

Micro and Nano Fibrils from Polypropylene/Nylon 6 Blends

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ABSTRACT: Some previous publications are pointed out to put forward a technique to make fibrils in the range of micro and nano. Blends of polypropylene, nylon 6, and polypropylene grafted with maleic anhydride as compatibilizer were spun into continuous filaments by a laboratory extruder. In a sample containing 70% nylon 6, 25% polypropylene, and 5% polypropylene grafted with maleic anhydride, nylon 6 component that forms the matrix of the blend was dissolved in the solution of formic acid (98%) to leave the other component as micro and/or nanofibrils. The remaining polypropylene fibrils were examined by polarizing microscopy, scanning electron microscopy, FTIR

spectroscopy, differential scanning calorimetry, and wide angle X-ray diffraction. The extracted fibrils were found to be partially crystalline having melting temperature close to the neat polypropylene. The fibrils have diameter less than one micrometer. The diameter of the fibrils decreases by cold drawing. This particular finding suggests a possibility for making mat containing micro and nanofibers from polypropylene. © 2008 Wiley Periodicals, Inc. *J Appl Polym Sci* 108: 1473–1481, 2008

Key words: polypropylene; nylon 6; blends; fibril; nanofiber

INTRODUCTION

The term “nanofiber” was introduced to the fiber literature together with nanotechnology; it refers to the fibers with diameter less than one micrometer.¹ The diameters of these fibers are one or two order of magnitudes smaller than common textile fibers. The diameter of cotton fibers are in the ranges of 15–30 μm (15,000–30,000 nm), wool fibers have diameters greater than 10 μm (10,000 nm), common synthetic fibers have diameters comparable to the natural ones and the diameters of common commercial synthetic microfibers are greater than 1000 nm.² In nanotechnology, the fibers with the diameter of a few nanometers are frequently named nanofibers.³ As far as the diameter is concerned, it seems that there is a discrepancy between the definitions of nanofibers. Here, regardless of this probable inconsistency, our concern is nanofibers with submicron diameters.

In the recent years, nanofibers are produced in laboratory scale by a number of processing techniques, including drawing, template synthesis, phase separation, self-assembly, electro spinning, and so on.^{1,3} The most popular technique is electro spinning, where the polymer solution or melt is subjected to high-voltage electrostatic fields of several kilovolts. The polymer solution or melt ejects from a

nozzle and under the applied electrostatic force the polymer is drawn and collected on a suitable collector. There are several inherent factors that limit the process output, including the type of polymer, polymer concentration, viscosity, and processing speed.³

The nanofibers produced by any of the above techniques may have numerous applications. The applications include filtration, reinforcement for composites, artificial leather, biomedical, protective, and electrical appliances.^{1,3} All these applications are not yet commercialized, which can be due to the lack of information about the properties of these types of fibers. Nanofibers are generally characterized by small diameter and high specific surface area (surface area/volume ratio). It can be perceived that a nanofiber with the diameter of less than one micrometer and with the length of one millimeter would have a width-to-length aspect ratio comparable to cotton fibers, which leads to a comparable flexibility. On decreasing the diameter the structural defects of the fibers decreases considerably. This characteristic, in addition to large surface area, may make several advantageous properties for specific applications that are not yet envisioned.

Basic thought of preparing nanofibers from polymer blends, to be described in this article, like electro spinning, seems to be in the embryonic stage with promising futures. In discussing the properties of polymer blends, several investigators have found that one component of the blend forms the fibrils with diameter in the order of micrometers. For the

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TABLE I
Diameters of Micro Fibers in Some Polymer Blends

Authors	Polymer blends	Production facilities	Microfiber polymer	Microfibers diameter (μm)
Papero et al. ⁴	PET and N6	Melt spinning	PET	0.9
Blizard et al. ¹¹	PC and LCP PEI and LCP	Single screw extruder	LCP	0.26–0.42 0.22–1.36
Wu et al. ¹³	PP and N6	Twin screw extruder	PP	Spherical \sim 1.0
Li et al. ¹⁵	PP and N6	Single screw extruder	N6	2.12–9.15
Afshari et al. ¹⁶	PP and N6	Melt spinning	N6	0.33–2.9
Lyoo et al. ¹⁷	PET and PP	Melt spinning	PP PET	0.13–1.9 0.13–2.75

PET, polyethylene terephthalate; PP, polypropylene; N6, Nylon 6; LCP, liquid crystalline polymer (Vectra A950); PC, polycarbonate; PEI, polyetherimide.

sake of brevity, only a few are mentioned in the list of references.^{4–18} The production of bi-constituent fibers that consists of two chemically and physically distinct polymeric materials in form of fibril/matrix is considerably old.⁴ Hersh,⁵ in reviewing properties and using polyblend fibers up to 1977, reported the 0.1–0.2 μm polyacrylonitrile fibrils in the blend of cellulose acetate/polyacrylonitrile. Generally by dissolving one of the components of miscible or immiscible blends, a mat of small diameter fibrils was obtained.

In the study of high-density polyethylene/polystyrene blends, after melt spinning, the diameter of the extracted polyethylene microfibers were in the range of micrometers that depended on the imposed draw ratio.⁶ In the study of melt rheology of high-density polyethylene/nylon 6 blends, Utracki et al.⁷ described the effects of shear on the blend morphology. It is believed that capillary flow introduces extensive morphological changes in the blend. These changes are dependent on the concentration of the dispersed phase, the temperature, and the deformation rate. One of the morphological changes identified was fibrillation of the dispersed phase. Li et al.,¹⁵ in a study of polypropylene (PP)/ nylon 6 (N6) *in situ* composites, described the effects of processing temperature and rotating speed of the screw in a single screw extruder on the diameter of microfibrils. Recently, in a study of melt-spun PP/N6 alloy filaments, using a laser scanning confocal microscope, the matrix-fibril morphology with the nylon fibrils oriented along the fiber axes was observed.¹⁶ Length variations of the fibrils were high and it seemed that with drawing and increasing the take-up speed, the length of fibrils increases.¹⁸ When liquid crystalline polymers were used as the minor component in a blend, the formation of highly elongated structure parallel to the flow direction is also reported.^{9–11}

Table I shows the diameters of the microfibers in some selected polymer blends. It is not an exhaustive collection; it is just a collection of examples to show that the size of the fibrils varies from submi-

cron to a few micrometers. There are several production parameters and polymer properties that affect the size of the fibrils. These parameters include polymer relative viscosities that depend on temperature, shear rate, and imposed draw ratio during polymer solidification.

The objective of the previous works^{6–18} was mainly aimed to improve the properties of the blends. Although considerable attention has been paid to determine the effects of these fibrils on the properties of the blends, the behavior of the isolated fibrils alone remained unclear.

Removal of one component from blended polymer to improve the properties of the major component is also used for small-diameter electro-spun fibers. To produce fibers with nanoscaled morphologies, Bogwitzki et al.¹⁹ used the blend of polylactide and polyvinylpyrrolidone in electro-spinning. After spinning, fibers with fine pores with intrinsic structure patterns were generated by selective removal of one component in a few micron diameter fibers.

The objective of the present work is to describe the possibility of obtaining nanofibers from the blend of PP/N6 as a case of many other polymers to be examined for this purpose in the future. PP and N6 as two components for the blend were chosen, because both are common fiber forming polymers capable of undergoing high draw ratios, improved compatibility can be obtained by using polypropylene grafted with maleic anhydride (PP-g-MAH), and the melting and glass transition temperatures of these two polymers are far apart.

We believe that the proper matrix of a well mixed polymer is an appropriate medium for supporting the deformation during excessive extension of the fibrils. This excessive extension can probably reduce the size of the fibrils to the order of a few nanometers.

Previous studies^{12–14,16,18} have described the structure and properties of PP/N6/PP-g-MAH blend and the effects of the materials and production parameters on the blend during spinning, where a high draw ratio could be imposed. It is well known that in this

TABLE II
Composition of the Blends and Weight Losses

Blend compositions	Solvents	Weight loss (%)
20% N6/75% PP/5% PP-g-MAH	Xylene	79
70%N6/ 25% PP/5% PP-g-MAH	Formic acid	71

blend, the minor component forms fibrils with a considerably large length to width aspect ratio. MAH units react with the amine end groups of N6 to form block or graft copolymer. It acts as a compatibilizer, reducing the dimensions of the dispersed phase and strengthening the interface between the two phases.^{20,21}

EXPERIMENTAL

Materials

Commercial isotactic polypropylene (PP) was V30S, from Arak Petrochemical (Iran) with a melt flow rate of 16 g/10 min. The PP contained a phenolic antioxidant (IRGANOX[®]1010) and Ca stearate as heat stabilizer. Fiber grade nylon 6 (N6) granules were from Parsilon (Iran). Polypropylene grafted with maleic anhydride (PP-g-MAH) with MFI of 23.7 g/10 min and MAH index of 1.5% was obtained from DuPont (USA). Formic acid 98–100%, analytical grade, was from Merck, and xylene used was of industrial grade, which was a mixture of *ortho*- and *meta*-xylene.

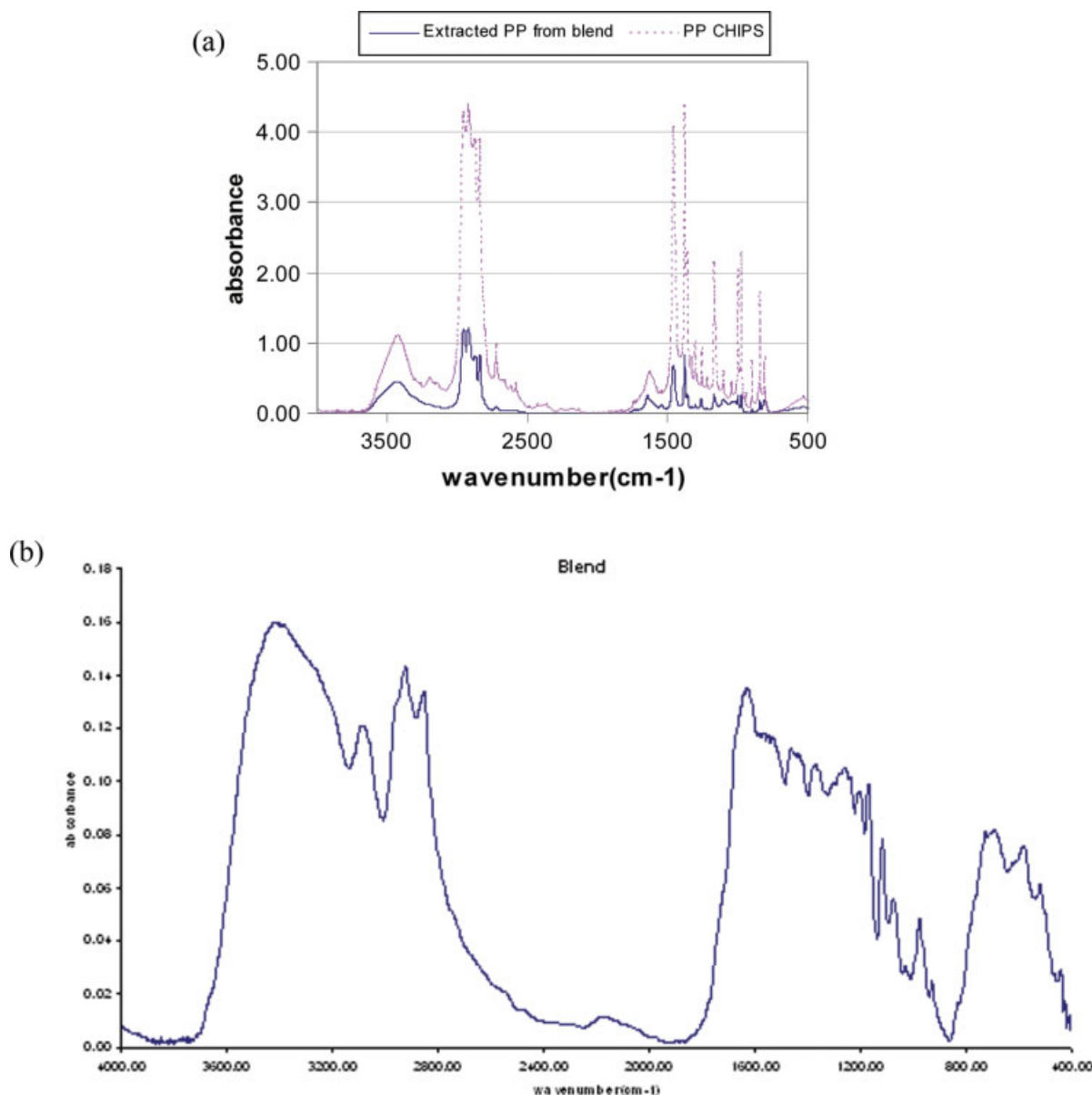


Figure 1 (a) FTIR spectrum of the extracted PP samples and PP chips, (b) FTIR spectrum of PP/N6 blend. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

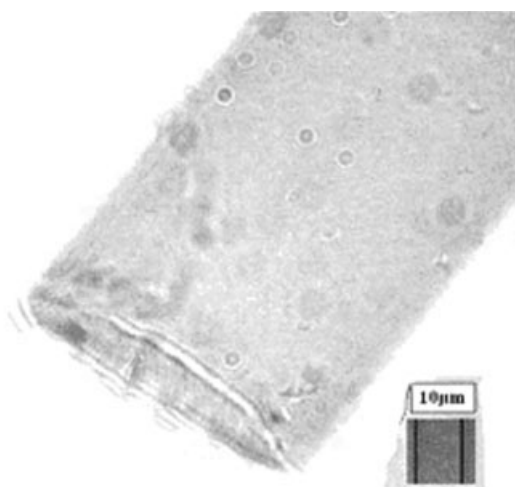


Figure 2 Optical micrograph of nylon 6 filament.

Methods of sample preparation

PP, PP-g-MAH, and N6 granules were dried in a vacuum oven for 24 h at 80°C prior to spinning. Melt spinning was done by a laboratory mixing extruder made by Dynisco, MA (USA). Depending on the required blend composition, proper amounts of granules were fed to the barrel of the extruder alternatively. The extruder was set with standard orifice header having one orifice with diameter of 3 mm. The temperature of the barrel zone was 220°C and the temperature of the die zone was 230°C, with a rotor speed of 16 rpm. The extruded filaments were wrapped around the spindle at a speed of 76.2 m/min. Different blend compositions from PP and N6 were made, but only two compositions (20% N6/75% PP/5% PP-g-MAH and 70% N6/25% PP/5% PP-g-MAH) were used for extracting the fibrils.

Samples of filaments were wound on a cardboard frame to form a bundle; the bundle was then drawn

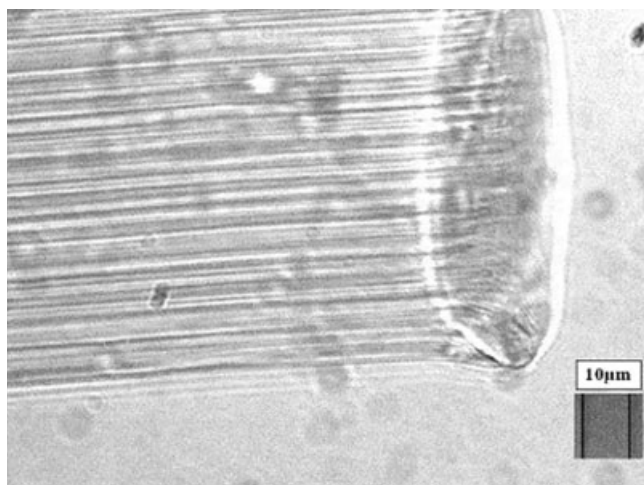


Figure 3 Optical micrograph of 70%N6/25% PP/5% PP-g-MAH blend filament.

using an Instron tensile tester at a constant jaw speed, 50 cm/min at room temperature. The draw ratios (the ratio of the final length to the original length of samples) were two and three.

The two component fiber samples were treated with solvents. Each PP and N6 components were extracted with xylene and formic acid solution, respectively, from spun and drawn filaments. Formic acid at room temperature dissolves N6 and xylene at boiling temperature dissolves PP. Only a preliminary experiment was made with 20% N6/75% PP/5% PP-g-MAH sample. The N6 fibrils were collected by filtering the solution of PP in xylene. The fibrils were found to be considerably coarse and interconnected. These samples were not examined further.

For the sample of (70% N6/25% PP/5% PP-g-MAH), formic acid solution was added to a beaker containing the filaments, the solution was stirred for 3 h then the solution was transformed to a conical decanter and left overnight. The bottom portion was then removed and fresh formic acid was added, and again left for another day. After removing the bottom portion, distilled water was added, and after one day the top portion was transferred to a flat dish and dried at room temperature. No attempt was made to optimize the time and the method of extraction of fibrils from the blends. There are several parameters, such as time, temperature, and stirrer type, which may have effects on the dissolution kinetic of the components. To find the efficient separation technique, may need further investigation.

To determine the amount of each component in the filaments the weight of the samples before and after extraction was determined and the percentage of weight loss (WL) was calculated.

Measurements

A Nicolet Nexus FTIR spectrometer was used to record the spectra between 400 and 4000 cm^{-1} in a transmission mode. The nominal resolution of the spectrometer was 4 cm^{-1} , averaging 32 scans.

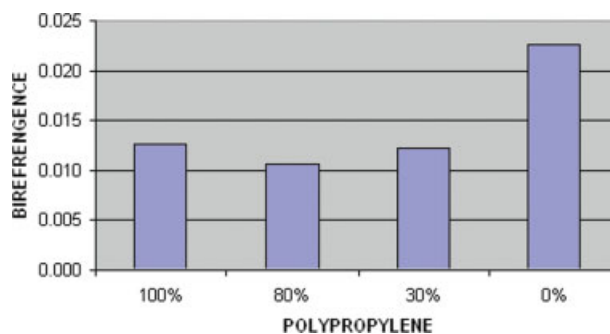


Figure 4 The change of birefringence versus % polypropylene in fibers made from PP/N6 polymer blends. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

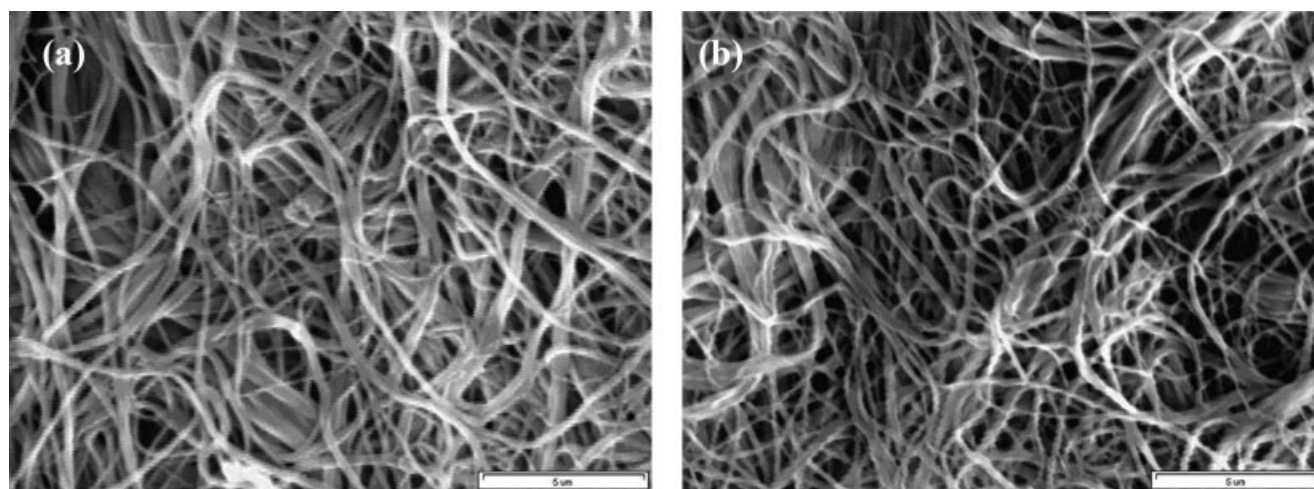


Figure 5 (a) SEM micrograph of PP fibrils from 70% N6/25% PP/5% PP-g-MAH blend after removing N6 with the solution of 98% formic acid (20 kV, $\times 6000$). (b) SEM micrograph of PP fibrils from 70% N6/25% PP/5% PP-g-MAH blend after removing N6 matrix with the solution of 98% formic acid (20 kV, $\times 6000$).

A Bausch and Lomb Greenough microscope and a Karl Zeiss polarizing microscope (Germany) were used to observe the fibers. Retardations were measured by a 6th order compensator and the birefringence was calculated for the samples. A Cambridge (England) scanning electron microscope (SEM) was used to examine the samples at higher magnification with different accelerating voltages. The samples were coated with gold in an automatic sputter-coater prior to the examination by SEM. The fibril diameters were measured on the stored images using Adobe Photoshop software. Several images were made from each sample and at least 30 different places were measured.

Wide angle X-ray diffraction was done by a Philips XPERT-MPD diffractometer using Cu as anode. The radiation wavelength was 1.541 Å, the diffraction angle varied from $2\theta = 5^\circ$ to $2\theta = 49^\circ$, and the equipment was operated at 40 kV. Samples were made from randomized chopped fibers.

Thermograph was prepared by a differential scanning calorimeter (DSC), Polymer Laboratories PL-DSC, (England). The aluminum encapsulated samples, containing 2–5 mg polymer, were heated at the rate of $10^\circ\text{C}/\text{min}$ in the heating range of $20\text{--}250^\circ\text{C}$. Crystalline fraction index were calculated by: $\% X = 100 \times \Delta H / \Delta H^*$ where ΔH is the fusion enthalpy of the sample and ΔH^* is the enthalpy of 100% crystalline sample. The fusion enthalpy of 100% crystalline PP was taken $8.7 \text{ J}/(\text{K mol})$ and that of 100% nylon was taken $26 \text{ J}/(\text{K mol})$.²²

RESULTS AND DISCUSSION

Table II shows the nominal composition of the blends and the measured WL after removing the ma-

trix with solvents. These results indicate that matrix in the blend is removed considerably.

FTIR spectrum of the extracted samples in addition to that of the raw PP chips are compared in Figure 1(a). The FTIR spectrum of PP/N6 blend is shown in Figure 1(b) for comparison. Lack of prominent peak at 3300 cm^{-1} that corresponds to amide group (CONH)^{23,24} in extracted PP sample from blend [Fig. 1(a)], supports the above asserted results that polyamide matrix is removed considerably. However, there is an indication of the presence of NH group in extracted samples that is indicated by the absorption peak at 1541 and 3422 cm^{-1} . Formation of linkage between PP-g-MAH and N6 prevents complete dissolution of N6 in formic acid. Formation

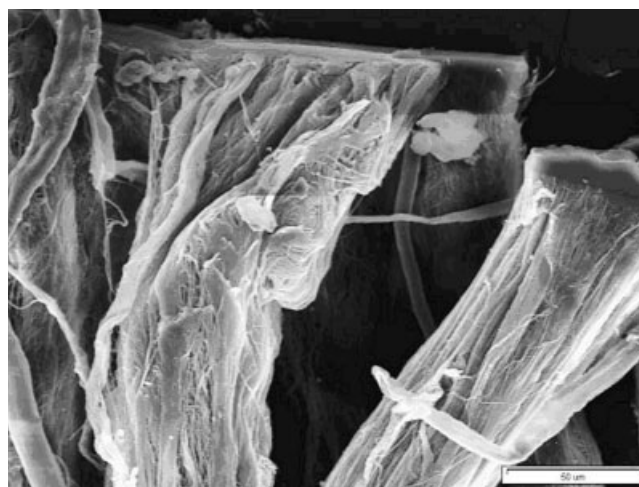


Figure 6 Bundles of fibrils in drawn samples with draw ratio of 3, 70% N6/25% PP/5% PP-g-MAH blend after removing N6 matrix with the solution of 98% formic acid.

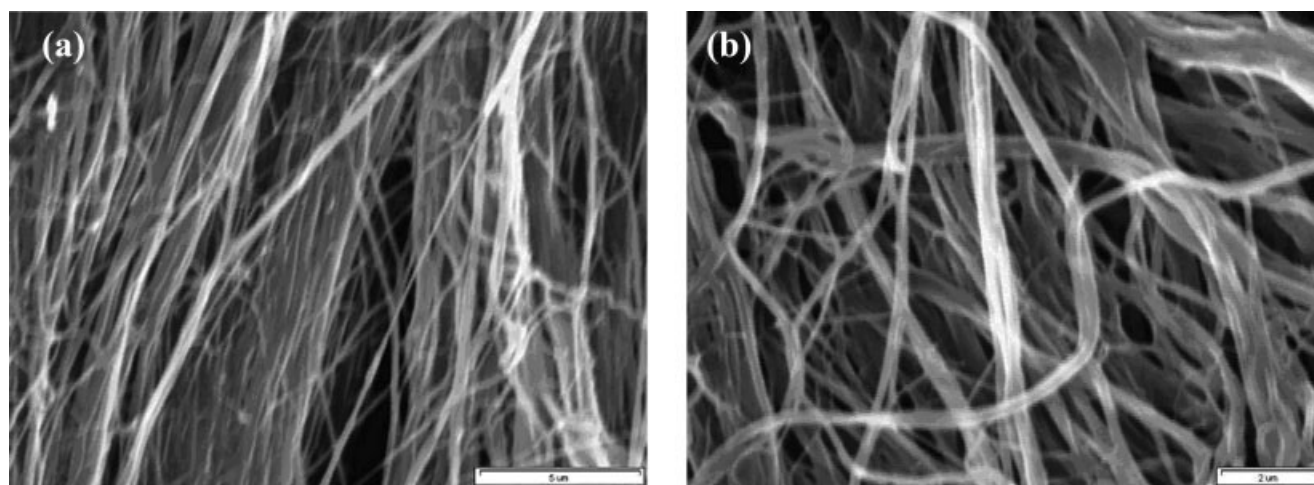


Figure 7 SEM micrograph of PP fibrils extracted from drawn filament, draw ratio 3, from 70% N6/25% PP/5% PP-g-MAH blend after removing N6 matrix with the solution of 98% formic acid: (a) 20 kV, $\times 6000$, (b) 20 kV, $\times 9000$.

of linkage between N6 and PP-g-MAH is reported by several investigators.^{14,20}

The peaks at $1654\text{--}1850\text{ cm}^{-1}$ are characteristics of carbonyl group (C=O) and those at $3250\text{--}3600\text{ cm}^{-1}$ are characteristics of hydro peroxide group (POOH).^{24,25} The spectrum of the extracted PP indicates that there could be some oxidation of PP that may have occurred during the process of extrusion and dissolving the N6 polymer.

Figures 2 and 3 show the representative optical micrographs of N6 and a blend filament, respectively. Neat N6 and neat PP filaments were found to be featureless, but the blend shows longitudinal striation lines parallel to the filament axes. Using polarized light, it was found that the filaments are positively birefringent, indicating that the filaments were considerably extended during extrusion.

The birefringence of all the samples was measured and the results are shown in Figure 4. It is shown that the birefringence decreases when the amount of PP in the blend increases. These decreases are likely due to the intrinsic refractive indices of the components in the blends or it is due to the differences in the imposed draw ratios.

PP fibrils from 70% N6/25% PP/5% PP-g-MAH blend after removing N6 matrix with the solution of 98% formic acid were also examined with polarizing microscope. The elongated bundles were found to be positively birefringent. Because of limitations in the resolution of optical microscope, it was not possible to determine the birefringence of single fibrils.

Figure 5(a,b) show two different SEM micrographs of PP fibrils from 70% N6/25% PP/5% PP-g-MAH blend after removing N6 matrix with the solution of 98% formic acid. Measuring the diameter of the fibrils on several SEM micrographs, they are consid-

erably variable. There are number of fibrils less than 200 nm in diameter and several more than 1000 nm. Considering the resolving power of the SEM, it was not possible to detect fibrils with diameters less than 150 nm.

The filaments were drawn by an Instron universal tensile tester and the matrix was then removed with formic acid. The fibrils are stuck together and form bundles similar to that is shown in Figure 6. Representative SEM micrographs of PP fibrils in drawn filaments with draw ratio of 3 are shown in Figure 7(a,b). The fibrils are oriented parallel to the drawing direction. The fibril diameters were measured, the results of the diameter measurements of the un-drawn and drawn fibrils, in the form of frequency diagram shown in Figure 8. The average diameter of the fibrils is reduced considerably upon drawing and the diameter distribution of the drawn

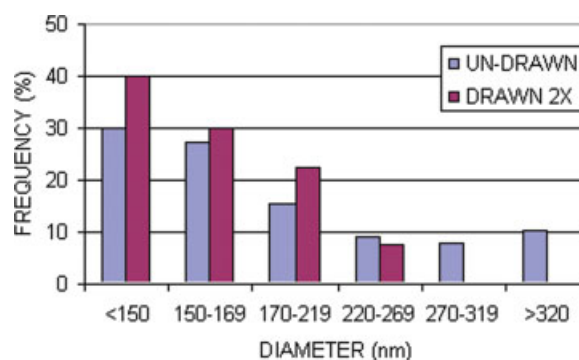


Figure 8 Diameter of PP fibrils in the un-drawn and drawn samples of 70% N6/25% PP/5% PP-g-MAH blend after removing N6 matrix with the solution of 98% formic acid. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

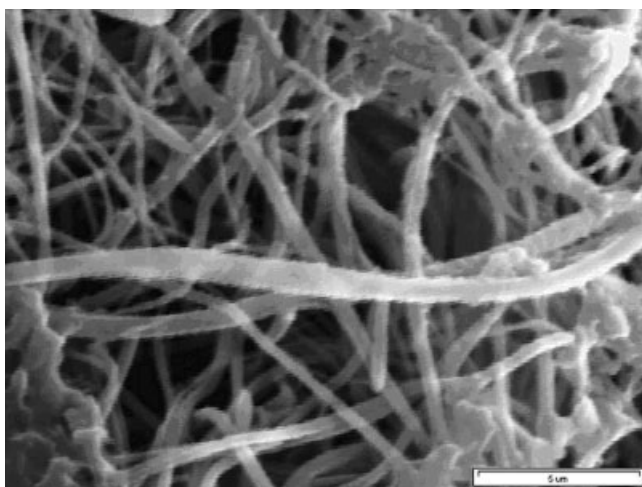


Figure 9 SEM micrograph of N6 fibrils extracted from 20% N6/75% PP/5% PP-g-MAH blend after solving PP matrix with xylene (20 kV, $\times 6000$).

fibrils is seemed to become narrower than un-drawn fibrils. The ratio of the average diameter of un-drawn fibrils to drawn fibrils are 1.2, which is less than the square root of imposed draw ratio, indicating that either the draw ratio of fibrils are less than the imposed draw ratio or the fibrils shrunk after the removal of N6 from the blend filament. Reduction of diameters of the fibrils upon drawing in polyethylene/polystyrene blend is also reported by Min et al.⁶

Figure 9 shows the SEM micrographs of N6 fibrils from 20% N6/75% PP/5% PP-g-MAH, the diameter of these fibrils ranges from 300 to 1200 nm. In this case, the PP matrix was removed with xylene. A histogram, showing the variations in the diameter of N6 fibrils is shown in Figure 10. The average diameter of N6 fibrils is considerably greater than those of PP fibrils.

It seems that during filament formation, probably, PP matrix could not transfer elongation force to N6 component. During the cooling and solidification of blend filament, because of the difference in the melt-

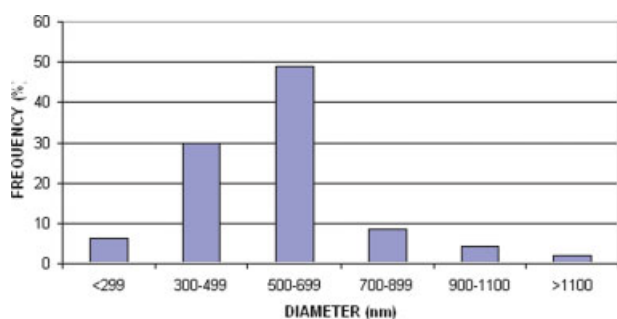


Figure 10 Diameter of nylon 6 fibrils from 20% N6/75% PP/5% PP-g-MAH blend after solving PP matrix with xylene. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

TABLE III
Diameters of Some Nanofibers Produced by Electrospinning Reported by Different Investigators

Authors	Polymers used	Diameters
Demir et al. ²⁶	Polyurethaneurea	7 nm–1.5 μ m
Dersch et al. ²⁷	Nylon 6	50 nm
Pedicini and Farris ²⁸	Polyurethane	~ 1 μ m
Lin and Martin ²⁹	Poly(hexylisocyanate)	2 μ m
Reneker et al. ³⁰	Polyimide	2 μ m
Khurana et al. ³¹	Polypropylene	250–500 nm
Hou and Reneker ³²	Polyacrylonitrile	100–300 nm
McKee et al. ³³	Poly(urethane urea)	5.5 ± 1.8 μ m
Dalton et al. ³⁴	Poly(ϵ caprolactone)	4.0 ± 1.5 μ m
Huang et al. ³⁵	Nylon-4,6	1.26 ± 0.19 μ m

ing points of PP and N6, PP was in molten state and could be elongated easily, whereas N6 solidified and became relatively stiff, and hence, the diameter of N6 fibrils did not reduced considerably.

Table III shows the diameters of some nanofibers produced by electro spinning by different investigators that ranged from 1.6 nm to a few micrometers. Comparison of the fibrils diameters produced in the present work and those presented in Table III indicates that it is possible to produce fibrils with diameters comparable to those produced by electro spinning. It needs further work to determine the smallest fibril diameters that can be produce by extraction from the blends.

Figure 11 shows the wide angle X-ray diffraction spectrum of 70% N6/25% PP/5% PP-g-MAH sample. In addition to an intense peak at $2\theta = 21.5^\circ$, which corresponds to poorly crystallized N6, there are some other weaker peaks (at about $2\theta = 14^\circ$, $2\theta = 17^\circ$) that could be due to the presence of crystal-

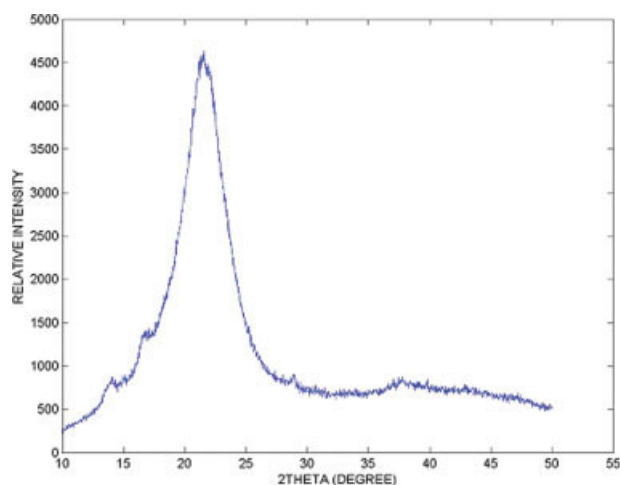


Figure 11 Wide angle X-ray diffraction spectrum of 70% N6/25% PP/5% PP-g-MAH blend sample. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

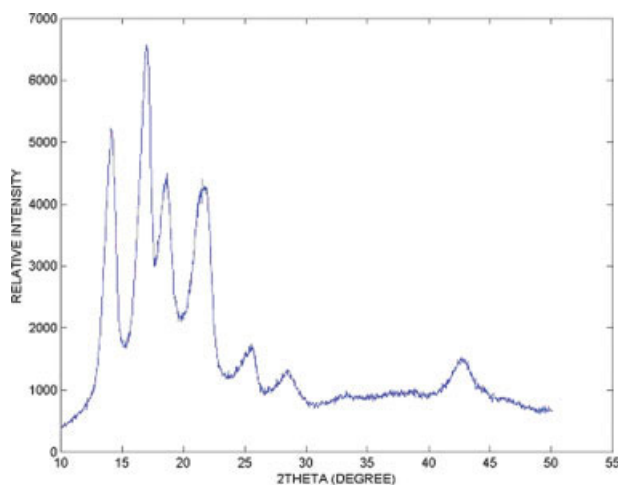


Figure 12 Wide angle X-ray diffraction pattern of PP fibrils after removing N6 from 70% N6/25% PP/5% PP-g-MAH sample by solution of 98% formic acid (20 kV, $\times 6000$). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

line PP and probably the different forms of N6 unit cell.^{36–38} Because of the lower concentration of PP in the blends, the crystalline peaks of PP are not well observed in Figure 11.

The X-ray diffraction spectrum of PP fibrils after removing N6 matrix with the solution of 98% formic acid from 70% N6/25% PP/5% PP-g-MAH sample is shown in Figure 12. The first three intense peaks that are at $2\theta = 14^\circ$, $2\theta = 17^\circ$, and $2\theta = 18.8^\circ$ are the reflections of, (110), (040), and (130) planes, respectively, the next intense peak at $2\theta = 21.9^\circ$ corresponds to (131) and (041) planes. The next two less intense peaks at $2\theta = 25.6^\circ$ and $2\theta = 28.6^\circ$ correspond to (060) and (220) planes, respectively, that is consistent with the literature results for partially crystalline PP.³⁹ This structure corresponds to α monoclinic form of isotactic PP with structural parameters $a = 6.65 \text{ \AA}$, $b = 20.96 \text{ \AA}$, $c = 6.5 \text{ \AA}$, and β

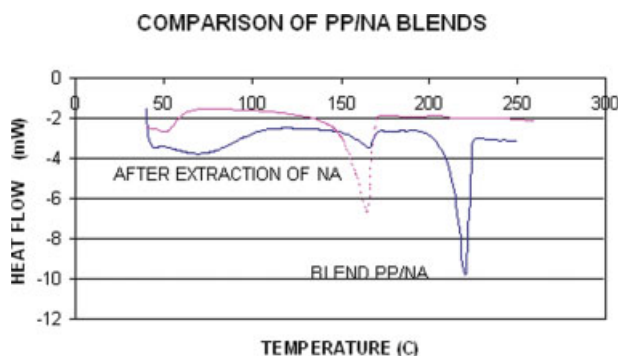


Figure 13 DSC thermographs of blended fibers (70% N6/25% PP/5% PP-g-MAH) sample and fibrils after extraction of N6 with formic acid.

TABLE IV
Crystalline Fraction and Melting Temperature of Samples Determined by DSC

Sample	Melting temperature (°C)	Enthalpy	Crystalline fraction (%)
PP/N6 blend			
PP in blend	165.4	8.060	14
N6 in blend	220.2	52.01	23
PP after extraction of N6	164.7	79.03	48
PP chips	166.2	81.2	49

$= 99.3^\circ$.³⁷ These results indicate that the extracted fibrils are partially crystalline.

The DSC thermographs of a blended sample (70% N6/25% PP/5% PP-g-MAH) and the fibrils after extraction of N6 with formic acid are shown in Figure 13. As expected, the results indicate that PP and N6 are immiscible, having separate distinct endothermic peak. The melting points for PP and N6 in the blend are close to those reported for neat PP and N6 in the literature.^{21,40} After treating with formic acid, the DSC thermograph of the PP fibrils does not show any endothermic peak in the range of 200–250°C, which indicates that considerable amount of N6 is extracted. The PP fibrils left are crystalline showing a single phase endothermic behavior. Multiple fusion endotherms similar to those that are reported in the literature⁴⁰ were not observed.

The crystalline fractions of different samples calculated from the enthalpies are shown in Table IV. Melting temperature of PP in the blend and that of the extracted fibrils are very close, but the crystalline fraction changed considerably. It is likely that the treatment with solvent has an effect on the crystallization process. The glass transition temperature of PP is well below room temperature (the temperature of dissolving N6). Probably, PP fibrils were then crystallized further after freed from the surrounding N6 matrix.

The DSC thermograms confirm the results obtained by X-ray diffraction, that the fibrils with diameters less than a few micrometers are remained partially crystalline.

CONCLUSIONS

Examining samples of PP, N6, and PP-g-MAH blend filaments, it was found that fibrils with diameters less than one micrometer can be produced by blending, extrusion, drawing, and removing the major component with solvent. Mat containing fibrils with submicron diameter was obtained. The mat of PP fibrils appears dull and soft.

The isolated PP fibrils from the blend were found to be crystalline. The fibrils showed positive sign of

birefringence, indicating the preservation of the molecular orientation after extraction from the blends. By drawing the blend filament, the N6 matrix can transfer the applied stresses to the fibrils in the longitudinal direction and elongate the PP fibrils. It is expected that by changing the temperature and the draw ratio the fibril diameter can be controlled and it can be lowered further.

This method may have some advantages as well as disadvantages over the alternative processes. There are some limitations and several obstacles in the way of producing well controlled products. Different polymer types for different fields of applications should be examined.

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