# Impact Behavior of Phenolphthalein Poly(ether sulfone)/ Ultrahigh Molecular Weight Polyethylene Blends

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**ABSTRACT:** This work presents the structure and impact properties of phenolphthalein poly(ether sulfone) blended with ultrahigh molecular weight polyethylene (PES-C/ UHMWPE) at different compositions. The addition of UHMWPE can considerably improve the Charpy and Izod impact strength of the blends. The fracture surface is examined to demonstrate the toughening mechanics related to the modified PES-C resin. © 1998 John Wiley & Sons, Inc. J Appl Polym Sci **67:** 113–118, 1998

**Key words:** impact behavior; phenolphthalein poly(ether sulfone); ultrahigh molecular weight polyethylene

## INTRODUCTION

Phenolphthalein poly(ether sulfone) (PES-C) is a high performance thermoplastic developed in this institute in 1985.[1] Because of its bulky phenolphthalein side group, PES-C is an amorphous polymer with a very high glass transition temperature (245°C by DSC), and above 330°C it will soften and melt gradually because it does not have a distinctive melting point. Its high thermal resistance and excellent mechanical properties allow its use as a high performance engineering material.

Toughening of polymers such as polycarbonate (PC),[2–7] poly(ethylene terephthalate),[8–10] polyamide,[11–14] and others[15–18] with PE has been reported. In these toughened blends, the toughening effect of PE has been found to be quite remarkable.[5,6] Sue et al. examined the toughening mechanism in the PC/PE system and found that the toughening process in the blend is not internal cavitation of the toughener phase, as in the case of the rubber toughened polymer system, but is instead debonding of the PE particles from the matrix.[7]

In these PE toughened blends, the toughening phases are either high density PE or low density PE. In fact, ultrahigh molecular weight PE (UHMWPE) can also be used as the toughening phase.

UHMWPE is one of the leading plastics that has been developed in recent decades. The outstanding properties of UHMWPE, such as toughness, high wear strength, and abrasion resistance, provide not only new utility but also scientific interest.[19] But because of its very high molecular weight (over $10^6$), UHMWPE is actually in an elastic state and resists flow above its melt point; thus, it is difficult to process. Because of the poor flow of UHMWPE, the number of reports on UHMWPE blends with other polymers has been limited, despite the explosion in polyblend uses, especially with engineering polymers.[20–26] This work on PES-C/UHMWPE blends is a continuing study in our laboratory[27–29] on toughening the PES-C matrix; the thermal properties will be reported on elsewhere.[30]

## EXPERIMENTAL

### Materials and Sample Preparation

The PES-C matrix used in this study was provided by Xuzhou Engineering Plastic Co. of China.
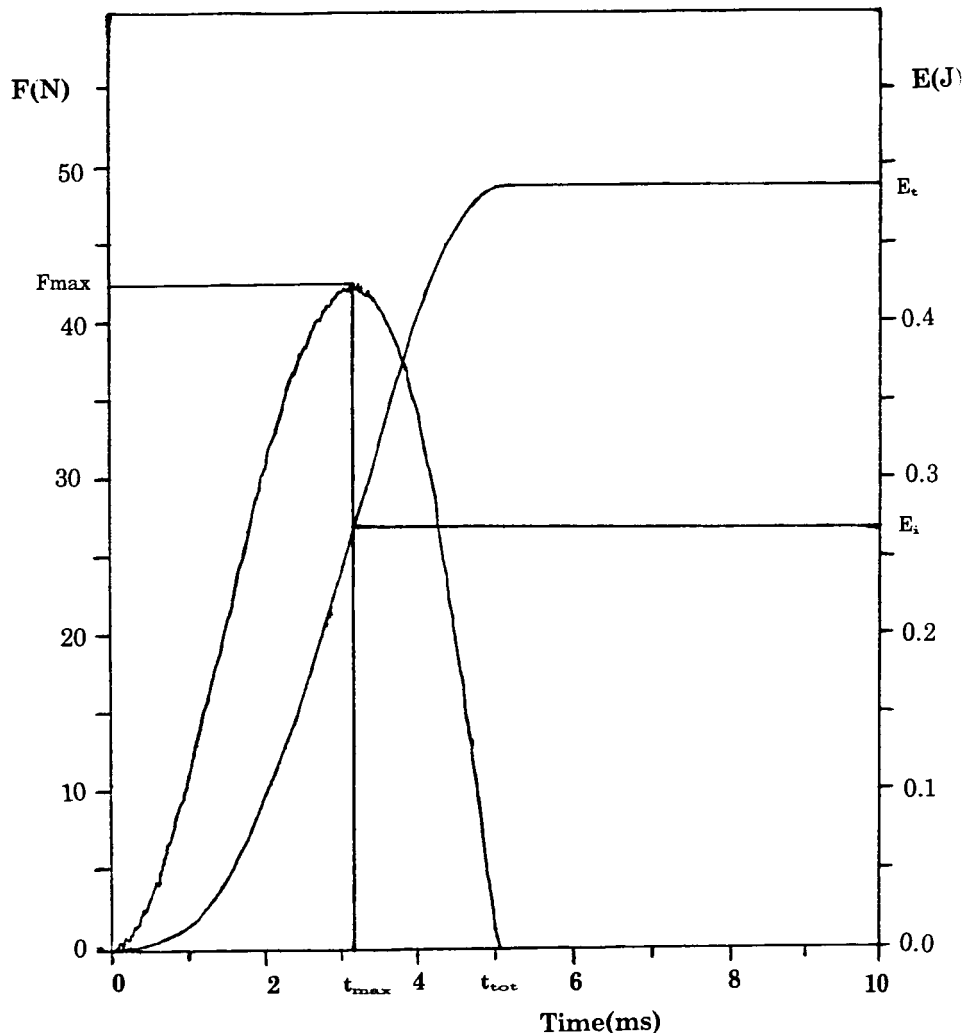
**Figure 1**   Load time and energy time of PES-C/UHMWPE blends.

Its reduced viscosity in chloroform at a temperature of 25°C is 0.34 dL/g. UHMWPE was obtained from the No 2 Reagent Plant of Beijing; its molecular weight exceeded $10^6$. Both polymers were obtained in powder form; the UHMWPE particle size was 110 mesh (diameter 0.140 mm).

Powders of PES-C and UHMWPE were mechanically mixed with compositions ranging from 2 to 25% (weight) of UHMWPE in the PES-C matrix. The blends were then extruded in an SHJ-30 twin-screw extruder (Nanjing Rubber and Plastic Machinery Co., China) and pelletized. Charpy and Izod impact test specimens were injection molded in a JSW-17SA injection-molding machine (Japan) with a barrel temperature of 340–345°C.

## Impact Tests

Charpy and Izod impact strengths were measured with a JJ-20 Mode Instrumented Impact machine (The Intelligent Instrument and Apparatus Institute, Changchun, China). The impact machine was instrumented so that the load time, $F(t)$, curve could be recorded automatically, and this curve was integrated to also record the energy time, $E(t)$, curve. The impact speeds for the Charpy and Izod were 3.8 and 3.35 m/s, respectively. A dimensionless parameter, the ductile index (DI), obtained here (see Fig. 1) was used to characterize the toughness of the material,[30] which was defined as the ratio of propagation energy to the initiation energy. In addition, the maximum load and the effective impact time were also determined.

## Morphology Observation

The fractured surface morphologies were observed using a scanning electron microanalyzer
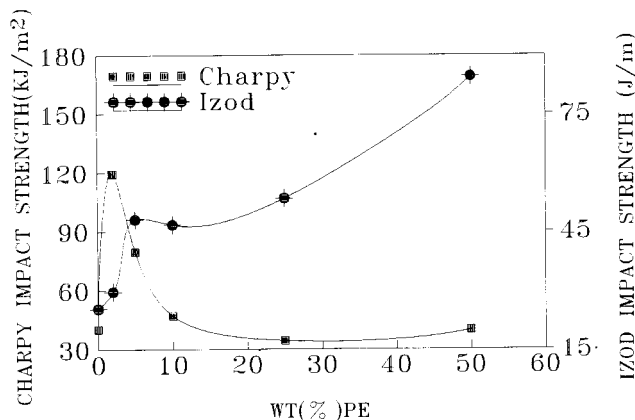
**Figure 2** Charpy and Izod impact strengths of PES-C/UHMWPE blends vs. PE concentration.

(SEM) (model JXA-840). The samples were sputter coated with gold before viewing under the microscope.

## RESULTS AND DISCUSSION

### Impact Results

Figure 2 shows the Charpy and Izod impact strengths of the PES-C/UHMWPE blends against blend composition content. The influence of the incorporation of the UHMWPE is significant. In this study, when the UHMWPE concentration was 2 wt %, the Charpy impact strength was considerably higher (about 200%) than the pure PES-C. With the concentration of UHMWPE increased to 5 wt % and higher, the Charpy impact strength decreased gradually. Compared to the Charpy impact strength, the notched Izod impact strength (NIS) increased slightly when the UHMWPE was 2 wt %. When the concentration of UHMWPE reached 5 wt %, NIS greatly increased. The NIS stayed at almost the same level when the UHMWPE was increased further.

Tables I and II show the details obtained from the Charpy and Izod impact tests. From the tables

we can see that all of the ductility indexes are approximately equivalent, but differ as the impact mode is changed. That indicates that the failure processes in Charpy and Izod impact are different. In Charpy impact the failure mode is cracking on the unimpacted side. The cracks are initiated by internal flaws or weakness. When the subcritical cracks propagate into catastrophic ones, complete fracture will occur. But in notched Izod impact, the notch has a stress concentration effect, the cracks initiate from the root of the notch, and they consequently propagate through the specimen. The invariability of the DI of the blends might mean that it is an intrinsic characteristic property of the matrix in the blends. In addition, in the Charpy test a bar specimen rests on horizontal supports against two upright pillars and is struck centrally. On impact the specimen fractures as a result of the whole specimen synergetic effect. In the Izod test the clamp at the lower end causes a significant difference in impact energy absorption. The fracture and energy absorption processes are localized in the notch root region.

### Morphology Study

The fracture surfaces of the pure PES-C and of the blends in the notched Izod impact tests are shown in Figures 3–6. The brittle fracture surface is observed in the pure PES-C (Fig. 3). The surface possesses distinctive fast-fracture features; that is, the surface is relatively smooth and very limited plastic deformation can be observed. This might be the reason for the low toughness of the pure PES-C.

The semibrittle fracture surfaces observed for 2 and 5% UHMWPE blends are essentially the same (Figs. 4, 5). Plastic deformation can be seen in the surfaces. UHMWPE at low content disperses finely in the PES-C matrix. The small-scale yielding appears to be strongly promoted by the presence of the modifier particles. Whitening can be observed at the root of the notch in the blends.

**Table I   Details of PES-C/UHMWPE Blends in Charpy Impact Test**

| Composition (PE %) | $F_{max}$ (N) | $t_{max}$ (ms) | $t_{tot}$ (ms) | $E_t$ (kJ/m²) | $E_i$ (kJ/m²) | $E_p$ (kJ/m²) | DI |
|---|---|---|---|---|---|---|---|
| 0 | 109 | 2.74 | 4.40 | 41.6 | 23.4 | 18.2 | 0.77 |
| 2 | 242 | 3.49 | 5.68 | 119.4 | 67.1 | 52.3 | 0.78 |
| 5 | 173 | 3.12 | 5.09 | 79.9 | 45.7 | 34.2 | 0.75 |
| 10 | 116 | 2.74 | 4.61 | 47.1 | 26.9 | 22.1 | 0.75 |
| 25 | 95 | 2.55 | 4.28 | 34.4 | 19.5 | 14.9 | 0.76 |

**Table II   Details of PES-C/UHMWPE Blends in Izod Impact Test**

| Composition (PE %) | $F_{max}$ (N) | $t_{max}$ (ms) | $t_{tot}$ (ms) | $E_t$ (J/m) | $E_i$ (J/m) | $E_p$ (J/m) | DI |
|---|---|---|---|---|---|---|---|
| 0 | 19.5 | 2.20 | 4.03 | 25.4 | 12.7 | 12.7 | 1.00 |
| 2 | 22.5 | 2.35 | 4.15 | 29.7 | 15.1 | 14.6 | 0.97 |
| 5 | 35.6 | 2.55 | 4.35 | 46.6 | 23.4 | 23.2 | 0.99 |
| 10 | 34.5 | 2.43 | 4.30 | 46.7 | 23.8 | 22.9 | 0.96 |
| 25 | 39.2 | 2.46 | 4.33 | 53.4 | 27.1 | 26.3 | 1.03 |

Figure 6 shows the enlarged scanning electron micrograph of the 2% UHMWPE blends, from which we can discern the dispersed UHMWPE particles cavitating and stripping off the PES-C matrix. The existence of dispersed UHMWPE particles has a strong influence on the fracture behavior of the PES-C matrix.

When UHMWPE concentration reaches 10%, the fracture surface is unique: the UHMWPE phase coalesces into fibers and the blends break in a more ductile manner (Fig. 7).

In the Charpy impact tests, visual observation shows that the pure PES-C specimen fractures in a brittle manner, the mirror area (fracture nuclei) is nucleated at random from the unimpacted side, and it suddenly propagates to a final fracture. But in 2% UHMWPE blends the fracture specimen shows significant shear yielding regions at the unimpacted side. No yielding can be observed in the blends containing higher UHMWPE.

Figure 8 shows the magnified photographs of the Charpy impact fracture surface of a 25% UHMWPE blend. The fracture surface is steplike. It can be observed that the blend fractures from the UHMWPE phase rich region. The dispersed PE phase has severe plastic deformation but no break can be observed. The slip fracture of the blend needs less energy, thus the Charpy impact strength is relatively low when UHMWPE concentration is high.

## DISCUSSION

It can be seen from the SEM micrographs of blends that the PES-C matrix and UHMWPE are immiscible in all of the composition range. This is also supported by the thermograms from DSC and dynamic mechanical analysis,[30] in which we can clearly discern the melting peak of UHMWPE at around 130°C, even in the blends containing as low as 2% UHMWPE. But for partially miscible PES-C/PPS blends, the melting peak of PPS does not appear until the Poly (p-phenylene sulfide) (PPS) concentration reaches 10% by weight.[27]

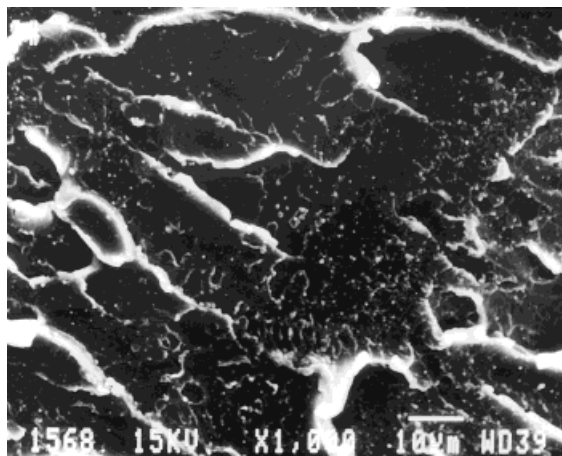The addition of UHMWPE is significant for the



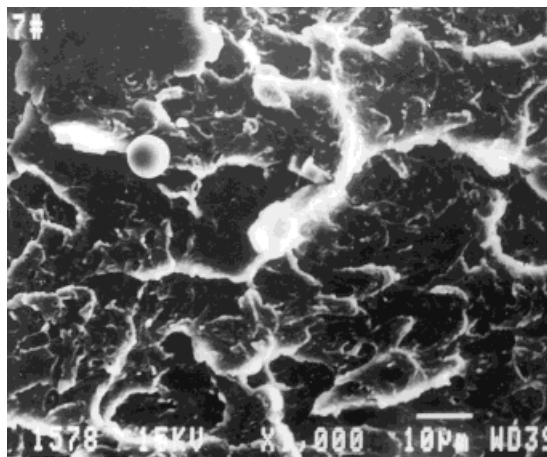**Figure 3**   SEM micrograph (×1000) of Izod impact fractured surface of pure PES-C.



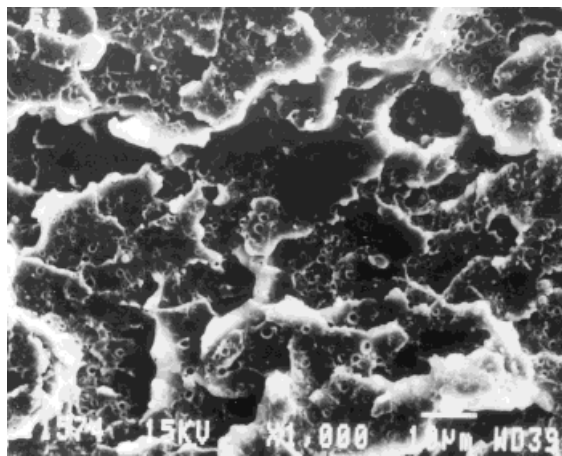**Figure 4**   SEM micrograph (×1000) of Izod impact fractured surface of PES-C/UHMWPE blends containing 2% weight PE.

**Figure 5**  SEM micrograph (×1000) of Izod impact fractured surface of PES-C/UHMWPE blends containing 5% weight PE.



**Figure 7**  SEM micrograph (×1000) of Izod impact fractured surface of PES-C/UHMWPE blends containing 10% weight PE.

improvement of toughness of the blends for both of the two impact modes, although the concentration of UHMWPE has different effects on the two impact modes. The toughening effect can be attributed to the following reasons.

When UHMWPE blends with the PES-C, there is an interdiffusion process at the PES-C/UHMWPE interface. UHMWPE, which diffuses into the PES-C matrix, improves the plasticity of the PES-C matrix around the dispersed UHMWPE, which makes the PES-C matrix in the blends less rigid than pure PES-C resin.

The uniform distribution of the UHMWPE disperse phase in the blends eliminates internal flaws and defects or decreases the size of flaws and defects to a harmless dimension, stabilizing the matrix and ensuring it will endure more severe stress conditions.
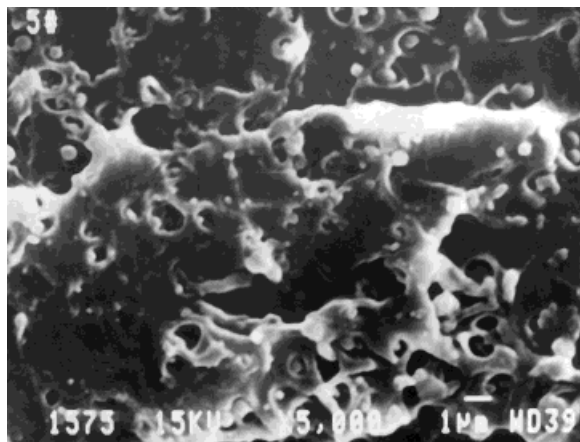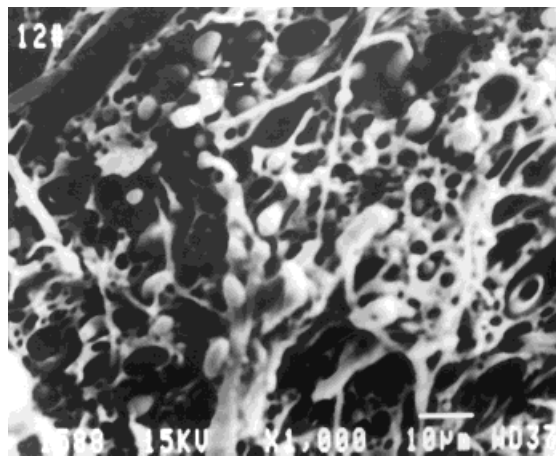
The diffused UHMWPE phase ensures local shear yield or deformation prior to the matrix beginning to deform and induces stress concentration in the blends, therefore changing the stress condition, which tends to improve the maximum load during impact.

Furthermore, the UHMWPE phase deformation and separation from the matrix dissipate much of the energy and assimilate the energy more effectively, postponing the fracture initiation and propagation by stabilizing the crack, thus improving impact strength.

## CONCLUSION

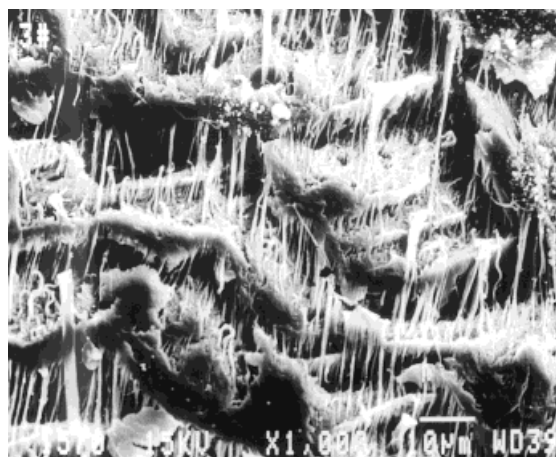The impact behavior of PES-C/UHMWPE blends is reported. The influence of the incorporation of



**Figure 6**  Magnified SEM micrograph (×5000) of Figure 4.



**Figure 8**  SEM micrograph (×1000) of Charpy impact fractured surface of PES-C/UHMWPE blends containing 25% weight PE.

UHMWPE in PES-C is significant. The Charpy impact strength (unnotched) increases significantly at low UHMWPE concentration (2% weight), and the notched Izod impact strength of the blends improves greatly when the UHMWPE composition reaches 5% and higher.

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