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Polymer 40 (1999) 4441–4450

polymer

Morphology and properties of compatibilized ternary blends (nylon 6/a thermotropic liquid crystalline polymer/a functionalized polypropylene) processed under different conditions

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Received 17 April 1998; received in revised form 3 August 1998; accepted 8 September 1998

Abstract

Relationships between the properties of ternary blends of nylon 6, a thermotropic liquid crystalline polymer (TLCP, poly(ester amide), 20 wt%) and a compatibilizer (maleic-anhydride-grafted polypropylene, MA-PP, 2 wt%) are studied under various processing conditions. The immiscible binary blend can be compatibilized by the addition of MA-PP. The compatibilizer provides extrudate surface stability, thus enabling high drawing. Strong elongational flow, which was not possible when maleic-anhydride-grafted ethylene-propylene-diene terpolymer was used as a compatibilizer, favors fibril development. The shear viscosity of the ternary blend is slightly lower than that of the binary blend. The morphology of the dispersed TLCP phase varies between droplets and oriented fibrils when the drawing is weak and is highly correlated with changes in tensile properties. The optimum die exit temperature (280°C) provides a more uniform morphology and more fibril shapes which are associated with the increased tensile properties. The die exit temperature effect still exists when the draw ratio is high. In all cases, it is manifest that, whenever applicable, extension is a decisive factor in the deformation of the dispersed TLCP droplets, which is necessary for significant improvements in the mechanical properties. © 1999 Published by Elsevier Science Ltd. All rights reserved.

Keywords: In situ formed compatibilizer; Drawing

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1. Introduction

The use of thermotropic liquid crystalline polymers (TLCPs) in blends with other thermoplastics has attracted considerable interest for many reasons [1–14]. One of these is that, under appropriate conditions, two-phase polymer blends containing a TLCP can be processed in such a way that the dispersed TLCP domains can be deformed into fibril shapes that reinforce the matrix upon solidification, leading to so-called in situ composites [1–6]. However, not all TLCP blends can produce self-reinforced (in situ) composites. Some thermoplastics having lower melt viscosities than that of TLCP at the processing temperature cannot deform the TLCP droplets even with strong drawing [7–11]. Dispersed droplet deformation and the parameters which affect it can be qualitatively described using the theory of the deformation and the break-up of isolated droplets which was originally developed by Taylor [7,15–22]. It is reported that a higher matrix viscosity than those of TLCPs is required to achieve droplet deformation into a fibril shape. Generally, polymers produced by a condensation reaction, such as polyamides and polyesters, have melt viscosities much lower (sometimes two or three orders) than those of the TLCPs at the usual processing temperatures and shear rates [8,11,14]. Hence, it can be easily expected that an in situ composite of nylon 6 will be hard, if not impossible, to obtain because of the low viscosity of the matrix. La Mantia et al. reported that they could not observe any elongated structure of the TLCP (Vectra B950) (VB) phase in a nylon 6 matrix even at a very high draw ratio of 100 [22].

Recently, we systematically searched for a preparation method for polyamide in situ composites [14,23–25]. What we found is that in situ composites of nylon 6 can be made even with the extrudates from a twin screw extruder where the shear rate is not high and with very weak or no drawing, provided a compatibilizer is added to the binary blend [23,25]. The compatibilizer can react with VB and nylons to produce a kind of graft copolymers that act at the interface between the nylons and the VB phase [25]. The action of the compatibilizer not only yields a reduction in the interfacial tension but also provides better adhesion which invokes effective stress transfer at the interface [14,24]. In

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PII: S0032-3861(98)00685-5

the shear flow field, the final shape of the dispersed phase is a dynamic equilibrium between the shear stress and the compatibilizing action. Therefore, addition of the compatibilizer, thus enabling both efficient stress transfer by improved adhesion at the interface and lowering the interfacial tension, is the only practical way to achieve deformation of the TLCP droplets in a nylon matrix. When the proper amount of a compatibilizer is added, some fine fibrils are formed in the ternary blend system even without strong elongational drawing [23–25]. However, in spite of the fibril formation in the nylon 6 matrix, the improvement in the mechanical properties was not remarkable, except in the optimum case, which is ascribed to the loss of ductility of nylon 6 as a result of the addition of a TLCP and the compatibilizer as well as to a degradation of the matrix and elastomer phase after blending at high temperature [23]. Also, nonuniformity across the surface contributes to the low values for the mechanical properties. Another fact that contributes to this is the compatibilizing action. Too much compatibilizing activity produces droplets which are too small to be deformed by a shear flow alone. When a maleic-anhydride-grafted EPDM (ethylene-propylene-dien terpolymer) was used as a compatibilizer for the nylon 6 and TLCP blend, the TLCP phase was deformed into microfibril shapes as well as small droplets [23]. Extension of the extrudate was not applicable in this case because of the onset of a surface instability with drawing. Part of the EPDM was cross-linked and was not deformed with the matrix resin. We found, however, that addition of a suitable compatibilizer can enhance the stability, thus enabling us to apply high drawing in order to obtain an extrudate of uniform diameter [25].

In the present paper, as part of continuous research to search for the optimum condition for preparing polyamide in situ composites, we report experimental results for ternary blends of a high melting TLCP (Vectra B950 (VB)) with nylon 6 and a maleic-anhydride-grafted polypropylene as a compatibilizing agent under different processing histories. We also investigated the effect of the mixing step to see if there was any variation of the compatibilizing action as a result of the mixing history.

2. Experimental

The material employed in this study was a copolyesteramide of 6-hydroxy-2-naphthoic acid (60%), terephthalic acid (20%), and aminophenol (20%), commercially known as Vectra B950 (VB) manufactured by Celanese Hoechst (USA). This material, which has been used and characterized by many researchers [4,10,11,22–26], was supplied in the form of pellets. The nylon 6 was supplied by Kolon Co. (KN111, Korea). Both the nylon 6 and Vectra B950 are immiscible [23]. The maleic-anhydride-grafted polypropylene (MA-PP) which was used as a compatibilizer, was obtained from the Honam Petroleum Co. (Korea), and had a maleic-anhydride-content of about 1%. In this study, 2 wt% of MA-PP was used because an excessive amount of the compatibilizer caused coalescence and coagulation of the dispersed phase and also formed a separate phase [23,26].

The pellets of nylon 6 and VB were dried in a vacuum oven at 120°C, and the MA-PP was dried at 100°C for at least 24 h before use. The TLCP content was maintained at 20 wt%, around which content the composite showed a maximum fibril aspect ratio [2,6,27]. The dried VB and MA-PP were blended first to investigate the effect of preblending. VB has a much higher viscosity than that of nylon 6 and fewer free-amine end groups to react with the anhydride group of MA-PP [25]. Hence, in order to provide a greater chance of reaction for VB with MA-PP, preblending was done. Dried pellets of VB and MA-PP were blended in a 42 mm Brabender twin screw extruder (AEV651) equipped with a pulling unit. The extrusion temperatures of the feeding zone/transporting zone/melting zone/die, were set as 140/290/290/290°C, respectively. After the extrudates were pelletized, the pellets were dried at 100°C in a vacuum oven for 24 h. The second blending with nylon 6 pellets was carried out in the same twin-screw extruder under the same temperature conditions except the die temperature. Die temperatures of 270°C, 280°C, and 290°C were used.

Differential scanning calorimetry (DSC) studies of thermal properties were performed on a Du Pont 910 DSC controlled by a 9900 thermal analyzer. The heating rate was 10°C min^{-1}, the cooling rate was 10°C min^{-1}, and the materials were scanned from 25 to 350°C. Thermograms were repeated at least twice, using different samples to verify the reproducibility. A Du Pont 2000 thermal analyzer with a thermogravimetric analyzer (TGA) was used to check the stability of the polymers at the processing temperatures. Dynamic mechanical thermal analysis (DMTA) of the blends was carried out with a Polymer Laboratories Dynamic Mechanical Thermal Analyzer (Model 2) at a frequency of 1 Hz. A clamping geometry in the tensile mode was used.

FT Raman spectra were obtained using a Perkin-Elmer system 2000 instrument equipped with near IR optics. Spectra were obtained with 4 cm^{-1} resolution and typically required 10–15 min of acquisition time.

Scanning electron microscopy (SEM) observations of the composite samples were performed on a Hitachi S-2500 model. The samples fractured in liquid nitrogen were coated with gold to provide electrical conductivity.

Rheological measurements were carried out using a capillary viscometer RH7 (Rosand, England) at 290°C. The capillary had 1 mm diameter and the length to diameter ratio of 32.

Testing of the mechanical properties of the blends was performed using an Instron Universal Testing Machine (model 4204) at constant temperature. A gauge length of 30 mm and a cross-head speed of 10 mm min^{-1} were used. All the reported results are averages of at least 7 measurements.

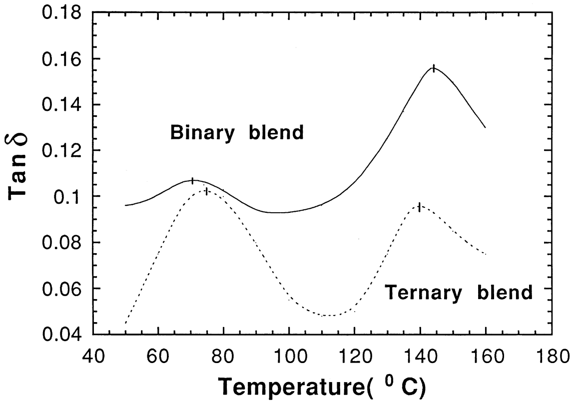


Fig. 1. Normalized $\tan\delta$ versus temperature for binary (——) and ternary (- - -) blends. Die exit temperature was 290°C.

3. Results

3.1. Thermal properties

Transitions of the binary blends and ternary blends as resolved by DMTA are shown in Fig. 1, which shows $\tan\delta$ as a function of temperature. In the binary blend, two distinct $\tan\delta$ peaks, one associated with the glass transition of nylon 6 and the other with that of VB, are located at 68°C and 143°C, respectively. The two distinct glass transition temperatures (T_g) indicate that nylon 6 and VB are immiscible. The higher and the lower $\tan\delta$ peaks in the ternary blend shift toward each other. The ternary blend extruded at 290°C shows peaks at the temperatures of 74°C and 138°C. The shift of T_g means that nylon 6 and VB become compatible in the ternary blend. DSC results confirm the shift in the glass transition temperature of the ternary blend (Fig. 2). The heat of crystallization and the crystallization temperature of the ternary blends did not change noticeably with the die exit temperature.

3.2. Flow properties

The flow properties of blended and neat materials were investigated at 290°C by using a capillary rheometer. Corrections for the end pressure loss (Bagley) and the departure from Newtonian flow (Rabinowitsch) were applied. The viscosity–shear rate relationship for the pure components and the blends are shown in Fig. 3. The viscosities of the binary and the ternary blends are lower than those of the neat polymers, indicating a synergistic effect in reducing the viscosity of the TLCP composite and indicating its great ability as a processing aid. Nylon 6 and the blend follow a Newtonian fluid behavior, while VB shows shear thinning at high shear rates.The average ratio of the measured extrudate diameter to the die diameter at different die temperatures showed almost no extrudate swell when no drawing was applied. The extrudates also showed no surface roughness under the processing conditions. The regularity of the filament surface was conserved during the extrusion process. These results are somewhat different from those of our previous experiment in which maleic-anhydride-grafted EPDM (ethylene-propylene-diene terpolymer) (MA-EPDM) was used [23]. In that case, the extrudate exhibited surface irregularities for certain processing conditions, the irregularity of the surface prevented the application of a high drawing ratio and the extrudate quality was not improved by lowering the extrusion temperature. In contrast, the extrudates in the present research all showed clean and smooth surfaces. Hence, drawing could be easily applied.

3.3. Morphology

SEM micrographs manifest the microstructure of the fractured surfaces of the blend extrudates prepared under various extrusion conditions. Fig. 4 shows the fractured surface of a VB/MA-PP binary blend. The TLCP exists as

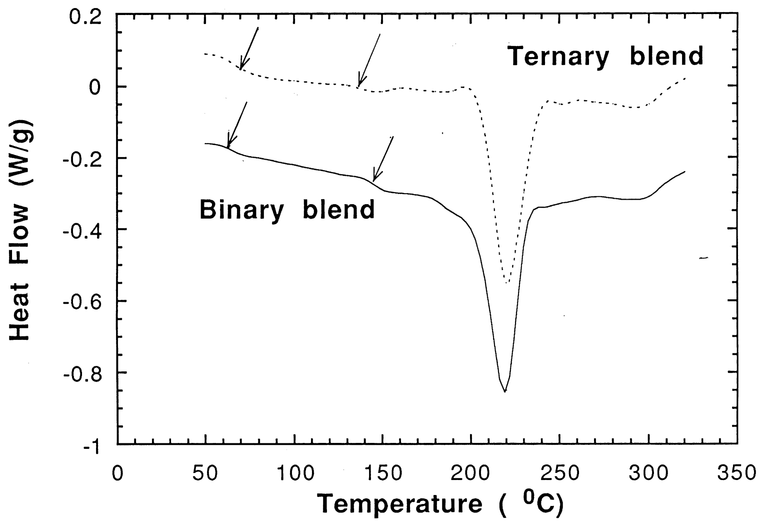


Fig. 2. DSC thermograms of nylon 6/VB binary (——) and ternary (- - -) blends. Die exit temperature was 290°C.

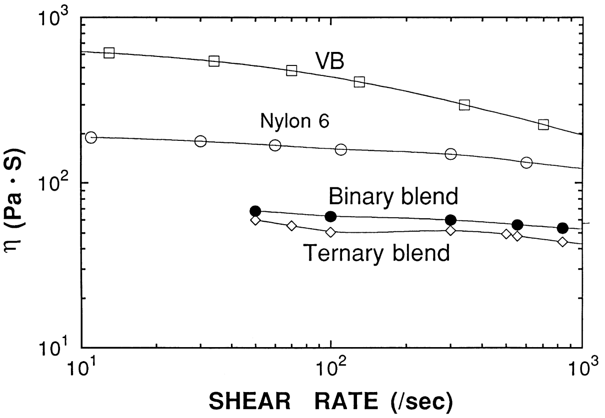


Fig. 3. Viscosity–shear rate relationship of nylon 6 (○), VB (□), binary (●) and ternary (◇) blends at 290°C.

fine and coarse fibrils and lamelar shapes. Fig. 5 shows the morphology of the ternary blend at different die exit temperatures at a low draw ratio of about 1.8. In spite of the weak drawing, the TLCP, 20 wt%, existed as fine and coarse fibrils, ellipsoids, and some droplets, all distributed in the nylon 6 matrix. The fibrils varied in diameter from 1 to 3 mm. The morphologies of the ternary and the binary blends at a die exit temperature of 280°C, Fig. 5 (a) and (d), clearly show the effect of the compatibilizer. (The magnification of the ternary blend photo is 3 times greater than that of the binary blend.) In the binary blends, most of the dispersed TLCP phases have droplet shapes which show almost no deformation. They are mostly larger than 3 μm in diameter. The open craters and holes, as well as the gaps between the dispersed TLCP phase and the nylon 6 matrix, indicate relatively poor adhesion at the interface. However, interfacial adhesion is evident in the ternary blend because of the spheroids and the hair-like texture of the fibrils. Significant fiber pull-out is also apparent. An increase in the fibrillarity (i.e. the number and fineness of fibrils) with increasing die temperature is noticeable in Fig. 5. A low draw ratio (ca 1.8) was applied to the samples so that the morphology of the final extrudate would predominantly reflect what had developed within the die. The low die exit temperature was expected to induce high shear stress because of both cooling and an increase in the viscosity. Although the temperature of 270°C is below the crystalline-nematic transition temperature of VB, detailed studies showed that the supercooling behavior of TLCP allowed the possibility of processing TLCP below its actual melting point once it was in the molten state [15,17]. More fine fibrils were observed when the extrusion was at 280°C. Also, fewer deformed shapes were observed at a die extrusion temperature of 290°C, than at a die temperature of 280°C.

Fig. 4. SEM photograph of fractured surface of VB/MA-PP binary blend at the draw ratio of ca 1.

The effect of the draw ratio on the blend microstructure is demonstrated in Fig. 6. The textures of the samples reveal the presence of finely dispersed TLCP fibrils. These fibrils range in diameter up to a maximum of 2 μm, but small fibrils predominate. The small holes distributed across the section indicate pulled-out areas of the TLCP fibrils. Comparison of Figs. 5 and 6 reveals that textured droplets of TLCP are more abundant in more highly drawn samples. The micrographs shown in Figs. 5 and 6 clearly demonstrate the influence of elongational flow on the development and the refinement of TLCP fibrils, with the compatibilizer inducing better adhesion and dispersion.

3.4. Tensile properties

The tensile modulus and strength for a blend extrudate are shown in Fig. 7. The sensitivities of the tensile properties to the die exit temperature are not very significant when the drawing is low (ca 1.8). The slightly higher tensile modulus for the 280°C die exit temperature extrudate is consistent with the fractured surface morphology. We speculate that the difference is a result of the effects of temperature on the fluid properties. Though it is possible to process VB below its actual melting point once it is molten, a low die exit temperature of 270°C seems to work for cooling down the extrudate, resulting in a viscosity and a modulus in the VB phase which were too high for that phase to be deformed very much by the stress transferred from the matrix. At 280°C, which is close to the melting point of VB, the shear stress effectively transferred to the still hot inner melt. At a die exit temperature of 290°C, a low matrix viscosity is maintained after die exit; hence, comparatively less shear stress is available for the TLCP deformation. This is a scenario based on the morphology and the mechanical

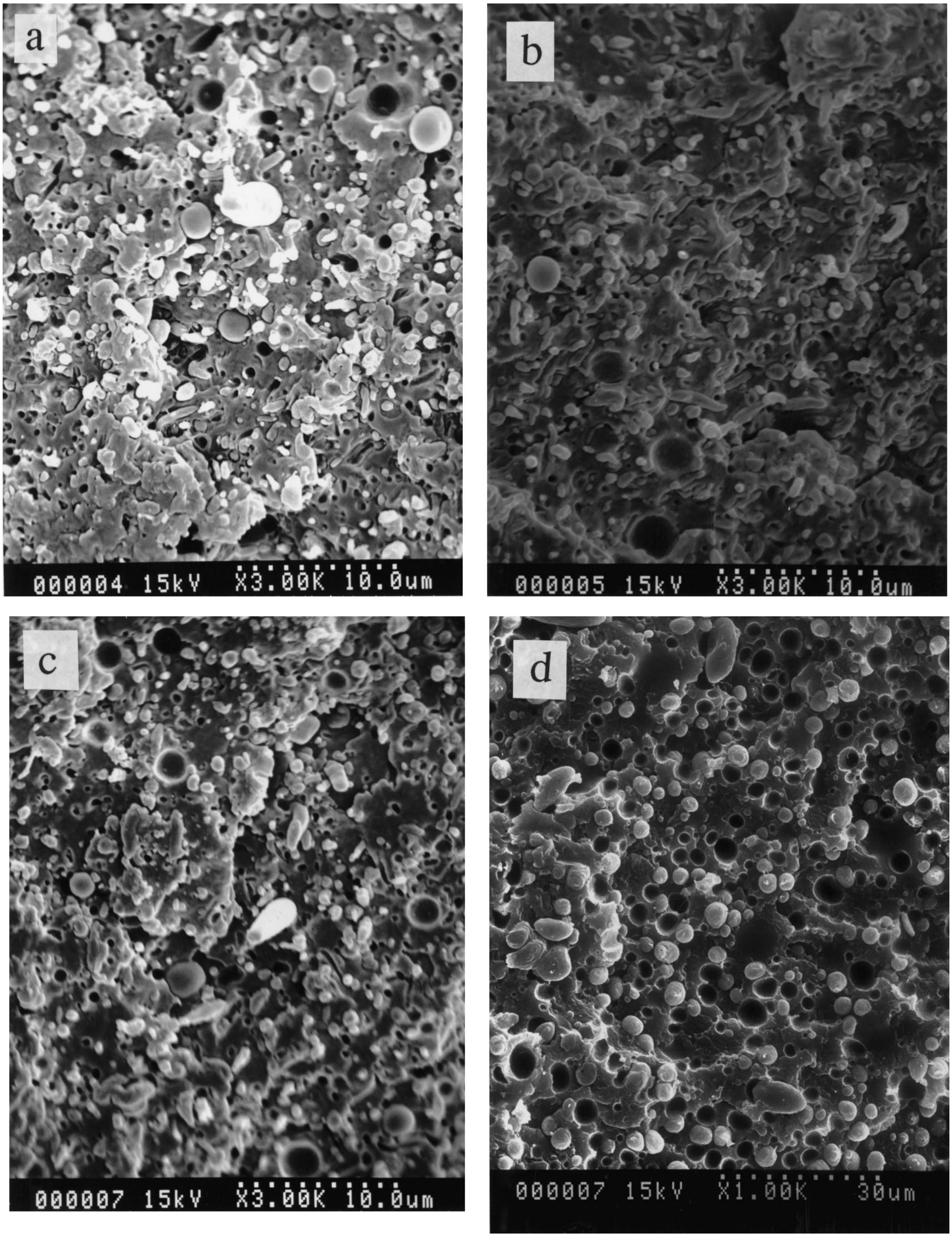


Fig. 5. SEM photographs of fractured surfaces of ternary blends at the die temperature of (a) 270°C, (b) 280°C and (c) 290°C, respectively. For comparison, a SEM micrigraph of the fractured surface of binary blend is also shown in (d). The magnification of ternary blends ((a),(b), and (c)) is 3 times bigger than that of the binary blend (d) (For the same magnification comparison, compare (d) with Fig. 6 (a)). Draw ratio was about 1.8.

performance of the extrudates. The effect of the die exit temperature (and hence, that of the shear flow field) still exists, even when the extrudates were extended. Fig. 8 shows the effect of the draw ratio. The influence of the draw ratio on the tensile modulus is attributed to a modification of the TLCP phase. The overall tensile properties of the ternary blends are similar to those found in our previous study [23], but they show a definite increase with draw ratio. Drawing of the ternary blend was possible because of the consistent surface regularity and the stability provided by MA-PP, which was not achievable when maleic-anhydride-grafted EPDM was used as the compatibilizer.

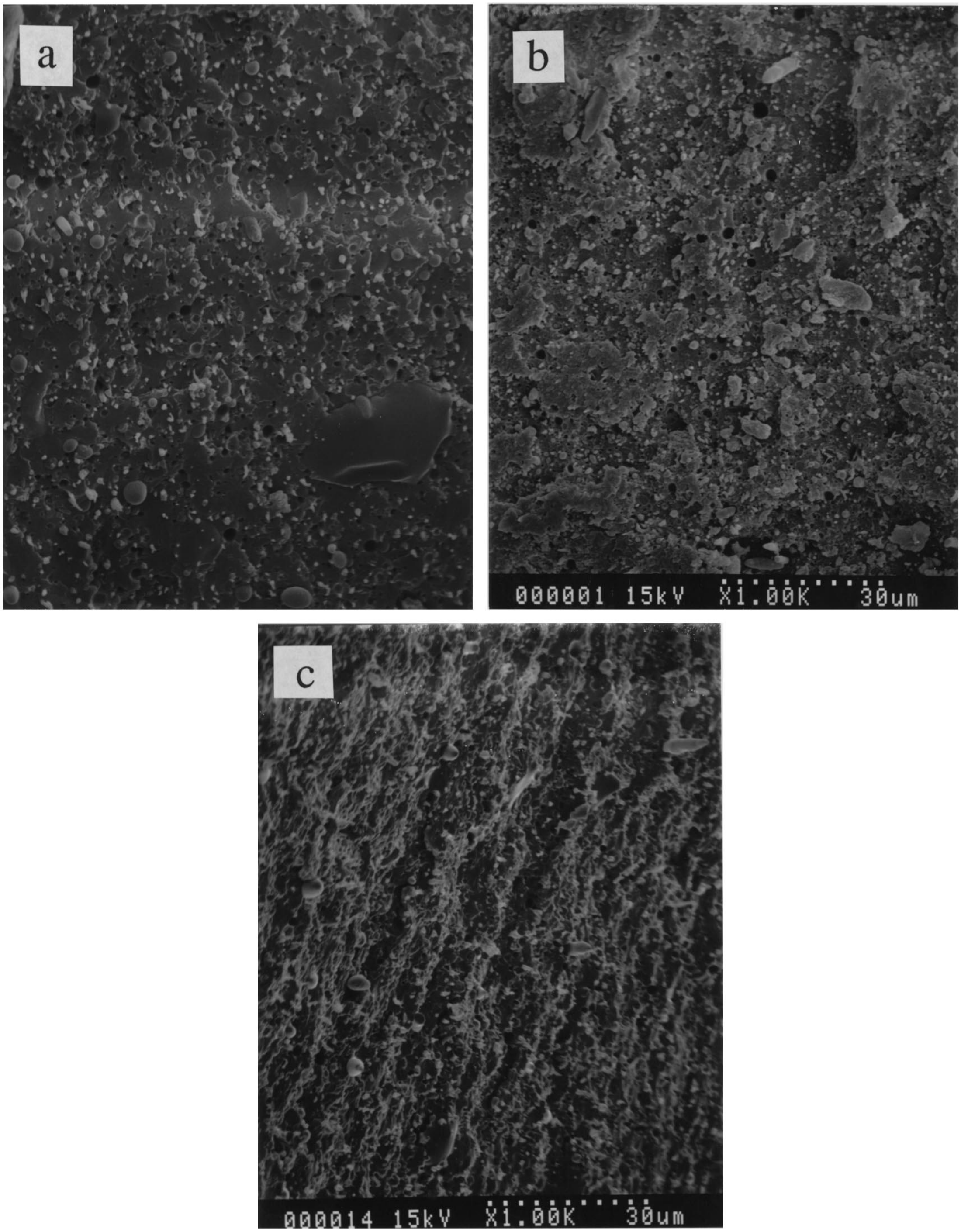


Fig. 6. SEM photographs of fractured surfaces of ternary blends at the die temperature of 280°C (a) Draw ratio of 1.8 (b) Draw ratio of 4 (c) Draw ratio of 6.

4. Discussion

The thermal properties and the microstructure reveal a change in the nature of the TLCP/nylon 6 blend with the addition of MA-PP. The shift in the T_gs of nylon 6 and TLCP in the ternary blends toward each other, reflecting partial compatibility, is consistent with the results of previous studies that reported changes in the glass transition temperatures of TLCP and polyamides (nylon 46 [14], nylon 66 [24], and nylon 6 [23]) with the addition of a compatibilizer. The development of fibrils reflects the compatibilizer effect. The compatibilizer yields not only a reduction in the interfacial tension (thus decreasing the resisting force against deformation, which has the same effect as increasing the viscosity of the matrix [23]) but also a better adhesion which induces effective stress transfer

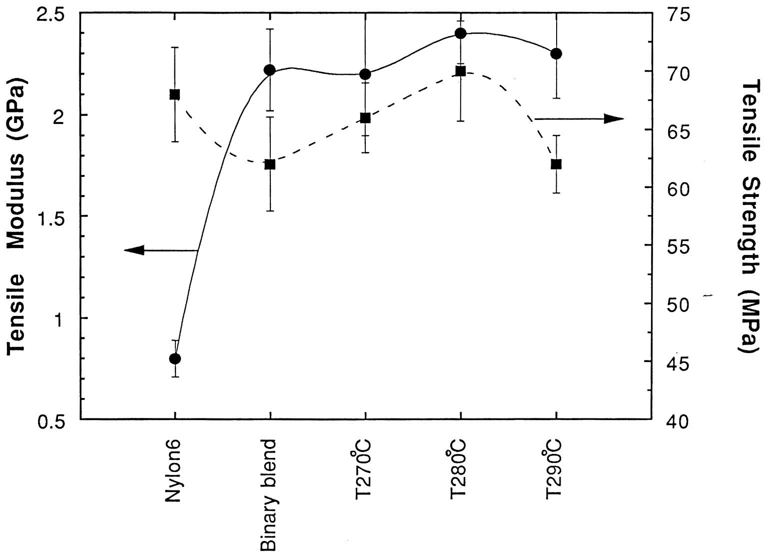


Fig. 7. Tensile modulus (●) and tensile strength (■) of binary and ternary blends. Draw ratio was ca 1.8. Lines are guides for the eyes.

through the interface. Hence, without a compatibilizer, the dispersed phase hardly deforms because of the immiscibility between the two phases. Slippage on the surface causes the droplet to tumble in shear flow [5,9]. When the compatibilizer is added, it is located at the interface and prevents the droplets from tumbling because of the adhesion at the interface. However, fractured surfaces show the TLCP existing as fine and coarse fibrils, as well as ellipsoids and droplets, in the nylon 6 matrix when the draw ratio is low (Figs. 5 and 6). This is partly attributable to the non-uniform distribution of the compatibilizer. Also, the possibility of thermal degradation of the nylon 6 matrix existed, but thermo-gravimetric analysis proves that the degradation of the nylon 6 at the processing temperature (290°C) was very slight [23]. After processing, the decrease in the intrinsic viscosity of the nylon 6 extracted by formic acid and then dissolved in 98% sulfuric acid was less than 3%.

The fibrillation and the droplet deformation caused by the addition of MA-PP can be ascribed to two possible mechanisms: the occurrence of a chemical reaction or an interaction such as hydrogen bonding. Recently, O'Donnel and Baird [28] investigated the possibility of these two mechanisms for ternary blends of polypropylene/maleic-anhydride-grafted polypropylene/TLCPs (Vectra A950, Vectra B950, LC 3000). Based on their IR analysis, they concluded that hydrogen bonding between maleic anhydride and TLCP is the mechanism leading to compatibilization. They conducted comparison testing only for the ternary blend

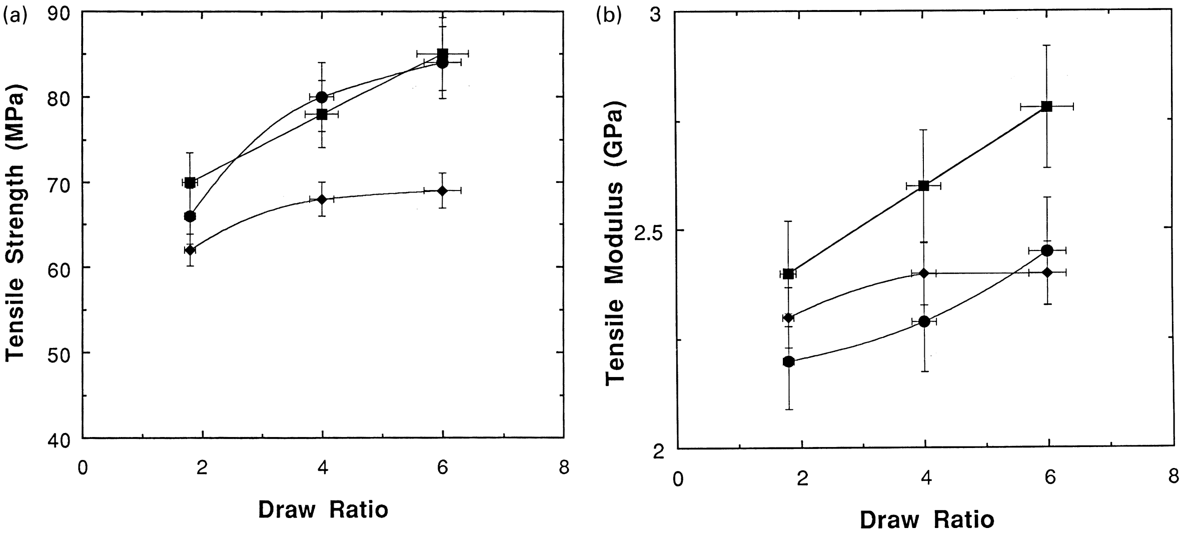


Fig. 8. (a) Tensile modulus and (b) tensile strength of ternary blends vs draw ratio. Die temperatures were (●) 270°C, (■) 280°C, and (◆) 290°C. Lines are guides for the eyes.

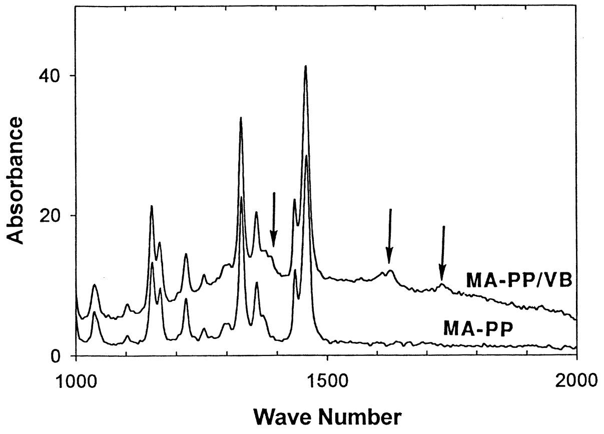
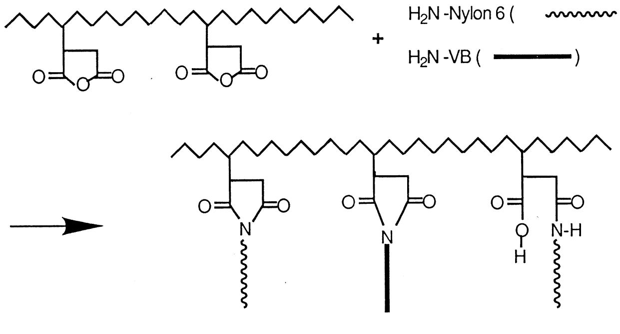


Fig. 9. FT Raman spectra of MA-PP and the extracts from the binary blend of MA-PP and VB.

of PP/MA-PP/Vectra A with the binary blend of PP/PP-MA by quantifying the maleic-anhydride content obtained from the absorption peak at 1784 cm^{-1}. However, their results are somewhat uncertain because of experimental uncertainty. For a better analysis, the maleic anhydride content of the binary blend of VB and MA-PP should be compared with that of MA-PP. We prepared a binary blend of VB and MA-PP (50:50 ratio) under the same processing conditions. Then, using a soxhlet extractor with boiling dichlorobenzene, we extracted the soluble portion (MA-PP phase). After two days of extraction, the extracted solution was poured into the ethanol. The precipitate was dried in a vacuum oven at 60°C for two weeks to remove any solvent residue. FT Raman spectra were taken of the remnants. The Raman spectra of MA-PP and the extract are shown in Fig. 9. The characteristic peaks of the aromatic and the ester groups, which can not be seen in the MA-PP spectrum, are observable at 1400 cm^{-1}, 1620 cm^{-1} and 1742 cm^{-1}. This indicates that the VB moiety is included in the extracts. Since VB is not soluble in dichlorobenzene, we speculate that some reactions have occurred to produce a type of graft copolymer. Recently, we proposed some possible reactions which could occur between the maleic-anhydride group and the end groups of nylon 6 or VB [25]. It is well known that maleic anhydride can react with the amine end group of nylons. The hydroxyl end groups can also react with the maleic anhydride to produce graft copolymers. The amount of the amine end group remaining in VB is not detectable from IR analysis because of the overlapping of the amine peak with the hydroxyl peak, but the existence of the hydroxyl group is clearly seen at 3300 cm^{-1}. (See fig. 21 of [14]) Also, the ester moiety in VB can proceed, such as acidolysis with the maleic anhydride group. Although this reaction usually requires a catalyst for speed, remnant catalysis in VB can promote it. Since there is no aromatic moiety in the neat MA-PP polymer, we believe that a chemical reaction has occurred to graft the VB moiety to MA-PP. It may be conjectured that the reacted VB moiety is from the low-molecular-weight VB formed by thermal depolymerization. However, the TGA thermogram of the TLCP(VB) showed no signs of thermal degradation until the temperature reached 350°C [25].



Scheme 1. Reaction between MA-PP and nylon 6 or VB.

If the compatibilizing action occurs solely as a result of hydrogen bonding, the binary blend of nylon 6 and VB, both of which have strong hydrogen bonding, should be compatible [5]. As already seen from the properties and the morphologies of binary blends, they are not compatible [23]. Little interaction can be observed between VB and nylon 6. The amine end groups of VB and nylon 6 competitively react with the anhydride group of MA-PP (Scheme 1) to form a kind of (comb-shape) block copolymer having different branches, and this copolymer acts as the compatibilizer at the interface. This copolymer obviously migrates to the interfacial region and contributes significantly to the interfacial reduction and to the adhesion between the two phases (Figs. 5 and 6). Graft copolymers increase the mechanical strength at an interface by increasing the number of molecular entanglements between the two phases. However, the compatibilizer must overcome two obstacles to its migration to the interfaces: diffusion and micelle formation. These factors prevent the migration of the graft copolymers to the interface. When there are not enough graft copolymers, some of the dispersed phase may have the same shape as that in the binary blend. Thus, it cannot be deformed at all because of poor adhesion. However, when there are more than enough graft copolymers, coagulation and coalescence of the dispersed phase can happen, although this does not seem to happen in the present case [23]. Another possibility is that the compatibilization produces particles which are too small to be deformed. Some of the dispersed droplets have diameters of less than 0.1 μm. The drawing applied in this study may not be strong enough to deform such small droplets [16].

Blending of 20 wt% TLCP induced a decrease in the viscosity to a value lower than those of the constituent materials. The overall shape of the blend curve follows that of nylon 6. The exact mechanism of viscosity reduction in TLCP blends is not yet completely understood [5,10,19,21]. According to a relationship proposed by Bye and Miles [29], the observed flow behavior is consistent with stratification of the flow and with interfacial slip in the melt. La Mantia and Valenza [11] proposed that the immiscibility between phases and the formation of fibrils at the entrance of the capillary lubricate the matrix. Ternary blends show almost the same viscosities as those of binary blends because of mixed morphologies. The relative amount of viscosity reduction for different die exit temperatures was not significant. For a highly extended extrudate, more abundant fibrils contributed to the viscosity reduction, but the high melting temperature in the capillary viscometer destroyed any previous shape; hence, the viscosity effect was not evident.

Other blend studies have also shown improvements in the tensile properties with decreasing extrusion temperature. In a report by Beery and co-workers [30], extrusion was undertaken 15°C below the melting temperature of TLCP. This indicates the possibility that lower temperatures favor improved fibril formation owing to the greater shear stress developed at lower temperatures when the TLCPs have low crystallization temperature and high melting temperature. Low die exit temperature (270°C), below the crystalline-nematic transition temperature in this study, seems not to provide enough thermal driving force. Such low die exit temperature induces rapid cooling, and hence a rapid solidification and/or increase of the viscosity of TLCP phase, rather than a high shear stress resulting from an increased matrix viscosity. When the draw ratio is low, there is an optimum die exit temperature (280°C) where increased shear stress in the matrix and low cooling can be obtained simultaneously. Higher drawing increases the number of fibrils, but the previous shear-field effect (and/or die exit temperature effect) still exists. The distributions of the fibrils and the droplets across the microstructure, however, do not reveal a consistent pattern when the draw ratio is low. The patterns become more consistent with strong drawing.

The presence of fibrils in the microstructure correlate with an increased tensile modulus. This is in accordance with the fractured surface morphology. Results show that fibril formation is favored when a significant level of drawing is applied and when processing is undertaken at temperatures slightly lower than the crystalline-nematic transition temperature of VB. The increased number and fineness of the fibrils developed at higher draw ratios result in an increased value of the tensile modulus. The die exit temperature influences the morphology and the resultant tensile properties, but this effect is somewhat less than that of the draw ratio. A melting zone temperature of 290°C was applied to insure that the TLCP phase was in the molten state. The reason that two-step mixing was applied here was to hopefully enhance the reaction between VB and MA-PP. In one-step mixing, since the viscosity of nylon 6 (hence, the fluidity) is much lower than that of VB and since nylon 6 has more reacting amine groups than VB, nylon 6 is expected to react more actively with MA-PP than VB is. An attempt was made to provide more reactions between VB and MA-PP by extruding first the VB and MA-PP. The result is, however, not so evident. The tensile moduli and the strengths of the extrudates of one-step mixing are slightly lower than those of two-step mixing, but the difference is less than 5%.

The current study shows that the stability of the ternary blend is better than the case when MA-EPDM is used as a compatibilizer. Whether this occurs as a result of different processing conditions and/or different materials [25] is not manifest yet; however, the latter is more probable because of MA-PP's low viscosity and because of non-cross linking formation in MA-PP. Extrudates of VB and MA-PP binary blend show fibrils and tape-like fibril shapes for the VB. This can be applied to make a reinforced composite if the extrusion temperature is lower than the melting temperature of VB. By doing this, the compatibilizer will enhance the adhesion at the interface, and the VB phase will be able to keep its fibril shapes in the extruder. This is under investigation and will be reported in the future.

5. Conclusions

We have investigated the effect of a compatibilizer on the properties of nylon 6/ VB blends processed under different conditions. Ternary blends show complicated behaviors because of their multiphase characters which depend on the processing conditions. Addition of MA-PP evidently leads to a compatibilizing action at the interface of VB and nylon 6. The state of the dispersed TLCP phase varies between droplet and fibril morphologies. The balance between these structures is evidently influenced by the processing history. The optimum die exit temperature is found to be 280°C, which is close to the TLCP-phase melting temperature. Die exit temperatures lower than this do not provide more fibril formation and neither do die exit temperatures which are higher. In the two step case, the fibrils generated in the first step seem to be lost in the extruder because of its high processing temperature. The resulting properties reflect the effect of different processing conditions in the second mixing. When the draw ratio is low, the difference in the tensile properties between one-step and two-step mixing is not dramatic, although the latter provides slightly better tensile properties.

The compatibilizer also provides the extrudate stability necessary for the application of a relatively high draw ratio, which was not possible when MA-EPDM was used as the compatibilizer. A high draw ratio results in more oriented fibrils and uniform morphologies which correlate with increased mechanical properties. Whenever applicable, extension is a decisive factor in fiber formation and is necessary for significant improvement in the mechanical properties (tensile modulus and strength).

Acknowledgements

This work was supported by Korea Institute of Science and Technology (KIST) under Grant No. 2E15291. Special thanks to Dr Dong Young Kim in Polymer Material

Laboratory at KIST for FT Raman measurement and Mr Youngjun Kim for his help with experiments.

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