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Development of structure and properties during spunbonding of propylene polymers

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Abstract

The production of a spunbond fabric involves the interrelation of numerous process variables. The development of fiber morphology is influenced and controlled by the extrusion variables. Fabric properties are greatly influenced by the properties of the filaments composing them, web structure and the bonding conditions. Understanding the relation between the process parameters and the properties is of utmost importance since the desired properties of the end product can be predicted and engineered by adjusting the process conditions. Two types of polypropylenes (PP) prepared using different catalyst systems were processed on our spunbond pilot line. Filament samples collected before bonding and the bonded fabrics were analyzed for aspects of structure and properties such as crystallinity, birefringence, density, thermo-mechanical stability and tensile properties. Structure and properties of the fibers produced from metallocene catalyzed PP were much better than that of the Ziegler Natta (ZN) catalyzed PP.

Keywords: Polypropylene; Differential scanning calorimetry (DSC); Scanning electron microscopy; TMA (thermo mechanical analysis); Fibers

1. Introduction

Continuous filament nonwovens are produced by spunbonding and meltblowing by the direct lay processes, wherein webs are made directly from fibers as they are being spun from molten plastics [1]. In spunbonding, the fabrics are produced by depositing extruded spun filaments onto a collecting belt followed by bonding the fibers. Spinning is comparable to the production of continuous filament yarns and uses similar extruder conditions for a given process. The formed filaments are quenched by cool air and then attenuated either mechanically or pneumatically depending on the process. The filaments are then deposited on a moving belt as a web, which is subsequently bonded, either mechanically, thermally or chemically. Thermal point bonding is mostly used for webs of low to medium weight [2].

There are several process variables that have impact on the structure and properties of the fibers, and subsequently on the structure and properties of the final fabric [3]. The entire process is a continuous one and hence, changes in process variables are complex to the extent that, changing one necessitates other process changes. Thermal bonding of the filaments is an inherent part of the process and is affected by the varying spinning conditions. Bonding conditions will have to be modified to accommodate different conditions of spinning. For example, increasing the rate of polymer throughput when producing a fabric with a certain basis weight necessitates an increased line speed. The change in throughput causes change in filament diameter, quench rate, internal morphology and lay-down pattern. One of the most important characteristics is the filament diameter, which is affected by the melt

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temperature, melt throughput, quench air temperature and, of course, the suction air. An experimental investigation within the most commonly used range of quench air temperatures showed a tendency for the fiber diameter to decrease with decrease in quench air temperature. Earlier studies showed that the decrease in filament diameter was accompanied by a simultaneous increase in crystallinity, birefringence, tensile strength, initial modulus, thermal stability and density [4–7]. These results are attributed to the spinline stress effects. Similar trends were observed for a polypropylene (PP) copolymer as well [8,9].

Metallocene-based isotactic propylene polymers have been widely studied since their commercialization in 1995. In comparison with conventional Ziegler Natta (ZN) systems, metallocene based catalysts offer higher versatility and flexibility both for the synthesis and the control of structures of polyolefins due to their identical reactive sites [10]. Other advantages are high strength to weight ratio, narrow molecular weight distribution, lower melting point and cost effectiveness. There are significant differences between the two polymers with respect to melt spinning behavior, fabrication process as well as to the properties of the end products.

In thermal point bonding, commercially the most commonly used technique, fiber-to-fiber fusion is accomplished by temperature and pressure. Both the strength and elongation of the fabric increase with bonding temperature and then decrease after an optimal value. The optimum bonding temperature depends on fiber morphology and the web basis weight. Web thickness or basis weight has an effect on bonding as the heat transfer is affected by the thickness/mass. The choice of bonding conditions will have to consider these factors to produce fabrics with optimum properties. In this article, a summary of evolution of structure and properties during the formation of filaments and the consequences on the thermal calendering, in a spunbonding process, is reported.

2. Experimental details

2.1. Processing

Samples were produced at the Textiles and Nonwovens Development Center (TANDEC) of the University of Tennessee, Knoxville using the Reicofil® spunbonding line [5]. Polypropylene polymers with melt flow rates of about 35 dl/g, supplied by ExxonMobil were used. The samples were produced by changing three process variables, viz. polymer throughput rate, web basis weight and bonding temperature. Each variable was increased in several steps to obtain a broad range of process conditions. Other process conditions for each sample were chosen based on suggestions made by the machine manufacturer. Airflow was increased with increase in throughput and calender pressure was increased with increase in web basis weight.

2.2. Characterization

Filament diameter was measured by optical microscopy. Birefringence was computed by the retardation technique using an optical microscope with a compensator. An average of 30 readings is reported. Crystallinity was measured using the differential scanning calorimetry (DSC). DSC scans were done at a rate of 20 °C/min using the Mettler DSC 25. Crystallite sizes were measured by the wide angle X-ray diffraction method using the Rigaku Geigerflex diffractometer in reflection mode. The Phillips flat plate X-ray diffractometer was employed to obtain X-ray photographs. Samples were prepared with the filaments placed parallel on a sample holder. The sample was exposed to X-rays of wavelength 1.54183 Å with an exposure time of 6 h. Thermo-mechanical analysis was carried out using the Mettler TMA 40 at a scanning rate of 10 °C/min.

Tensile testing of the filaments was done with a bundle of five filaments at a gauge length of 5.08 cm and a cross-head speed of 5.08 cm/min using a united tensile tester. Fabric samples were tested with a gauge length of 12.7 cm and a cross-head speed of 12.7 cm/min. A Hitachi S-3000N environmental microscope was used to obtain scanning electron microscopy (SEM) pictures of fabrics.

3. Results and discussion

The structure and properties of the znPP filament samples collected before bonding are shown in Table 1. The diameters of the filaments with increasing throughputs are almost the same. To maintain the fiber

Table 1
Structure and properties of the znPP filaments.

Throughput (g/hole per min)	Filament diameter ($\times 10^{-6}$ m)	Density	Crystallinity (%; by DSC)	Crystallite size (Å)	Birefringence ($\times 10^{-3}$)
0.15	19.3	0.8923	42.3	43	16.6
0.25	17.4	0.8928	43.6	65	22.3
0.35	17.7	0.8928	43.6	66	23.0
0.43	18.4	0.8971	43.9	86	22.0

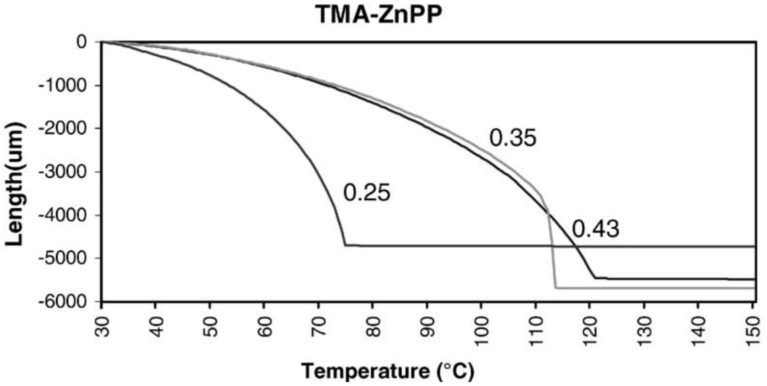


Fig. 1. TMA scans of znPP fiber produced at different throughputs.

diameters within a small range, airflow was adjusted corresponding to throughput, so that there was higher air provided at increasing throughputs. Hence, there is an increasingly higher draw force with increase in throughput. This higher extent of draw leads to improvements in filament morphology. As it is evident from the X-ray and birefringence data, with increase in throughput, there is an increase in crystallinity and orientation. Consequently, the filament becomes thermo-mechanically more stable as shown by the TMA scans (Fig. 1).

Metallocene PP also shows a similar trend with change in processing conditions as far as the morphology development is concerned (Table 2). However, actual values are quite different with both crystallinity and birefringence values being lower than that of the znPP counterparts. The TMA scans also show a difference, with the mPP deforming rather easily or at relatively lower temperatures (Fig. 2). The deformation of the mPP at lower temperature is probably due to lower melting temperature of the polymer. As can be seen from the DSC scans (Fig. 3), mPP has a melting temperature 10–15 °C lower than that of znPP.

A comparison of the tensile properties of the two sets of filaments and their crystallinity values are shown in Table 3. For all the spinning conditions, mPP filaments had much higher strength and lower breaking elongation. The crystallinity of the mPP

Table 2
Structure and properties of the mPP filaments

Throughput (g/hole per min)	Filament diameter ($\times 10^{-6}$ m)	Crystallinity (%; by DSC)	Birefringence ($\times 10^{-3}$)
0.24	17.7	33.3	16.7
0.35	18.1	34.2	18.5
0.43	18.2	35.6	20.5

Table 3
Comparison of mPP and znPP Filaments

Throughput (ghm)	Peak strength (g/Tex)		Peak extension (%)		Crystallinity (%)	
	mPP	znPP	mPP	znPP	mPP	znPP
0.24	34.56	24.0	162	312	33.29	43.6
0.35	45.34	23.7	133	297	34.15	43.6
0.43	67.38	25.2	120	296	35.58	43.9

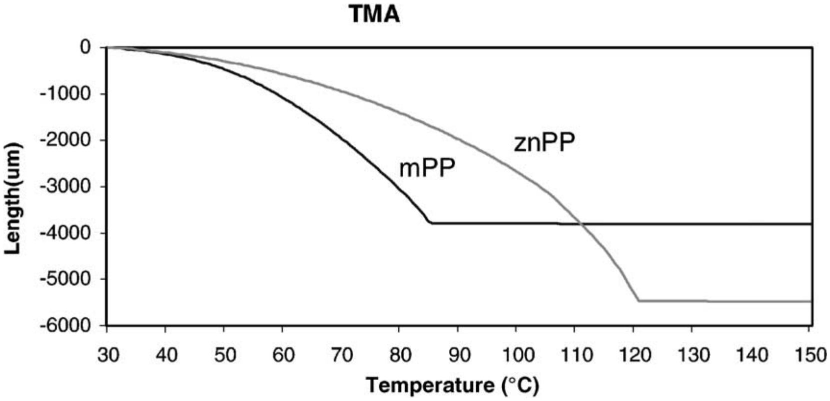


Fig. 2. TMA scans of mPP and znPP polymers.

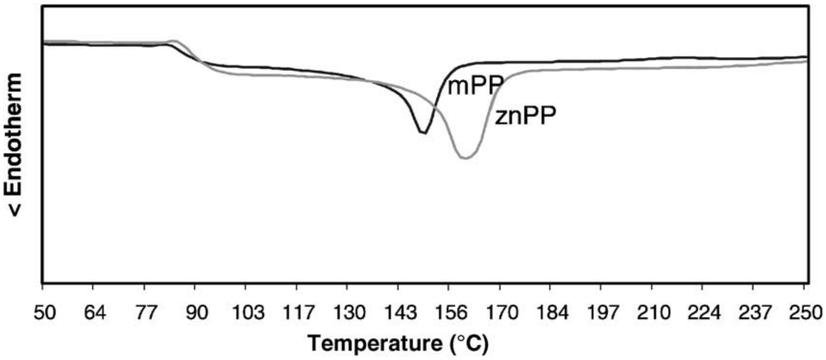


Fig. 3. DSC scans of mPP and znPP polymers.

fibers was consistently lower by 8–10%. Thus, mPP fibers, although appear to have less developed morphology, the tensile properties reflect that of a fiber with better crystallinity and orientation.

The tensile properties of the bonded fabrics for the two polymers are compared in Fig. 4. It is obvious that with the metallocene polymer, higher strength is realized at a relatively lower bonding temperature. SEM photographs (Fig. 5) clearly show that in the case of mPP there is better melting of fiber surface with the formation of good bond due to sufficient polymer flow. Also, the strength of the fabrics increases with increase in bonding temperature for both the cases. The strength values are supposed to drop off after reaching the maximum value under certain optimum bonding temperature [1]. Whereas the znPP webs

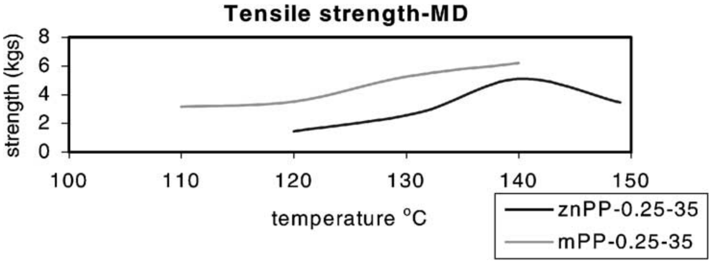
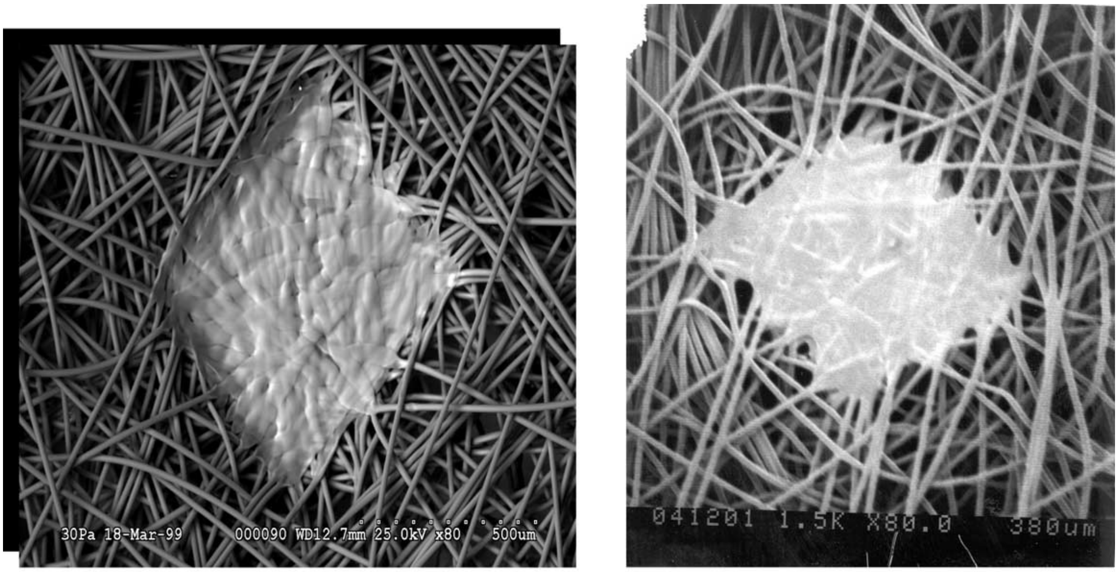


Fig. 4. Tensile strengths of bonded webs from mPP and znPP polymers.



(A) (B)

Fig. 5. SEM photographs of znPP (A) and mPP (B) webs showing the bond points.

show a decrease in strength after a bonding temperature of 140 °C, mPP shows high strength values even at that temperature, despite the fact that mPP has a much lower melting temperature. This observation is important as it suggests that the temperature window available for bonding is much winder in the case of mPP.

4. Conclusions

The filament structure and properties are influenced by the processing conditions. As a result, thermomechanical stability is different. Fibers that show higher thermal stability do not bond as easily as the others do. As a result, fibers with higher thermal stability require higher bonding temperatures as well. For both the polymers, the structure changed with processing conditions. For corresponding process conditions and filament diameters, mPP resulted in relatively lower crystallinity and birefringence. However, in contrary to what one would expect based on structural parameters, the mPP filaments had higher tensile strength and lower breaking elongation than the znPP fibers. This difference is attributed to the differences in molecular structures and rheology. The mPP filaments also resulted in better tensile properties of the bonded fabrics due to more efficient bonding. Also, range of bonding temperatures that could be used for mPP appeared to be much wider than that for znPP as far as the tensile properties are concerned. Thus mPP seems to have an obvious advantage over znPP in the spunbonding process.

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