J Mater Sci (2007) 42:8006–8009
DOI 10.1007/s10853-007-1607-9

POLYMER FIBERS 2006

The influences of slot width of an attenuator on the properties of PET spunbonded fibers

Hong Wang · Xiangyu Jin · Haibo Wu · Baopu Yin

Received: 8 August 2006 / Accepted: 12 February 2007 / Published online: 26 June 2007

Abstract In this paper, poly(ethylene terephthalate) (PET) spunbonded fibers with tensile strength of 9.67 cN/dtex and diameter of 7 µm were produced in Nordson's MicroFil$^{\text{TM}}$ Spunbond System with a positive attenuator pressure. The influences of the slot width of the attenuator on the properties of PET spunbonded fibers were studied, and Fourier transformation infrared spectrophotometry (FT-IR) and Wide-angle X-ray diffraction were applied to characterize the crystalline and orientation structure of PET spunbonded fibers as well. It was found the attenuator with positive air pressure is more advantageous to spin PET spunbonded fiber and the fiber becomes finer and its' tensile strength becomes higher with the decrease of the slot width. The air speed in the attenuator was predicted as well.

Introduction

Spunbonding process is one in which polymers are extruded through spinnerets and the filaments are drawn by high velocity air in the attenuator. The continuous filaments are sucked onto the running web and forms nonwovens [1, 2]. Spunbonded nonwovens are developing very quickly with its' excellent properties and high process efficiency. Spunbonded fibers are drawn by high velocity air with positive or negative pressure in the spunbonding process, in comparison with fibers drawn by godet in the high-speed spinning process [3, 4]. The properties of PET fibers are strongly influenced by the drawing process and it is not very easy to produce PET spunbonded fibers in the spunbonded nonwoven system with negative attenuator pressure. Nordson's MicroFil$^{\text{TM}}$ Spunbond System with a positive attenuator pressure makes it possible to produce PET spunbonded nonwovens with excellent properties.

A few papers have investigated the drawing process of high velocity air with negative pressure, such as "Reiconfil" spunbonding process [5–7], but there is few report about the drawing process with positive air pressure. In this paper, the influences of the slot width of the attenuator with positive pressure on the properties of PET spunbonded fibers were studied.

Experimental

Preparation of PET spunbonded fibers

In this paper, PET spunbonded fibers were produced in Nordson's MicroFil$^{\text{TM}}$ Spunbond System with different slot width of the attenuator. The normal inherent viscosity of PET resin is 0.65 dL/g. The processing conditions are presented in Table 1.

Measurements

Equatorial X-ray diffraction patterns were obtained by a Rigaku D/Max-BR diffractometer with Cu-K_α radiation (λ = 1.54 Å) at 40 KV. The crystalline orientations (f_c) of the samples were estimated by the azimuthal intensity distribution of well-resolved wide-angle X-ray reflection lines from (100), (010), and (110) planes and were written as follows [8]:

H. Wang (✉) · X. Jin · H. Wu · B. Yin
Nonwovens R & D Center, Donghua University,
Shanghai 200051, P.R. China
e-mail: wanghong@dhu.edu.cn

Table 1 Processing conditions of PET spunbonded fibers

Process	Sample 1	Sample 2
Pressure of the attenuator (MPa)	0.24	0.24
Spinning temperature (°C)	290	290
Width of the slot (mm)	5	2

$$f_c = \frac{180^\circ - B^\circ}{180^\circ} \times 100,$$

where B is the half-width of the intensity distribution on the (100), (010) and (110) planes on the equator of the two samples.

The polarized Fourier transform infrared (FT-IR) spectra of sample 1 and sample 2 with electric vector parallel and vertical to the draw direction were obtained using a NEXUS-670 (Nicolet Corp.) spectrometer in the spectral region of 4,000–350 cm^{-1}.

Tensile properties were measured using a YG (B) 003A tensile machine with a 20-mm length of monofilament at a crosshead speed of 60 mm/min. The tenacity was obtained by averaging 20 trials of the tensile test for each sample.

Results

Mechanical properties of PET spunbonded fibers

Table 2 showed the fineness and tensile properties of PET spunbonded fibers. It could be found that PET spunbonded fibers produced in this paper were very fine and had high tensile strength. The diameters of sample 1 and sample 2 were 10.5 and 7 μm, respectively. However, the minimum diameter of PP under Reifenhauser standard conditions is only about 8 μm (It is easier to make PP fibers with finer diameter than PET). The tensile strengths of sample 1 and sample 2 are 6.43 and 9.67 cN/dtex, respectively. It is suggested that PET spunbonded fibers have better mechanical properties with the decrease of the slot width.

Generally speaking, the tensile strength of PET fibers increases with the increase of crystallinity and orientation. Therefore, X-ray diffraction and FT-IR were used to investigate the crystalline and orientation structure of PET spunbonded fibers.

Table 2 Fineness and tensile properties of PET spunbonded fibers

	Diameter (μm)	Strength (cN/dtex)	Elongation rate (%)
Sample 1	10.5	6.43	84.3
Sample 2	7.0	9.67	81.2

Crystalline and orientation structure of PET spunbonded fibers by X-ray diffraction

It is reported that PET can be an amorphous structure or crystalline structure [9]. The principal X-ray diffraction peaks of PET fibers are near $2\theta = 17.5°$, $2\theta = 22.5°$, and $2\theta = 25.5°$ with CuK_α, while that of amorphous structure is near $2\theta = 21.3°$ with CuK_α. Figure 1 showed the WAXD intensity curves for sample 1 and sample 2.

There was only a broad peak near $2\theta = 21.3°$ in the WAXD intensity curves for sample 1. With the decrease of the slot width, the peak was remarkably sharpened and three peaks near $2\theta = 17.5°$, $2\theta = 22.5°$, and $2\theta = 25.5°$ were observed for PET crystalline structure. The crystallinity of the samples was estimated by resolving contributions from amorphous and crystalline peaks. On the other hand, the crystalline orientations (f_c) of the samples were estimated by the azimuthal intensity distribution of well-resolved wide-angle X-ray reflection lines from (100), (010), and (110) planes. It was found the crystallinities of sample 1 and sample 2 were 32.5% and 35.6%, and the orientations of crystalline of sample 1 and sample 2 were 74.5% and 80.6%, respectively. This showed that sample 2 had perfect crystal structure and its' crystallinity and orientations of crystalline were higher than that of sample 1, and this might be the reason why the tensile strength of sample 2 was higher than that of sample 1.

Conformation and orientation structure of PET spunbonded fibers by FT-IR

Because PET spunbonded fibers produced in this paper are very fine, it is very difficult to detect their overall

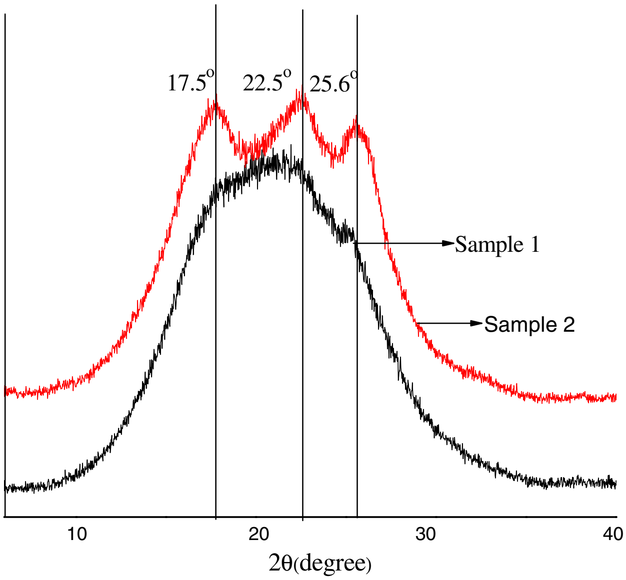

Fig. 1 WAXD curves for PET spunbonded fibers

molecular orientation structure by sound velocity method or polarized light microscope [10]. Therefore, FT-IR was used to analyze orientation structure of PET spunbonded fibers indirectly [11].

On the FT-IR spectra of PET fibers, the band at 848 and 899 cm^{-1} are assigned to trans and gauche conformations of ethylene glycol segment of PET molecular chain. The band at 1578 cm^{-1} is assigned to the symmetric stretching of the phenylene ring, and the band at 875 cm^{-1} is assigned to the out-of-plane ring C–H ring bending. These two bands have strong dichroic characteristics and can be used to calculate the overall molecular orientation and orientation of the chain in the amorphous [11]. On the other hand, the band at 1386 cm^{-1} is assigned to in-plane-ring C–H bending and only appears when the crystalline of the sample is very high. The polarized FT-IR spectra of sample 1 and sample 2 with electric vector parallel and vertical to the draw direction were shown in Figs. 2 and 3.

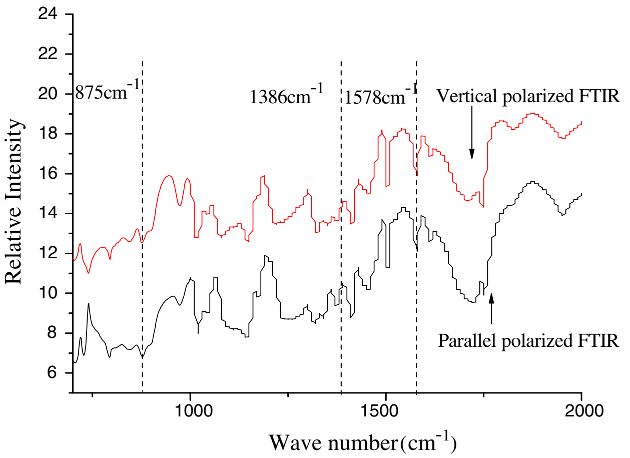

Fig. 2 Polarized FT-IR spectra of sample 1

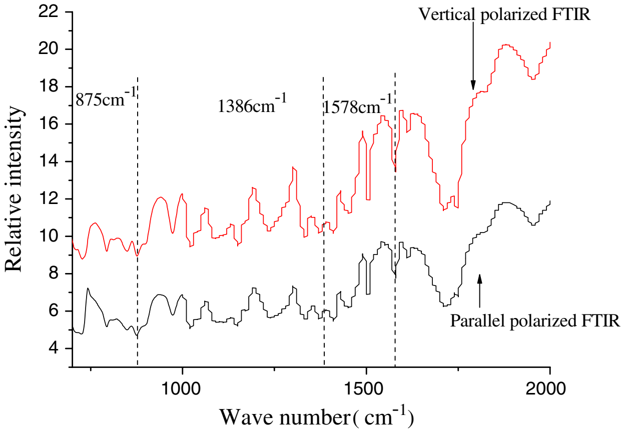

Fig. 3 Polarized FT-IR spectra of sample 2

It could be found that the band at 1386 cm^{-1} appeared on Figs. 2 and 3, which means that sample 1 and sample 2 all had high crystalline content. Thus, the FT-IR spectral result is consistent with the WAXD result. In order to investigate the orientation structure of PET spunbonded fibers, the bands at 1578 and 875 cm^{-1} were selected to calculate the overall molecular orientation (f_o) and orientation of the chain in the amorphous (f_a), respectively.

It is well known that the Ratio of Dichroism (R) of polymer fibers can be written as follows [11]:

$$R = A_{\parallel}/A_{\perp}$$

where $A_{\parallel}$ is the intensity of the band at 1578 or 875 cm^{-1} on the parallel polarized FT-IR spectrum, and $A_{\perp}$ is the intensity of the band at 1578 or 875 cm^{-1} on the vertical polarized FT-IR spectrum.

The Function of Orientation f (f_o or f_a) can be written as follows [11]:

$$f = \frac{(R-1)}{(R+2)} \times \frac{2}{3\cos^2\alpha - 1}$$

where α is the angle of the transition moment of a vibration mode and the PET molecular chain (α of 1578 and 875 cm^{-1} are 0° and 85°, respectively). The results were shown in Tables 3 and 4.

It could be found from Table 3 that the overall orientations of samples 1 and 2 were 0.03 and 0.43, respectively. Table 4 showed that the orientations of the chain in the amorphous of samples 1 and 2 were 0.03 and 11.2, respectively. It was suggested that the overall orientation and orientation in the amorphous of sample 2 were higher than those of sample 1 and this might result in the higher tensile strength of sample 2. It also could be found that there was a good correlation between X-ray diffraction curves and FT-IR spectra.

Table 3 The overall molecular orientation (f_o) of PET according to band at 875 cm^{-1}

	Sample 1	Sample 2
$A_{\parallel}$	6.83	2.34
$A_{\perp}$	7.5	1.31
R	0.91	1.79
f_o	0.03	0.43

Table 4 Orientation of the chain in the amorphous (f_a) of PET according to band of 1578 cm^{-1}

	Sample 1	Sample 2
$A_{\parallel}$	12.06	3.87
$A_{\perp}$	10.94	2.81
R	1.1	1.38
f_a	0.03	11.2

Prediction of the air speed in the attenuator

From the above analysis, it was found that the tensile strength of PET spunbonded fibers increases with the increase of crystallinity and orientation of PET spunbonded fibers. The crystalline and orientation of PET spunbonded fibers were induced by the drawing of the high-speed air in the slot of the attenuator. Therefore, it is necessary to study the air distribution in the slot of the attenuator. The slot of the attenuator in Nordson system is over 3 mm long and the air field in the slot is very complicated. Hence, the air distribution in the slot can only be simulated by sophisticated computer software combined with apparatus/process experience. In this paper, the air speed in the attenuator when sample 1 and sample 2 was produced was predicted.

It is well known there is only a broad peak on the X-ray curve of PET fibers produced with a drawing speed lower than 4,000 m/min. The peak becomes sharper and will split into several peaks with the increase of the drawing speed, and three obvious diffraction peaks corresponding to PET crystalline structure will appear near $2\theta = 17.5°$, $2\theta = 22.5°$, and $2\theta = 25.5°$ when the drawing speed is about 5,500 m/min [9]. The drawing speed of PET spunbonded fibers is equivalent (or a little lower than) the air speed in the attenuator. Therefore, X-ray diffraction results could be used to predict the air speed in the attenuator. From the results of X-ray diffraction of PET spunbonded fibers, it could be predicted that the air speed in the attenuator was not higher than 4,000 m/min when the slot was 5 mm in width, while the air speed was about 5,500 m/min when the slot was 2 mm in width.

Conclusions

In this work, PET spunbonded nonwovens were produced in Nordson's MicroFil™ Spunbond System with a positive attenuator pressure. The fineness and tensile properties of PET spunbonded fibers were tested, and X-ray diffraction and FT-IR were applied to characterize the crystalline and orientation structure of PET spunbonded fibers as well. It was found that the attenuator with positive air pressure is more advantageous to spin PET spunbonded fibers with excellent properties and the slot width has a big influence on the properties of PET spunbonded fibers. PET spunbonded fiber becomes finer and its' tensile strength becomes higher with the decrease of the slot width. It was predicted that the air speed in the attenuator when the slot width is 5 or 2 mm is about 4,000 or 5,500 m/min, respectively.

Acknowledgements The authors thank for Yaolong Spun-bond Technology Co., Ltd for their assist to make the two samples on their production line (Nordson's MicroFil™ Spunbond System).

References

1. Zhang D, Bhat G, Malkan S, Wadsworth L (1994) In: Proc Forth Annual TANDEC Conference on Nonwovens, November
2. Zhang D, Bhat G, Malkan S, Wadsworth L (1998) Textile Res J 68:27
3. Ke QF, Jin XY (2004) In: Nonwovens, Donghua University Publishing Company, Shanghai, p 223
4. Hajji N, Spruiell JE, Lu FM, Malkan S, Richeson GC (1991) INDA J Nonwovens Res 4:16
5. Patel RM, Spruiell JE (1991) Polym Eng Sci 31:730
6. Zieminski KF, Spruiell JE (1988) J Appl Polym Sci 35:2223
7. Misra S, Spruiell JE, Richeson GC (1992) INDA J Nonwovens Res 4:13
8. Ziabicki A (1976) In: Fundamentals of fibre formation. Wiley and Sons, New York, p 186
9. Guo DS, Wang WK (2001) In: Polyest Fiber Science and Engineering. China's Textiles Publishing Company, Beijing, p 64
10. Zhan HY (2005) In: Fiber Chemistry and Physics. Science Publishing Company, Beijing, p 143
11. Jiang Y, Guo FM, Sun L et al (2000) Spectroscopy Spectral Anal 20:665