Blends of isotactic polypropylene and ethylene-propylene rubbers: rheology, morphology and mechanics

Sergio Danesi* and Roger S. Porter
Polymer Science and Engineering Department, Materials Research Laboratory, University of Massachusetts, Amherst, Massachusetts 01003, USA
(Received 22 June 1977; revised 7 October 1977)

Blends of isotactic polypropylene and ethylene–propylene rubbers have been studied. The purpose of this work is to establish relationships between morphology and physical properties as well as to point out the principles which govern the morphology development. In particular, we are attempting to clarify the influence on blend morphology of such compositional variables as molecular weight, chemical affinity and percentage of components in the blend. We are also exploring how the states of dispersion are affected by conditions of blend preparation and extrusion.

INTRODUCTION

Blends based on isotactic polypropylene (PP) and ethylene–propylene (EP) rubbers are gaining increasing industrial importance beyond the traditional applications of the high impact polypropylene. Moreover, the recent development of ethylene–propylene thermoplastic rubbers has greatly increased the potential applications of such blends. Indeed EP/PP mixtures are now industrially important over the full range of their compositions.

Isotactic polypropylene and ethylene–propylene rubbers are generally incompatible and their mixtures are thus heterogeneous[1,2]. Phenomena such as segregation, stratification and phase inversion are therefore to be expected as in other multiphase polymer systems[3-12].

Experimental work has been undertaken to establish relationships between morphology and physical properties and to examine the principles which govern morphological development. We have aimed to clarify the influence of compositional variables (molecular weight, chemical affinity and percentage of components in the blend) on blend morphology. We are also exploring how the states of dispersion are affected by conditions of blend.

EXPERIMENTAL

Starting polymers

Most of the ethylene–propylene rubbers (EP) and isotactic polypropylene (PP) used in this work are commercial products of Montedison Company, (Dutral and Moplen are the trade names). The only exception is the sample indicated in *Table 1* by the code 034 which is an experimental sample also provided by Montedison. Among the ethylene–propylene rubbers studied, two are terpolymers (EPDM) with ethylidene–norbornene (ENB) as the

termonomer and one is a copolymer (EPM). *Table 1* summarizes the principle molecular properties of the polymers used in this study.

Intrinsic viscosities have been measured in decalin at 135°C and gel permeation chromatography has been used as the measure of molecular weights and molecular weight distributions. The rheology of each sample and blend was characterized in a Instron Rheometer equipped with a capillary of 0.76 mm diameter and 67 *L/D* ratio. All extrusions were performed at 200°C. *Figure 1* shows the uncorrected viscosity data.

Blends

From literature sources on incompatible systems, it seems that their morphology is determined predominantly by the rheological factors of the components[3,12]. To test this point for the EP/PP blends, a systematic variation in relative melt-viscosity differences of the components as well as in the composition of the mixtures has been made by preparing a set of blends over the full range of compositions (*Tables 1* and *2*). In each blend the melt viscosity of the EP rubber is either equal to or greater than that of the polypropylene.

Blending technique

A Brabender single screw extruder was used in combination with a 'Static Mixer' of Kernics Corporation for preparation of all blends. The mixing performance of this equipment has been evaluated by other authors[3,5] and compared positively with other commercial compounding machines. In our experiments, the hopper of the extruder was filled with the dry blend of small cut pieces of rubber and pellets of polypropylene. The extrusion temperature and pressure were held near constant at 200°C and 2000 p.s.i., respectively.

The Brabender extruder had a *L/D* ratio of 20 and a diameter of 1.9 cm. The 'Static Mixer' contained 10 mixing units. The output of the mixer was extruded

---

* On leave from Montedison, Divisione Materie Plastiche, Centro Ricerche, 44100 Ferrara, Italy.

Table 1 Starting polymers for blends

Polymer	Code	Intrinsic viscosity* (dl/g)	A_W	M_W	M_W/M_n	Propylene (wt %)	ENB (wt %)
EPDM	038	2.3	8580	160 000	2.3	~30	~4
EPDM	034	2.1	7450	130 000	2.4	~30	~4
EPM	054	2.4	11 200	210 000	4.3	~50	—
PP	C	2.1	12 700	260 000	6.7	100	—
PP	Q	3.1	22 200	420 000	6.5	100	—

*Decalin at 135°C. EPDM is a terpolymer from ethylene, propylene and a diene monomer; EPM is a copolymer from ethylene and propylene; PP is an isotactic polypropylene; ENB is a ethylidene—norbornene termonomer
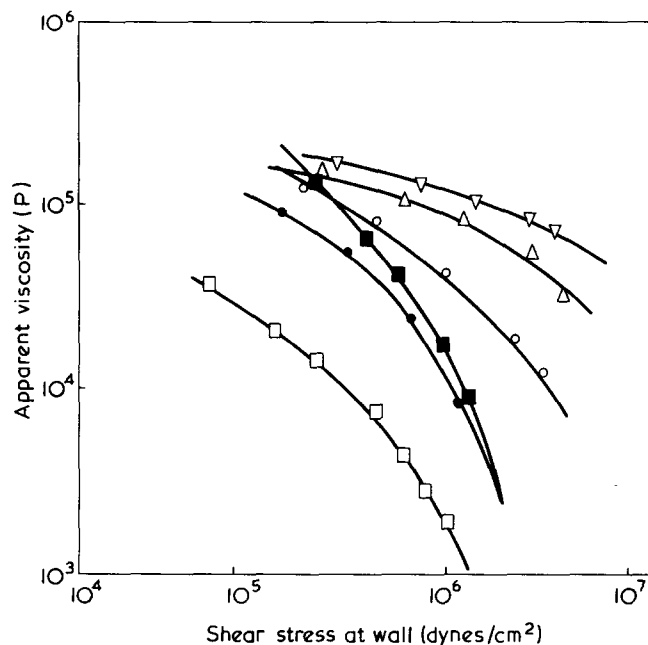

Shear stress at wall (dynes/cm²)

Figure 1 Capillary rheology of starting polymers: ■, PPQ; □, PPC; ▽, EPDM 038; △, EPDM 034; ○, EPM 054; ●, EPM Block. T_{Ext} = 200°C

Table 2 EP/PP blends

Blend system	Composition (wt %)					
038/C	0/100	20/80	40/60	60/40	80/20	100/0
034/Q	0/100	20/80	40/60	60/40	80/20	100/0
054/Q	0/100	20/80	40/60	60/40	80/20	100/0

through a circular die to facilitate the subsequent cutting of the extrudate into small pellets.

All three series of blends were prepared starting from the 80 EP/20 PP mixture by adding increasing amounts of PP to achieve the other composition ratios. For several of the blends, the macroscopic homogeneity was checked by infra-red analysis comparing the values of the absorbance ratios A_{1150}/A_{720} in six different points of each blend. The results obtained have shown that two passes through the extruder plus 'Static Mixer' were necessary to assert at 95% confidence level that the two components were uniformly mixed. Accordingly, each blend was passed twice through the extruder and 'Static Mixer'. Possible degradation or grafting during the mixing was evaluated by comparing the intrinsic viscosity of the blend after the second extrusion with the intrinsic viscosity of the corresponding dry blend of the same two polymers. The results, reported

Table 3 Influence of melt mixing on the intrinsic viscosity of the blends

Blend	$[\eta]$ Calculated*	$[\eta]$ Dry blend†	$[\eta]$ After melt mixing†
038/C 60 EP/40 PP	2.2	2.3	2.5
034/Q 60 EP/40 PP	2.5	2.3	2.4
054/Q 60 EP/40 PP	2.7	2.7	2.8

*Additive from the corresponding values of the components; †Decalin at 135°C

in *Table 3*, show a systematically higher value of the intrinsic viscosity of the blend prepared in the melt. This increase could be ascribed to grafting, branching or cross-linking processes which could take place during the mixing. This effect is sufficiently contained to allow a meaningful interpretation of subsequent tests on the blends.

Preparation of samples for the mechanical and morphological characterization

The mechanical and morphological characterization was performed directly on the extrudates obtained from the Instron capillary rheometer. The material was left inside the barrel at 200°C for about 1 h and then extruded at a shear rate of 5.5 sec⁻¹. In the case of the 60 EP/40 PP blend of the series 034/Q, the unextruded material, which remained inside the barrel for about 1 h, was also collected for the morphological characterization. All the compositions of the series 034/Q were also extruded at 137 sec⁻¹, following a similar procedure. The samples for the mechanical characterization were annealed, after the extrusion, for 2 h at 140°C.

Mechanical characterization

All the samples were mechanically characterized at room temperature with the Instron testing machine. The yield stress, the elongation at break, the secant modulus at 1% of deformation and the elastic recovery were measured.

Each extrudate was stretched in the extrusion direction at 5 cm/min starting from a gauge length of 2 cm; a speed of 0.5 cm/min was used only for the measure of the secant modulus. Where possible, samples were elongated to 1000% and then removed from the clamps for the measure after 24 h of elastic recovery.

The stress—strain curves for blends rich in rubber did not show a clear yield point nor a propagating neck; in these cases, the yield stress was defined as the stress at which the slope of the stress—strain curve equals zero.
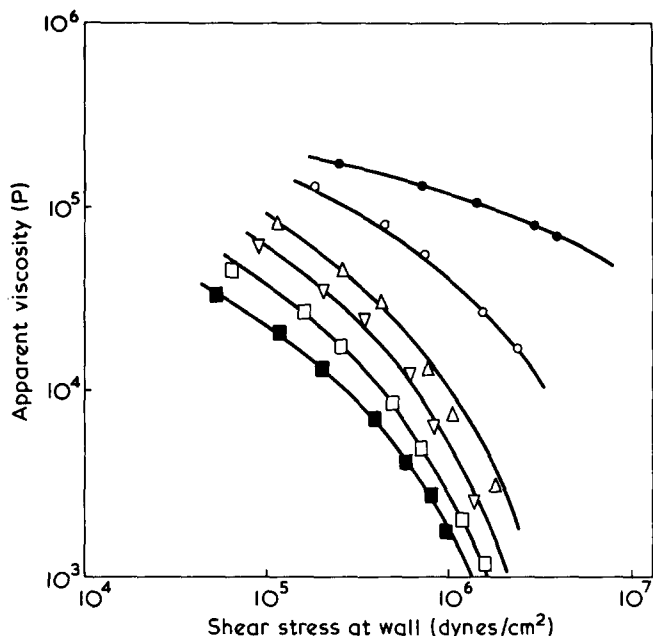
Figure 2 Capillary rheology of the blends 038/C: ■, PPC; □, 20 EP/80 PP; ▽, 40 EP/60 PP; △, 60 EP/40 PP; ○, 80 EP/20 PP; ●, EPDM 038. Blends 038/C, 200°C
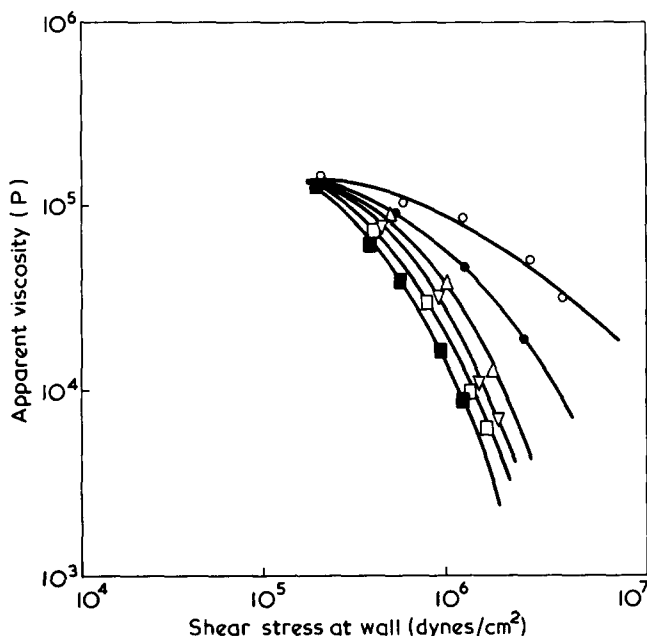

Figure 3 Capillary rheology of the blends 034/Q: ■, PPQ; □, 20 EP/80 PP; ▽, 40 EP/60 PP; △, 60 EP/40 PP; ●, 80 EP/20 PP; ○, EPDM 034. Blends 034/Q, 200°C

Morphological characterization

The experimental techniques normally used for the morphological characterization of heterophase systems are based on interference polarizing microscopy[3,4,13], transmission electron microscopy[3,12] and scanning electron microscopy on etched samples[3,5,12].

Of these techniques, phase contrast microscopy has been found to be the most suitable for our samples and purposes. The experimental procedure consists in preparation of 10 μm thick cross-sections of the extrudate using an ultra-microtone (Sorval MT 2—B) at −100°C, followed by immersion of the slices at room temperature in a suitable oil (Cargylle, type A) which is a good solvent for the rubber and has a refractive index higher than that of PP (1.52 and 1.49, respectively). This difference is sufficient

to provide a reasonable contrast between the phases with the dark and light areas corresponding to the EP and the PP, respectively. The comparison among the microstructures of different blends is based on a relative evaluation of the fineness of the dispersed phase. Smaller domain sizes and more uniform distribution of the minor component are generally referred to as finer microstructures.

In a search for an experimental technique to evaluate stratification quantitatively (i.e., the distribution of phases across the extrudate), which can occur during the extrusion of multiphase systems, a selected blend was extruded at different shear rates and examined by infra-red spectroscopy in reflection. With this technique it is possible to measure the composition of the 10 μm thick surface and compare this value with the known average composition of the blend. In particular a Perkin—Elmer Model 180 spectrometer equipped with a Perkin—Elmer Multiple Internal Reflection Accessory (part no. 186—0335) has been used. Test samples 3.2 mm wide and 0.15 mm thick were extruded at 200°C through a slit die in the Instron Rheometer.

Differential calorimetry was also carried out at a scanning rate of 10°C/min on the blend series 038/C to study the influence of the rubber on the kinetics and thermodynamics of polypropylene crystallization.

RESULTS

Mechanical and morphological properties of the blend: influence of composition ratio and of difference in the melt viscosities of the components

The rheological characterization of all blends, reported in *Figures 2—4*, points out the monotonic dependence of blend melt viscosity on composition and the progressive reduction in component melt viscosity difference going from the series 038/C to the series 054/Q. As mentioned previously, the viscosity of each rubbery component exceeds or equals viscosity of polypropylene component.

According to the procedure described in the Experimental part, extrudates corresponding to a shear rate of 5.5 sec^{-1}
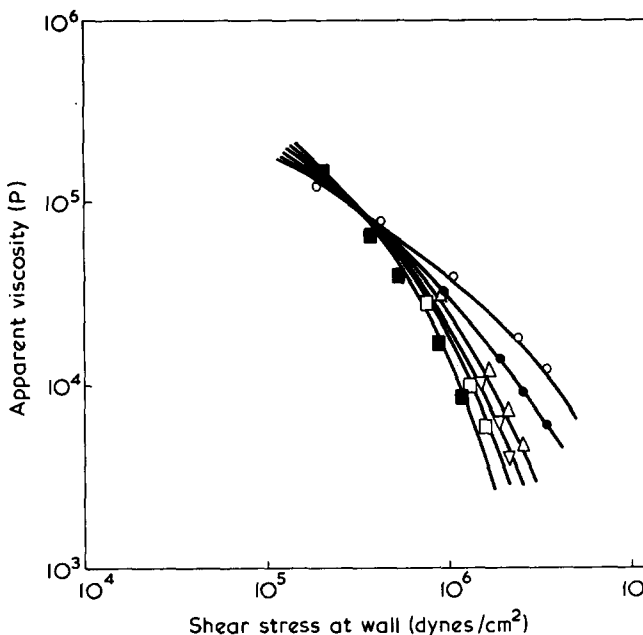

Figure 4 Capillary rheology of the blends 054/Q: ■, PPQ; □, 20 EP/80 PP; ▽, 40 EP/60 PP; △, 60 EP/40 PP; ●, 80 EP/20 PP; ○, EPM 054. Blends 054/Q, 200°C
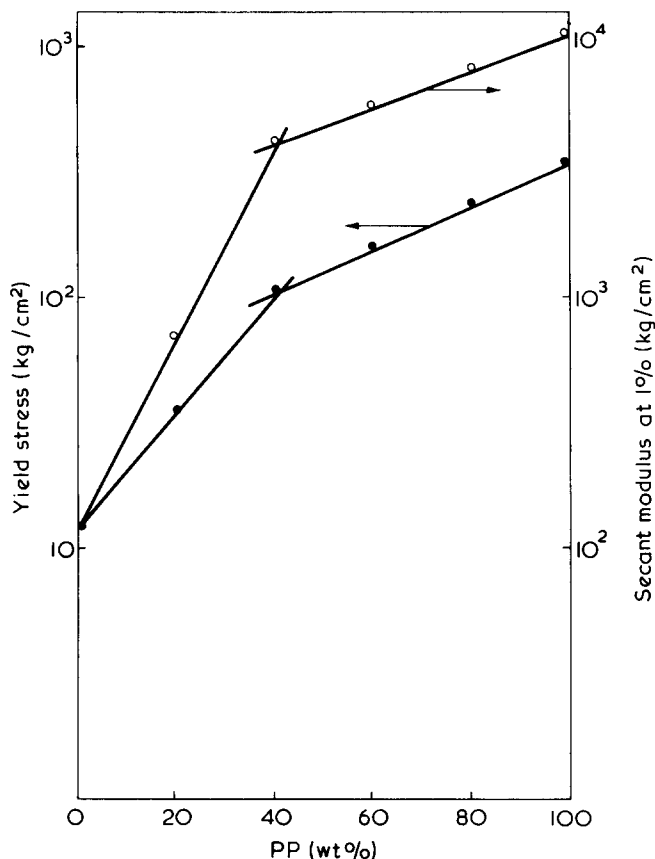
Figure 5 Influence of the composition on the yield stress and the secant modulus of the blends 038/C. $\dot{\gamma}$ = 5.5 sec^{-1}; temperature = 200°C

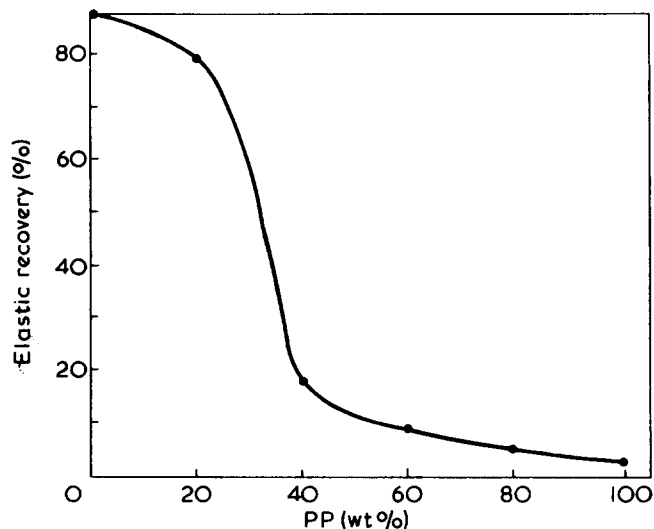*Figure 6* Influence of the composition on the elastic recovery of the blends 038/C. Extruded, $\dot{\gamma}_W$ = 5.5 sec^{-1}; temperature = 200°C; strain = 1000%

stress and secant modulus increase with increasing amount of polypropylene in the blends. An abrupt change in the slope of the yield stress (or secant modulus)—composition curves occurs in the composition range 60 EP/40 PP to 40 EP/60 PP. The position of this abrupt change seems to depend on the difference of the melt viscosities of the components; in particular, as this difference is reduced, the critical ratio seems to move from a composition of 60 EP/40 PP (blends 038/C of *Figure 5*) to 50 EP/50 PP (blends 054/Q of *Figure 9*).
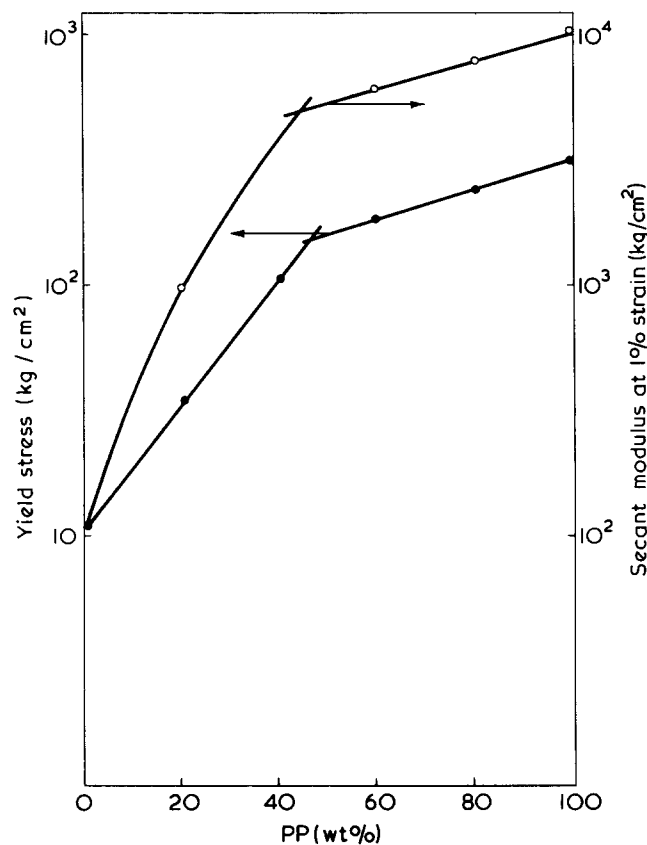

Figure 7 Influence of the composition on the yield stress and the secant modulus of the blends 034/Q. Extruded, $\dot{\gamma}_W$ = 5.5 sec^{-1}; temperature = 200°C

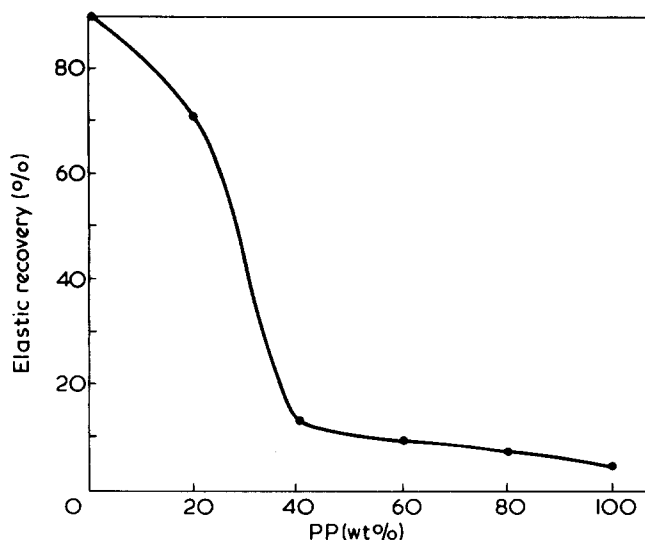were collected and annealed for 2 h at 140°C before the mechanical characterization. The results are shown in *Figures 5—9*. The elongations at break are not reported since they exceed 1000% for most blends. The exceptions are the blends 054/Q of low PP content. The elongations at break of this series are shown in *Table 4*. For the same reason the elastic recovery of this series was not measurable over the full range of compositions; the data are reported in *Table 4*.

The mechanical characterization shows a clear influence of the composition on the properties considered. Both yield

Figure 8 Influence of the composition on the elastic recovery of the blends 034/Q. Extruded, $\dot{\gamma}_W$ = 5.5 sec^{-1}; temperature = 200°C; strain = 1000%

Similarly changes in blend composition substantially influence the state of dispersion of the phases in the blend, as it can be seen from the photographic data of *Figures 10* and *11*. This effect is particularly evident for compositions from 60 EP/40 PP to 40 EP/60 PP, where all the considered series exhibit a phase inversion (compare *Figure 10b* with *10c* and *Figure 11b* with *11c*.

The dispersion characteristics of the phases are influenced by the difference in the melt viscosities of the components. Blends with a greater disparity in the melt viscosity of the constituents show a greater variation of the microstructure with the composition (compare, for example, *Figure 10* of the series 038/C with *Figure 11* of the series 054/Q).

The difference in the melt viscosity of the components also influences the domain sizes of the dispersed phase. For the same composition ratio, blends of the series 038/C exhibit domains larger than in blends of the series 054/Q, as in particular the rubber is the dispersed phase (compare *Figures 10a* and *10b* with *Figures 11a* and *11b*). As the amount of rubber in the blend is increased, the viscosity difference becomes less important in determining the state of dispersion. All blends of the composition ratio of 80 EP/20 PP exhibit a fine dispersed-phase structure, which is essentially independent of the difference in the melt viscosity of the components.
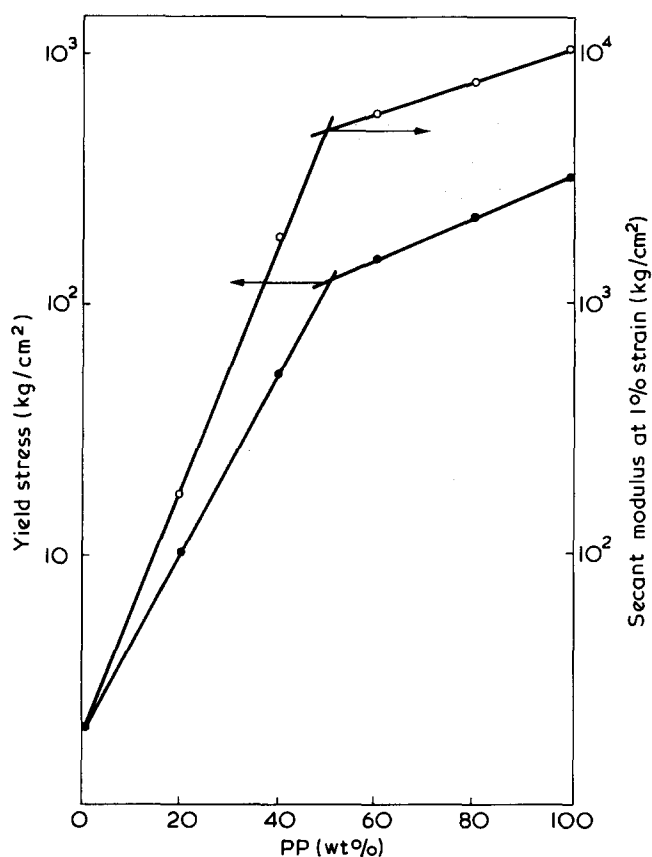

Figure 9 Influence of the composition on the yield stress and the secant modulus of the blends 054/Q. Extruded, $\dot{\gamma}_w$ = 5.5 sec^{-1}; temperature = 200°C

Figure 10 (a) Phase contrast micrograph of the blend 038/C 20 EP/80 PP extruded at 5.5 sec^{-1}. (b) Phase contrast micrograph of the blend 038/C 40 EP/60 PP extruded at 5.5 sec^{-1}. (c) Phase contrast micrograph of the blend 038/C 60 EP/40 PP extruded at 5.5 sec^{-1}. (d) Phase contrast micrograph of the blend 038/C 80 EP/20 PP extruded at 5.5 sec^{-1}
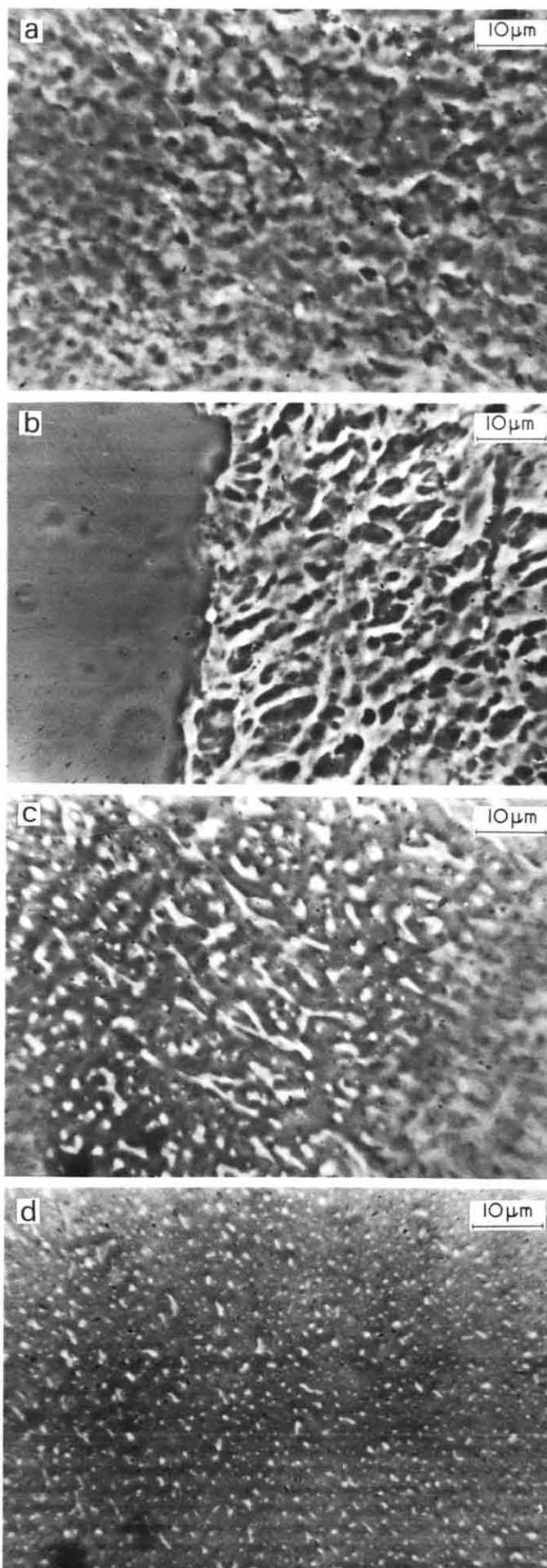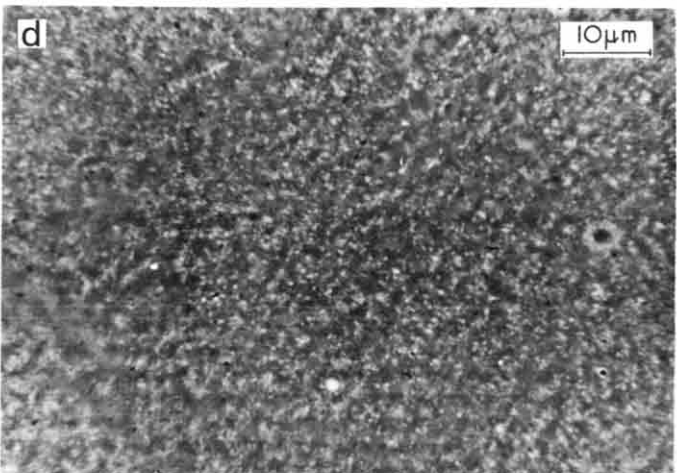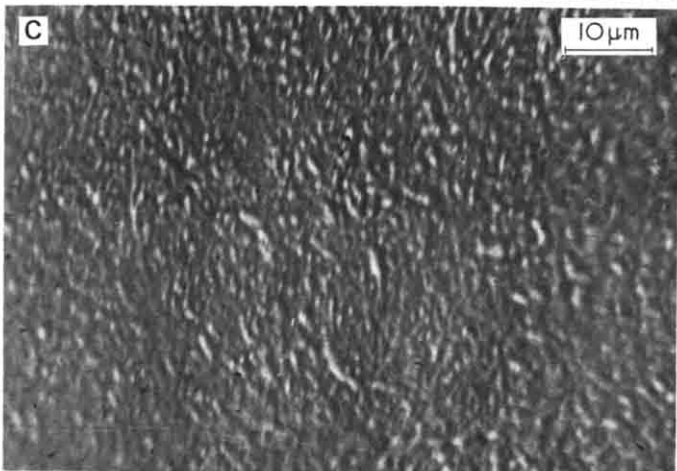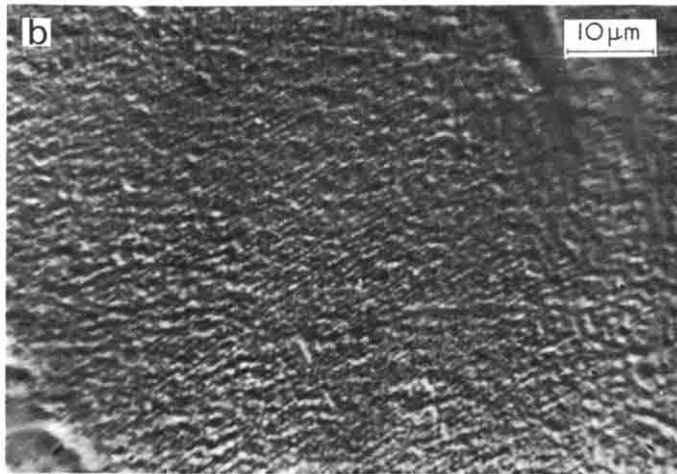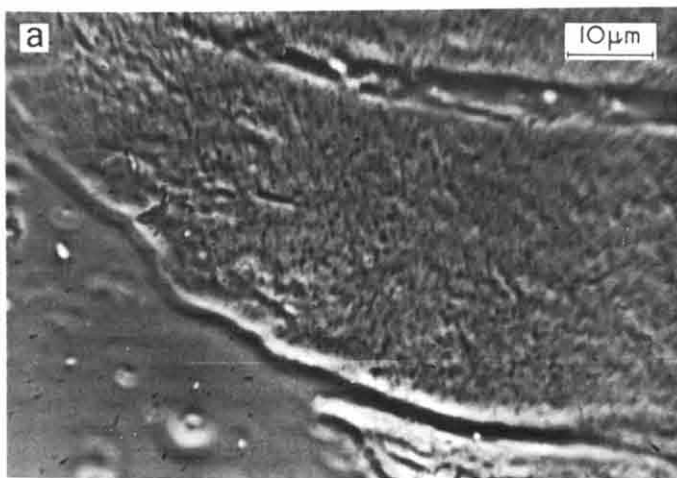
The mechanical properties of all mixtures depend essentially on the properties of the component polymers. In particular for compositions rich in rubber, the yield stress, the secant modulus and the elastic recovery of the blend reflect the corresponding properties of the rubber component.

Mechanical and morphological properties of the blend: influence of processing history

To study the mechanism of formation of the dispersed phase, blends of the series 034/Q were characterized after the mixing process and prior to capillary extrusion. The results (see for example, *Figure 12*) show a fine dispersion of the phases for all ratios considered. The same set of blends exhibits a coarser morphology after extrusion through the capillary under the conditions described in the Experimental part (compare *Figures 13* and *12*).

This change in morphology can be due to the extrusion alone or due to the combined effect of extrusion plus the annealing which takes place during the residence of the mixture inside the rheometer reservoir. In order to explain this phenomenon, the morphology of the unextruded material was also characterized. In the blend 60 EP/40 PP of the series 034/Q, a coarse distribution of the polypropylene

Table 4 Elongation at break and elastic recovery for the blends 054/Q

Blend	Elongation at break* (%)	Elastic recovery[†] (%)
EPM 054	120	–
80 EP/20 PP	250	–
60 EP/40 PP	360	–
40 EP/60 PP	>1000	20
20 EP/80 PP	>1000	12
PP Q	>1000	4

*Deformation speed 5 cm/min; [†]recovery after 24 h of 1000% deformation
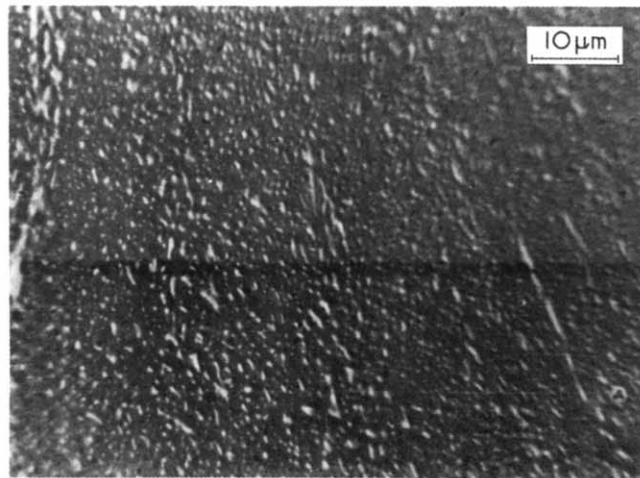

Figure 12 Phase contrast micrograph of the blend 034/Q 60 EP/ 40 PP after the mixing process and prior to capillary extrusion

Figure 11 (a) Phase contrast micrograph of the blend 054/Q 20 EP/80 PP extruded at 5.5 sec⁻¹. (b) Phase contrast micrograph of the blend 054/Q 40 EP/60 PP extruded at 5.5 sec⁻¹. (c) Phase contrast micrograph of the blend 054/Q 60 EP/40 PP extruded at 5.5 sec⁻¹. (d) Phase contrast micrograph of the blend 054/Q 80 EP/20 PP extruded at 5.5 sec⁻¹
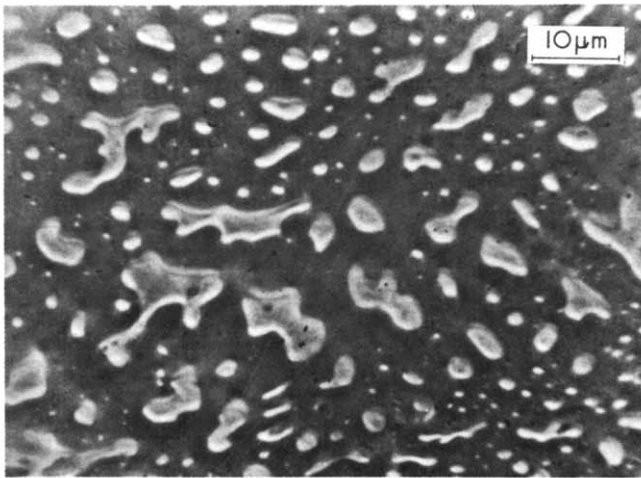
Figure 13 Phase contrast micrograph of the blend 034/Q 60 EP/ 40 PP extruded at 5.5 sec^{-1}
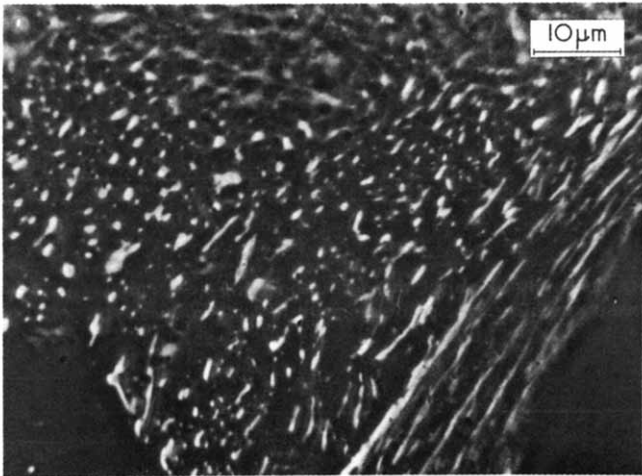

Figure 14 Phase contrast micrograph of the blend 034/Q 60 EP/ 40 PP retained for 1 h at 200°C. Inside the barrel of the rheometer

phase with very large domain sizes was easily noted *(Figure 14)*.

All compositions in the series 034/Q were also extruded through the capillary at a shear rate of 137 sec^{-1}. The experimental procedure for the preparation of the samples was identical to that for extrusion at 5.5 sec^{-1}. The mechanical characterization of this set of extrudates is shown in *Figures 15—17* together with the corresponding data of the blends extruded at low shear rate. An increase in extrusion rate produces a decrease in yield stress and secant modulus and an increase in the elastic recovery of all the compositions. This effect is less important for blends with polypropylene as the major component than for blends with the rubber as the major constituent.

The morphology of the extrudate is also influenced by extrusion speed. At higher shear rate, the dispersed domains are larger and, for intermediate compositions, non-spherical (see, for example, *Figure 18*).

Influence of extrusion speed on stratification

The 60 EP/40 PP composition of the 038/C series was extruded through a slit die at four extrusion rates, 5, 20, 200 and 500 sec^{-1}. The infra-red analysis in reflection was performed on these samples as well as on the parent polymers and on the blend before extrusion. The absorb-
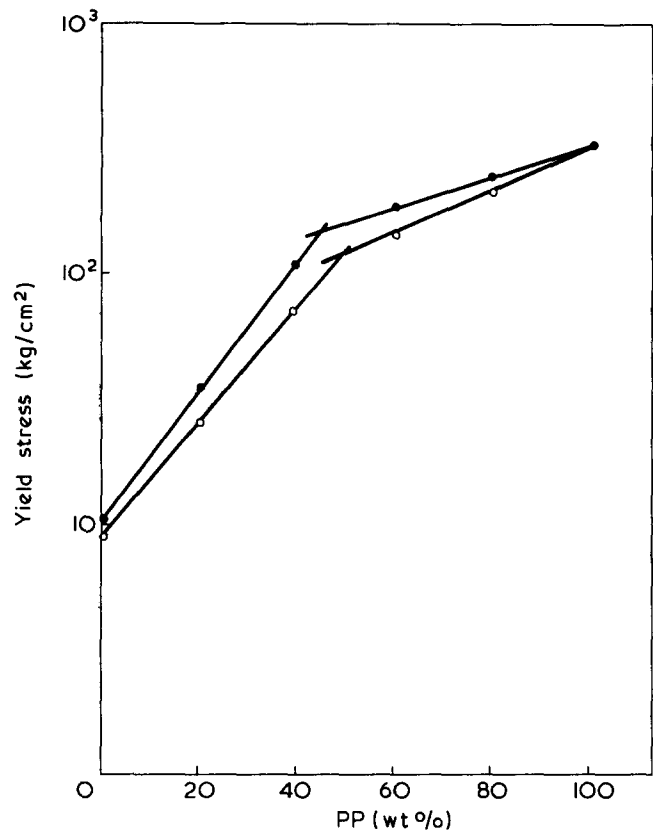

Figure 15 Influence of the composition and of the shear rate on the yield stress of the blends 034/Q. Extrusion speed: ●, $\dot{\gamma}_w$ = 5.5 sec^{-1}; ○, $\dot{\gamma}_w$ = 137 sec^{-1}. Extrusion temperature = 200°C
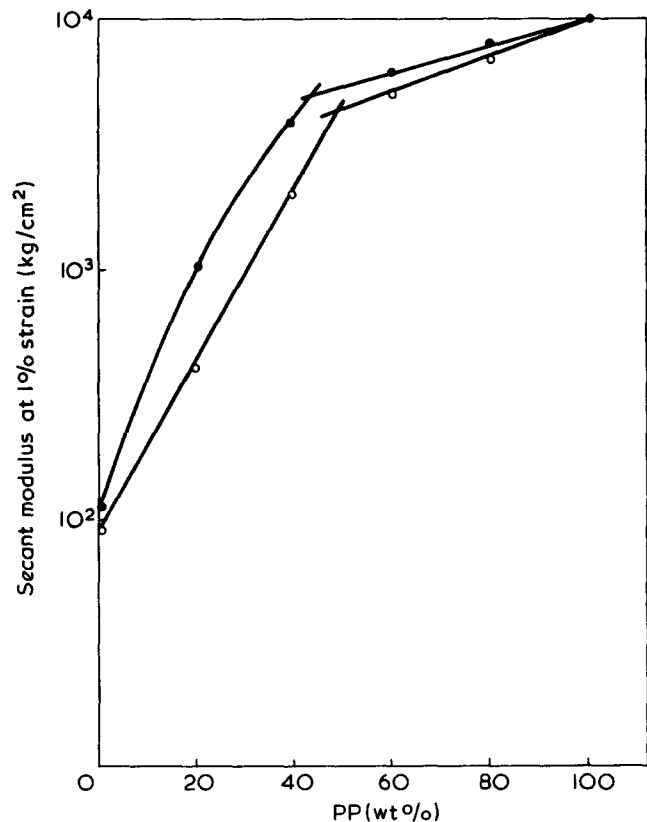

Figure 16 Influence of the composition and of the shear rate on the secant modulus of the blends 034/Q. Extrusion speed: ●, $\dot{\gamma}_w$ = 5.5 sec^{-1}; ○, $\dot{\gamma}_w$ = 137 sec^{-1}. Extrusion temperature = 200°C
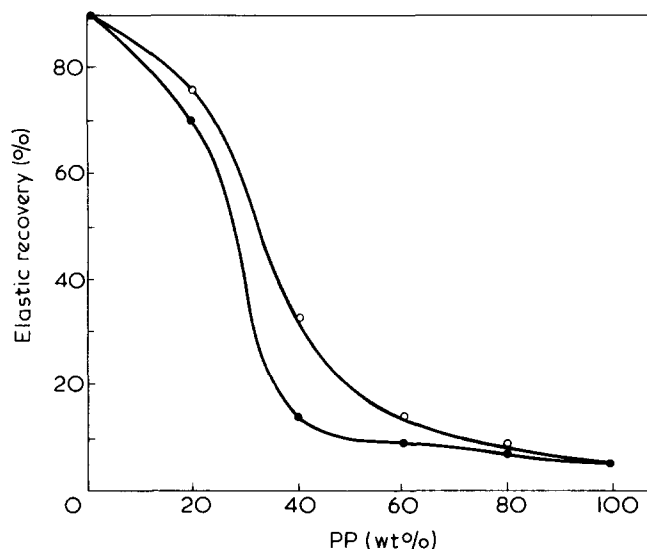
Figure 17 Influence of the composition and of the shear rate on the elastic recovery of the blend 034/Q. Extrusion speed: ●, $\dot{\gamma}_W$ = 5.5 sec^{-1}; ○, $\dot{\gamma}_W$ = 137 sec^{-1}. Extrusion temperature = 200°C strain = 1000%

ances corresponding to the 1450 cm^{-1} and 1380 cm^{-1} bands are sufficiently strong and sharp to establish a signific ant relationship between the ratio A_{1450}/A_{1380} and the blend composition. For expediency, a linear relationship between these two parameters was assumed *(Figure 19)*. From this hypothesis, the absorbance ratios of the blend extruded at low shear rates (5 and 20 sec^{-1}) correspond to lower percentages of rubber than the average composition (40 instead of 60%). On increasing the shear rate, the absorbance ratios approach the expected value for the 60 EP/40 PP composition. This result is consistent with a composition variation across the extrudate and in particular with an increased quantity of the lower melt viscosity polymer (PP) at the surface as the extrusion rate is decreased. This process seems to be time dependent in the sense that the final effect is favoured by an increased residence time of the material in the slit die and a minimum of elastic turbulence inside the capillary.

Influence of the rubber in the blend on polypropylene crystallization

The differential calorimetry of the series 038/C is reported in *Table 5*. The melting temperatures, the heats of fusion and the ratios of fusion heats for the blends to the fusion heat for the polypropylene point out the marginal effect of the rubber on the crystallization of the polypropylene: namely, the extent of crystallization is essentially independent of rubber content.

DISCUSSION

When two incompatible polymers, such as EP rubber and PP, are mixed, a heterophase system results. The corresponding morphology may be roughly described as a dispersion of the minor component in the matrix of the major one. The extent of dispersion depends on the processing history and on the rheological properties of the components.

For the same processing history, the composition ratios and the melt viscosity differences for the components determine the morphology. The general rules are provided by the morphological characterization of the samples extruded

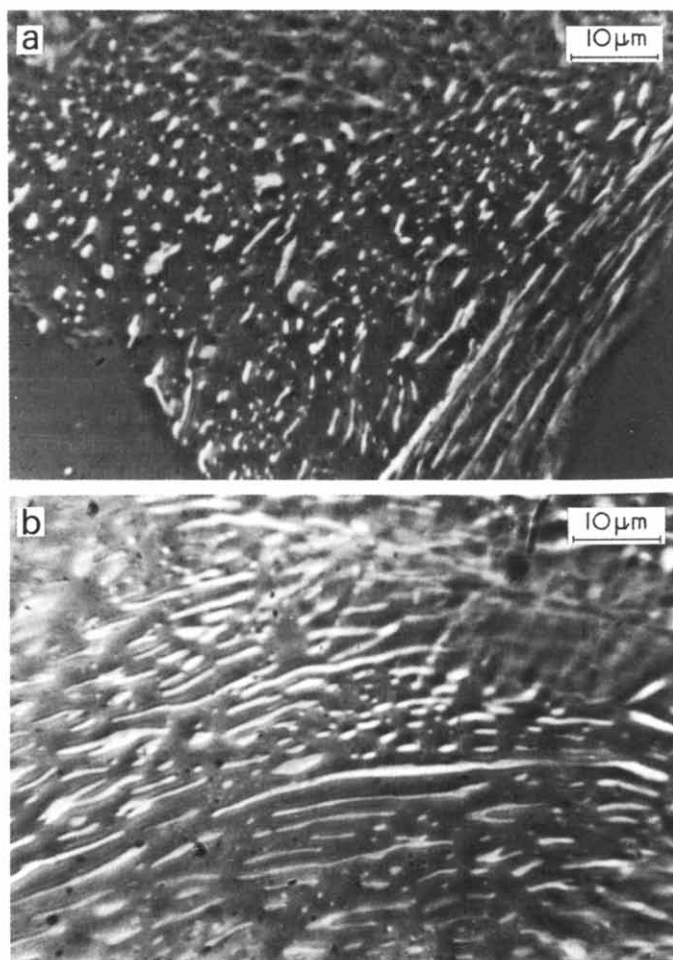*Figure 18* Phase contrast micrograph of the blend 034/Q 60 EP/ 40 PP extruded at 5.5 sec^{-1} (a) and 137 sec^{-1} (b)
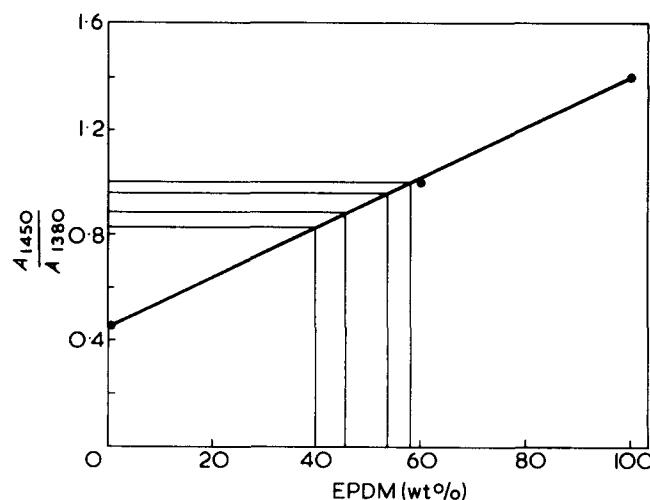

Figure 19 Reflecting infra-red data of the EPDM 038, of the PPC and of the blend 038/C 60 EP/40 PP extruded at different shear rates:

60 EPDM/40 PP (sec^{-1})	I.r. band ratio	EPDM calculated (%)
5	0.83	40
20	0.88	45
200	0.96	54
500	1.00	58

Table 5 Differential scanning calorimetry on the blends 038/C

Blend	Extrusion conditions γ_w (sec^{-1})	T_{max} (°C)	ΔH (cal/g)	$\dfrac{\Delta H \text{ Blend}}{\Delta H \text{ PP}}$ (%)
80 EP/20 PP	5.5	163	3.8	18.5
60 EP/40 PP	5.5	163	7.8	38.0
40 EP/60 PP	5.5	162	11.7	57
20 EP/80 PP	5.5	162	15.4	75.1
PP C	5.5	164	20.5	—

at low shear rate (*Figures 10* and *11*). Each series of blends exhibits a critical composition ratio at which phase inversion occurs.

When the mixed polymers have similar melt viscosities, the resultant morphology is a very fine and uniform distribution of the minor component in the major one, no matter which is the minor component *(Figure 11)*. Moreover, in the case of intermediate compositions (60 EP/40 PP and 40 EP/60 PP) both phases are continuous (*Figures 11b* and *11c*).

When the components have different melt viscosities, the morphology of the resultant blend depends on whether the minor component has a lower or higher melt viscosity than the major one. If the minor component has a lower viscosity, this component will be finely and uniformly dispersed with domains oriented in the extrusion direction *(Figure 10d)*.

In contrast, the minor component will be coarsely dispersed in essentially spherical domains if its viscosity is higher than that of the major constituent (*Figures 10a* and *10b*).

A reasonable explanation of these results can be found in the concomitant deformation of both the continuous and discreet phases during the extrusion through the Instron capillary. The relative viscosities of the components determine the extent of deformation of the phases. When the viscosity of the minor component is equal or lower than that of the major one, the dispersed component experiences the same extent of deformation which is imposed to the continuous phase. In contrast, if the viscosity of the minor component exceeds that of the major one, the deformation of the dispersed phase is always less than the deformation imposed to the continuous phase. The experimental conditions of extrusion (low shear rates and a long capillary) assure a laminar flow inside the capillary. Under these conditions the continuous phase in all blends experiences the same deformation while the dispersed phase undergoes a different deformation according to its melt viscosity. The morphological consequence is that capillary extrusion is less capable of providing a fine and uniform dispersed phase when the minor component is more viscous than the major one. Moreover the types of structures obtainable under these circumstances are more spherical, i.e. less oriented in the extrusion direction.

According to the results (see for example, *Figure 12*) all compositions in the series 034/Q as received from the mixing process, exhibit a fine dispersion of the minor component. This morphology is drastically modified by annealing for 1 h inside the barrel of the rheometer and before the extrusion. The polypropylene particles coalesce to larger domains despite the high viscosity of the dispersion medium *(Figure 14)*. This result points out the high instability of the morphological species observable in the EP/PP mixtures with any annealing above the melting point of the polypropylene.

When the blend is flowing, the dispersed elements are elongated at the entrance of the capillary under the action of the longitudinal velocity gradient. The deformation and the consequent breakdown of the dispersed domains is accompanied by a competitive process of coalescence which is facilitated by the narrowing and the turbulence of the stream at the capillary entrance. However, if the extrusion shear rate is sufficiently low to assure a laminar flow before the exit from the capillary, the deformation process of the dispersed component should become predominant and bring about fine, uniform structures highly elongated in the extrusion direction. The effectiveness of this process is indeed dependent, as mentioned previously, on the relative viscosities of the two phases. The coarse domains exhibited by the blend 60 EP/40 PP of the series 034/Q after the mixing process, and prior to capillary extrusion, are modified by the extrusion at low shear rate into fine, uniformly distributed structures (*Figures 13* and *14*). This situation corresponds to a blend in which the minor component has a melt viscosity at 5.5 sec^{-1} slightly lower than that of the major one.

As the extrusion rate is increased, the higher values of shear stress and the concomitant higher values of swelling facilitate the breakdown process of the dispersed elements oriented in the flow direction[14-17]. The morphological consequence is an overall reduction in the state of orientation of the dispersed domains and, for intermediate compositions, the formation of telescopic structures. This difference in morphology explains the lower values of yield stress and secant modulus and the higher values of elastic recovery observed in the samples extruded at high shear rate *(Figures 15–17)*.

CONCLUSIONS

A reasonable explanation of the microstructure in EP/PP blends has been developed in terms of composition ratio and melt properties of the components.

For the same processing history, a melt viscosity of the minor component lower or equal to that of the major one brings about a finer and more uniform dispersion than for the case of a minor component with a higher melt viscosity.

A phase inversion is exhibited by all the blends considered as pointed out by the mechanical and morphological characterization.

Two continuous phases are shown by blends with intermediate composition ratios and with similar melt viscosity of the constituents.

Any type of annealing above the melting temperature of the polypropylene brings about a substantial increase in the domain sizes of the dispersed phase.

A fully developed laminar flow and a low value of swelling facilitates the developing of highly oriented structures in the extrusion direction. The efficiency of this process is a maximum when the minor component has a melt viscosity lower or equal to that of the major one. High values of shear stress and swelling bring about telescopic or composite structures of the dispersed phase according to the type of flow experienced by the blend during extrusion. The mechanical characterization reflects the different states of orientation of the dispersed domains.

REFERENCES

1   Onogi, S. and Asada, T. *Prog. Polym. Sci. Jpn,* 1971, **2**, 261
2   Sperri, W. M. and Patrick, G. R. *Polym. Eng. Sci.* 1975, **15**, 668
3   Van Dene, H. *J. Colloid Interface Sci.* 1972, **40**, 448
4   Starita, J. *Trans. Soc. Rheol.* 1972, **16**, 339
5   Han, C. D., Kinn, J. W. and Chen, G. J. *J. Appl. Polym. Sci.* 1975, **19**, 2831
6   Lee, B. L. and White, J. L. *Trans. Soc. Rheol.* 1975, **19**, 481
7   Lee, B. L. and White, J. L. *Trans. Soc. Rheol.* 1974, **18**, 467
8   Han, C. D. and Yu, T. C. *Polym. Eng. Sci.* 1972, **12**, 81
9   Han, C. D. *J. Appl. Polym. Sci.* 1973, **17**, 1289
10   Han, C. D. and Kinn, Y. W. *J. Appl. Polym. Sci.* 1974, **18**, 2589
11   Kandyrin, L. D. and Kulernvev, V. N. *USSR Colloid J.* 1974, **36**, 431
12   Averopoulos, G. N., Wissert, F. C., Biddison, P. H. and Bohn, G. G. A. *Rubber Chem. Technol.* 1976, **49**, 93
13   Tsebrenko, M. V., Jacob, M., Kuchinska, M. Yu., Yudin, A. V. and Vinogradov, G. V. *Int. J. Polym. Mater.* 1974, **3**, 99
14   Hand, C. D. and Yu, T. C., *J. Appl. Polym. Sci.* 1971, **15**, 1163
15   Walczak, Z. K. *J. Appl. Polym. Sci.* 1973, **17**, 169
16   White, J. L., Ufford, R. C., Dharod, K. R. and Price, R. L. *J. Appl. Polym. Sci.* 1973, **16**, 1313
17   Albanova, T. I., Tsebrenko, M. B., Yudin, A. B. V., Vinogradov, G. V. and Yarbykov, B. V. *J. Appl. Polym. Sci.* 1975, **19**, 1781