Fibre-Forming Blends of Polypropylene and Polyethylene Terephthalate

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Summary: Bicomponent fibres represent of the new ways for the preparation of synthetic fibres with more variable properties. The polypropylene (PP)–poly(ethylene terephthalate) (PET) fibre-forming blend is very interesting because of the improvement of dyeability from bath and some mechanical properties of PP fibres. The new polymer additives containing ester groups which can be added as masterbatches during melting and extrusion processes have been developed in the last years. It has been found that rheological properties of the basic polymer (PP) and polymer additives have a significant role in the blend formation and in spinning. In this work, the influence of some non-reactive low-molecular compounds on the processing of fibre-forming PP-PET blends and on the properties of blend fibres are presented.

Introduction

Bicomponent fibres represent new ways for the preparation of synthetic fibres with variable properties. Polypropylene (PP)–polyethylene (PE) fibres have remarkable softness and thermo-bonding properties[1]. Elastomer fibres prepared from the poly(ethylene–octane) copolymer and the semi-crystalline polypropylene–ethylene block copolymer have higher mechanical properties in the concentration range of the co-continuous phase structure[2]. Most of polyamides and polyesters are miscible in the melt and in the solid state. Fibres based on the PA 6 and PA 66 blend with special polyamides exhibit improved mechanical properties and dyeability[3]. The significant improvement in dyeability by the exhaust process was observed also for polyester blend fibres[4]. In the past, much work has been devoted to fibres from polypropylene–polar polymer blends. The PP – poly(ethylene terephthalate) (PET) fibre-forming blend is very interesting because of the improvement of dyeability from bath and some mechanical properties of PP fibres[5–7]. New polymer additives containing ester groups have been developed in the last few years[8,9] for masterbatch preparation during melting and extrusion.

It has been found that rheological properties of the basic polymer (PP) and polymer additives have a significant role in the blend formation and in spinning. It has also been found[8,9] that

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there is a positive effect of the viscosity decrease on the dispersed (PET) phase on the polyfibrillar morphology of oriented blend fibres.

In this work, the influence of some non-reactive low-molecular compounds on the processing of fibre-forming PP-PET blends and on the properties of blend fibres are presented.

Experimental

Materials

Commercial polypropylene and modified polyethylene terephthalate were used for the preparation of blend fibres in an experimental work as follows:

- PP, TATREN TG 900, (PP TG 900), MFI = 12.5 g/10 min, Slovnaft Co.
- PET, intrinsic viscosity (IV) = 0.5, SH Senica Co.

Low-molecular compatibilizers based on the derivatives of polyalkylene oxide (PAO) and on the amide of carboxylic acids with alkylene diamine (ACA) were used for improving the flow properties of a mixture and for obtaining a higher degree of dispersity of the minority PET component in the PP matrix. The content of PET in a fibre-forming polymer blend was 10-20 wt%. The content of compatibilizers varied between 1 and 3 wt%.

The following disperse dyes of the Bemacron type (Bezema, Co) were used for dyeing:

1. Blau SE-RDL
2. Blau E-RD
3. Rubin SE-RDL
4. Rot E-RD
5. Rot SE-RDL
6. Orange SE RDL
7. Gelb E-RD
8. Gelb SE-RDL

Preparation

The conditions for the PP-PET blend preparation were optimised and the PP-PET blend fibres were prepared using a pilot-scale equipment with a single-screw extruder (diameter of 32 mm) and a dynamic homogenizer. The spinning temperature was 290°C and the take-up speed 400m.min^{-1}. The spinneret with 40 orifices (diameter of 0.5 mm) were used. The fibres were drawn and textured with a false twist. The linear density of the fibres was T_{dt} = 333 dtex. f 40.

Method Characterisation

The compatibility of components was calculated and semiqualitatively evaluated on the basis of rheological and thermal measurements.

The technological compatibility of PP and PET was investigated in terms of extent of deviation (Δi) of experimental viscosity of the mixture from an additive one; i.e. $\Delta i = (\eta_{exp} - \eta_{ad})/(\eta_1 - \eta_2)$, where η_{exp} and η_{ad} are experimentally determined viscosity and/or the calculated additive value, respectively, and η_1 and η_2 are viscosities of the blend forming components.

Thermal properties of polypropylene and PP-PET blend fibres were studied by DSC 7 apparatus (Perkin Elmer) using the following procedure: Sample of the original fibre was heated by a rate of 10 K.min^{-1} up to 553 K. Melting enthalpy ΔH_m was determined from the surface of endotherm, between two selected temperatures. Calculated values of the melting enthalpy of the component in the blend were evaluated from enthalpies of PP and PET multiplied by their weight fraction. In the measurements nitrogen atmosphere was used. The semiquantitative evaluation of compatibility was estimated on the basis of the change in the melting enthalpy of blend components and the deviation of the experimental enthalpy from calculated values.

The mechanical properties of blend fibres were measured with an Instron equipment, type 1112.

Scanning electron microscopy was used to investigate the structure of blend fibres. The blend fibres were dyed with disperse dyes and their colour properties were evaluated.

The colour strength of fibres was determined using the colorimeter DATACOLOR Texflash and application of the Kubelka-Munk formula. A software for the OSIRIS colorimetry was used to determine the degree of dye exhaustion. The fastness to rubbing was evaluated according to the standard ISO 105-X12 and the fastness to washing was detected according to the standard ISO 105-CO3.

Results and Discussion

The technological compatibility of PP and PET was investigated in terms of the extent of deviation of the experimental viscosity of the mixture (Δi) from an additive one. The three-phase model for a two-component blend assumes the synergistic behaviour of a mixture with the higher experimental viscosity in comparison with the additive one. The viscosity of the interface layer, η_i, is higher than the viscosity of the dispersed component, η_2, and in this case also that of the matrix, η_1. On the other hand, the experimental viscosity decreases especially as a result of a decrease in the viscosity of the interface[10] suggesting that the interface layer has acquired also a character of the other phase.

It has been shown[9] that the PP-PET blend behaves as an incompatible system. Increasing the viscosity above the additive value by a compatibiliser results in a pseudo-compatible PP-PET system. The selected modification procedure reduces the viscosity of the polyester component and can increase the viscosity of the interface layer, which leads to the improvement of the component compatibility (Figures 1 and 2).

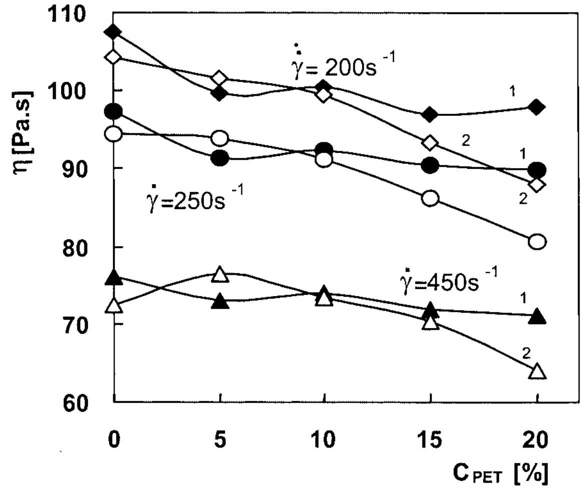


Figure 1. Dependence of PP-PET blend viscosity (η) on concentration of polyester component without compatibiliser (1) and with compatibiliser (2) at various shear rate at 270°C.

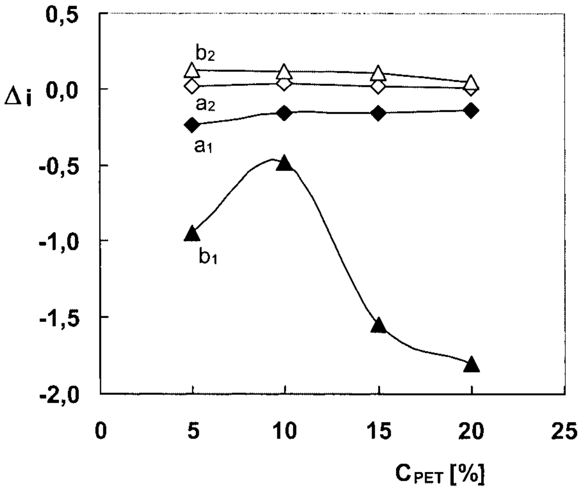


Figure 2. Dependence of viscosity deviation Δi of PP-PET blend on the concentration of the polyester component. Share rate : 200 s^{-1} (a) and 450 s^{-1} (b), without (a_1, b_1) and with compatibiliser (a_2,b_2), at 270°C.

A decrease in the melting enthalpies of polymer components in the blend fibres is proportional to the content of the PET phase and reveals the "amorphousation" of PP and PET in the blend. It can be assumed that an increase of the amorphous portion of polymer in the blend is proportional to the internal surface on the boundary of PP-PET (Fig. 3).

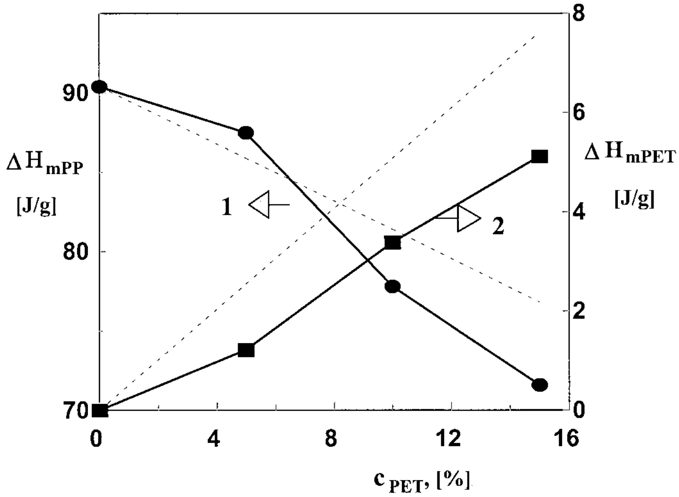
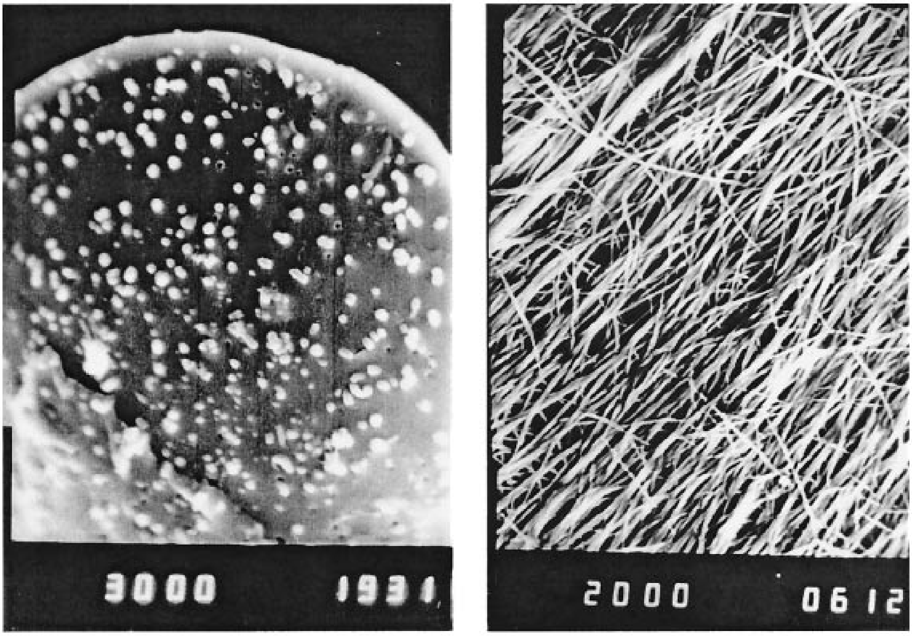


Figure 3. melting enthalpies of polymer components in PP7PET blend fibres: PP in the blend (1) and PET in the blend (2).

The process of polymer mixing in conditions of the laminar flow can be studied using a simple model. The three-layer model shows that during deformation of the polymer melt a shear gradient in the dispersed phase depends on a viscosity ratio of the dispersed phase, η_2 and the matrix, η_1[11]. The relations show that a viscosity decrease of the polyester phase considerably supports its deformation in the matrix. Moreover, the mixing process is positively influenced by interactions of the compatibilizer at the interface of the components (Figures 1, 2 and 3).

The polyfibrillar structure of the PP-PET blend fibres with long microfibrils of PET in the PP matrix (Figure 4) results from the interaction on the interphase, from the rheological properties of the polymer blend and conditions in the fibre preparation.



a

b

Figure 4. Cross section (a) and polyfibrillar structure of PP-PET blend fibres after matrix disolution (b) content of PET-10%

Standard tenacity is a characteristic for blend fibres; tenacity decreases with higher PET content in the PET-PP mixture. The fibre elongation is about 30 % and does not change significantly with the PET concentration. Despite the lower tenacity of blend fibres their elasticity is increased proportionally to the content of the polymer additive in PP fibres. The synergistic effect is observed in the elastic efficiency of fibres, ε^0. Modified PP fibres exhibit the higher elasticity in comparison with unmodified PP fibres already at a low concentration of PET (Table 1).

Table 1. Mechanical properties of PP-PET fibres blend after 30min annealing at 100°C.

Sample No	c_{PET} %	Tenacity cN/dtex	Elongation %	Elasticity at 50 % tenacity		
				ε_{tot} %	ε_{el} %	ε^{0}_{el} %
1	0	2.22	27.0	7.4	6.2	83.9
2	5	1.98	27.1	8.2	7.1	86.6
3	10	1.96	29.4	8.6	7.6	88.9
4	15	1.95	27.3	7.3	6.6	89.7
5	100	1.55	19.3	8.0	7.0	87.5

Table 2. Colour yield and fastness properties of PP-PET fibres blend dyed with Bemacron disperse dyes, 2 % dyestuff (red. clear. – reduction clearing[12]), Sample 6: PP-PET blend fibre (10 % PET), 1,0% compatibiliser, Sample 7: PP-PET blend fibre (15%PET), 1,5% compatibiliser

Sample	Dyestuff	K/S 100°C	Rub fastness		Wash fastness
			Before red. clear.	After red. clear.	
1	Rubin SE RDL	2.5	-	-	-
6	Blau SE RDL	28.3	5	5	5
	Blau E RD	19.5	5	5	5
	Rubin SE RDL	31.2	5	5	5
	Rot E RD	17.8	4	4	5
	Rot SE RDL	10.3	5	5	5
	Orange SE RDL	19.5	4	4	5
	Gelb E RD	23.1	5	5	5
	Gelb SE RDL	18.8	5	5	5
1	Blau SE RDL	4.8	-	-	-
7	Blau SE RDL	26.1	5	5	5
	Blau E RD	19.5	5	5	5
	Rubin SE RDL	29.0	5	5	5
	Rot E RD	18.7	4	5	5
	Rot SE RDL	13.7	5	5	5
	Orange SE RDL	13.0	4	4	5
	Gelb E RD	24.1	5	5	5
	Gelb SE RDL	13.7	5	5	5

The polyester dispersed in the PP matrix significantly influences the dye uptake in the exhaust process that increases about 5-10 times in comparison with unmodified PP fibres (Table 2). The main assumption here is that diffusion of disperse dyes penetrates primarily into the amorphous regions of blend fibres, mainly at the interface. This is in harmony with a decrease of the total crystallinity of blend fibres if compared with the original PP and PET component.

Conclusions

1. PP-PET blend behaves as an incompatible system. The selected modification procedure reduces the viscosity of the polyester component and increases the viscosity of the interface layer, which leads to the improvement of the component compatibility.
2. Total melting enthalpy and enthalpies of the components in PP-PET blends exhibit a negative deviation from the additive values.
3. A balance between the dispersion and coalescence process in shear and elongation conditions results in the formation of dispersed phase particles in the fibril shape with a relatively low diameter distribution and thickness of about 1 μm.
4. PP fibres modified by PET have good mechanical-physical properties: show higher elasticity and significant increase in the disperse dyestuff sorption in compared to unmodified PP fibres.
5. PP fibre modification by a polyester additive results in significant, almost a ten-fold increase in the disperse dyestuff sorption of Bemacron groups under polyester fibre dyeing conditions. Higher colour strengths were achieved with disperse dyestuffs of the SE-RDL type.

Acknowledgement

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[1] K. Schäfer, *Chem. Fiber. Int.* **1995,** 45, 116.

[2] R.Vogel, G. Schauer, G. Schmack, R. Beyrouther, E. Meyer, *Chem. Fiber. Int.* **1996**, 46, 421.

[3] R. Gutman, *Chem. Fiber. Int.* **1996**,46, 418.

[4] W. Operman, P. Hirt and C. Fritz, *Chem. Fiber. Int.* **1999,** 49, 33-35.

[5] A. Marcincin, et al., *"Polypropylene fibers dyeable by exhaustion process", in 38th Man-Made Fibres Congress*, Dornbirn, Austria ,1999.

[6] K. Ondrejmiska, *Vlakna a textil* **1994,** 1, 11.

[7] A.K. Sengupta, K. Sen, A. Mukhopadhyay, *Text. Res. J.* **1986,** 56, 511.

[8] L. Ruys, *Chem. Fiber. Int.* **1997**,47, 376.

[9] A. Marcincin, O. Brejka, A. Murarova, P. Hodul, A. Brejkova, *Vlakna a textil* **1999,** 6, 119-124.

[10] E.U. Okoroafor, J.P. Villemaire and J.F. Agassant, *Polymer* **1992 33,** 5264.

[11] A. Marcin in, A. Ujhelyiová, E. Zemanová, T. Marcin inová, Journal of Macromolecular Science - Pure and Applied Chemistry **1998,** A35, 1239.

[12] J. Rivlin, "The Dyeing of Textile Fibres, Philadelphia College of Textiles and Science", Philadelphia 1992, p.162.