STRUCTURE AND PROPERTIES OF POLYPROPYLENE FILAMENTS IN A SPUNBONDING PROCESS

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Abstract

Polypropylene homopolymer (PP) and a copolymer (P/E) were processed using the Reicofil® spunbonding line at the Textiles and Nonwovens Development Center of the University of Tennessee, Knoxville. The properties of the filament samples taken before thermal-bonding were determined through a variety of techniques such as differential scanning calorimetry, thermomechanical analysis, thermal deformation analysis and mechanical properties. The two process variables investigated, primary air temperature and throughput had a strong influence on the structure and properties of both the filaments and the bonded nonwovens. As the primary air temperature and throughput decreased, there was a tendency for decrease in filament diameter with a simultaneous increase in their crystallinity, birefringence and thermal stability. The copolymer filaments showed lower crystallinity and orientation for all the corresponding processing conditions.

Keywords: copolymers, crystallinity, polypropylene

Introduction

Thermal analysis is widely used to study the development of structure and properties of polymeric materials during processing. Spunbonding is the most productive of all the non-conventional methods of textile fabric formation and is based on the spinning technique and bears many similarities [1]. The spunbonding process involves extrusion, followed by non-isothermal extensional flow of the melt, and crystallization, accompanied by molecular orientation [2, 3]. In the Reicofil® system [4], the molten polymer is forced by spinning pumps through special spinnerets having a large number of holes. The primary blow ducts, located immediately below the spinneret block continuously cool the filaments with conditioned air. Secondary blow ducts, located below the primary blow ducts, continuously supply auxiliary air at room temperature. A blower at the bottom of the enclosed spinline creates a suction for the filaments and mixed air. The continuous filaments are sucked through a venturi (high velocity low pressure zone) and a distributing chamber, which ensures entangling of the filaments. The entangled filaments are deposited as a random web on a moving porous belt for thermal calendaring.

Although the effect of processing variables on the properties of the webs has been studied, there is no information available on the development of structure and

properties of the filaments [5, 6]. It is obvious that structure and properties of the spunbonded webs are determined by that of the filaments. This research was done to elucidate the development of morphology and properties of the filaments.

Experimental

Polypropylene homopolymer and a P/E copolymer, supplied by Exxon Chemical Company, were processed using the Reicofil® spunbonding machine, based on the established optimum process window for 35 MFR PP by earlier research [6], and a series of filament samples (before bonding) and the corresponding nonwoven samples was collected. The copolymer had a lower melting temperature than that of the homopolymer and was processed at a correspondingly lower temperature. Different throughputs and cooling air temperatures were used to study their influence on the structure and properties.

Differential scanning calorimetry of the filaments and the non-woven samples was carried out using the Mettler DSC 25. The samples were scanned at a heating rate of $10°C$ min^{-1} in the nitrogen environment. Enthalpies of melting were determined so that the crystallinity of the samples could be calculated. A ΔH value of 146.5 J g^{-1} for 100% crystalline polypropylene was used for estimating the crystallinity of the samples [7]. Thermomechanical analysis responses were recorded using the Mettler TMA 40 with a heating rate of $10°C$ min^{-1}. The samples were scanned in the nitrogen environment with different levels of pretension using tension, compression, and dynamic mode. The gauge length for the samples was 10 mm and the width of non-woven samples was approximately one mm. Isothermal scanning of the samples was done at different temperatures and pretensions.

For determining large scale deformations, thermal deformation analysis (TDA) was done using a tubular oven mounted on rails. One end of the leader filament was fixed, while the other end was passed over a smooth roll and pretensioned by applying required load. The tension or stress was adjusted by changing the mass hung at the free end. Changes in dimension of the samples exposed to different temperatures were measured. Diameters of filaments were measured using an optical microscope. Thirty measurements were taken for each condition. Birefringence of the filament samples was determined using the retardation technique. Ten measurements were taken for each sample.

Results and discussion

The sample identification, fiber diameter, birefringence and crystallinity of the filaments are shown in Table 1. The fiber diameter increased as the throughput and primary air temperature increased with a simultaneous decrease in birefringence. The higher the birefringence, the higher the orientation of the filaments. This may be due to the fact that the low temperature is helpful in generating higher spinline stress, which leads to reduction in fiber diameter. The crystallinity decreased with increasing throughput. The results indicate that low primary air temperature is helpful for crystallization of filaments. The overall orientation and crystallinity of

Table 1 Sample specification and physical properties

Sample	Throughput (g/hole/min)	Cooling air temp./$^{\circ}$C	Diameter/ μm	Birefringence	Crystallinity$_{\text{from DSC}}$/ %
H_1	0.2	10	21.8	0.0244	57.5
H_2	0.2	18	23.6	0.0213	55.4
H_3	0.3	10	24.8	0.0224	55.8
H_4	0.3	18	26.2	0.0209	53.2
H_5	0.3	27	27.1	0.0191	52.6
H_6	0.4	10	27.2	0.0203	54.4
H_7	0.4	18	28.9	0.0195	53.2
C_1	0.2	10	23.8	0.0208	41.5
C_2	0.2	18	24.5	0.0181	40.4
C_3	0.3	10	25.1	0.0185	41.3
C_4	0.3	18	26.1	0.0166	40.2
C_5	0.3	27	27.5	0.0136	39.5
C_6	0.4	10	27.8	0.0203	41.2
C_7	0.4	18	28.2	0.0161	39.9

Note: H = PP homopolymer, C = P/E copolymer

the copolymer filaments are lower than that of the homopolymer for corresponding processing conditions.

As shown by the DSC curves (Fig. 1), the melting point and heat of fusion for the copolymer are lower than those of the homopolymer. That allows the bonding temperature and processing temperature of the copolymer to be lower than that of the homopolymer. The lower heat of fusion for the copolymer is an indication of lower crystallinity, because the PE segments in PP chains are not favorable for crystallization during solidification of the filaments.

Figure 2 shows the thermomechanical responses of the filaments produced at different cooling air temperatures. The filaments produced at lower primary air
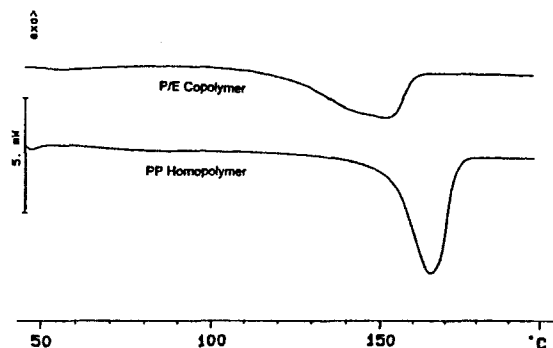
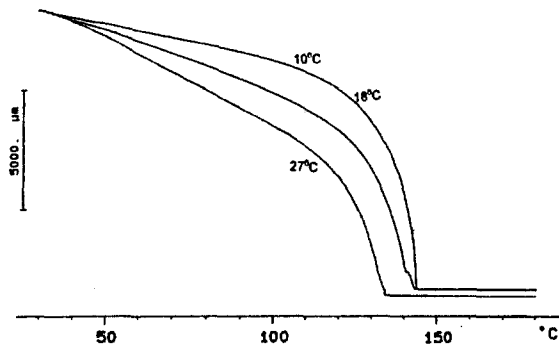**Fig. 1** DSC scans of the PP homopolymer and P/E copolymer

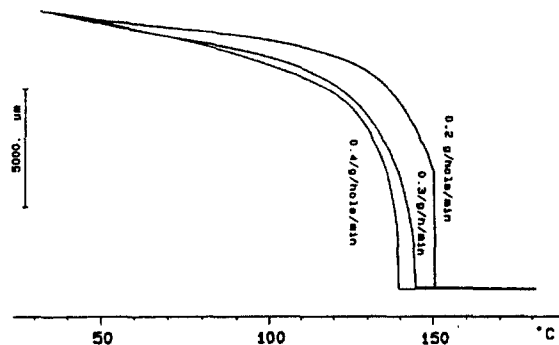**Fig. 2** TMA responses of filaments produced at different cooling air temperatures

Fig. 3 TMA scans for filaments produced at different throughput

temperatures were more stable than those spun at higher temperatures. For the same primary air temperature, the thermomechanical stability of filaments improved with decreasing throughput (Fig. 3). TMA studies indicate that there is a large difference in the observed response for the filaments, especially in the temperature range of 90 to 120°C.

The difference of TMA responses of filament samples between the PP homopolymer and the copolymer are shown in Fig. 4. The homopolymer filament shows better thermomechanical properties than those of the copolymer filaments. This is due to the fact that the homopolymer filaments are of higher crystallinity and orientation than those of the copolymer filaments. More importantly, response of the filaments during the calendering process will be different in the two cases, which in turn determines the properties of the bonded nonwovens.

Thermal elongation of samples at on-set melting temperature for two minutes measured at two different tensions is shown in Table 2. At both 2.6 MPa and 7.9 MPa pretension, the thermal elongation increased as the primary air temperature and throughput increased. The relatively large thermal elongation showed that
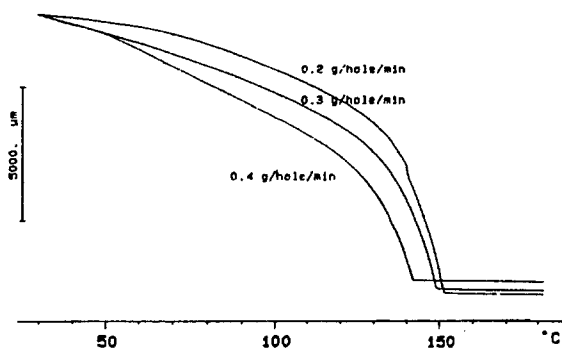
Fig. 4 TMA responses of nonwoven samples

Table 2 Thermal elongation at on-set melting temperature for 2 min with given tension

PP Spunbound filaments	Elongation at	
	7.94 MPa pretension/%	2.60 MPa pretension/%
H_1	17	8
H_2	23	15
H_3	31	17
H_4	36	18
H_5	42	26
H_6	33	10
H_7	54	13
C_1	31	11
C_2	38	19
C_3	40	22
C_4	45	24
C_5	49	30
C_6	39	13
C_7	47	17

the filaments have a lot of potential for drawing. Lower the crystallinity and orientation of the samples, thermal elongation was higher. The trend observed for the copolymer was same as seen with the homopolymer filaments.

Figure 5 shows the isothermal TMA scans of filament samples at different temperatures for 60 min with a constant tension. As shown, the creep increased with time and temperature. The maximum extension took place in the first 10 min. After that, time-dependent elongation increased slowly and evenly. Apparently, the creep increased proportionately as the temperature of scan increased from 30 to 90°C. However, there is a larger difference in the observed response between 90 and

120°C. This suggests that there is a significant effect on mechanical properties at temperatures between 90 to 120°C for the homopolymer PP filaments as discussed before.
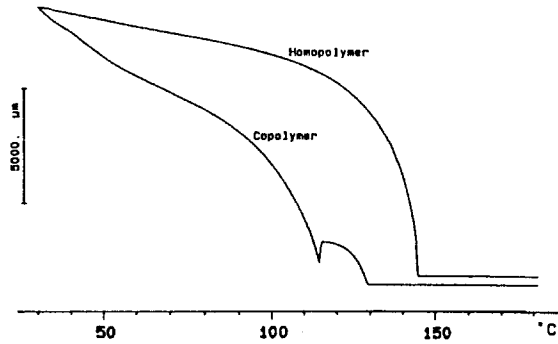
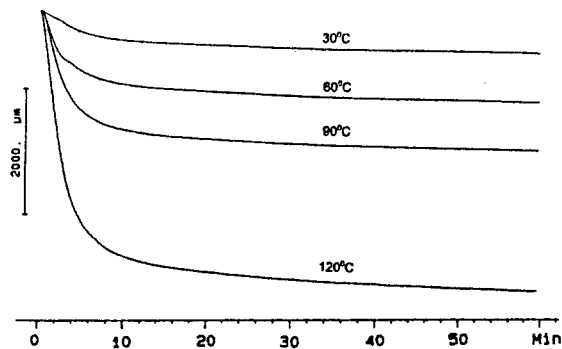Fig. 5 TMA scans of the homopolymer and copolymer filaments

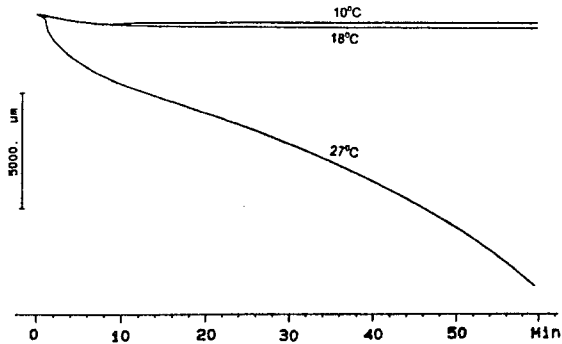Fig. 6 Isothermal TMA scans at different temperatures for a PP filament

Fig. 7 Isothermal TMA scans for different PP filaments at 30°C

Figure 6 shows the TMA scans of filament samples produced at same through-put and different primary air temperature at a constant heating temperature of 30°C, and a constant tension of 9.0 MPa for 60 min. Creep of the filament of 10°C quench air is slightly lower. TMA scans of filament samples with same primary air temperature but different throughput, at a constant heating temperature of 30°C, and a constant tension of 9.0 MPa for 60 min as shown in Fig. 7. The creep of the filaments increased as the throughput increased. The observed difference in flow behavior of filaments is due to the difference in structure of these filaments. The smallest creep was observed for the filaments of high birefringence. It is important to note that even at low temperatures, the filaments that do not have well developed morphology deform considerably under stress.

Conclusion

The study showed that the primary air temperature, throughput and thermal his-tory have a strong influence on the structure and properties of both the filaments (before bonding) and the nonwovens (after bonding). As the primary air tempera-ture and throughput decreased, there was a tendency for decrease in filament di-ameter. The decrease in filament diameter was accompanied by a simultaneous in-crease in their crystallinity, birefringence and thermal stability. The copolymer fila-ments showed lower crystallinity and orientation for all the corresponding process-ing conditions. The lower melting temperature helps in processing these materials at lower temperatures leading to energy savings. Thermomechanical analysis showed that filaments from low primary air temperature had better mechanical properties as well as thermal stability. With well developed morphology, the defor-mability of the filaments decreased during subsequent thermomechanical operation.

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References

1 S. R. Malkan and L. C. Wadsworth, Int. Nonwovens Bull., 3 (1992) 24.
2 G. S. Bhat, D. Zhang, S. R. Malkan and L. C. Wadsworth, Proc. of the Fourth Annual TAN-DEC Conference, Knoxville, TN, Nov. 14–16, 1994.
3 S. Misra, J. E. Spruiell and G. C. Richeson, INDA J. Nonwovens Res., 5 (1993) 13.
4 D Zhang, Fundamental Investigation of Spunbonding Process, Ph.D. Dissertation, The Uni-versity of Tennessee, Knoxville, 1995.
5 S. R. Malkan, L. C. Wadsworth and C. Davey, Proc. of Third Annual TANDEC Conference, Knoxville, Tennessee, Nov. 1993.
6 S. R. Malkan, L. C. Wadsworth and C. Davey, Int. Nonwovens J., 6 (1992) 42.
7 W. N. Taylor, Jr. and E. S. Clark, Polym. Engin. Sci., 18 (1978) 518.