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Effect of Relaxation Heat Setting at Various Temperatures on Molecular Orientation in Polypropylene Fiber

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Abstract. Commercially available polypropylene fiber (PPF) samples with relaxation heat setting for 30 minutes in a drying oven at various temperatures (room temperature, 90 °C, 100 °C, 110 °C, 120 °C, 130 °C, 140 °C, 150 °C, respectively.) were prepared for measurement of their sonic velocity, orientation degree, orientation angle and modulus. According to the obtained data for the PPF molecular orientation before and after the relaxation heat setting, it is found that, with the increasing of relaxation heat setting temperature, the sonic velocity in PPF, orientation degree and modulus decreased, while the orientation angle increased. The result may be helpful to choose proper working temperature for PP hernia patch fabrication.

1. Introduction

Polypropylene fiber (PPF) has been extensively used in the manufacture of synthetic hernia meshes [1]. It is necessary and interesting to find the corresponding detailed process condition. In this preliminary study, we aimed to gain a better understanding of the molecular orientation of a commercially available polypropylene filament. So that it may be of benefit to choose proper working temperature for PP hernia patch fabrication.

2. Experimental

2.1. Starting Materials

Commercially available polypropylene fiber (PPF) was derived from Nantong NTEC Monofilament Technology Co. Ltd., China. For the PPF, diameter $d = 0.16$ mm, density $\rho = 0.91$ g·cm⁻³, linear density $x = 18.3$ tex i.e., =165 den.

2.2. Preparation of PPF Samples

PPF samples with relaxation heat setting for 30 minutes in a drying oven at various temperatures (room temperature, 90 °C, 100 °C, 110 °C, 120 °C, 130 °C, 140 °C, 150 °C, respectively.) were denoted as starting PPF, 90 °C PPF, 100 °C PPF, 110 °C PPF, 120 °C PPF, 130 °C PPF, 140 °C PPF, 150 °C PPF, respectively. All data are the average from 5 samples by the machine.

2.3. Measurement of Molecular Orientation in PPF Samples

A sonic velocity orientation degree, angle and modulus tester for fibers (model SCY-IV, Shanghai Donghua Kaili New Material Technology Co. Ltd., China) was employed. The preload of 20 g was loaded on each PPF sample with a linear density of 165 den, so the pretension was 0.12 gf/d. The



value of C_u (sonic velocity of completely unoriented fiber) for PPF is 1.45 km/s. As shown in Fig. 1, a PPF sample (line in red) tightened as a pretension of 0.12 gf/d was applied by a counterweight of 20 g.

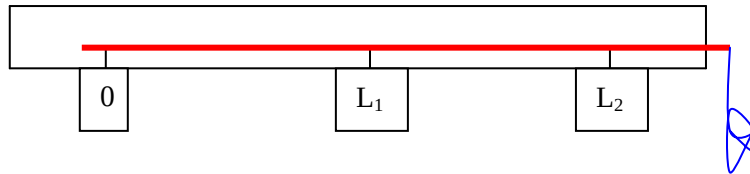


Figure 1. Schematic for the sonic velocity orientation degree, angle and modulus tester for fibers.

Firstly, sound propagation time in PPF samples from 0 to L_1 was measured and denoted as T_{L1} (including the delay time ΔT caused by the machine itself); Secondly, sound propagation time in PPF samples from 0 to L_2 was measured and denoted as T_{L2} (including the delay time ΔT caused by the machine itself). When $L_2 = 2 L_1$ (for example, $L_2/L_1 = 10 \text{ cm}/5 \text{ cm}$, $20 \text{ cm}/10 \text{ cm}$, $30 \text{ cm}/15 \text{ cm}$, $40 \text{ cm}/20 \text{ cm}$, respectively.), $\Delta T = 2T_{L1} - T_{L2}$. Then, in PPF samples, the exact sonic velocity $C = L/(T_L - \Delta T)$, where the unit of C is km/s, the unit of T_L and ΔT is μs , and the unit of L is m.

The sonic velocity orientation degree, orientation angle and modulus for PPF samples were then calculated by the following formula:

(1) The Moseley formula [2]: $F = 1 - (C_u/C)^2$, where F is orientation factor, or orientation degree, without any unit; the unit for C_u and C is km/s.

(2) The Hermans formula [3]: $F = [(3\cos^2\theta) - 1]/2$, where F is orientation factor, or orientation degree, without any unit; the unit for orientation angle is ($^\circ$).

(3) The modulus $E = 11.3C^2$, where E is the modulus (MPa) for PPF, ρ is the density (910 kg/m^3) for MPP fiber, and C is the sonic velocity (km/s) tested in PPF samples. For more simplification, $E = 11.3C^2$ (The unit of E is gf/d, and the unit of C is km/s).

3. Results and Discussion

3.1. Effect of Relaxation Heat Setting Temperature on PPF Molecular Orientation

The sonic velocity (C , km/s) in PPF, orientation degree (F_s), modulus (E , gf/d) and orientation angle (θ , $^\circ$) under a pretension of 0.12 gf/d are shown in Tab. 1. According to the obtained data for the PPF molecular orientation before and after the relaxation heat setting, it is found that, with the increasing of relaxation heat setting temperature, the sonic velocity in PPF, orientation degree and modulus decrease, while the orientation angle increases.

Table 1. Molecular orientation data measured by sonic velocity method for PPF samples under a pretension of 0.12 gf/d.

	$L_1/L_2(\text{cm/cm})$	$T_{L2}(\mu\text{s})$	$\Delta T(\mu\text{s})$	$C(\text{km/s})$	F_s	$\theta(^\circ)$	$E(\text{gf/d})$
Starting PPF	20/40	319.0	213.4	3.79	0.85	18.2	162.1
90 °C PPF	20/40	318.0	208.4	3.65	0.84	18.9	150.5
100 °C PPF	20/40	320.8	211.6	3.66	0.84	18.9	151.6
110 °C PPF	20/40	322.0	208.8	3.53	0.83	19.6	141.1
120 °C PPF	20/40	323.0	210.2	3.55	0.83	19.5	142.1
130 °C PPF	20/40	328.6	214.2	3.50	0.83	19.8	138.1
140 °C PPF	20/40	336.8	213.6	3.25	0.80	21.4	119.1
150 °C PPF	20/40	353.2	214.4	2.88	0.75	24.3	93.8

For example, the effect of relaxation heat setting temperature on PPF molecular orientation degree is shown in Fig. 2. Between 110 °C and 130 °C, when just below the PP softening point (~ 140 °C), it may be the proper working temperature for PPF postprocessing and fabrication in mesh form.

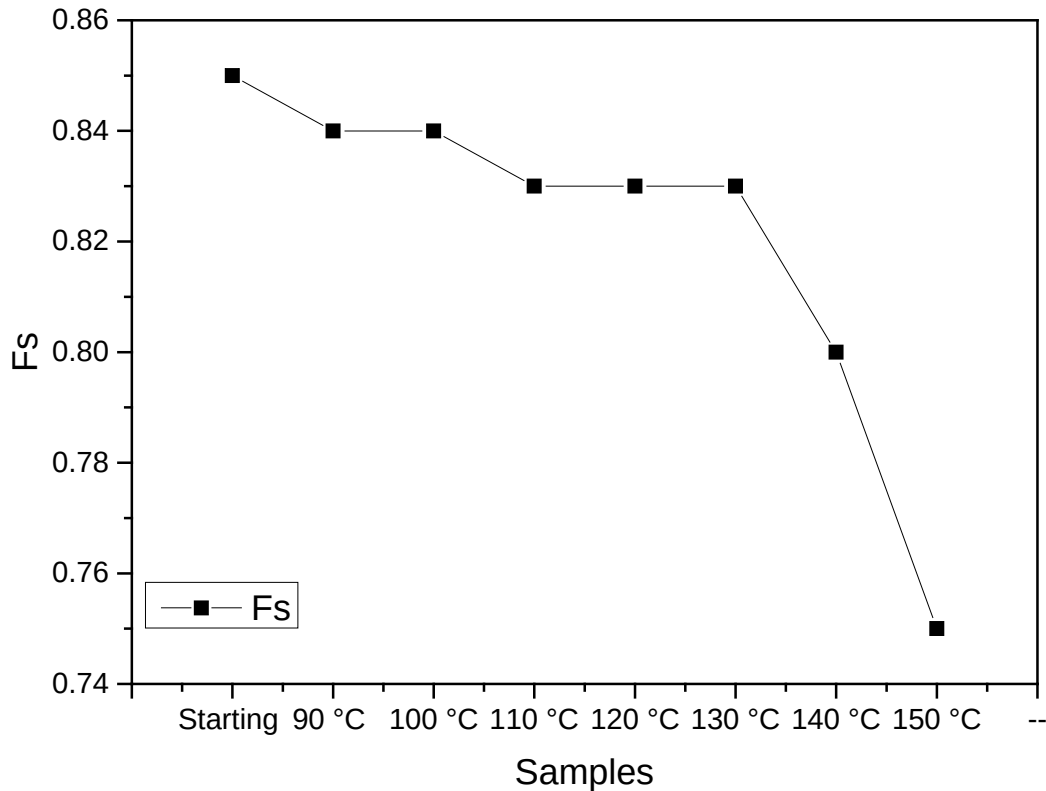


Figure 2. Effect of relaxation heat setting temperature on PPF molecular orientation degree under a pretension of 0.12 gf/d.

3.2. Effect of Pretension on PPF Molecular Orientation at Same Temperature

The sonic velocity (C , km/s) in PPF, orientation degree (F_s), modulus (E , gf/d) and orientation angle (θ , °) under a pretension of 0.18 gf/d are shown in Tab. 2. Similarly, according to the obtained data for the PPF molecular orientation before and after the relaxation heat setting, it is found that, with the increasing of relaxation heat setting temperature, the sonic velocity in PPF, orientation degree and modulus decrease, while the orientation angle increases.

Table 2. Molecular orientation data measured by sonic velocity method for PPF samples under a pretension of 0.18 gf/d.

	L_1/L_2 (cm/cm)	T_{L2} (μ s)	ΔT (μ s)	C (km/s)	F_s	θ (°)	E (gf/d)
Starting PPF	20/40	318.8	213.8	3.83	0.86	18.0	165.9
90 °C PPF	20/40	318.6	208.2	3.62	0.84	19.1	148.3
100 °C PPF	20/40	320.2	210.2	3.64	0.84	19.0	149.4
110 °C PPF	20/40	323.8	211.8	3.57	0.84	19.4	144.1
120 °C PPF	20/40	323.8	210.4	3.55	0.83	19.5	142.1
130 °C PPF	20/40	328.2	209.8	3.38	0.82	20.5	129.0
140 °C PPF	20/40	337.0	212.6	3.22	0.80	21.6	116.8
150 °C PPF	20/40	354.4	213.6	2.84	0.74	24.6	91.2

For example, the effect of relaxation heat setting temperature on the sonic velocity in PPF under a pretension of 0.12 gf/d and 0.18 gf/d is shown in Fig. 3. Between 110 °C and 130 °C, when just below the PP softening point (~ 140 °C), it may be the proper working temperature for PPF postprocessing and fabrication in mesh form. Moreover, when the value of the pretension is between 0.1 to 0.2 g/d, it is proper to measure the molecular orientation.

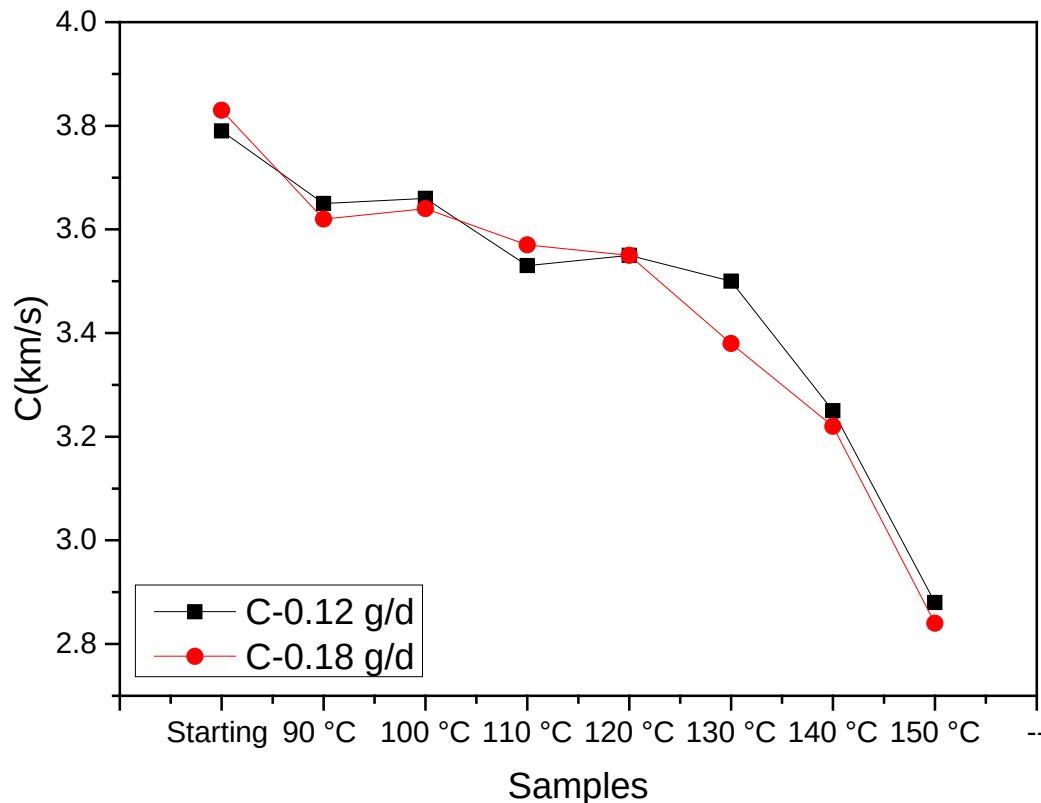


Figure 3. Effect of relaxation heat setting temperature on the sonic velocity in PPF under a pretension of 0.12 gf/d and 0.18 gf/d.

4. Conclusions

The data for the PPF molecular orientation before and after the relaxation heat setting showed that, with the increasing of relaxation heat setting temperature, the sonic velocity in PPF, orientation degree and modulus decreased, while the orientation angle increased.

5. Acknowledgements

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6. References

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