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Polypropylene/polyamide-6 blends based on commingled plastic wastes

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Synthetic polymers possess many advantages, including well-balanced supply, low cost, and good processability compared to other conventional materials, so that these properties have led to useful applications of polymers from cheap daily necessities to expensive industrial composites. However, these polymers, generally obtained from the petrochemical industry have been rarely recovered and reused, causing environmental pollution. These problems can be reduced by either recycling or using biodegradable polymers [1].

Among these, as an economically desirable way of reusing recycled polymeric compounds with satisfactory cost/performances and application potentials, we can recycle mixed waste plastics in the form of blends. This approach of reusing is attractive, because it avoids the difficult task of separating waste plastics [2, 3]. Furthermore, polymer blending techniques have been utilized to improve the performance of polymeric materials by combining the best characteristics of each constituent, making it possible to fit the customers' specifications at relatively cheap price [4, 5].

Nonetheless one technical problem associated with plastics waste is its heterogeneous composition, immiscibility and poor interfacial adhesion between dispersed phase and matrix, resulting in the polymer blends having poor physicomechanical properties such as low tensile strength and impact toughness [3, 6]. To solve this problem, compatibilizers such as graft or block copolymers are now being used as a well-established route, whose segments can give rise to interactions with the blend components, by not only reducing the interfacial tension but also improving the phase dispersion and adhesion through interpenetration and entanglements at the polymer/polymer interface [6].

In the work described in this letter, using polypropylene (PP)/nylon blend based on commingled polymer wastes which was melt-processed with styrene-ethylene-butylene-styrene (SEBS) as a compatibilizer, we invetigated the effect of compatibilizer on its fractured surface morphologies, rheological behavior, and mechanical properties. Especially through rheological measurements, we focus on flow behavior of the polymer blends which is of great importance to optimize their processing conditions.

Blends of recycled PP and nylon (polyamide-6) with the composition ratio of 75/25 by weight were prepared using a corotating twin-screw extruder (PRISM TSE 16TC, $L/D = 7.5$, Thermo Electron Co., Woburn, MA, USA). In the temperature range of 180–250 °C, the extrudate was processed in the form of pellet at a screw speed of 50 rpm. Then, the prepared composites were carefully dried under vacuum at 80 °C for 24 hr. During the process, SEBS was added into the twin-screw extruder as a compatibilizer. Fractured surface morphologies were investigated using scanning electron microscope (SEM) with 2 k magnification at 15 kV. In addition, to measure the rheological properties, we used a rotational rheometer (MCR 300, Physica, Stuttgart, Germany) equipped with a parallel-plate geometry of 1.1 mm thickness and 25 mm diameter at 190 °C. Furthermore, samples for the tensile (Model 420, Instron) and impact (ITR-2000, RADMANA) tests were prepared using Baby Plast 6/10 under 120 bar at 250 °C. The tensile and impact properties for the prepared samples were measured at a crosshead speed of 10 mm/min and averaged.

The fractured surface morphologies of the PP/nylon (75/25) blend compatibilized with SEBS and without compatibilizer were investigated to verify the role of compatibilizer in the PP/nylon blend. For the morphological investigations, fractured surfaces were coated with platinum to provide conductivity on its surfaces. By the addition of SEBS, it was expected that the roughness of the fractured surface would be decreased due to the enhancement of miscibility between PP and nylon. However, Fig. 1a shows the relatively smooth surface of PP/nylon blend without compatibilizer at the magnification of 2 k compared with Fig. 1b which represents a rougher surface than that from the PP/nylon blend (75/25), though the SEBS as a compatibilizer was added. On the basis of this result, we can conjecture that compatibilizing effect of the SEBS for the PP/nylon blend is not good enough.

As one of the rheological properties at 190 °C, the dependence of shear viscosity was plotted as a function of shear rate for PP, nylon, and its blends, measured via a rotational rheometer. From this steady shear test, we could find that the steady shear viscosities increased

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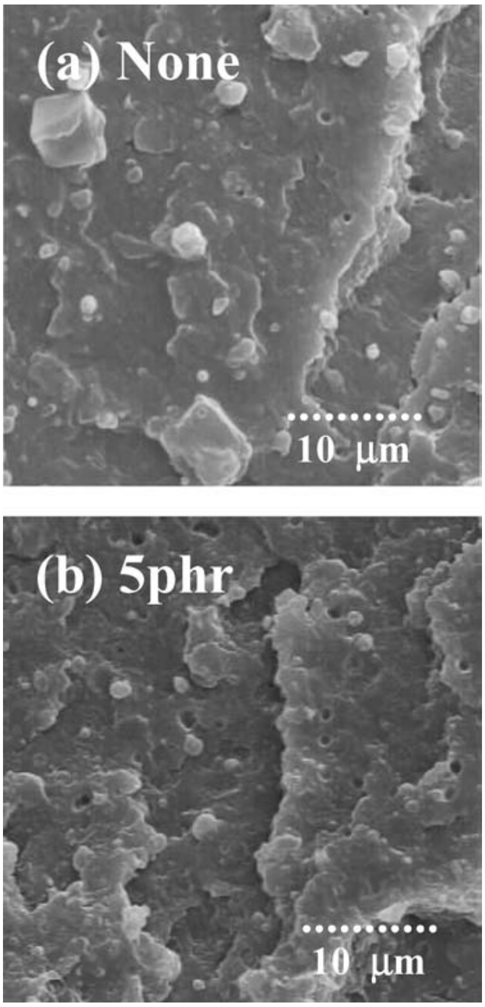

Figure 1 Scanning electron micrographs (SEM) of PP/nylon (75/25) blends containing SEBS (a) None and (b) 5 phr at the magnification of 2 k.

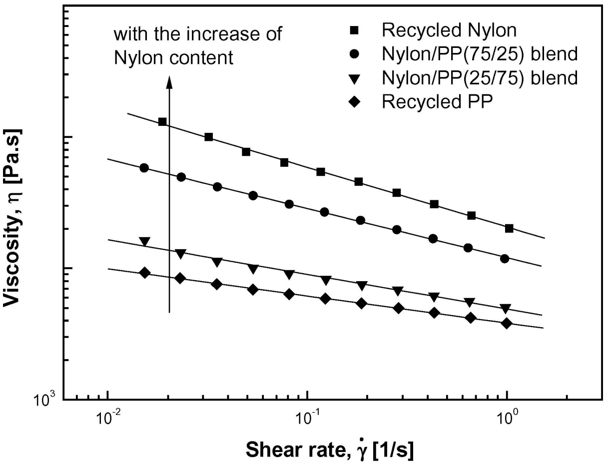

Figure 2 Steady shear viscosity of PP, nylon, and its blends at 190 °C.

with recycled nylon contents, however the shear viscosity of all the blend compositions tested decreased with shear rate, which is an indication of a pseudoplastic behavior. Moreover, the degree of shear thinning is more enhanced by the addition of recycled nylon. However, in the case of recycled PP, not much shear dependence was observed. From these results, we can conclude that the recycled nylon exhibited solid-like property with a long relaxation time as compared to the recycled PP.

Furthermore, in order to investigate the effect of SEBS as a compatibilizer on relaxation behavior for PP/nylon blend (75/25), we fitted the measured shear viscosity using the following Carreau model equation [7]:

$$\eta = \frac{\eta_0}{[1 + (\dot{\gamma}\lambda)^2]^{(1-n)/2}} \tag{1}$$

where η_0 is the zero shear rate viscosity, λ is the characteristic time, and n is a dimensionless parameter. The slope in the power-law region is given by $n - 1$. Note that in the special case of $n = 1$ or $\dot{\gamma}\lambda \to 0$, this model reduces to the Newtonian fluid model possessing a constant shear viscosity, and if $n < 1$, the model predicts a shear-thinning behavior [8, 9]. From the results obtained by the curve fitting of the experimental data in Fig. 3, we could find that the n value for PP/nylon blend is independent of the SEBS contents, and the steady shear viscosity slightly increased with SEBS content. This result may be attributable to the weak interaction of SEBS to PP and nylon. Thus, we could expect that the compatibility promoted by the added SEBS results in a weak network structure between the blend components at the interface, causing the reduction in the interlayer slip, thereby increasing the viscosity [10]. The contribution of this network structure in viscoelastic behavior can be effectively expressed by a frequency dependence of phase angle (δ) [11, 12], and its detailed investigation will be considered in future communications.

As the mechanical properties, tensile strength and impact strength with a compatibilizer content for the PP/nylon (75/25) blends are shown in Fig. 4. With increasing a compatibilizer content, we can expect that interfacial adhesion would be improved, and thus, tensile strength would be increased. This is thought to be attributable to the compatibilization effect of the SEBS at the interface; that is, the formation of a network structure at PP/nylon interface [3, 13]. However, the tensile strength of the PP/nylon blends compatibilized with SEBS was not enhanced as compared to the PP/nylon

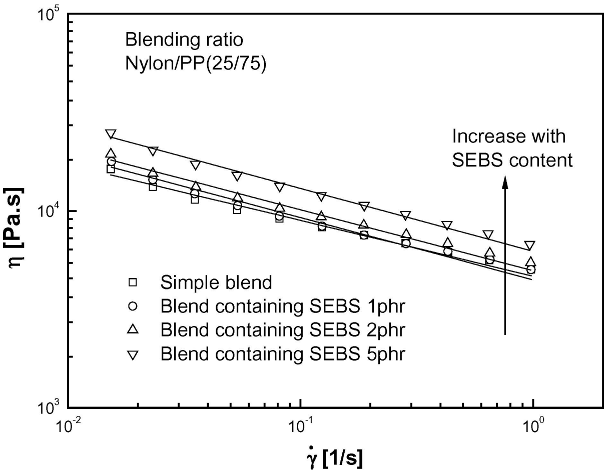

Figure 3 Steady shear viscosity of simple PP/nylon blend and PP/nylon blend containing SEBS at 190 °C. (Lines represent the curve-fitting results based on Equation 1.)

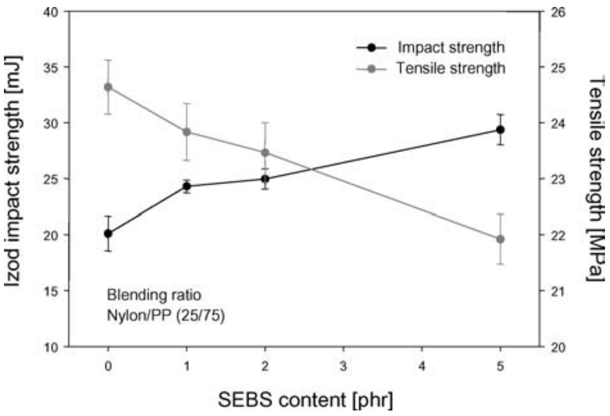

Figure 4 Tensile strength and impact strength versus SEBS content for PP/nylon blend at room temperature.

blend without a compatibilizer. The decreased tensile strength of the PP/nylon blends with increasing SEBS content can be explained in conjunction with the results of SEM and rheometry. On the other hand, it should be noted that the impact strength was much improved with increasing SEBS content. In this case, we can confirm that the SEBS work as effective impact modifier for the PP/nylon blend, although the tensile strength of PP/nylon blend was not enhanced by the addition of SEBS.

In summary, we investigated the effects of SEBS as a compatibilizer on the morphological, rheological, and mechanical properties of the PP/nylon blends prepared from commingled plastic wastes. By SEM analysis, we could find that the fractured surface of the PP/nylon blends compatibilized with the SEBS is rougher than that of the PP/nylon blend without a compatibilizer. These morphological characteristics were further analyzed with the results of rheolgical and mechanical tests. From the Carreau model, we could explain the effect of SEBS as a compatibilizer on relaxation process of the PP/nylon blend. Finally, the mechanical properties were also interpreted in conjunction with the formation of internal structures at the PP/nylon interface by the addition of compatibilizer.

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