

# PHYSICAL PROPERTIES OF HIGHLY-ORIENTED POLYVINYLALCOHOL FIBER

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## 1. INTRODUCTION

Polyvinylalcohol (PVA) is a crystalline polymer, capable of hydrogen bonding, which makes the polymer useful for many industrial applications: production of high strength fibers, medical substitutes, adhesives, and so on[1]. Specially, among fiber-forming polymers, PVA has the second highest crystal modulus and extreme strength after polyethylene because the polymer chain can take a planar zig-zag conformation. The high degree of crystallinity and excellent alkali resistance make PVA fiber appropriate for reinforcement for cement and substitute for cancer-causing asbestos. In general, the hydroxyl groups of PVA molecules is known to be of help to the mechanical properties of PVA. However, they may deteriorate mechanical performance of PVA fiber because strong hydrogen bonding through hydroxyl groups can interrupt orientation of polymer molecules during the drawing or annealing stage. It is hence recommended that the strong hydrogen bonding and rigid crystal have to be eliminated to prepare high modulus/strength PVA fiber through effective drawing[2-9].

In this study, the microstructure and mechanical properties of PVA fiber were investigated in terms of spinning conditions, drawing, and heat treatment.

## 2. EXPERIMENTAL

PVA fibers were prepared by dry jet-wet spinning. The molecular weight of PVA was  $7.5 \times 10^5$ , whose solutions in a mixture of 80/20 dimethylsulfoxide/water seemed to form a gel. The solvent included in the prepared gel fibers was entirely extracted by wet drawing (3.5 times) and immersing in methanol for 48 hrs, and followed by drying for 24 hrs at 90 °C. The resultant PVA fibers were preheated for 30 sec at 150 °C to prevent loose during main heat-treatment process. Each fiber sample for

heat treatment experiments was made up of 120 filaments, whose thickness was ca 4.5 denier

The crystallization and orientation of fibers were examined by wide-angle X-ray scattering (WAXS) diffractometer (MX18, MAC Science Co.). The diffraction pattern was obtained at the scanning rate of 1 °/min at 40 kV and 300 mA. To compare the ratio of diffraction intensities, the samples was made uniform to a thickness of 0.5 mm and width of 10 mm.

The mechanical properties of monofilament PVA fibers were measured by Instron tensile tester (Instron model 4201). The crosshead speed was 10 mm/min, and the gauge length was 25 mm.

### 3. RESULTS AND DISCUSSION

Generally, the heat-treatment is a process designed to improve the hot-water resistance and the mechanical properties of PVA. The most important change taking place in the heat-treatment is the increase of the crystallinity of PVA through removal of residual solvent and formation of new hydrogen bonds between the polymer chains. Time, temperature, and tension level proved to be factors affecting fiber properties in the heat-treatment.

The X-ray diffraction result of PVA fibers annealed at 230 °C for 15 minutes at applied stress level of 0.15 g/d is given in Table 1. This table suggests that the heat-treated fiber is highly oriented and possesses a high degree of crystallinity.

The effect of mechanical properties of annealed PVA fibers is summarized in Table 2. One can see a high tensile strength of 19.3 g/d and tensile modulus of 400 g/d at some particular combination of annealing conditions.

### REFERENCES

1. M. Shibayama, M Adachi, F. Ikkai, H. Kurokawa, S. Sakurai, and S. Nomura, *Macromolecules*, **26**, 623 (1993).
2. T. Kunugi, T. Kawasumi, and T. Ito, *J. Appl. Polym. Sci.*, **40**, 2101 (1990).
3. S. Matsuzawa, L. Sun, and K. Yamaura, *Kobunshi Ronbunshu*, **48**, 691 (1991).
4. D. T. Grubb and F. R. Kearney, *J. Appl. Polym. Sci.*, **39**, 695 (1990).

5. R. Schellekens and C. Bastiaansen, *J. Appl. Polym. Sci.*, **43**, 2311 (1991).
6. K. S. Hwang, C. A. Lin and C. H. Lin, *J. Appl. Polym. Sci.*, **52**, 1181 (1994).
7. K. Yamaura, T. Tanigami, N. Hayashi, K. I. Kosuda, S. Okuda, Y. Takemura, M. Itoh and S. Matsuzawa, *J. Appl. Polym. Sci.*, **40**, 905 (1990).
8. H. Fujiwara, M. Shibayama, J. H. Chen and S. Nomura, *J. Appl. Polym. Sci.*, **37**, 1403 (1989).
9. W. I. Cha, S. H. Hyon and Y. Ikada, *J. Polym. Sci.: Part B: Polym. Phys.*, **32**, 297(1994).

Table 1. Diffraction angle ( $2\theta$ ), crystal plane( $hkl$ ),  $d$ -value, and diffraction intensity corresponding to crystalline peaks of PVA fiber, annealed for 15 minutes at the stress 0.15 g/d at 230 °C

No of peak	a	b	c	d	e	f	g	h
$2\theta$ ( ° )	11.12	15.98	19.60	22.42	27.56	28.24	32.62	34.36
Crystal plane ( $hkl$ )	(100)	(001)	(101)	(200)	(201)	(-201)	(002)	(10-2)
$d$ -value (Å)	7.950	5.542	4.525	3.962	3.234	3.157	2.743	2.608
Intensity	935	577	9192	2968	268	243	589	192
No of peak	i	j	k	l	m	n	o	p
$2\theta$ ( ° )	38.74	46.46	50.78	35.42	74.76	37.08	40.52	78.32
Crystal plane ( $hkl$ )	(301)	(400)	(103)	(010)	(020)	(110)	(111)	(121)
$d$ -value (Å)	2.323	1.953	1.796	2.532	1.269	2.423	2.224	1.220
Intensity	181	194	148	82	3960	485	289	63

Table 2. Effect of annealing temperature and annealing time on the mechanical properties of PVA fiber

Temp. (°C)	Annealing		Strain (%)	Strength (g/d)	Modulus (g/d)	Tough- ness (g/d)
	Stress (g/d)	Time (min)				
Drawn	-	-	6.8	16.7	305.2	0.62
210	0.15	1	10.2	17.4	370.0	0.91
		5	10.9	17.7	353.3	1.07
		15	10.0	17.8	368.6	1.00
		30	8.2	12.6	341.4	0.57
		60	8.9	11.8	291.9	0.6
		120	8.0	9.2	222.6	0.4
		300	6.8	4.9	164.0	0.24
220	0.15	1	10.57	19.3	392.0	1.15
		5	13.6	19.1	381.5	1.35
		15	10.4	15.3	247.1	0.90
		30	9.3	11.2	208.0	0.57
		60	7.3	8.2	173.5	0.37
		120	6.9	5.9	149.8	0.23
		300	4.8	3.1	90.8	0.07
230	0.15	1	10.3	18.2	408.1	1.01
		5	9.2	15.5	282.3	0.65
		15	6.2	11.7	237.8	0.41
		30	9.3	7.8	149.5	0.42
		60	8.5	6.3	151.4	0.03
		120	6.1	3.3	94.9	0.02
		300	3.1	1.6	50.8	0.003