Optimization of Composites Based on PET Fiber-Reinforced Thermoplastics

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ABSTRACT

The effect of short polyester fibers on the mechanical behavior of low density polyethylene (LDPE) and polypropylene (PP) homopolymers and their blends has been studied by means of an experimental design. The percentages of LDPE and PP vary from 0 to 100% of the matrix composition and the fiber content from 0 to 40% in the composite. The analysis of the tensile and flexural behavior shows that, in both cases, the moduli increase as fiber and PP contents increase, this effect being more accentuated at LDPE/PP ratios above 1. However, the strength of the composites mainly depends on matrix composition, and only at very high LDPE percentages (> 60%) in the matrix a sensible increase is observed as fiber percentage increases.

KEYWORDS:

blends, PET fibers, composites, mechanical properties

INTRODUCTION

In order to widen the possibilities of recycling polymer wastes consisting mainly of polyolefin blends, such as low and high density polyethylene and polypropylene, studies have previously been carried out in our laboratories to investigate the reinforcing effect of several fillers, such as sepiolite /1/, mica /2/, talc /3/ and short glass fibers /4/ on their mechanical properties. On the other hand, textile fibers can be used as reinforcements with even lower stiffness matrix materials, such as rubbers and thermoplastics /5/. The main goal of the present study is to analyze the effect of short polyester PET fibers on the morphology and mechanical behavior of composites based on LDPE, PP, and their blends, by means of an experimental design.

EXPERIMENTAL

Materials

Polypropylene (PP) melt flow index of 2.9 at 190°C and 5 kg and density of 0.905 g/cc) and low density polyethylene (LDPE) (melt flow index of 6.7 at 190°C and 2.16 kg and density of 0.916 g/cc) supplied by Repsol Quimica, under the trade name Isplen PP-051 and Alkathene PE-017, respectively, were used. Short polyester PET fibers, whose physical and mechanical properties are compiled in Table 1, were supplied by Velutex-Flock S.A. and were also used to prepare the composites.

Table 1
Physical and mechanical properties of PET fibers

Density (g/cc	1.38
Melt temperature (°C)	250-260
Tensile strength (cN/dtex)	2.9-3.7
Elongation at break (%)	85/105
Moisture absorption (%)	0.4

Planning of the study

In order to analyze the influence of the considered variables, matrix composition and fiber percentage, on the tensile and flexural behavior of these composites, the experiments were planned on the basis of a Uniform Net of Doehlert /6-8/. The compositions of the studied composites are compiled in Table 2.

Sample preparation and testing procedures

A Collins twin-screw extruder, Model ZK-50, coupled with two vibratory feeders, was used to prepare the composites at a screw speed of 25 r.p.m. The temperatures in the five zones of the extruder were 220, 220, 230, 230 and 230 °C, respectively. The short polyester fibers were introduced into the melt flow of the polymer blends at the melting zone. The extrudate was cooled in water at room temperature, cut into pellets, and then dried overnight at 60°C in a vented oven. The previously obtained compounds were injection-molded in a Margarit M50/125 Model injection molding machine to prepare dog-bone specimens. The temperatures in the three zones of the injection molding machine were 210, 220, and 230 °C, respectively. A mold temperature of 60°C and a specific injection pressure of 750 kg/cm^2 were used. The periods of time for the packing and cooling stages were 30 and 20 s, respectively.

The injection-molded specimens were used to measure the tensile properties of the materials. Tensile tests were carried out on a TT-CM Model Instron at room temperature and at a cross-head speed of 5 and 0.5 cm/min for measuring the tensile strength and the modulus, respectively, and according to ISO standard specifications. Flexural tests were performed on a Model 1026 Instron at room temperature and at a cross-head speed of 2 mm/min. The span was 60 mm and the nominal dimensions of the specimens were 80 x 10 x 4

Table 2
Composition and mechanical properties of the composites

Exp.	%PP (X_1')	%PET (X_2')	Modulus (MPa)	Strength (MPa)	Elongation (%)	Modulus (MPa)	Strength (MPa)
1	100	20	1513	29.80	0.62	1407	44.12
2	75	37.32	1519	24.10	0.28	1400	38.55
3	25	37.32	1054	18.50	0.28	933	28.10
4	0	20	337	13.26	1.55	335	13.73
5	25	2.68	494	15.91	1.93	414	15.56
6	75	2.68	1164	27.87	0.97	991	32.40
7	50	2.68	746	21.03	1.14	660	22.40
8	50	37.32	1201	18.42	0.29	1072	30.38
9	50	20	1133	20.56	0.75	923	28.26
10	50	20	932	19.70	0.71	800	25.82
11	50	20	1061	19.60	0.88	803	25.47

%PP: PP percentage in the polymer matrix
%PET: PET fiber content in the composite

mm in accordance with the standard specifications. The specimens for flexural testing were obtained from the injected dog-bone specimens.

Fracture surfaces of several composites were observed on a scanning electron microscope in order to study the composite and interface morphology.

RESULTS AND DISCUSSION

Mathematical treatment and optimization of the composites

The mechanical properties or responses of the composites, as well as their compositions, are compiled in Table 2, and the corresponding response surface equations, as calculated by means of multivariable analysis techniques, are shown in Table 3.

Mechanical behavior

The values of the tensile and flexural strengths and moduli of the composites as well as the tensile elongation are shown in Table 2. From the obtained results the response surface equations of the studied mechanical properties have been calculated. It must be pointed out that in all cases a high correlation factor has been observed between the experimental values and those calculated from the theoretical equations obtained by statistical treatment of the results.

The high modulus of the polyester fibers contributes perceptibly to the increased stiffness of the polymer matrix. As can be deduced from Figure 1, where the tensile modulus of the composites is represented graphically as a function of matrix composition and fiber percentage in the composite, this increase is more noticeable at low PP percentages in the matrix, which shows that the reinforcing effect of the fiber is more accentuated as the stiffness of the matrix decreases. On the other hand, the moduli of the composites also depends on the matrix composition. Thus, a considerable decrease of this characteristic is observed as the PP/LDPE ratio increases. In this case, the increase is less marked at high fiber content in the composite. The combined effect of both variables on the composite stiffness is very noticeable. However, as can be seen in Figure 2, the tensile strength of the studied materials fundamentally depends on the matrix composition, and, in some cases, at very high PP percentages, a negative effect of the polyester fibers on this property and a decrease of the tensile strength are observed as fiber content increases. As a general rule, the strength of short-fiber composites does not follow a predictable

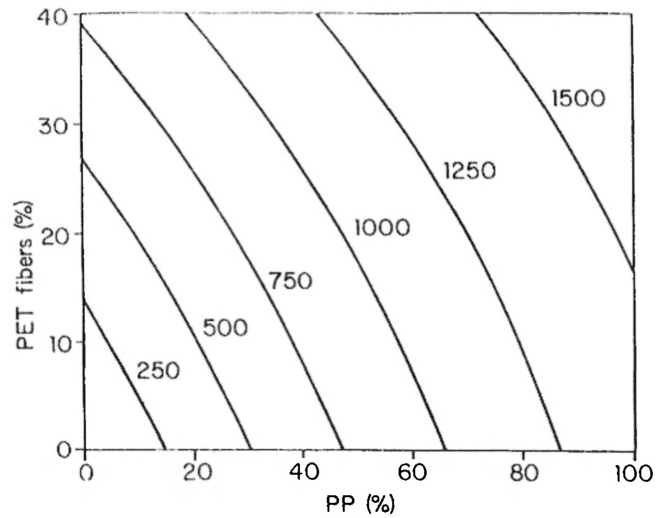

Fig. 1: Tensile modulus (MPa) of PET fiber-filled composites based on LDPE/PP blends as a function of matrix composition and fiber content.

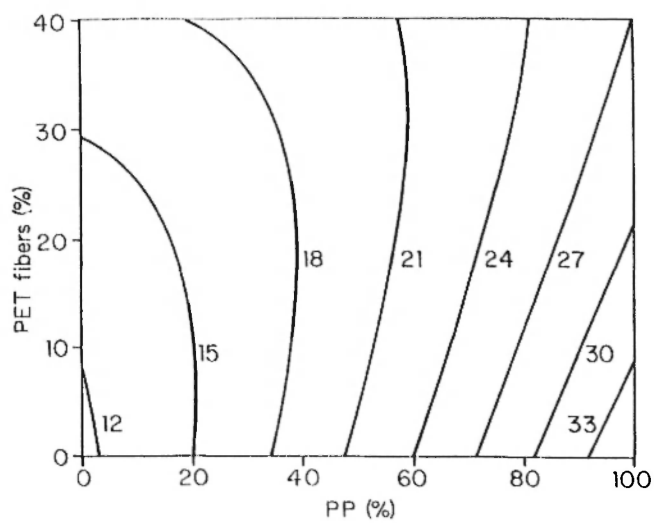

Fig. 2: Tensile strength (MPa) of PET fiber-filled composites based on LDPE/PP blends as a function of matrix composition and fiber content.

Table 3
Response surface equations of the composites

Property	Equation of the response surface	Correl. coeff.
Tensile modulus	$Y = 1030.21 + 581.17 X_1 + 263.66 X_2 - 87.52 X_1^2 + 18.73 X_2^2 - 118.36 X_1 X_2$	0.987
Tensile modulus	$Y = 19.8 + 8.44 X_1 - 0.729 X_2 + 1.96 X_1^2 + 1.127 X_2^2 - 3.67 X_1 X_2$	0.988
Tensile elongation	$Y = 0.772 - 0.47 X_1 - 0.614 X_2 + 0.324 X_1^2 - 0.015 X_2^2 + 0.55 X_1 X_2$	0.989
Flexural modulus	$Y = 835.64 + 531.33 X_1 + 257.89 X_2 + 44.91 X_1^2 + 91.4 X_2^2 - 63.51 X_1 X_2$	0.990
Flexural strength	$Y = 26.34 + 14.68 X_1 + 5.13 X_2 + 2.84 X_1^2 + 1.44 X_2^2 - 3.69 X_1 X_2$	0.990

X_1' and X_2' are the PP percentage in the polymer matrix and the fiber content in the composite, respectively.
X_1 and X_2 are the codified variables, calculated from the following equations:

$X_1 = (X_1' - 50) / 35.36$ $\quad$ $X_2 = (X_2' - 20) / 14.14$

behavior pattern, since at these levels of material deformation (elongation), the high concentration of fiber ends may have a negative effect on this property.

The tensile elongation of the composites is graphically represented in Figure 3. The great influence of matrix composition on this property at fiber contents below 25% must be pointed out. However, at high fiber percentages (above 30%), the tensile elongation hardly varies with the matrix composition, which indicates that above this fiber content the defects created by its own fibers are responsible for the composite breakdown before its deformation, and only in the case of a homogeneous and ductile (LDPE) or strong (PP) matrix a slight increase in the tensile elongation is observed.

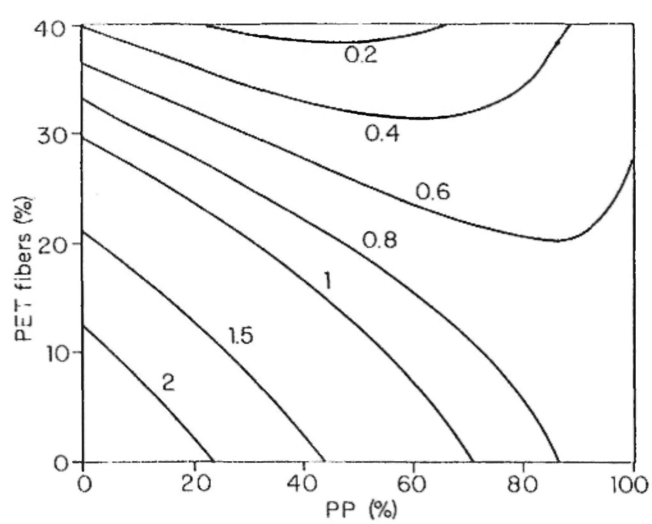

Fig. 3: Tensile elongation of PET fiber-filled composites based on LDPE/PP blends as a function of matrix composition and fiber content.

The flexural modulus and strength of the composites as a function of matrix composition and fiber content are graphically represented in Figures 4 and 5, respectively. From these figures, it is deduced that the flexural modulus behaves similarly to the tensile modulus. Thus, this characteristic increases as fiber and PP contents increase, and the effect is more noticeable in the case of polymer matrices with high LDPE percentages (>50%). The combined effect of both variables on the stiffness of the composite is very noticeable. On the other hand, the flexural strength of these materials depends more on the matrix composition than on the fiber content, and only polymer matrices with high LDPE percentages show a noticeable increase in the flexural strength as fiber content increases.

Scanning electron micrographs of impact fracture surfaces of the homopolymers and a 50/50 PP/LDPE

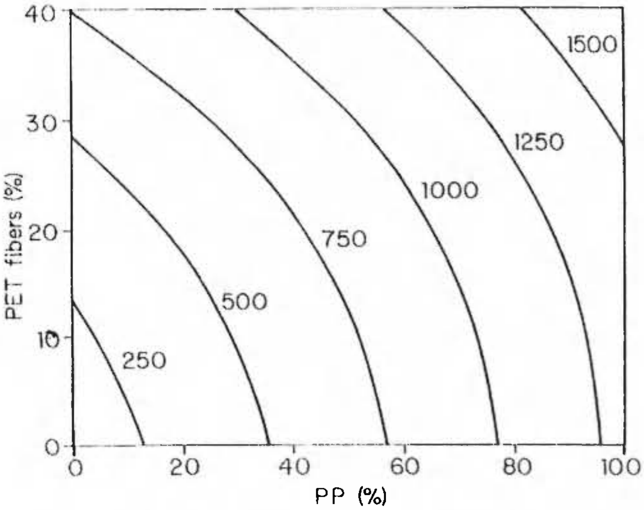

Fig. 4: Flexural modulus (MPa) of PET fiber-filled composites based on LDPE/PP blends as a function of matrix composition and fiber content.

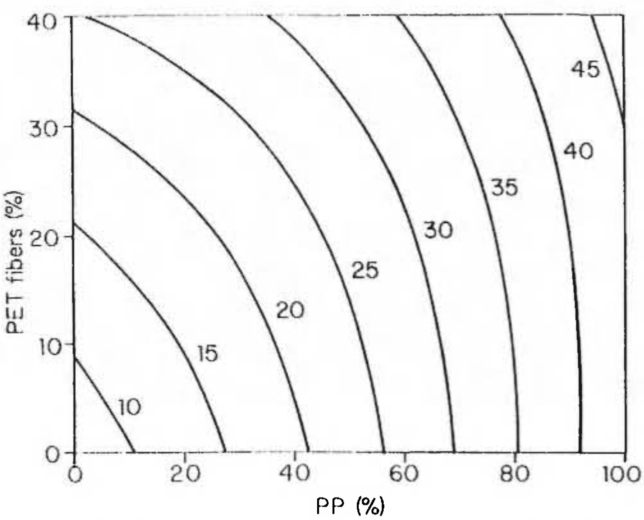

Fig. 5: Flexural strength (MPa) of PET fiber-filled composites based on LDPE/PP blends as a function of matrix composition and fiber content.

blend filled composite are shown in Figures 6 and 7, respectively. A certain degree of adhesion between the LDPE and the fibers is observed in Figure 6(a), where some deposits of the homopolymer can be seen on the fiber surface. In the case of the LDPE/PP blend matrix based composite, the fibers show a similar aspect and

a

b

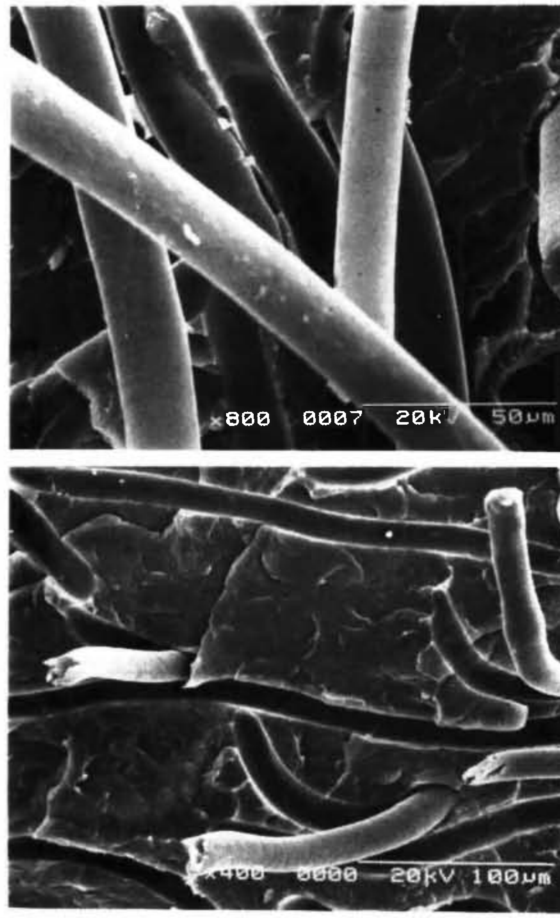

Fig. 6: Fracture surfaces of PET fiber-filled composites based on LDPE (a) and PP (b) polymer matrix.

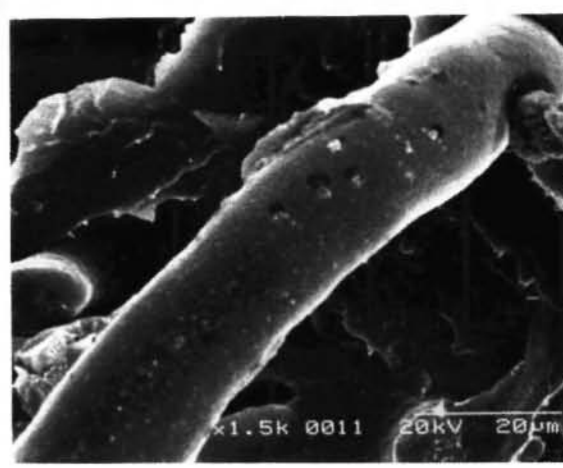

Fig. 7: Fracture surface of PET fiber-filled composites based on LDPE/PP blend matrix (50/50 ratio).

some defects are also observed in the fiber surface (Figure 7). It may be suggested that a better affinity between the LDPE and the organic fiber exists.

CONCLUSIONS

From the above results the following conclusions can be drawn:

- The reinforcing effect of short polyester fibers on the stiffness of polyolefin blend matrices is more noticeable at high LDPE contents (>50%) in the matrix, and a better affinity between the PET fibers and the LDPE homopolymers is suggested.
- The strength of the composites depends more on the matrix composition than on the fiber content in the composite, and only in the case of polymer matrices with LDPE/PP ratios above 1, the flexural strength shows a very perceptible increase as fiber content increases.
- From an economical point of view, there are obviously many advantages to be gained in recycling plastic wastes, fundamentally based on polyolefin blends with high LDPE percentages, and polyester short fibers coming from spinning scraps.

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