Structure and Mechanical Properties of UHMWPE/EPT Blends and Their Vulcanizates

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INTRODUCTION

Polymer blends and alloys have been widely studied concerning the preparation method, the statistical thermodynamic approach on compatibility, the mechanical property, the formation of structures in various blend or alloy systems, summarized in several books[1-4]. Much attention has been paid to the high performance of elastomers, including the reinforcement of rubber by blends[5]. Among them, the short-fiber reinforced rubber must be one of the most useful methods to improve the mechanical property[6,7].

Recently, the mechanical properties, the morphology and the crystallization behavior have been investigated in the systems[6-12] of ethylene-propylene-diene terpolymer (EPT) or ethylene-propylene copolymer (EPR) blended with crystalline polyolefins, such as high-density polyethylene (HDPE), low-density polyethylene (LDPE) and isotactic polypropylene (iPP).

On the other hand, ultra-high molecular weight polyethylene (UHMWPE) is well known to have a special character of ultra-high drawability by gel-spinning, resulting in a limited extended structure to give a fine property such as ultra-high strength and modulus[13,14].

This report illustrates some structure and properties of UHMWPE/EPT blends and thieir vulcanizates.

EXPERIMENTAL

Material

Ultra-high molecular weight polyethylene (UHMWPE: Hizex Million 240M, $Mv=2\times10^6$) was kindly supplied from Mitsui Petroleum Chemical Co. Ethylene-propylene-diene terpolymer (EPT: Esprene 505, 52wt% ethylene, 48wt% propylene component, a little of ethylidene norbornene) was purchased from Sumitomo Kagaku Kogyo Ltd.

Blend film preparation

The blend films of UHMWPE and EPT were prepared from 1 wt% solution in hot decalin with the different weight ratio of UHMWPE/EPT, according to the method of Iguchi et al[17]. The thickness of the blend was about 0.1 mm.

Vulcanized EPT rubber preparation

The EPT rubber was mixed with the UHMWPE/EPT (50/50) blend film or the UHMWPE powder so as to contain 10 phr (parts per hundred resin) of UHMWPE on a roll mill at 40 rpm at 140°C for 10 min. Then, the vulcanizer, consisting of 3 phr of zinc oxide, 2 phr of each stearic acid and sulfur, and 1.6 phr of facilitating agent of TBBS, was added and they were mixed at 40 rpm at 110°C for 4 min to produce a sheet about 1 mm thick. The sheet was vulcanized at 160°C for 20 min.

Measurements

DSC measurement was performed on a Seiko Denshi Kogyo DSC 200 differential scanning calorimeter at a constant heating rate of 10 K/min.

Tensile test was carried out on a Shimadzu AUTOGRAPH IM 100 at 10 mm/min at 25°C for UHMWPE/EPT blend films 0.3 cm wide and 2 cm long.

Wide-angle X-ray diffraction photographs were obtained with a Toshiba Model XC100H, utilizing nickel-filtered CuKα radiation.

RESULTS AND DISCUSSION

A relatively large and monotonous decrease in the melting temperature of UHMWPE can be seen with decrease of the UHMWPE content as shown in Figure 1. It seems that the amorphous EPT molecules may prevent the crystal lamellae of UHMWPE from growing, as observed in other blend systems[18,19], though there is also a little possibility of compatibility of both polymers.[20,21] Whereas, the heat of fusion changes linearly with the UHMWPE content, which means that the EPT component does not affect the crystallinity of UHMWPE. Accordingly, a lot of small crystallites should be formed in the blend films, which was realized in a polarized optical microscopic observation that many scattered retardations with brightness (or optical anisotropy) appeared under a cross polarizing condition.

The glass transition temperature of the blend films, judging from the baseline gap of DSC curves, may shift slightly to higher temperatures as the EPT content decreases. This may suggest the partial miscibility between EPT and UHMWPE molecules in the amorphous phase.

Stress-strain curves of blend films are shown in Figure 2. The yield stress, the Young's modulus (estimated from the initial slope) as well as the breaking strength decrease as the EPT content increases. However, the variation of breaking strains should be noticed; it has a maximum strain at the 50% EPT content. It was very large and several times as much as that of the pure UHMWPE film though the pure EPT film (0/100) behaved like a clay to be torn off easily. It implies that there must exist an intermolecular interaction between them, while the modulus simply varies with the UHMWPE content. In other words, the molecules of two components should be partially in a miscible state in the amorphous phase. The large breaking strain must be due to the adequately loose chain entanglements between UHMWPE and EPT molecules.

Figure 3 shows the stress-strain curve of vulcanized EPT rubber, which was mixed and rolled with the UHMWPE/EPT (50/50) blend, together with those of the corresponding reference rubbers. You can see the remarkable effects such as the higher strength and Young's modulus, i.e., the improvement of mechanical properties in the EPT rubber. This must be caused by the UHMWPE molecules with

the content of 10 phr in the EPT rubber. However, the UHMWPE powder (or the original UHMWPE sample) indicated the opposite effect on mixing; the decrease of strength and the increase of elongation, implying rather the effect like an internal lubricant. It is, after all, important to utilize the blend film for improvement. At the same time, it should be noted that the UHMWPE fibers, long enough and 10 to 20 μ m thick without a fine circular cross-section, were formed only when the blend film was used for mixing. Thus, there must be a quite difference in the molecular behavior of UHMWPE, depending on the UHMWPE/EPT blend film or the original UHMWPE powder, on roll mixing to EPT rubber.
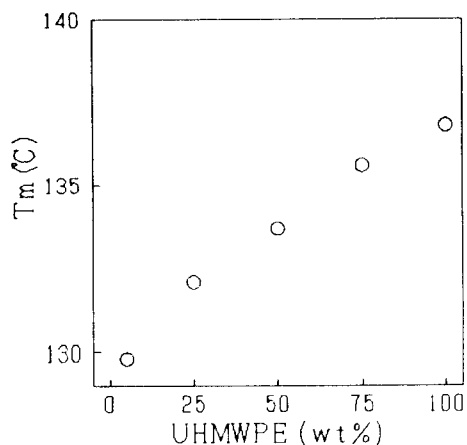

Figure 1   Variation of melting temperature of UHMWPE/EPT blends as a function of UHMWPE content.
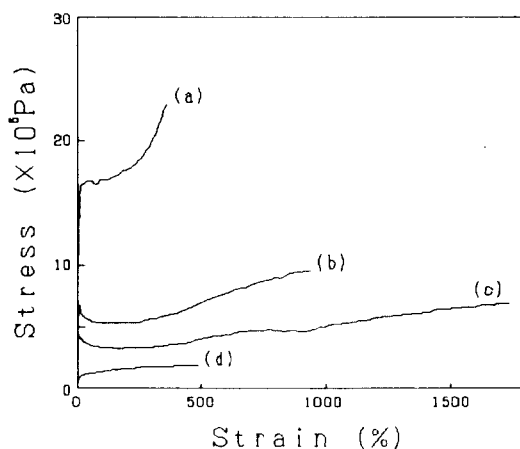

Figure 2   Stress-strain curves of UHMWPE/EPT blend films prepared from the solution, with the weight ratio of (a) (100/0), (b) (75/25), (c) (50/50) and (d) (25/75), measured at 25 °C.
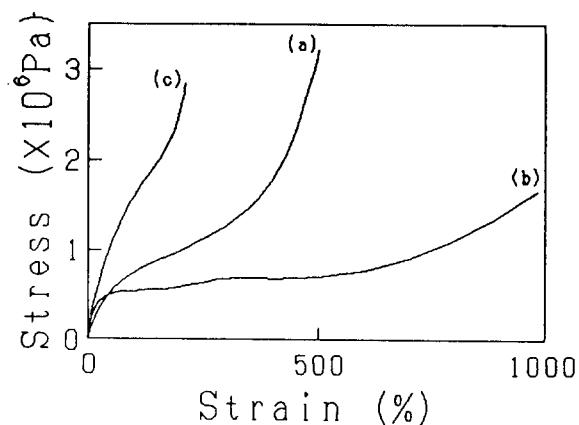
Figure 3　Stress-strain curves of vulcanized EPT rubbers; (a) pure EPT,
(b) and (c) EPT mixed with UHMWPE powder or UHMWPE/EPT(50/50)
blend film so as to contain 10 phr of UHMWPE before vulcanization.

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