Effect of the Blending of Low isotacticity Component on Properties of isotactic Polypropylene Fibers Prepared by High-speed Melt Spinning Process

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ABSTRACT

Polypropylene blends were prepared by blending low isotacticity PP (LMPP) of different levels of stereo-regularity into ordinary isotactic PP (IPP). When high-speed melt spinning process was applied, the PP blends exhibited higher spinnability than the IPP irrespective of the stereo-regularity and amount of the LMPP. It was speculated that the improvement of spinnability originated from the suppression of crystallization in the spinning process, which was caused by the presence of low isotacticity PP. Higher-order structure and mechanical properties of the high-speed spun fibers were also investigated.

Keywords: Melt spinning, Spinnability, Polypropylene, Low isotacticity

1. Introduction

Polypropylenes (PP) of good spinnability are often used for the production of fine denier fibers. The fine denier PP fibers and the nonwoven fabrics consisting of such fibers have various applications such as diapers, sanitary items, hygiene products, clothes, packaging mediums etc.

Vast amount of researches have been conducted on the production of fibers and nonwoven fabrics of high isotacticity polypropylene (IPP). It has been reported also that the softness of PP nonwoven fabrics can be improved by lowering crystallinity by adding low isotacticity PP (LMPP). In addition to the improvement of softness, spinnability of IPP was found to be improved by blending LMPP into IPP [1][2].

On the other hand, demand for PP nonwovens with combined characteristics of fine denier and high tensile strength is increasing recently for the reduction of the weight of fabrics. For this reason, with the aim of producing fine denier and high strength spunbonded nonwoven fabrics, effects of the composition and stereo-regularity of LMPP component in high-speed melt spinning of IPP/LMPP blends were investigated in this study.

2. Experimental

2-1. Materials

High isotacticity PP (Prime Polymer Co., Ltd. Y2000GP) and two types of low isotacticity PPs, LMPP-S and LMPP-L (Idemitsu Kosan Co., Ltd. L-MODU^{TM} S901 and X901L), which were polymerized by a double cross-linked metallocene catalyst, were used in this study. Properties of these polymers are listed in Table 1. Melting points of LMPP-S and LMPP-L are much lower than that of IPP. This means that the LMPPs have lower isotacticity than IPP. Difference of melting point also suggests that the isotacticity of LMPP-L is lower than that of LMPP-S.

Table 1: Properties of IPP and LMPP

Sample Code	Mw	Mw/Mn	Tm (^{o}C)
IPP	242,000	5.0	165
LMPP-S	137,000	2.1	76
LMPP-L	128,000	2.2	46

Five types of polymers, i.e. IPP-100%, S-10% (IPP/LMPP-S=90/10wt%), S-20% (IPP/

LMPP-S=80/20wt%), L-5% (IPP/LMPP-L=95/ 5wt%) and L-10% (IPP/LMPP-L=90/10wt%) were applied for the melt spinning experiment.

2-2. Melt spinning

Extrusion of the polymers was performed using a 25 mmϕ single screw extruder equipped with a gear pump. The spinneret has twenty spinning holes of 0.6 mm diameter. Extrusion temperature and throughput rate were set at 240 °C and 1.0 g/min per hole, respectively. Fibers were taken-up using a winder placed at 320 cm below the spinneret. Spinning velocity was increased with an interval of 500 m/min to the attainable highest speed.

2-3. Birefringence measurement

Birefringence of as-spun fibers was analyzed through the measurements of fiber diameter and optical retardation using a polarizing microscope.

2-4. Tensile Test

Tensile behavior of the as-spun fibers was obtained using a tensile testing machine. The gauge length was 50 mm and the tensile speed was 50 mm/min. Tensile modulus and tensile strength were analyzed from the obtained stress-strain curves.

3. Results and Discussion

3-1. Effect of the blending LMPP-S

Maximum spinning velocity and diameter of corresponding as-spun fibers are shown in Table 2. Attainable maximum spinning velocity increased from 3500 m/min to 6000 m/min as LMPP-S content increased. Especially, S-20% showed significantly higher spinnability in comparison with the IPP-100%.

It was speculated that the improvement of spinnablity is originated from the suppression of crystallization caused by the presence of low stereo-regularity component. Consequently, fine diameter fibers were obtained by blending 20 wt% of LMPP-S into IPP.

Table 2: Maximum spinning velocity and fiber diameter of various PP blends

Sample Code	Maximum spinning Velocity (m/min)	Fiber Diameter (μm)
IPP-100%	3500	21.5
S-10%	4000	19.0
S-20%	6000	15.3

Dependence of birefringence of as-spun fibers on spinning velocity is shown in Fig.1. Birefringence of S-10% and S-20% was similar to that of IPP-100% at the spinning velocity of 3500 m/min, and increased further with the increase of spinning velocity. Improvement of the molecular orientation is attributable to the increase of spin-line stress at higher speeds.

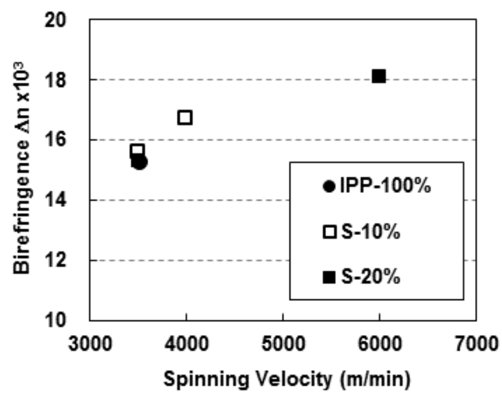

Fig.1: Dependence of birefringence of as-spun fibers on spinning velocity.

Dependence of tensile modulus of as-spun fibers on spinning velocity is shown in Fig.2. At the spinning velocity of 3500 m/min, tensile modulus of as-spun fibers decreased with the increase of the content of LMPP-S. In general, tensile modulus of as-spun fibers is affected by both molecular orientation and crystallinity in crystalline polymers. As birefringence of these fibers were similar, lower crystallinity of LMPP-S is considered to be the origin of lower tensile modulus. Tensile modulus of S-10% and S-20% increased with increasing spinning velocity. This result is due to the improvement of molecular orientation at higher velocities.

Dependence of tensile strength of as-spun fibers on spinning velocity is shown in Fig.3. At the same spinning velocity of 3500 m/min, tensile strength of as-spun fibers decreased with increasing of LMPP-S content. On the other hand, tensile strength increased with increasing spinning velocity. Especially, S-20% prepared at

6000 m/min showed significantly higher tensile strength than the IPP-100%.

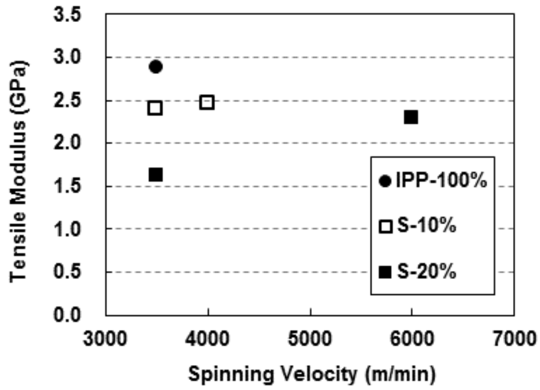

Fig.2: Dependence of tensile modulus of as-spun fibers on spinning velocity.

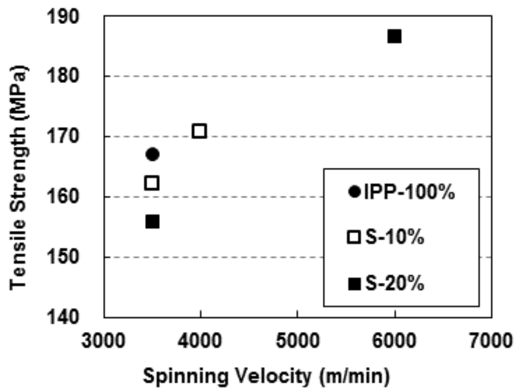

Fig.3: Dependence of tensile strength of as-spun fibers on spinning velocity.

3-2. Effect of the stereo-regularity of low isotacticity polypropylene

As described above, spinnability of IPP was improved by blending LMPP-S. With the expectation of further improvement of the attainable maximum take-up velocity, effect of the stereo-regularity of LMPP on spinnability and tensile properties of as-spun fibers was investigated by blending the LMPP of lower isotacticity (LMPP-L) into IPP. Maximum spinning velocity and diameter of corresponding as-spun fibers are shown in Table 3.

Even though the contents of LMPP-S and LMPP-L were the same, maximum spinning velocity of L-10% was higher than that of S-10%. This result may suggest that the improvement of spinnability was due to the decrease of the stereo-regularity of LMPP.

Table 3: Maximum spinning velocity and fiber diameter of various PP blends

Sample Code	Maximum Spinning Velocity (m/min)	Fiber Diameter (μm)
IPP-100%	3500	21.5
S-10%	4000	19.0
L-10%	4500	17.7

Dependence of tensile modulus of as-spun fibers on spinning velocity is shown in Fig.4. At the same spinning velocity of 3500 m/min, tensile modulus of as-spun fibers decreased with the decrease of the stereo-regularity of low isotacticity PP. This result is probably due to the lower crystallinity of IPP/LMPP-L fibers in comparison with that of IPP/LMPP-S fibers.

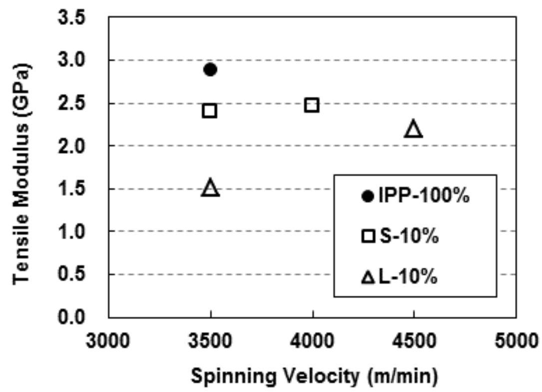

Fig.4: Dependence of tensile modulus of as-spun fibers on spinning velocity.

Dependence of tensile strength of as-spun fibers on spinning velocity is shown in Fig.5. Tensile strength of S-10% and L-10% were similar at 3500 m/min. In addition, S-10% and L-10% as-spun fibers at maximum spinning velocity showed similar values, which was higher than the maximum tensile strength of the IPP-100% fibers.

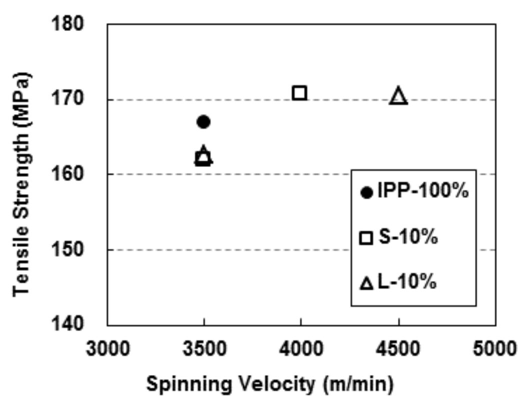

Fig.5: Dependence of tensile strength of as-spun fibers on spinning velocity.

3-3. Further improvement of spinnability and tensile properties by blending smaller amount of lower isotacticity polypropylene

As IPP/LMPP-L blend showed higher spinnability in comparison with IPP/ LMPP-S blends, we studied the effect of the reduction of the amount of LMPP-L. It was found that the IPP/LMPP-L blend kept its high spinnability even when the LMPP-L content was decreased to 5 %, and the maximum take-up velocity of 4500 m/min (fiber diameter 18.2 μm) was attained.

Dependence of tensile strength of as-spun fibers on LMPP content at the attainable highest spinning velocities is shown in Fig.6. L-5% showed significantly higher tensile strength in comparison with IPP-100%, S-10%, S-20% and L-10%. In other words, it can be said that high spinnability and high tensile strength could be attained simultaneously by blending only a small amount of LMPP of extremely low stereo-regularity.

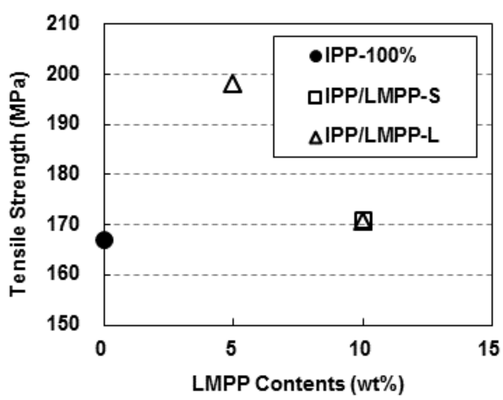

Fig.5: Dependence of tensile strength of as-spun fibers on LMPP contents at attainable highest spinning velocity.

4. Conclusions

(1) Spinnability of IPP was improved by blending LMPP-S. Spinnability was further improved with the increase of the content of LMPP-S, and at the weight fraction of 20%, maximum spinning velocity reached 6000 m/min, at which as-spun fibers of significantly high tensile strength was obtained.

(2) Spinnability of IPP was further improved by blending LMPP of lower stereo-regularity, LMPP-L.

(3) High spinnability and high tensile strength of as-spun fibers could be attained simultaneously when the content of LMPP-L was reduced to 5%.

5. References

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