

The influence of interfacial interactions on the morphology and thermal properties of binary polymer blends

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In order to understand the influence of interfacial modification in polyamide/ionomer/polypropylene ternary blends, the binary blends were investigated. In this study two multiphase blends have been chosen, PP/ionomer and PA/ionomer, where the ionomer was a copolymer of polyethylene and of a mixture of methacrylic acid, zinc methacrylate and isobutylacrylate. The PP/ionomer blend is a classic example of an incompatible system which displays a high degree of interfacial voiding in SEM fracture surfaces, a strong negative deviation from additivity in the viscosity/composition relationship and an important coalescence effect on increasing dispersed phase concentration. This blend demonstrated increased nucleation and crystallization rate, compared to pure polypropylene. The second blend, PA/ionomer, demonstrates a very fine multiphase structure evident only after microtoming/etching of the sample, strong additive behaviour in the viscosity/composition curve. Formation of an amide bond was identified by Fourier transform-infrared spectroscopy. This evidence supports the conclusion that much stronger interactions exist between the ionomer and the polyamide than between the ionomer and the polypropylene.

1. Introduction

Polyamide/polyolefin blends compatibilized with an ionomer have potential applications as barrier materials, particularly with respect to hydrocarbon solvents [1–4]. The control of the morphology of the blend and the enhancement of interfacial interactions between the dispersed phase and the matrix are critical in order to improve the barrier properties of the blend. Commercially available polypropylene/polyamide blends already use interfacial modification to improve mechanical properties [5, 6]. The resulting blends show an improvement in processability, water sensitivity and impact strength compared to pure polyamide. This article is one of a series of papers which considers the influence of interfacial modification on the morphology/processing/property relationships of polymer blends.

In previous work [7], the morphology of compatibilized polyamide/polyolefin blends, prepared by melt blending the resins in an internal mixing chamber, was studied quantitatively. The dimensions of the dispersed phase were significantly dependent upon the concentration of an ionomer compatibilizer in the blends. The phase size was found to have decreased by as much as three to four times with the addition of as

little as 0.5% ionomer by weight to the blends. Moreover, the size reduction of the dispersed polyamide was greater than that of the dispersed polyolefins. These observations illustrate the interfacial activity of the ionomer in these compatibilized polyamide/polyolefin blends. However, a more detailed interpretation necessitates an understanding of the interactions which occur between the ionomer and the individual components of these blends.

Thermal analysis is another important technique from which additional information can be obtained. In the literature, the fusion behaviour and crystallization kinetics of polymer blends have been studied in order to understand how one component of the blend affects the crystalline structure formed by the other component. An excellent review of these topics has been written recently by Martuscelli [8]. In addition, the results obtained from thermal analysis are important because impact resistance and many other properties are dependent on the crystalline structure of the blend components. In the past few years, more emphasis has been placed on non-isothermal crystallization. This type of study has been gaining importance because in reality, plastics processed in industry commonly experience non-isothermal treatments. It is

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TABLE I Characterization of the ionomer, polypropylene and polyamide-6 resins

Resin	Melt index (g/10 min)	Density (g ml ⁻¹) at 250 °C	Torque (N m) at 250 °C	Dynamic viscosity ^a (Pa s)	Storage modulus ^a (MPa)
Ionomer	1.0	0.74	14.3	500	0.046
PP	4.0	0.75	8.6	320	0.036
PA	—	0.96	8.6	620	0.026

^a At 250 °C and 100 rad s⁻¹.

primarily for this reason that the crystallization of the binary blends was studied under non-isothermal conditions in this work.

Several studies of the morphology and properties of binary blends of polyamides with ethylene-based multifunctional copolymers can be found in the literature [9–14]. In all cases, a two-phase morphology was observed for these blends. McKnight *et al.* [9] observed a reduction in the size of the dispersed ethylene-methacrylic acid copolymer phase as the acid content of the copolymer was increased. A detailed infrared spectrometric investigation of these blends showed that the enhanced compatibility at higher acid concentrations was attributed to amidation reactions occurring between the terminal amine groups of the polyamide and the carboxylic acid groups of the copolymer. Chuang and Han [10–12] have shown similar compatibility between polyamides and ethylene-based multifunctional copolymers, where the size of the dispersed copolymer diminished as the reactivity of the copolymer increased. Blends of polyamide with maleic anhydride grafted ethylene-propylene random copolymers were found by Cimmino *et al.* [13, 14] to display a much finer morphology than that observed for the blends containing unmodified elastomers.

In the above studies, the effect of introducing specific interactions, or actually inducing reactions between the polymers at the interface has not only produced a finer dispersion but also gives rise to blends having superior properties. The impact resistance [12–14] and tensile properties [10, 12, 13] of these blends showed marked improvements in comparison to blends where no interactions were present. For blends of polyamide with ethylene-based multifunctional copolymers, the measured values of the viscosity were higher than the values predicted by Taylor's equation [10–12]. In one of the few studies dealing with the properties of blends of polyolefins with ethylene-methacrylic acid copolymers, Fairley and Prud'homme [15] also observed an improvement in the tensile properties of these blends. However, the melting and crystallization of one component of the blend was not affected by the second component, as observed from the results obtained from light scattering and differential scanning calorimetry. These authors interpreted this effect as an absence of specific interactions occurring between the blend components.

Blends of the ionomer compatibilizer with each of the polypropylene and the polyamide were prepared in order to observe more favourably the interactions between the ionomer and these polymers, and to characterize the influence of these interactions on the

crystallization and morphological behaviour. A Fourier transform-infrared (FT-IR) spectrometric study was performed on these binary blends, because vibrational spectroscopy has become an established technique for the characterization of specific interactions in polymer blends. Many studies have dealt with intermolecular hydrogen bonding and ionic interactions in ionomers and their blends [16–25]. The introduction of such specific interactions in blends is an important method of improving compatibility and may promote miscibility [26].

Previous studies have shown that a polyethylene-co-methacrylic acid-co-isobutylacrylate ionomer is an effective emulsifying agent in polypropylene/polyamide blends. The addition of the ionomer copolymer to PP/PA blends resulted in a significant decrease in the dispersed phase size and showed a phase size/percent interfacial modifier dependence typical of emulsified systems where interfacial tension has been diminished.

Based on the above results, the objective of this study was to characterize the binary relationships between PA/ionomer and PP/ionomer in order to understand more fully the relative interaction of the individual components with the interfacial modifier. The morphology, viscosity, chemical interactions and crystallization behaviour were studied.

2. Experimental procedure

2.1. Resin characterization

The polypropylene (PP) resin, Pro-fax 6501, was received in powdered form. This resin was compounded with an antioxidant, Irganox 1076, on a twin-screw extruder and transformed into pellets. The polyamide-6 (PA) resin, Zytel 211, was also obtained in the form of pellets. None of these resins contain nucleating agents.

The ionomer used in this study, Surlyn 9020, is a random terpolymer consisting of approximately 80% polyethylene and 20% of a mixture of methacrylic acid and isobutylacrylate. The exact proportion of this mixture is unknown. The methacrylic acid is partially neutralized with zinc to approximately 70%.

Some properties obtained for these resins are given in Table I. It was possible to determine the torque of each resin by mixing 60 ml resin in the Brabender mixing chamber at 250 °C for 5 min with the rotors turning at 50 r.p.m. The torque (N m) represents a measure of the work required to turn the rotors in the mixing chamber. The densities of the resins were determined after they had been mixed in the Brabender, and are also reported in Table I.

The storage modulus and dynamic viscosity of each resin were obtained as a function of frequency at 250 °C, using a Rheometrics Mechanical Spectrometer (model RMS 605). The values of the storage modulus and dynamic viscosity at 100 rad s⁻¹ are given in Table I, and the frequency sweeps are presented elsewhere [7]. The instrument was operated in the dynamic mode, with a gap of 1.2 ± 0.1 mm between parallel plates. All experiments were performed under dry nitrogen.

2.2. Compounding

The resins were dry blended and dried under vacuum at 95 °C overnight. It should be mentioned that throughout the text, the blend compositions are given in terms of weight fraction. The mixed pellets were then melt blended in the Brabender mixing chamber using the roller blades recommended for high shear applications. A typical blending experiment consisted of the following steps. With the mixing chamber initially set at 250 °C and the blades turning at 50 r.p.m., the resin mixture was fed into the chamber. Once all of the resin was added, the blend was allowed to mix for 5 min under a constant flow of dry nitrogen. At the end of 5 min, the melt was rapidly transferred to a mould which was then held in a hydraulic press under 2.5 MPa pressure until the sample had cooled down to room temperature (approximately 3 min). The morphology of a blend prepared in this manner was found to be identical to that observed for a blend which was simply removed from the mixing chamber and rapidly quenched in ice water.

2.3. Scanning electron microscopy

The freeze-fractured surfaces were prepared by first immersing a small rectangular strip of each sample in liquid nitrogen for 10–15 min prior to fracturing. The surfaces of each blend were coated with an -Pd alloy and then examined under scanning electron microscope (SEM, JEOL model 35-CF), operating at 10–15 kV. The phase size of polyamide/ionomer blends were measured from plane faced samples. They were etched with boiling decalin prior to SEM.

2.4. Image analysis

The semi-automatic image analyser used to measure the diameters of the dispersed phase was developed in-house. The operation of this instrument has been described elsewhere [27]. For each sample, approximately 200 diameter measurements were obtained from the scanning electron micrographs.

2.5. Copolymer extraction

The goal of the extraction process was to concentrate the interfacial material for subsequent FT-IR analysis. The extraction procedure was applied to two blends. The first one, containing 80 wt % PA and 20 wt % ionomer, was mixed at 250 °C and 50 r.p.m. for 5 min. The second one, chosen as a reference sample, was

prepared under the same conditions as the latter experiment with the exception that it contained PP instead of ionomer.

For each sample, a 1 g piece was cut into 30 µm slices. It was then dissolved in formic acid and poured into water, while stirring, in order to break the matrix and make the dispersed phase accessible. The precipitate was filtered, washed with methanol and extracted with decalin overnight in a Soxhlet apparatus to remove some part of the unreacted ionomer (or PP) in order to concentrate the reaction product. The extracted polymer was then washed, again with methanol, to remove decalin and avoid co-solvent effects.

Each sample was then stirred in 10 ml formic acid at room temperature to remove the unreacted polyamide. After standing for 1 h, the ionomer phase separated to form the supernatant. The solvent was then removed with a syringe. This procedure was repeated with fresh formic acid until all polyamide was removed, as seen by precipitation in water (up to 20 solvent changes over 2 days).

The remaining solid was then washed five times with methanol using the previous procedure (one washing overnight), and dried for 15 h at 80 °C under vacuum. In methanol the rubber phase sinks to the bottom of the flask.

For the first sample, 125 mg copolymer concentrate was recovered. It was insoluble in formic acid or hot decalin, but, it may contain a certain amount of unreacted surlyn. Only pure PP, about 120 mg, was found after extraction of the second sample.

2.6. Fourier transform-infrared spectrometry

For FT-IR spectroscopy, a few milligrams of the extracted samples were pressed between two teflon sheets at 260 °C, under 20 tons. Pressure was released five times in order to degas the film, which was then finally quenched down to room temperature. The infrared spectra were then measured in transmission using a Nicolet Fourier Transform infrared spectrometer. For each sample, 128 scans were accumulated before the Fourier transformation.

2.7. Differential scanning calorimetry

A Setaram differential scanning calorimeter (DSC) was used to observe the crystallization of the pure resins and their binary blends. The samples were held in the melt for 6 min before recording the crystallization at a cooling rate of 5 °C min⁻¹. The quantity of material analysed was 100 ± 20 mg. All experiments were performed under a constant flow of dry nitrogen.

3. Results and discussion

3.1. Characterization of the blends

3.1.1. Specific interactions

The FT-IR absorbance spectra measured for the blends containing 50% ionomer are shown in Fig. 1. For the PP/ionomer, both of the ionomer carbonyl bands are readily observed, and no significant change in relative intensities was visible. Consequently, no specific interactions have been identified.

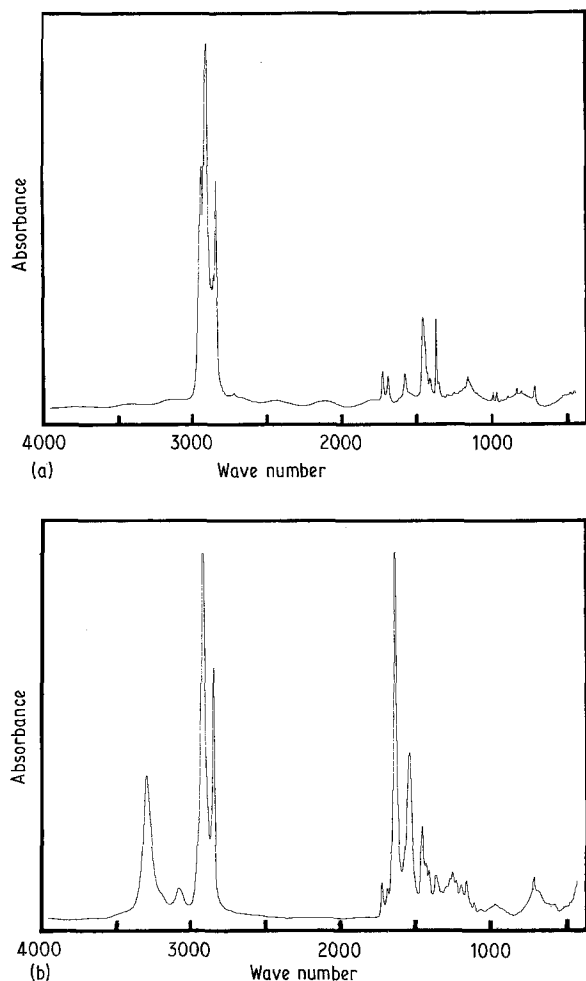


Figure 1 FT-IR spectra of (a) 50% PP/50% ionomer and (b) 50% PA/50% ionomer binary blends, measured in transmission.

For the PA/ionomer blends, the three peaks appearing in the carbonyl frequency region are partly resolved at ionomer contents greater than 40% by weight. It is not possible to resolve the carboxylate stretching frequencies at 1585 and 1420 cm^{-1} due to overlap with the polyamide spectrum. From all the interactions which could possibly occur, hydrogen bonding and chemical reaction at the interface are the most plausible ones.

For polyamide/ionomer blends, it should be possible to monitor changes in the hydrogen bonding of the ionomer carbonyl groups as a result of interactions which may have occurred during the melt mixing with the polyamide. However, no monitorable changes in relative intensity of free and bonded carbonyl peaks of the ionomer was observed. Such a change would be an indication of an increase of hydrogen bonding. It is also possible for the CO groups of the polyamide to undergo hydrogen bonding with the OH groups of the ionomer. However, the width at half height, $W_{1/2}$, of the polyamide carbonyl band at 1640 cm^{-1} did not change with ionomer content. Furthermore, although it was larger for pure polyamide than for blends, $W_{1/2}$ was the same for a blend containing 90% ionomer or those containing 90% PP. Because $W_{1/2}$ normally increases with hydrogen bonding [28], this suggests that this carbonyl band was not experiencing any changes in hydrogen bonding.

Chemical bonding could also occur at the interface, through amide formation between terminal amines and acid functions. The reaction between the terminal amine of polyamide and acid functions have been previously proposed by McKnight *et al.* [9]. In a study of the binary blends of polyamide and ethylene-methacrylic acid copolymers, they suggested that graft copolymers were formed at the interface between the two phases as a result of amidation reactions taking place during melt mixing. They also indicated that hydrogen bonding between the polyamide and the ethylene-methacrylic acid copolymers was an important interaction occurring at the interface of these two polymers.

We found no evidence of hydrogen bonding, as measured by ionomer C=O relative intensities or by PA carbonyl $W_{1/2}$. On the other hand, there was a strong increase in the amide C=O peak intensity at 1640 cm^{-1} , indicating an increase of amide function concentration or an effect of the multiphase state of the blend [29]. A slight increase was also observed for PA/PP blends, but it was not as strong as for ionomer blends.

To confirm that a chemical reaction occurs, the interface material was isolated from a 20 wt % ionomer/80 wt % PA blend as described in the experimental section. A 25 wt % PP/75 wt % PA blend was used as a blank because no reaction would be expected in this case. It should be mentioned that we

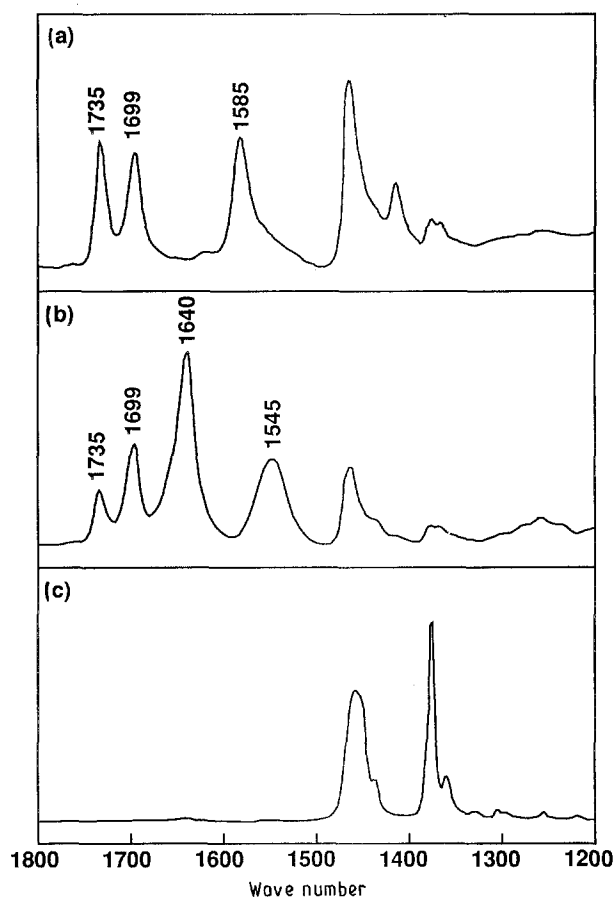


Figure 2 FT-IR spectra of copolymers extracted from various blends: (a) pure ionomer; (b) 20 wt % ionomer/80 wt % PA melt blended 5 min at 250 $^{\circ}\text{C}$ and 50 r.p.m.; (c) 25 wt % PP/75 wt % PA melt blended 20 min at 250 $^{\circ}\text{C}$ and 80 r.p.m.

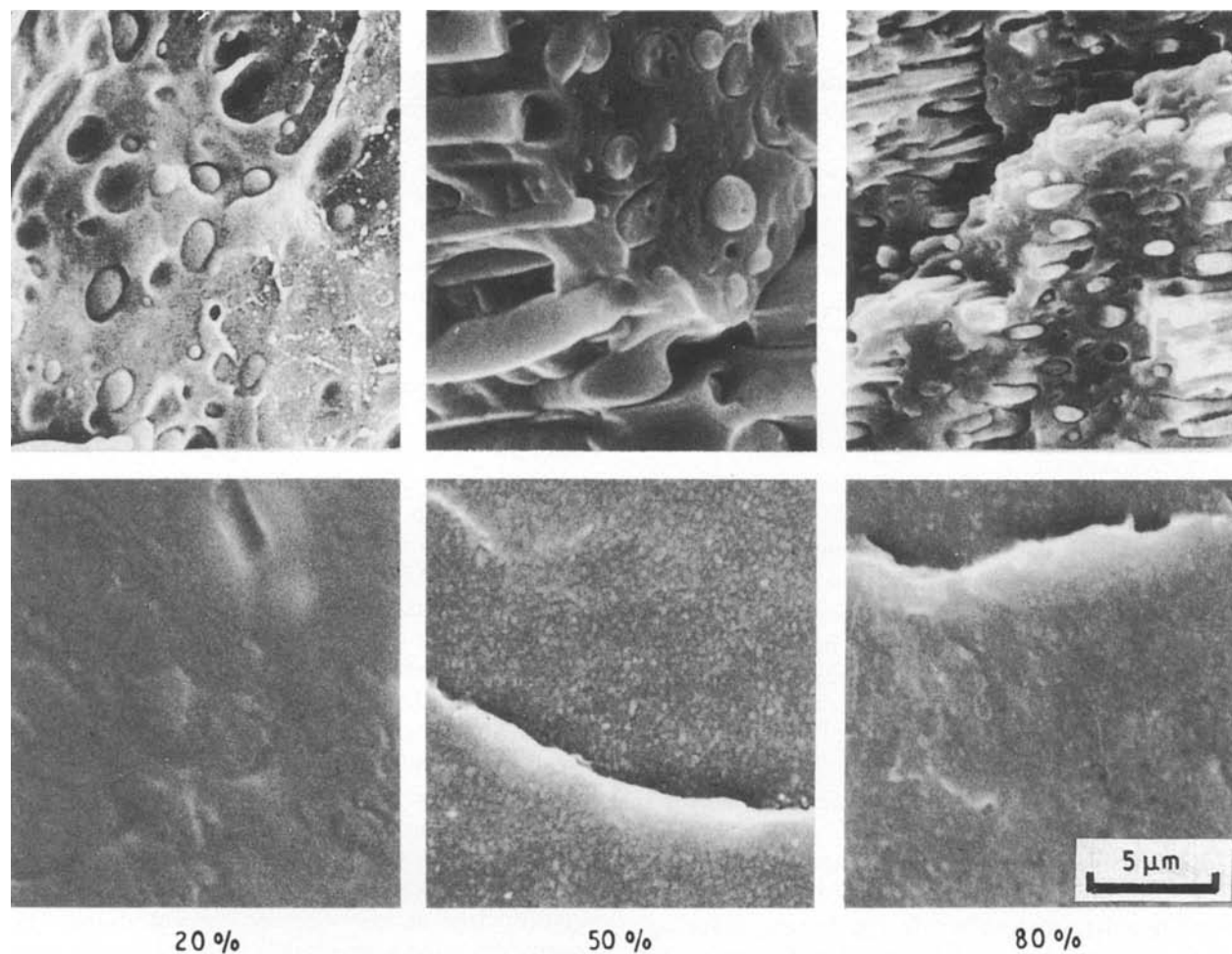


Figure 3 Scanning electron micrographs of fracture surfaces of PP/ionomer (top) and PA/ionomer binary blends (bottom), containing 20%, 50% and 80% ionomer. All micrographs were taken at the same magnification.

obtained, for ionomer blends, a positive Molau test [30], which is an indication of copolymer formation.

Fig. 2 shows FT-IR spectra of pure ionomer and of extraction products. For pure ionomer (Fig. 2a), the hydrogen-bonded carbonyl stretching frequency can be seen at 1699 cm^{-1} . Non-hydrogen-bonded carbonyls appear at 1735 cm^{-1} . The peak at 1585 cm^{-1} corresponds to the antisymmetric stretching mode of the carboxylate groups present in the ion clusters. For the ionomer blend, even after several formic acid washings, the polyamide peaks ($\text{C}=\text{O}$ at 1640 cm^{-1} and $\text{N}-\text{H}$ at 1545 cm^{-1}) are still present in the extraction product (Fig. 2b). Under these conditions the acid salt was neutralized. Because hydrogen bonding would not resist an acid extraction, this result confirms the presence of a chemical reaction at the interface, responsible for the compatibilization of the blend. The same procedure, applied to the PP blend, did not leave any copolymer, as seen by infrared spectroscopy. In that case no carbonyl peak at 1640 cm^{-1} was visible (Fig. 2c) indicating the absence of polyamide in the extraction product. All the peaks observed in that case are related to the polypropylene. This result is consistent with the absence of a chemical reaction between the polyamide and the polypropylene. Because there is no polyamide graft to polypropylene, the chemical reaction observed with the ionomer is related to its chemical nature and not to the blending process.

Although it was initially believed that hydrogen bonding was the predominant interaction in these blends [7], these more detailed studies strongly suggest rather the formation of an amide bond between the carboxylic acid of the ionomer and the terminal amines of polyamide, as proposed by McKnight *et al.* [9].

3.1.2. Morphology of polypropylene/ionomer binary blends

The scanning electron micrographs obtained for the freeze-fractured surface of binary blends of polypropylene with 20%, 50% and 80% ionomer are shown in Fig. 3. The two phases are distinct for each composition. There is no evidence of adhesion between the dispersed phase and the matrix.

The number average diameters of the dispersed phase were determined for these blends, and the results shown in Fig. 4. As the weight per cent of the dispersed phase increases, larger domain sizes are observed for the dispersed polymer. This type of phase size/composition relationship is generally observed for immiscible blends [27, 31–36]. It is related to the higher rate of coalescence at higher concentration.

When the blend components are inverted, such that the polypropylene is dispersed in the ionomer, the torque ratio becomes small and has values of about 0.5. This viscosity effect is reflected in the reduction in

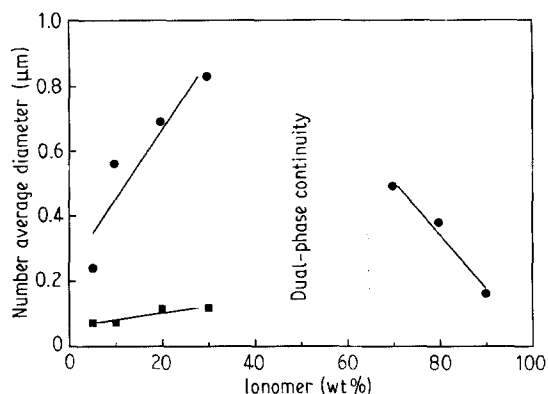


Figure 4 The number average diameters determined for the binary (●) PP/ionomer and (■) PA/ionomer blends, as a function of ionomer concentration.

the size of the dispersed polypropylene relative to that of dispersed ionomer, and can be seen in Fig. 4 at high ionomer concentrations. The dependence of phase size on torque ratio (viscosity ratio) has been investigated recently by Favis and Chalifoux [37] for polypropylene/polycarbonate blends.

3.1.3. Morphology of polyamide/ionomer binary blends

The morphology of the binary polyamide/ionomer blends was found to be very different from the corresponding polypropylene blends. Fig. 3 shows scanning electron micrographs of freeze fractured samples obtained for the polyamide blends containing 20%, 50% and 80% ionomer. For each composition, these binary blends appear homogeneous: it is not possible to observe the presence of a dispersed phase. This apparent absence of minor phase was also observed by Van Gheluwe *et al.* [38] in a study of the mechanical properties of extruded PA/ionomer/PP blends. However, when the microtomed surface of the 80% PA/20%ionomer binary blend is etched to remove the dispersed ionomer domains located at the surface [7], the dispersed phase is readily observed as shown in Fig. 5. The size of the dispersed ionomer domains is extremely small. The number average diameter deter-

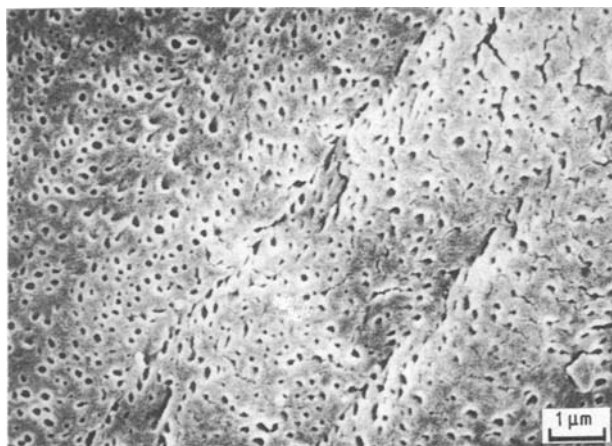


Figure 5 Scanning electron micrograph of the microtomed/etched surface observed for the 80% PA/20% ionomer binary blend.

mined for the 80%PA/20%ionomer blend is only 0.12 µm, roughly five times smaller than corresponding polypropylene blend. This ratio varies from 2 to 5 on increasing ionomer content from 0 to 30%. For PA/ionomer blends, phase size is less influenced by composition as shown on Fig. 4, indicating a lower coalescence rate for this system. Therefore, from a morphological standpoint, it appears that the polyamide/ionomer blend is significantly more compatible than the polypropylene/ionomer blends.

3.2. Torque measurements

The torques measured for the polypropylene/ionomer blends during melt mixing in the Brabender are shown in Fig. 6a. A negative deviation can be seen between the measured points and the tie-line joining the torques of the pure components, over the whole composition range. At low ionomer contents, the torque of the blend is actually lower than that of the polypropylene resin. This shape of torque/composition curve is characteristic of an incompatible blend [39]. In such cases, there is likely a significant degree of interlayer slip occurring at the interface during the melt blending [40].

For the binary blends of polyamide with the ionomer, a strong positive deviation was found for the torque at low ionomer contents, as shown in Fig. 6b. This is quite different from what was observed for the polypropylene at low ionomer concentrations. The positive deviation suggests that there are strong interactions between the polyamide and the ionomer. At high ionomer contents, the torque displays a slight negative deviation from additivity.

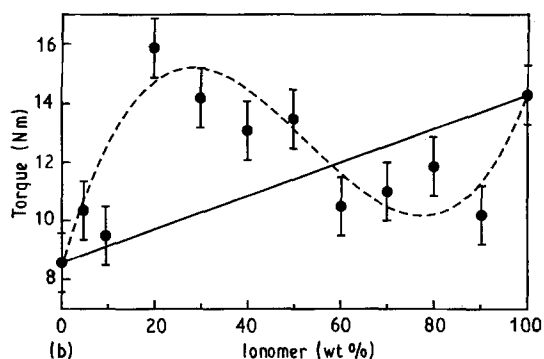
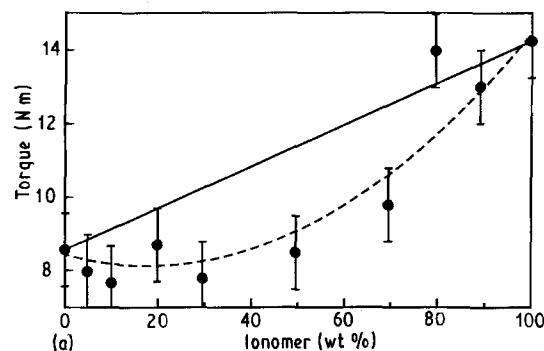


Figure 6 The torques measured in the Brabender at 250°C for the binary blends, as a function of ionomer concentration. (a) PP/ionomer. (b) PA/ionomer.

3.3. Thermal analysis

The crystallization exotherms of the binary blends of polypropylene with 30% ionomer and of polyamide with 30% ionomer are shown in Fig. 7. Each crystallization trace is characterized by two peaks: one rather broad peak around 55°C corresponding to the ionomer, and a sharper peak at higher temperatures corresponding to the other component. Only the peaks corresponding to the polypropylene and the polyamide were analysed because the ionomer peaks were too broad to allow for an accurate analysis.

The areas of the crystallization exotherms were integrated as a function of temperature (equivalent to time because the DSC scans were performed at 5°C min⁻¹). Thus, the per cent transformation of crystalline material is the ratio of the area measured up to temperature, *T*, divided by the total area. It is possible to determine the half-time, *t*_{1/2}, of the crystallization process by measuring the difference between the temperature corresponding to 50% transformation and the temperature corresponding to the onset of crystallization, divided by the scan rate. Fig. 8 illustrates the dependence of the crystallization half-times of the polypropylene and polyamide on the ionomer content of the corresponding binary blends. For the PP/ionomer blends, there is an initial sharp decrease followed by an equilibration of the half-time. The reduction observed for the half-time indicates that the ionomer is accelerating the crystallization of the polypropylene, and is possibly acting as a nucleating agent. However, in contrast to what was observed for the polypropylene, the half-time of the PA/ionomer blends increases dramatically. This indicates that the crystallization process is impeded by the presence of the ionomer in these blends. This result was expected

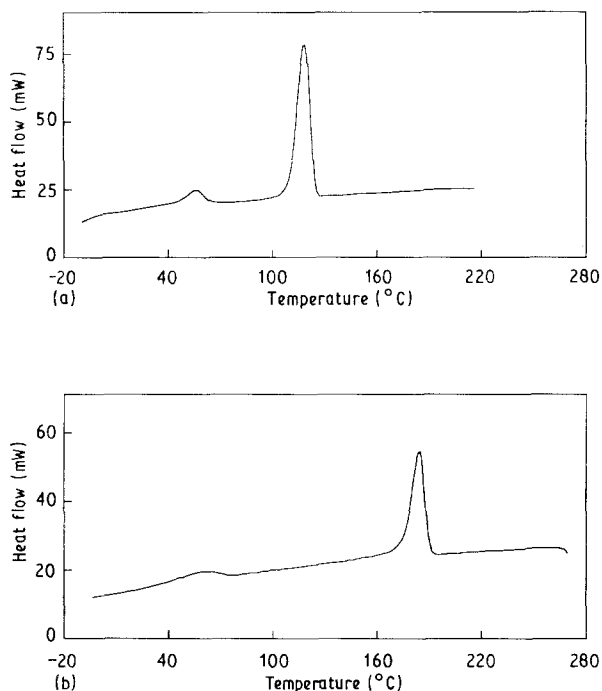


Figure 7 The crystallization exotherms observed for the binary blends with 30% ionomer, obtained at 5°C min⁻¹. (a) Polypropylene. (b) Polyamide.

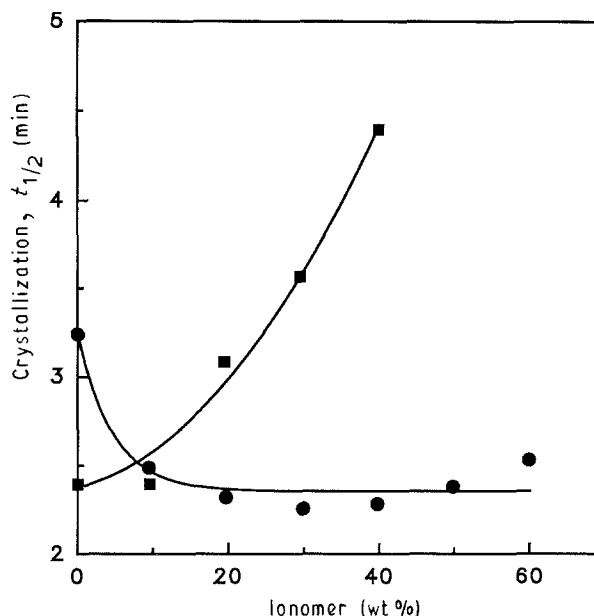


Figure 8 The crystallization half-times, *t*_{1/2}, measured for the binary blends as a function of ionomer concentration. (●) PP/ionomer, (■) PA/ionomer.

in view of the strong interactions which have been found to occur between the polyamide and the ionomer, using FT-IR spectrometry.

The temperature corresponding to the maximum of the crystallization exotherms, *T*_c, is shown in Fig. 9 for the binary blends, as a function of ionomer concentration. A significant increase in *T*_c was observed for the PP/ionomer blends which again suggests that the ionomer is behaving as a nucleating agent for polypropylene. In contrast, the maximum crystallization temperature of the PA/ionomer blends decreased with ionomer concentration. This concurs with the increase in the half-time of the crystallization, and indicates that the ionomer is interfering with the crystallization of the polyamide in these blends.

Recently, Caldas *et al.* [41] studied the isothermal spherulitic growth of polypropylene in PP/ionomer blends. The nucleating ability of the ionomer for polypropylene was demonstrated directly using optical microscopy. However, it was not possible to verify the nucleation of the PA/ionomer blends since the polyamide polymer itself is inherently highly self-nucleating.

The width of the crystallization exotherms measured at half height, *W*_{1/2}, is given in Fig. 10 for the two binary blends. For the PP/ionomer blend, the *W*_{1/2} value does not change with ionomer concentration, indicating that the distribution of crystallite size is unaffected by the presence of ionomer. In a study of PP/PE blends, Gupta *et al.* [42] noticed that although the nucleation of the polypropylene was enhanced by the dispersion of polyethylene in the polypropylene matrix, a narrower crystallite size distribution was observed.

For the polyamide/ionomer blends, a more pronounced increase in the width at half height with ionomer concentration was observed. This result would be expected if the ionomer is interfering with the crystallization of the polyamide. Thus, a much

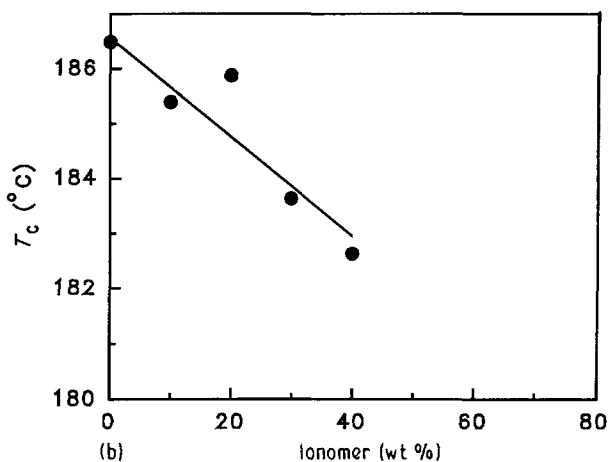
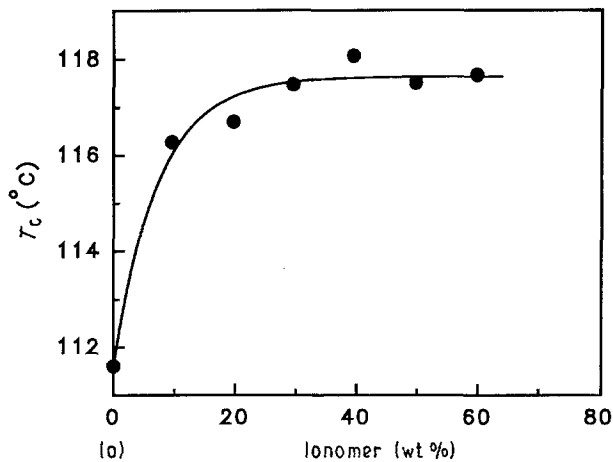


Figure 9 The maximum crystallization temperatures, T_c , observed for the binary blends, as a function of ionomer concentration. (a) PP/ionomer. (b) PA/ionomer.

wider distribution of polyamide crystallites occurs as a result of blending with the ionomer.

The relative crystallinity measured for the three binary blends is shown in Fig. 11. This value is determined by taking the ratio of the area of the crystallization exotherm of the blend to that of the pure polymer. It can be seen that the relative crystallinity follows the same trends as the crystallite size data presented in Fig. 10. From these results, it can be postulated that the interactions which occur between the polyamide and the ionomer are stronger than for polypropylene where dispersive forces are the principal interactions. Although definite trends are observed, the results given in Fig. 11 differ by only $\pm 5\%$ which suggests that the measurement of crystallinity is not highly sensitive to the interactions occurring between these polymers. Such observations were also made by Chuang and Han [10, 11], McKnight *et al.* [9] and Fairley and Prud'homme [15] for similar types of systems.

4. Conclusion

Although previous work shows that a polyethylene-co-methacrylic acid-co-isobutylacrylate ionomer has a significant emulsifying effect on PP/PA blends, this study clearly illustrates a higher level of interactions

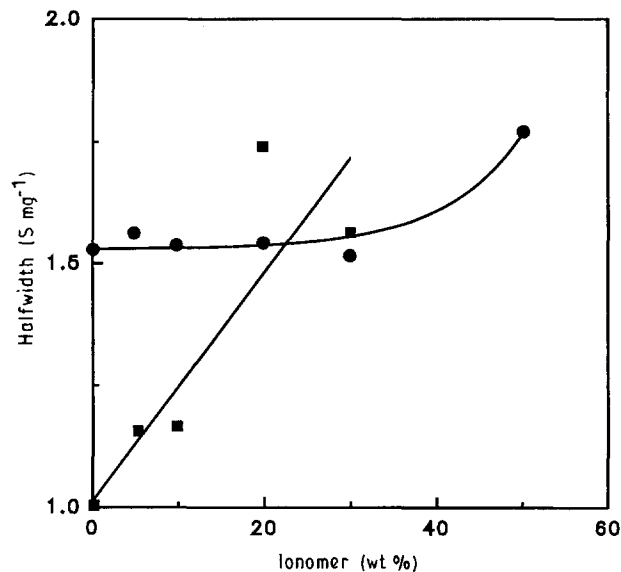


Figure 10 The widths at half height of the crystallization exotherms, measured for the binary blends as a function of ionomer concentration. (●) PP/ionomer, (■) PA/ionomer.

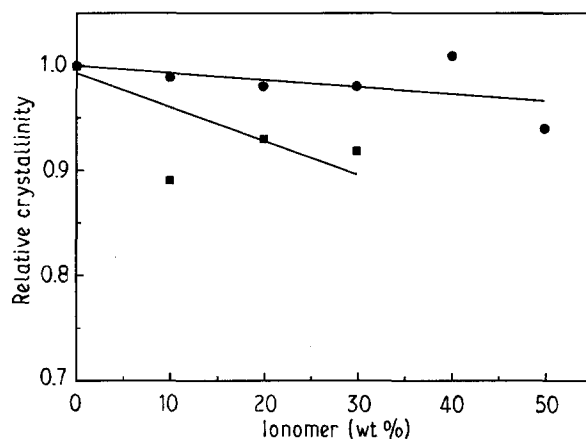


Figure 11 The relative crystallinity of (●) polypropylene and (■) polyamide in the binary blends, as a function of ionomer concentration.

between PA/ionomer but little evidence of interactions between PP/ionomer. In fact the latter shows physical characteristics typical of binary immiscible blends.

In the PA/ionomer blend, clear evidence of an amide bond is shown for this system by FT-IR/extraction. The morphology, viscosity and crystallization results all support the concept of a high level of chemical interaction. The morphology of the dispersed phase is indistinguishable in freeze-fractured samples, significant positive deviation from additivity is observed in the torque/composition data and the crystallization kinetics of the polyamide is significantly diminished in the presence of the ionomer.

By contrast, the PP/ionomer blends show all the characteristics of a classical immiscible blend with poor interfacial interactions. A mirror-like minor phase is clearly observed in the scanning electron micrographs of freeze fractured samples. Negative deviation from additivity is observed over the entire concentration range. It is interesting to note that the

presence of the ionomer actually accelerates the crystallization of polypropylene.

These results, when combined with previous studies [7, 31], indicate the potential of effectively emulsifying an immiscible blend even when one component has relatively weak interactions with the interfacial modifier.

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