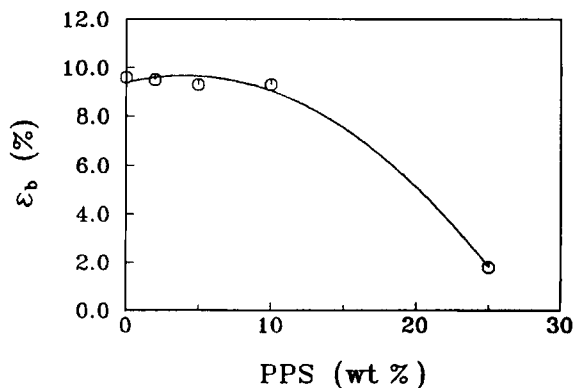
Figure 3 The tensile strength and flexural modulus of PES-C/PPS blends as a function of PPS content.

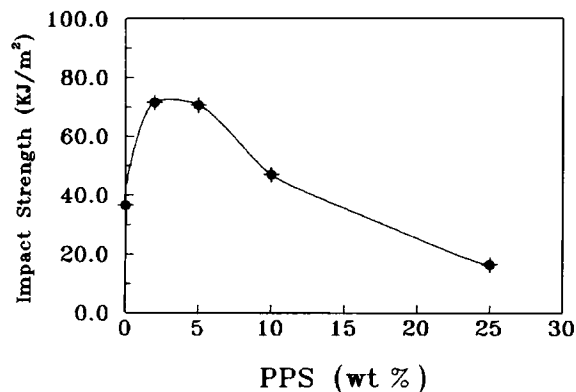**Figure 5** The impact strength of PES-C/PPS blends as a function of PPS content.

PPS and PSF/PPS blends, respectively. It is evident from these results that these PPS blends have good mechanical properties suitable for some components even though the tensile strength and elongation at break, which are about 60 MPa and 4%, respectively, are lower than those of pure PES-C and PEI and PSF.

The brittleness of any polymeric material is often characterized by its impact strength. The unnotched impact strengths of PES-C/PPS blends are shown in Figure 5. The impact strength of the blend exhibits a maximum value, with an increase of 90%, between 2 and 5% content of PPS. Blends with PPS content exceeding 5% show a decrease in the impact strength value. However, the impact strength of the blend with a PPS content of 10% is higher than that of pure PES-C. These results are similar to those of PES-C/LCP blends.[10]

It is understood that when an unnotched specimen is impacted, microcracks generally are initiated at internal weakness or flaws and then gradually develop into cracks that lead to specimen breakage.

Figure 4 The elongation at break of PES-C/PPS blends as a function of PPS content.

For a better understanding of the mechanical properties of the blends, a study of fracture morphology is necessary.

Morphological Studies

Morphological studies on PES-C/PPS blends were undertaken to correlate the mechanical properties with the morphology of the blends. Figure 6(a)-(e) show the scanning electron micrographs of the impact fractured surfaces of the blends. The photograph region was close to the center of the specimen. Many other researchers have reported that blends of PPS and thermoplastics consist of two phases.[3,4] The PPS phase is very finely dispersed in the PES-C matrix in the forms of elongated spherical particles or fibers, which are about 0.1 μm in diameter for blends with 5 and 10% PPS content and 1 μm or less for blend with 25% PPS content.

It can be seen from Figure 6(a) that the pure PES-C fractured in a macroscopically brittle manner for the flat fractured surface with evidence of ductility. The morphology of the blend with 2% PPS content shows no visible ductility [Fig. 6(b)], but the microdrawing structure generated by stress concentration becomes fine. At 5% PPS content, the fracture surface becomes rougher and is steplike [Fig. 6(c)]. Cavitation around the PPS fibers is observed. The morphology of the blend with PPS content of 10% is different from that of the others [Fig. 6(d)]. It seems that the blend fractured in a more ductile way than did the others because of the evidence of ductile tearing morphology for PES-C matrix. As can be seen from Figure 6(e), the fracture surface of the blend with 25% content of PPS is flat with no visible sign of deformation. Also, there is no cavitation
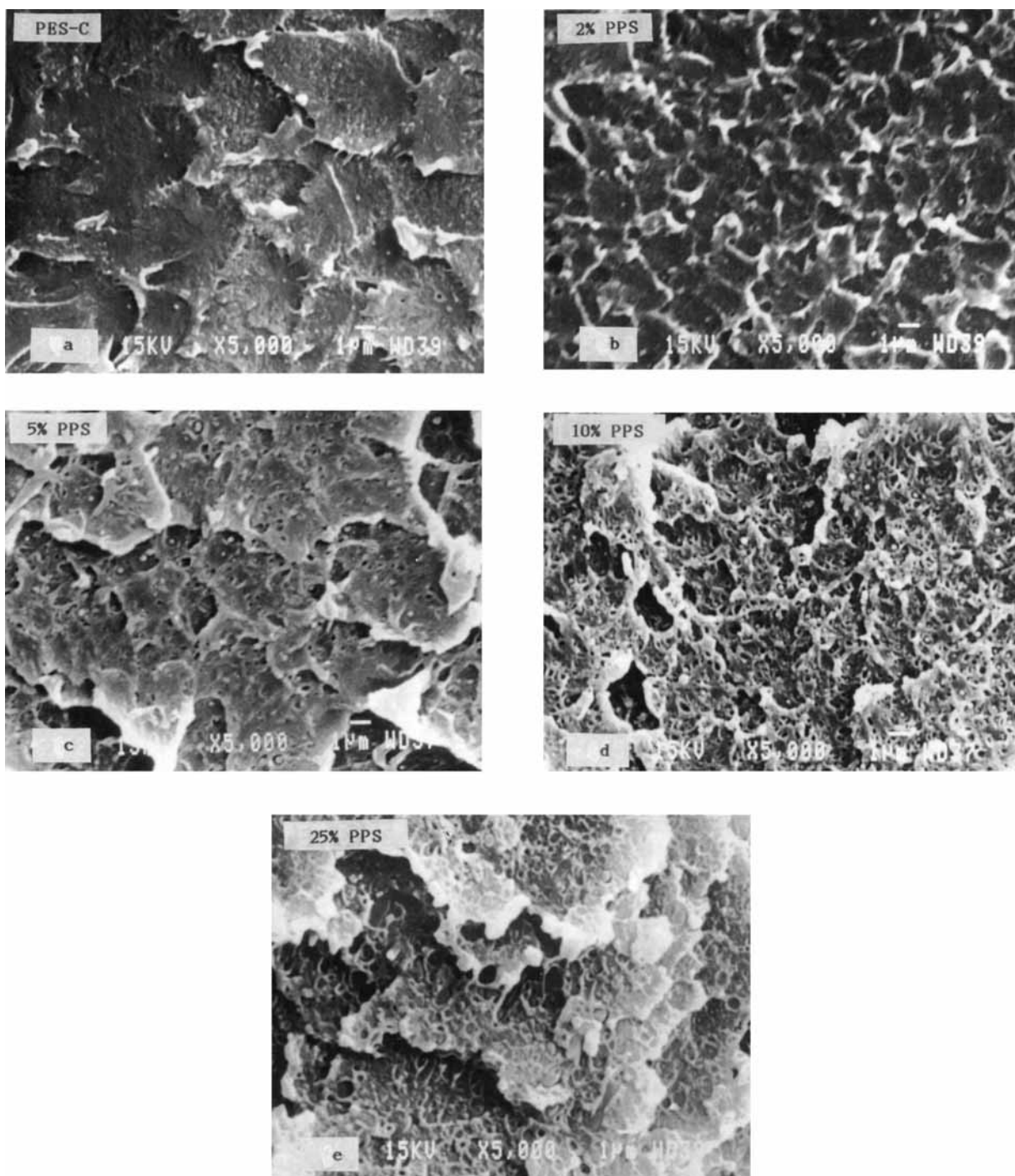
Figure 6 SEM photographs of the impact fractured surfaces of the PES-C/PPS blends.

around the dispersed PPS phase. In this case, the adhesion of the PPS phase to the PES-C matrix is found to be better. This also confirms the finding from thermal studies, indicating strong interaction between the two phases. One may therefore consider that amorphous PES-C blends well with the semi-

crystalline PPS. The cavitations shown in Figure 6(c) and (d) may be the result of the release of the interfacial stresses and not be evidence of poor interfacial adhesion.

The improvement in impact strength can be explained as follows: When mechanical stress is ap-

plied to the pure PES-C, the stress concentration at the internal weakness or flaws is known to initiate crazes that then develop into cracks more rapidly though the sample, thus causing complete failure in a brittle manner. However, incorporation of the PPS phase changes this case. Owing to the fine size of the PPS fibers dispersed uniformly in the PES-C matrix, the applied stress may concentrate at these fibers and disperse throughout the sample. The initiation and development of crazes may cause the PES-C matrix to undergo more deformation and therefore extend the regions of localized energy dissipation, thus resulting in more impact energy absortion. The energy required for loss of interfacial adhesion and the deformation of the amorphous PPS, which is essential in the PPS phase as mentioned above and has larger elongation at break than does crystalline PPS, may also contribute to the improvement of impact. In our next article on the PES-C/PPS blends, we will discuss the toughening effect from the deformation of PPS by means of the techniques of linear elastic fracture mechanics.

Processibility

Owing to the rigidity of the main chain and the pendant cardo groups, PES-C has many excellent properties, such as high-temperature stability, high T_g, and good mechanical properties and solvent-resistance, which rank it as one of the promising high-performance engineering plastics. But one of the disadvantages of PES-C is its very high melt viscosity. Therefore, improvement in processibility will be of considerable benefit to its application for engineering. One of the aims of blending PES-C with the semicrystalline PPS is to take advantage of the much lower flow viscosity of PPS for improving the processibility of PES-C.

In Figure 7, the melt flow index (MFI) of the blends, measured at 340°C, is plotted vs. PPS content. The MFI of the blends increase with increasing PPS content. But for 2% content of PPS, the MFI is slightly lower than that of pure PES-C, i.e., the melt viscosity of the blend is slightly higher than that of pure PES-C. This phenomenon has been called a positive deviation from the additivity rule and is considered to be due to a large interaction between the two phases of the blends.[13]

At 10% content of PPS, the MFI is much higher. So, the addition of PPS to PES-C, like that of LCP,[10] can improve the processibility of PES-C. This improvement would be reflected in a reduction in the
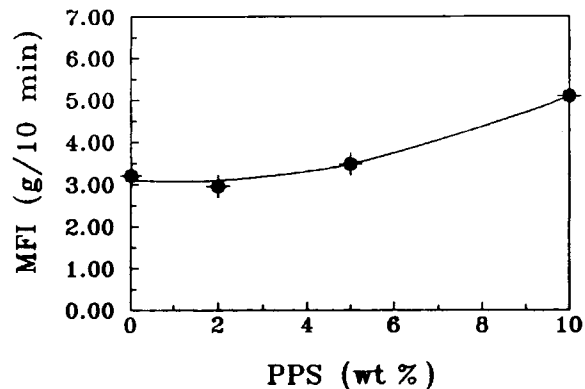
Figure 7   The melt flow index of PES-C/PPS blends as a function of PPS content.

extruder temperature, torque, and melt pressure and as a result the processing temperature (about 10°C lower than for pure PES-C for the blend with 10% content of PPS).

CONCLUSIONS

PES-C/PPS blends are multiphase systems and there are strong interactions between the two phases. The glass transition temperature of the PES-C phase decreases, while the melting peak temperature of the PPS phase increases with increasing PPS content in the blends.

Though the strength and ductility of PPS is lower than that of PES-C, PPS can be used as a toughening agent as well as flow aid for PES-C resin. The addition of a small amount of PPS into the PES-C matrix results in a significant improvement in the impact strength and processibility without changing the high strength of the PES-C resin. Compared with the PES-C/LCP blends, from the commercial viewpoint, the PES-C/PPS blends have a reasonable potential for application.

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