Morphology/Behavior Relationship and Recyclability of Composites Based on PP/EPDM Blends and Short Aramid Fibers

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ABSTRACT: The effect of short aramid fibers on the mechanical behavior of polypropylene (PP) and ethylene-propylene-diene (EPDM) and their blends has been investigated by means of an experimental design. The results have shown that aramid fibers are very effective reinforcing agents for composites when the continuous phase of the matrix is constituted by PP, so sensible increments in tensile modulus and strength are obtained as fiber content in the composites increases. An optimal matrix composition and fiber content has been observed that produced high abrasion resistance compounds. However, the abrasion resistance of very rich EPDM matrices is hardly affected by fibers content. The addition of fibers to EPDM rich (>50%) matrices gives rise to a sensible decrease of the impact strength of this polymer. However, at PP contents above 50% in the polymer matrix, an increase of impact strength is observed at fiber percentages in the composites above 10%. The different behavior of the fibers depending on matrix type can be attributed to a better affinity of these fibers for PP matrix. Morphological studies of the composites have been carried out by scanning electron microscopy. Finally, the price and recyclability of these materials have been analyzed. © 2002 John Wiley & Sons, Inc. J Appl Polym Sci 83: 2474–2484, 2002

Key words: composites; recycling

INTRODUCTION

Polypropylene (PP) is one of the most general-purpose plastics with the largest consumption per annum in the world owing to its good processing characteristics and other interesting properties. However, as an engineering plastic, its application is somewhat limited because of its relatively poor impact resistance, particularly at room or low temperatures. Under impact conditions unnotched polypropylene exhibits a brittle–ductile transition temperature between 0 and 20°C,[1] while the corresponding transition temperature of the notched polypropylene is about 100°C.[2] The toughness of PP can be outstandingly improved by the addition of elastomers, but other mechanical properties, such as stiffness and strength, decrease rapidly. The deformation and impact behavior of polypropylene–rubber blends have been studied extensively.[3–18] The modulus,[6,15,19] as well as the yield stress,[6,16] decrease with rubber content. This decrease exceeds expectations based on the Rule of Mixtures. Consequently, how to reinforce and simultaneously toughen PP has received considerable attention. Numerous studies have been carried out with the aim of improving PP toughness, stiffness, and strength balance. Many research projects have studied the structure/property relationship of PP/rubber blends

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filled with rigid inorganic particles to identify the toughening and reinforcing effect of these materials.[17,18,20,21]

From that point of view, fiber reinforced rubber composites have widely been in use for some time because of their good mechanical properties. Most systems employed continuous fibers because of the vastly improved properties of the composites.[22] Recently, interests have turned to short-fiber–reinforced rubbers because of the greater speed and flexibility in processing inherent in these systems. Various studies on short-fiber systems include Rayon, poly(vinyl alcohol), Nylon, *p*-aramid (Kevlar/Twaron), *m*-aramid (Nomex), polyester, and glass fibers.[23,24] As far as mechanical properties are concerned, aramid fibers are good candidates as reinforcement.

On the other hand, the protection of the environment and new recycling legislation has become of paramount importance to plastic manufacturers, processors, and consumers. This was one of the reasons that encouraged the development of thermoplastic elastomers. In fact, the global demand for these revolutionary materials has grown at a rate of 8–9% per year over the last decade. They have the best of both worlds; they behave like vulcanized rubber and yet can be processed like thermoplastics.[25] Among these materials olefinic thermoplastic rubbers based on polypropylene/EPDM blends are particularly well suited for those applications requiring outstanding aging and weathering characteristics, ozone and heat resistance, ease of fabrication, and low cost.

These were some of the principal reasons for performing this study with the aim of carrying out a systematic investigation on polypropylene/EPDM physical blends filled with aramid short fibers to analyze their effect on the behavior of these composites. The EPDM ter-polymer is a commercial product that was synthesized via "metallocene." The final goal of this study is to get composites with balanced properties and to analyze their behavior/morphology relationships. Possible applications of these products will be suggested and their recyclability examined.

EXPERIMENTAL

Materials

Throughout this study, the Polypropylene chosen was Isplen PP-050 produced by REPSOL Química. It is a medium-high fluidity polypropylene, good for the injection molding of technical pieces withstanding temperatures of up to 120°C. Although general in its application description, its uses are mainly aimed at raffia, monofilaments, electrical appliances, the automotive industry, valve manufacture, propellers, closures, and gaskets. Isplen PP-050 is an isotactic polypropylene (PP) with a density of 0.905 g/cm^3 and a melt flow index of 6 g/10 min.

The EPDM thermoplastic elastomer used was Nordel IP 4725P (E/P = 70/25; ENB = 5%; density = 0.87 g/cm^3; Mooney viscosity-ML-125°C = 25) produced by DuPont Dow Elastomers. Nordel IP is a new generation of EPDM, based on the proprietary Insite catalyst and process technology. The typical target market application for this model of Nordel IP is the molding of materials, rolls, high hardness compounds, conveyor belts, and gaskets.

Aramid fiber, whose physical characteristics are compiled in Table I, was supplied by Cordis under the trade name of Twaron 1488. It is a reinforcing fiber suitable for all thermoplastic and thermoset materials that are used in wear-resistant applications (e.g., for PA, POM, PC, epoxy, polyester, and vinyl–ester resins).

Table I Properties for Twaron 1488

Fiber length	6 ± 0.5 mm
Fiber diameter	12 Micrometers
Amount of sizing	4–6%
Moisture absorption	<8% (20°C, 65% rel humidity)
Decomposition temp	>450°C
Residual strength	90% (200°C, 48 h)

EXPERIMENTAL DESIGN

To analyze the influence of the matrix composition and Twaron percentages on the behavior of the composites, response surface methodology[26–28] was used. In this case, the two variables method was used and the experimental mixtures were planned on the basis of an Uniform Net of Doehlert.[29] This type of design defines the minimum number of experimental combinations in the domain under consideration to maximize the information obtained from the proposed model. A second-degree equation has been postulated. Among the Doehlert design properties, one must

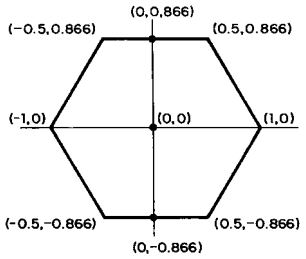

Figure 1 Scheme of a compound design based on a uniform Net of Doehlert.

assume a uniform distribution: a set of points within the model is uniformly distributed in the space following a rhombic lattice, which allows exploration of the whole experimental domain. Three equivalent experiments are carried out in the center of the domain to establish the experimental error. A design of this type is shown in Figure 1.

The advantage of this type of experimental design is that besides the individual effect of each variable, their combined effect can also be analyzed. The physical values (or uncoded values) of the variables x_1 and x_2 were obtained from eq. (1):

$$x = \frac{x_A + x_{B'}}{2} + X\frac{x_A - x_B}{2} \quad (1)$$

where X is the coded value and x is the physical value of the variables. A and B refer to the high and low levels of the variables, in our case, 100 and 0 for the PP percentage in the matrix composition, and 20 and 0 for the Twaron fiber percentage in the composite. The composition of the samples used in this study, as well as the codified values of the variables, are compiled in Table II. By multiple regression analysis of the experimental results, the equations of the response surfaces were obtained. The general equation was of the form:

$$Y = b_o + b_1x_1 + b_2x_2 + b_{11}x_{12} + b_{22}x_{22} + b_{12}x_1x_2 \quad (2)$$

where Y is the value of the characteristic property of the mixture being studied, x_1 and x_2 are the coded values of the percentage of PP in the matrix and the contents of Twaron in the composite, respectively. It may be pointed out that in all cases a good correlation factor between the experimental values and those calculated from the theoretical equations obtained through the statistical treatment of the results has been observed.

Sample Preparation and Testing Procedures

The materials were compounded in a roll mill, at 180°C. Once the PP was melted, the appropriated amount of EPDM was added and homogeneously blended. Finally, the aramid fiber was incorporated. The blending time was 30 min. After pelletization and drying them, the compounds were injection molded to prepare dog-bone specimens. The temperatures in the three zones of the injection molding machine were 210, 220, and 230°C, respectively. The period of time for the packing and cooling stages were 30 and 20 s, respectively.

Table II Coded and Uncoded Values of the Experimental Combinations and Composition of the Composites

	Codified Values		Uncodified Values		Composition of the Composites		
Experiment	x_1	x_2	X_1 (%)	X_2 (%)	% Twaron	% PP	% EPDM
1	1.0	0	100	10	10	90	0
2	0.5	0.866	75	18.66	18.66	61.005	20.335
3	−0.5	0.866	25	18.66	18.66	20.335	61.005
4	−1.0	0	0	10	10	0	90
5	−0.5	−0.866	25	1.34	1.34	24.665	73.995
6	0.5	−0.866	75	1.34	1.34	73.995	24.665
7	0	0.866	50	18.66	18.66	40.67	40.67
8	0	−0.866	50	1.34	1.34	49.33	49.33
9	0	0	50	10	10	45	45
10	0	0	50	10	10	45	45
11	0	0	50	10	10	45	45

Table III Response Equations of the Composite Characteristics

Characteristic	Response Equation	R
Tensile modulus	$Y = 524.32 + 624.17\,X_1 + 337.19\,X_2 + 57.78\,X_1^2 + 74.71\,X_2^2 + 479.10\,X_1X_2$	95.4
Tensile strength	$Y = 13.10 + 14.61\,X_1 + 0.95\,X_2 + 6.22\,X_1^2 + 4.88\,X_2^2 + 4.17\,X_1X_2$	97.7
Elongation at fracture	$Y = 365.95 - 212.22\,X_1 - 444.93\,X_2 - 39.71\,X_1^2 + 54.28\,X_2^2 - 38.08\,X_1X_2$	79.7
Abrasion resistance	$Y = 4.06 - 7.56\,X_1 + 1.59\,X_2 + 8.90\,X_1^2 + 6.88\,X_2^2 + 1.74\,X_1X_2$	80.2
Impact strength	$Y = 6.90 - 19.49\,X_1 - 8.08\,X_2 + 10.82\,X_1^2 + 11.58\,X_2^2 + 27.48\,X_1X_2$	77.4
Price of the composites	$Y = 474.92 - 83.17\,X_1 + 275.21\,X_2 + 22.19\,X_1^2 + 25.39\,X_2^2 + 8.66\,X_1X_2$	99.1

Tensile tests were carried out on an Instron T-4301 model, at room temperature and a crosshead speed of 5 and 50 mm/min for measuring the tensile modulus and ultimate tensile strength, respectively. An abrasion test was used to evaluate the resistance of the composites to wear. The abrasion testing procedure followed ISO 4649: 1985 standard specifications. The method consists in determining the volume loss of the sample from the abrasive action of the specimen being pressed with a constant frictional force for a set distance against a sheet of high friction sandpaper. Thus, one must calculate the density of the test samples, run the specimens at a standard pressure against a sandpaper roller for a fixed distance, and finally, determine the volume of material lost during this process. Three standard test specimens of each mixture were prepared using a Collins Press machine under high temperature and pressure. The impact tests were carried out following the ISO 180/1A standards for Charpy testing at −40°C. Because of the low temperature, the samples needed a 2-h temperature gradient to reach the required cooling area. The cooling was carried out using a Julabo FP-40 Machine chilling the test pieces to a temperature of −41°C. Once the pieces had been cooled, the samples were individually taken out as quickly as possible from the liquid ethanol in which they were being cooled and inserted in the clamp of the fracture pendulum. The tests were carried out on a Ceast Fractoscope 6545/000 Machine for Izod/ISO impact testing (Model number E-PO-02-0040). The test specimens were cut out of the dumbbells made for the tensile tests. The samples used were notched with a B-type notch and then allowed to rest for 24 h prior to the tests commencing.

Morphological Study

Fracture surfaces of several composites were observed on a JEOL T-330A scanning electron microscope to study the composite and interface morphology. The samples were chosen due to their position within the mathematical model. Parts of each mixture were cooled using liquid nitrogen and then broken under fragile fracture conditions so as to analyze the break surface.

RESULTS AND DISCUSSION

To optimize the composition of the polymeric matrix and the percentage of fiber in the composite, the Uniform Net of Doehlert method was applied. From the result, treated in a computer program, the equations of the response surfaces were obtained. These equations are compiled in Table III.

Tensile Behavior

The results for the tests are summed up in Table IV. The results obtained from the multiple regression analysis are graphically represented in Figures 2 to 4—the Young's modulus, the Ultimate Tensile Strength, and the Elongation, respectively. From the obtained results, it is possible to conclude that the modulus (stiffness) of the composites increases as PP percentage in the matrix and fiber content in the composite increases. However, the reinforcing effect of the fibers is much more sensible at high PP percentages in the polymer matrix. The strength of the materials shows a different behavior depending on the matrix composition. So, the fibers act as a reinforcing agent for PP, notwithstanding in the case of the EPDM matrix, the strength decreases as fiber

Table IV Tensile Behavior of the Composites

	Young's Modulus (MPa)	Tensile Strength (MPa)	Elongation at Fracture %
F-1	1110.50	34.61	9.48
F-2	1562.47	27.76	5.54
F-3	341.00	9.97	16.35
F-4	44.55	4.95	668.30
F-5	60.34	10.62	704.36
F-6	452.00	21.19	759.51
F-7	742.50	18.12	22.32
F-8	381.57	19.12	892.18
F-9	546.43	13.03	514.96
F-10	541.16	12.83	25.86
F-11	494.52	12.50	531.75

content increases. In fact, it is very difficult to predict the effect of reinforcing short fibers on those properties measured at very high elongation (in this case, elongation to break) because fiber ends and overlapping of fibers can act as stress concentrators, making the material more sensitive to fracture, thus counterbalancing the reinforcing effect of the fibers. From the above results, as deduced from Figures 2 and 3, it can be suggested that a better affinity between these fibers and the PP exists, and in all cases an improvement of these properties is observed as PP percentage in the matrix increases. As can be seen in Figure 4, and as could be expected, the elongation of the materials at fracture decreases as fiber content increases and EPDM percentage in the matrix decreases, due to the stress concentrations created by the fibers and the higher elasticity of the EPDM. In this case, the combined effect of both variables is very sensible.

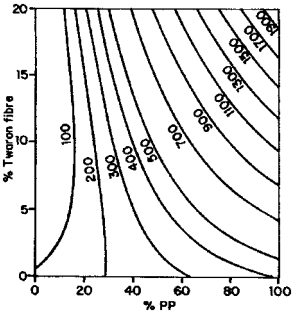

Figure 2 Tensile modulus of the composites as a function of PP percentage in the matrix and fiber content in the composite.

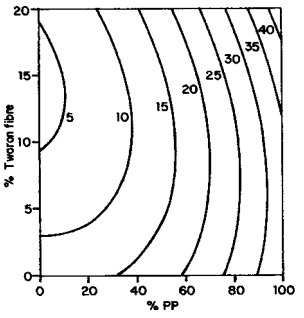

Figure 3 Tensile strength of the composites as a function of PP percentage in the matrix and fiber content in the composite.

Abrasion Resistance

An abrasion test evaluates the resistance to wear that a material may have, if it resists scratching well, and what amount of material loss can be expected. Because of the compounds' percentage of aramid fiber, and its renowned resistance to wear, it was suspected that the materials could fair quite well under abrasion and would give some good results on improving the properties of both the EPDM and the PP.

Each of the samples was placed in the cradle on the abrasion roller. The drum turned at a constant speed of 40 rpm, and had a diameter of 150 mm. The contact distance where the specimen was rubbing against the sandpaper was 400 mm wide and so rendered a frictional distance covered by the specimen of 40 m. Once the piece had been worn, the sample was ejected from the cradle and reweighed to determine the mass lost during the process. Using this value, together with the previously calculated density and D = M/V, it was possible to find the volume of material consumed through the abrasion operation. The results pro-

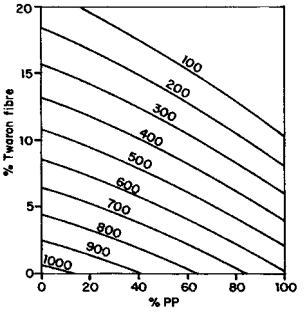

Figure 4 Elongation at break of the composites as a function of PP percentage in the matrix and fiber content in the composite.

Table V Abrasion Test Results

Composite	Volume (mm^3)
F-1	7.15
F-2	8.92
F-3	20.16
F-4	17.09
F-5	18.86
F-6	4.61
F-7	7.17
F-8	4.51
F-9	4.80
F-10	4.94
F-11	4.14

duced from the abrasion tests are tabulated in Table V. The contour plots (see Fig. 5) for the materials were produced from the polynomial equation of Table III. A maximum in the abrasion resistance of the composites is obtained with a PP/EPDM ratio of 7/3 in the matrix composition and a fiber content of about 8% in the composite. Above this fiber content and this PP/EPDM ratio the abrasion resistance of the material decreases. This is a very peculiar behavior of these composites, which could be due to an interaction between the effects produced by both variables (PP and fiber % in the polymer matrix and composite, respectively).

Impact Strength

Impact was one of the most interesting areas of study, particularly as EPDM is already used in industry as a very effective impact modifier for polypropylene. The results produced were statistically treated in the same way as previous experiments to produce a contour plot for impact energy required to break the test samples in relation to their exact composition.

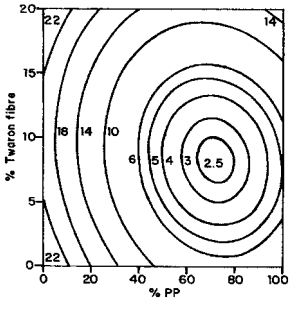

Figure 5 Abrasion resistance of the composites as a function of PP percentage in the matrix and fiber content in the composite.

Table VI Impact Test Results

	Impact Resilience	
Sample	KJ/m^2	Type of Fracture
F-1	3.21	H—(64%)
F-2	6.15	H—(100%)
F-3	15.47	H—(92%)
F-4	28.58	P—(100%)
F-5	61.55	NB—(67%)
F-6	4.64	C—(85%)
F-7	9.57	H—(100%)
F-8	6.97	H—(100%)
F-9	8.98	H—(85%)
F-10	7.85	H—(100%)
F-11	7.54	H—(100%)

Types of Fracture: C: complete; P: partial; H: hairy; NB: nearly broken.

In each case a differently weighted hammer was attached to the end of the pendulum to actually break the samples. A 2-kJ hammer was used for all the samples (2 kJ), with the exception of the F-5 sample. This had an exceptionally high impact resistance and so a hammer of 4 kJ was required to break the samples. Once in place, the hammer was released from its standard height and allowed to impact against the test specimen. The distance that the pendulum/hammer traveled up the other side was then converted into the energy required to break the sample and displayed on a digital counter on the machine. Once the impact had been carried out, each broken piece was categorized as to the type of fracture it had suffered. The different types of possible fracture are shown at the foot of Table VI. For each of the 10 samples measured for each mixture, a qualification was given, and an average was calculated in relation to the most frequently occurring fracture type and its percentage occurrence was annotated.

The impact test results are displayed in Table VI. These show the energy consumed in the impact with the test sample, the fracture type that was most commonly observed for each sample, and the percentage of that fracture types recorded. From the measured impact values, the coefficients of the general equation, and the response surfaces were obtained and graphically represented, as shown in Figure 6. In general, the influence of fibers on the impact strength of a

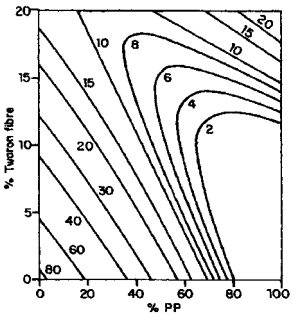

Figure 6 Impact strength of the composites as a function of PP percentage in the matrix and fiber content in the composite.

polymer matrix cannot be easily predicted because different and opposed effects can take place simultaneously. On one hand, fiber ends and overlapping of fibers can act as stress concentrators and, on the other hand, when a material is being broken, during the propagation of the fracture, fibers may increase the energy to fracture due to debonding and/or pull-out mechanisms. The debonding and pull-out mechanisms are attributed to the separation and extraction of the fiber from the matrix, both phenomena consume a certain amount of energy giving rise to an increase of the composite impact strength. In this case, the impact strength of polymer matrices with high percentages of PP (more than 80%) increases with the addition of fibers, which could confirm that a good affinity between Twaron fibers and PP exists. However, the impact strength of EPDM rich matrices decreases as fiber content in the composite increases. So, this different effect of the fibers on the impact strength, depending on matrix composition, gives rise to this peculiar behavior of the response surface in Figure 6. It can be concluded that Aramid fibers permit the improvement of the impact strength of the polypropylene, which is very interesting due to the reduced toughness of this polymer at low temperature.

Morphology of the Composites

Microphotographs of the fracture surfaces of different composites have been obtained by scanning electron microscopy and compiled in Figure 7(A)–(F). In the microphotograph of sample 1 [Fig. 7(A)], no good contact between the fibers and the matrix is observed, although the slippage rings along the fiber surface appear in the trace left by the fiber on the polymer matrix. A visible gap between both can be seen on the right of the photograph. The fracture surface of sample 4 [Fig. 7(B)] shows a similar aspect to the above mentioned sample, but in this case, the elastic nature of the matrix gives rise to filaments from EPDM, which in some cases can be seen at the interface. Small holes along the matrix surface are attributed to PP dispersed particles on the EPDM continuous phase. In the case of the sample 6 [Fig. 7(C)], where a high PP percentage is present in the polymer matrix, EPDM particles are dispersed in the PP continuous phase. The diameter of EPDM particles is in the range of 1.5 to 4.5 μm. Both 7 [Figs. 7(D) and (E)] and 8 samples [Fig. 7(F)] have 50% PP in the polymer matrix with fiber contents about 18 and 2%, respectively. In all cases there is poor adhesion at the fiber/matrix interface, and it is not easy to identify both phases in the microphotographs. It seems that the matrix is on the verge of phase inversion. It could be suggested that both polymer phases are interpenetrating each other.

Recyclability

Using the previously obtained excess dumbbell, that had been injection molded for the tensile tests, it was possible to make pellets for the new injection molding. By breaking down the dumbbells, up to 2 kg of recycled grain were produced. The grain was then inserted into an extrusion machine to produce a plastic rod, and then cut this down into pellets. A Collins twin-screw extruder ZK-50 model, coupled with two vibratory feeders, was used to prepare the composites at a screw speed of 50 rpm. The temperatures in the five zones of the extruder were 220, 220, 230, 230, and 230°C, respectively. The extrudate was cooled in water at room temperature, cut into pellets, and then dried overnight at 60°C in a vented oven.

The mold used was for the production of a small box with a lid (Fig. 8). Although the box has no specific application, it could easily be used as an electronics component box. The principal thickness of the box is 2 mm. However, some of the braces have a thickness of 1.5 mm. The maximum length of the melted fluid route for the material was 250 mm. This mold is used to evaluate the processability through injection of plastic materials (reinforced resins, resins with additives, mixtures of plastics, etc.). With the box and lid produced, it is also possible to evaluate the

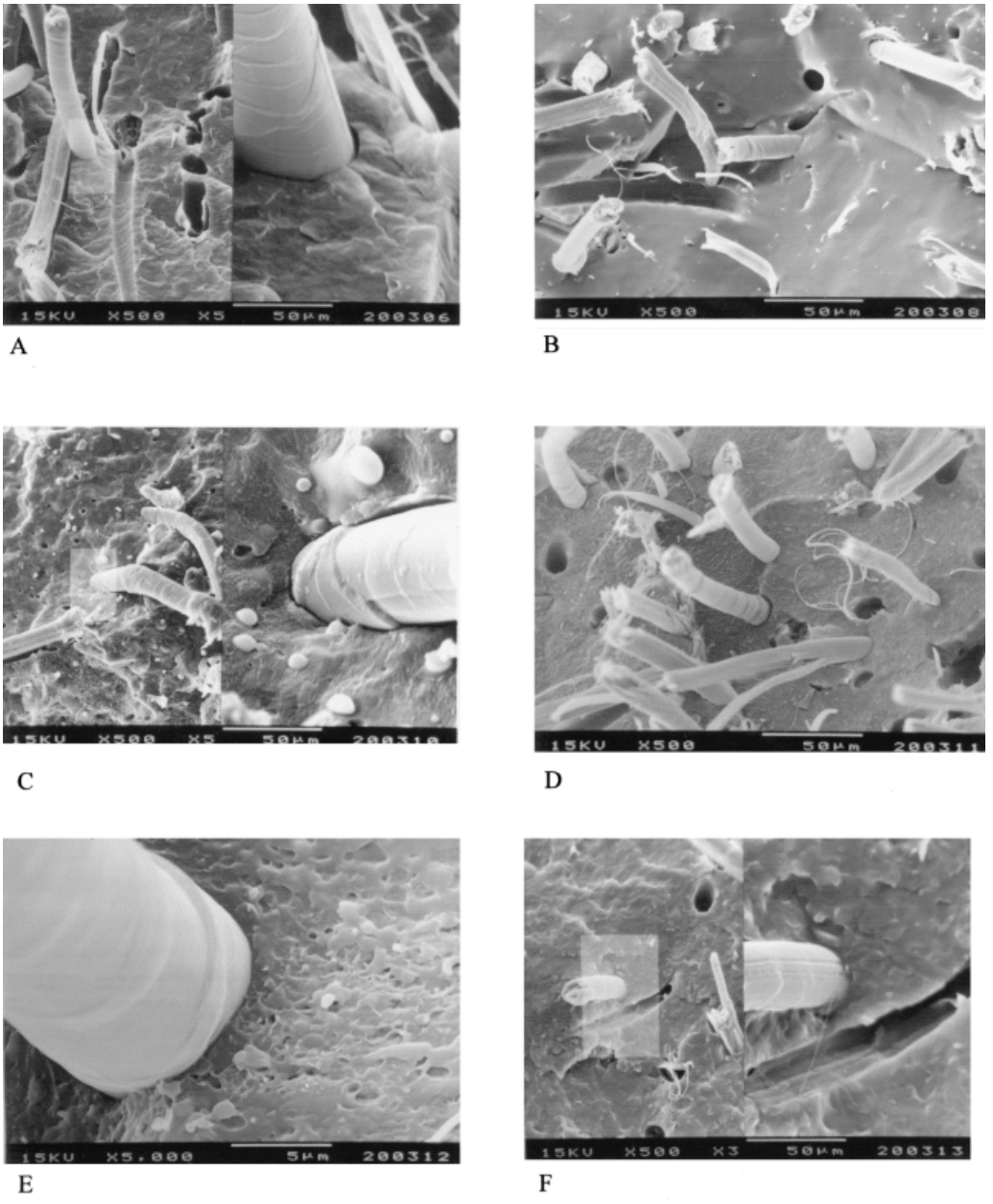

Figure 7 Microphotographs of fracture surface of several composites: (A) sample 1; (B) sample 4; (C) sample 6; (D) sample 7; (E) sample 7; (F) sample 8.

finish quality that can be obtained with the tested materials.

In this study, recycled samples of fiber-based mixtures of PP and EPDM were tested. Because an equal number of dumbbells have been taken from any of the different materials prepared, the recycled sample consist in almost a 50/50 PP/EPDM blend with a fiber content around 10% in the composite To have a reference, a pure polypropylene sample was also injected into the mold. The materials were injected, working with an untempered mold, and with an increasing temperature profile in the injection cylinder from the feeding zone to the nozzle. The temperature profile varied from 200 to 240°C. From the observation of the results, it was possible to conclude that the processability of the fiber mixtures was very good. The processability of the recycled materials was comparable to that of the commercial-grade polypropylene.

Figure 8 Box and lid produced (less milky: plain PP; more milky: recycled composite).

All rejected pieces that were not going to be used for the box injection were remilled and reinjected to make new dumbbells of recycled fiber samples. These dumbbells underwent as many of the tests as the other samples as possible. The aim of this was to see if the materials lost a significant proportion of their mechanical or physical properties by being recycled. The summary of the results produced is shown in Table VII. From the results there are no signs that compounds suffered to any great extent from the recycling process. Therefore, their potential recyclability was confirmed, particularly if comparison between the sample 9 (center of the experimental design) and the recycled material, which is supposed to have a similar composition, is made. In this case, it looks like the fiber content in the recycled material is slightly higher than 10% (which theoretically corresponds to the center of the design). If the reprocessed specimens had shown degradation, it would render the materials unrecyclable. In the ever faster and more environmentally conscious world that we live in, this would make the product's viability more complex.

Price of the Composites

The price for the materials considered in this study was calculated in terms of the price of each

Table VII Recycled Material Properties

Property	Units	Similar Virgin Material	Recycled Material
Youngs modulus	MPa	≈ 650	656
Tensile strength	MPa	≈ 18	18.21
Abrasion	mm^3	≈ 4.8	4.08

Table VIII Compound Prices

	Pts/kg	Euro/kg	£/kg
Polypropylene	130	0.78	0.46
EPDM	315	1.90	1.13
Twaron Fiber	2975	17.92	10.63

of the individual components and the percentage composition they make up of the final composite in each case. The prices were collected from the suppliers in Pts/kg, and Table VIII shows these prices, with the equivalent prices in pounds sterling and Euros. Because the prices of the composites are calculated from the price of the individual components through the rule of mixtures, the *R*-squared statistic indicates that the model as fitted explains 99.07% of the variability in the composites. As deduced from Figure 9, the price mainly depends on the fiber content in the composite, with a very sensible increase as Twaron content increases. An important increase in the price is also observed as EPDM percentage in the blend matrix increases. This last fact is what gives rise to a very interesting contour line going upwards from left to right. This indicates a way to keep the price constant while—depending on the mixture—possibly improving mechanical properties. It is this window that would prove particularly interesting on an EPDM commercial front. A mixture with a 50/50 blend—and only a little aramid reinforcement, could prove much more beneficial for the any required application.

CONCLUSIONS

The experimental design based on a Doehlert uniform lattice has permitted the deduction of the

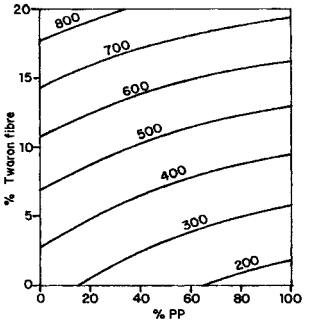

Figure 9 Price of the composites as a function of PP percentage in the matrix and fiber content in the composite.

theoretical equations needed to predict the technical characteristics of PP/EPDM blends (TPOs) filled with aramid short fibers. The tests were conducted using a wide experimental range (PP/EPDM ratios from 0/100 to 100/0 and filler contents from 0 to 20%). This allows the selection of different products with a wide spectrum of properties as a function of the requirements for a specific application. An appropriate selection of PP/EPDM ratio and a controlled addition of aramid fiber to it, allows the production of tailormade compounds with a well rounded balance of properties as a function of their requirements. The range of products varied from pure polypropylene to a thermoplastic rubber going through a high-impact polypropylene and a high strength reinforced thermoplastic rubber.

Mechanical and physical characteristics such as tensile strength and stiffness, elongation at fracture, abrasion resistance, and impact strength may be predicted in these materials, or adequate formulations developed to meet any desired property within the scope of the study. Aramid fibers are easily incorporated and homogeneously dispersed in the polymer matrices, and the fibers do not present any preferential orientation in the composites. One of the main advantages of these materials is their easy recyclability and reprocessing by the conventional techniques used for thermoplastic polymers, which render them an enormous interest from both an ecological and industrial point of view.

From the results reflected along this study the following conclusions were ascertained.

Twaron fibers are very effective reinforcing agents for composites when the continuous phase of the matrix is constituted by PP, so, sensible increments in tensile modulus and strength are obtained as fiber content in the composites increases. A better affinity between the Twaron fibers and the PP can be suggested. In all cases and as was expected, the addition of Twaron fibers gives rise to a decrease of the elongation to break. An optimal matrix composition and fiber content in the composite is observed, which produced high abrasion resistance compounds. However, the abrasion resistance of very high EPDM matrices is hardly affected by fiber content.

From an impact point of view, it is suggested that the addition of fibers to EPDM rich (more than 50%) matrices gives rise to a sensible decrease of the impact strength of this polymer. However, when the polymer matrix has PP contents above 50%, the incorporation of low percentages of Twaron fibers give rise to a sensible decrease of this characteristic while a small increase of impact strength is observed at fiber percentages in the composites above 10%. These results are attributed to a different effect of the fibers in both polymers. So, while stress concentrations, due to fiber ends or overlapping of fibers, could take place when the EPDM is the continuous phase in the polymer matrix, other effects such as debonding or pull-out of fibers from the matrix are taking place in PP rich matrices or when the PP constitutes the continuous phase of the polymer matrix. In the last case, debonding or pull-out of fibers are consuming energy; effects that contribute to increase the impact strength of the composites. The different behavior of the fibers, depending on matrix type, can be attributed to a better affinity of these fibers for PP matrix.

From the scanning electron microscope observations it can be deduced that fibers have been drastically shortened (mechanical degradation) during the compounding of the materials, and also a high amount of Twaron particles with diameters below 10 microns were visible. In general, no good adhesion between the Twaron fibers and the polymer matrices is observed. The continuous phase in the blend matrix is constituted by the polymer which is found in higher proportion. Normally, the blending and dispersion of one polymer in the other is very homogeneous, as dispersed PP particles are smaller than the EPDM particles. EPDM particles have sometimes been deformed during the processing of the material. Only at 50/50 PP/EPDM matrix compositions is it not easy to identify both phases and it can, therefore, be suggested that they are interpenetrating each other. No preferential orientation of fibers has been observed in the composites.

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