Influence of the Content of Polymer with Different Molecular Weights in Spinning Solutions on Properties of Acrylic Fibers

A. I. STOYANOV, *Economic Combine Neftochim, Plant Bulana, Bulgaria*

Synopsis

The effect of polymer concentration on the structural mechanical properties of acrylic fibers was investigated. The dope concentration, independent of molecular weight, influences the tenacity, loop tenacity, density, perfection of the structure, and the stability of fibers to repetitive deformation. These data were explained in terms of the processes performed in the coagulating bath and behavior of the protofibers during drawing.

INTRODUCTION

Spinning solutions with polymer concentrations of 10–25% are used in the manufacture of commercial acrylic fibers by the wet-spinning process.[1,2] The polymer concentration of a spinning solution depends on the molecular weight of the polymer and the nature of the solvent.

With an increase in concentration of the polymer (with fixed molecular weight) in the spinning solution, one can improve spinnability,[3] increase tenacity,[4] and reduce porosity in the cross sections of the fibers.[5] An increase in dope concentration leads to a slight decrease in the diffusion coefficient of solvent and nonsolvent.[6] Knudsen[7] observed that increasing dope concentrations (15–25%) improve the homogeneity of the fiber structure by reducing the incidence of large voids, slightly improve the tenacity, and also increase the density.

However, the influence of the dope concentrations of polymers with different molecular weights on the properties of the fibers, such as tenacity, elongation, loop tenacity, stability to repetitive deformation, density, orientation, and perfection of structure, has not been investigated. The purpose of this work was to obtain information on this subject.

EXPERIMENTAL

Preparation of Samples

The polymer used in this study was a copolymer of acrylonitrile containing approximately 6% methyl methacrylate. The molecular weight (specific viscosity of 0.5% solution in dimethylformamide) of the copolymer was varied by the amount of the catalyst (ammonium persulfate and sodium bisulfite) used.

The fibers were prepared by the same process used in the previous investigation.[8] The experimental conditions for preparation of fiber samples are shown in Table I. In all cases, the flow rate through the spinneret was constant.

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TABLE I
Sample Preparation Conditions

Molecular weight[a]	0.65–0.98
Dope concentration	21–32.9
Coagulation bath composition	50% DMF:50% H_2O
Coagulation bath temperature	25°C
Drawing ratio	3.6×
Drying temperature	120–125°C

[a] The polymer molecular weight is expressed as specific viscosity of 0.5% solution in dimethylformamide.

Measurements

The tenacity, the loop tenacity, the elongation, the density, the stability to repetitive deformation, the x-ray orientation, and the perfection of structure were measured by the usual methods.[8]

RESULTS AND DISCUSSION

The tenacity, the elongation, and the loop tenacity changed with dope concentration (Table II). The changes in elongation and loop tenacity are smaller in comparison with the changes in tenacity. These changes are very important in commercial wet spinning and can be attributed to the rheological properties

TABLE II
Effect of Dope Concentration on Fiber Properties[a]

Molecular weight, $\eta_{sp}^{0.5}$	Dope concentration, %	T.S.D. *Sn*, tex	T.E.D., %	L.S.D. *Sn*, tex	Density, g/cm^3	Reduction in tenacity, %	X-Ray orientation, H°	Perfection of structure, B°
1.65	24.0	18.7	37.5	10.3	0.30	34.9	43.4	1.26
	26.0	19.5	38.0	10.8		29.1	43.4	1.20
	30.0	22.0	37.8	11.0	0.31	25.9	42.8	1.16
	31.0	21.9	38.0	11.4	0.34	26.1	42.1	1.14
	32.9	20.6	36.0	10.3		30.1	42.5	1.16
1.74	24.0	19.5	36.8	11.7	0.31	26.6	42.9	1.19
	25.5	20.4	36.8	11.8		24.0	42.0	1.16
	28.0	22.1	37.0	12.2	0.32	21.5	42.0	1.13
	29.9	22.4	36.9	12.1		20.3	40.0	1.10
	31.0	22.4	36.7	11.9	0.34	21.2	41.0	1.10
	31.5	20.3	36.0	11.3		26.8	41.5	1.15
1.90	23.5	21.5	36.0	12.9	0.34	16.5	42.0	1.12
	25.0	22.5	36.0	13.0	0.36	14.1	41.0	1.08
	27.0	23.5	35.3	13.3	0.38	14.3	41.0	1.06
	28.4	22.9	34.8	12.9		17.1	41.6	1.09
	29.1	22.3	34.8	12.3	0.34	21.0	41.2	1.13
1.98	21.0	21.9	35.4	13.8		14.8	39.5	1.09
	22.0	22.8	35.0	14.4	0.39	12.9	40.2	1.05
	23.6	24.8	34.3	14.2		12.9	41.0	1.03
	25.0	24.6	33.5	13.9	0.41	13.2	40.0	1.05
	25.9	23.4	34.0	13.9	0.38	19.1	40.5	1.12

[a] T = tensile; L = loop; E = elongation; S = strength; D = dry.

of the spinning solution, the processes performed in the coagulating bath (especially near the spinneret face), and the behavior of the protofibers (fibers after the coagulating bath) during washing and drawing and after treatments.

If all other factors remain constant, the changes in dope concentration influence the density of the fiber produced, although the change is small. Furthermore, in extreme cases of low or high dope concentration, some protofibers remain on the take-up roll. Wet-spun fiber is involved with the formation of a solid skin which partially regulates the counterdiffusion of solvent and nonsolvent.[9–11] The average residence time of the protofibers in the spinning bath increases with decrease in polymer concentration. This permits formation of the "slowly hardened"[11] protofibers. However, the solidification is incomplete, and this results in filament breakage, because the skin and the fluid core do not support the tension. The average residence time of the protofibers in the spinning bath decreases with increase in dope concentration. The increase in dope concentration causes an increase in viscosity. The hardening of the surface is rapid, causing formation of skin. On the other hand, in the production of fibers with equal fineness, it is necessary to increase the velocity of the take-up roll. Breakage by "slippage" is possible between the solid skin and the fluid core.[11]

Therefore, a very high or a very low polymer concentration increases the frequency of fiber breakage and thus gives rise to a heterogeneous structure of the protofibers.

On the other hand, the effectiveness of drawing is dependent on the structure of the protofibers. The heterogeneous structure of the fibers (for example, at extremely low or high dope concentration) leads to irregular distribution of tension during drawing. In the fiber production by spinning solution with high polymer concentration, the heterogeneous structure is also obtained since there is a decrease in the plasticizing effect of the water, because of an increase in velocity of the take-up rolls. The dope concentration does not influence the crystalline orientation (Table II). However, it does influence the perfection of the structure. There is correlation between the density, the perfection of the structure, the tenacity, and the stability to repetitive deformation. The optimum dope concentration depends on the molecular weight of the polymer.

CONCLUSIONS

The influence of polymer concentration of (21–32.9%) with different molecular weight in spinning solution on the tenacity, elongation, loop tenacity, density, orientation, perfection of the structure, and stability to repetitive deformation of acrylic fibers was presented. Independent of molecular weight (in the investigation range), the dope concentration influences density, tenacity, stability to repetitive deformation, and perfection of the structure. A dope concentration exists (at a given molecular weight) at which the best improvement of the fiber properties can be achieved.

The hypothesis presented for the influence of dope concentration on the processes taking place in the coagulating bath is based on the mechanisms of fiber breakage advanced by Paul[10] and Han and Segal.[11]

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REFERENCES

1. P. Koch, *Faserstoff-Tabellen*, New Ausgabe, August 1967.
2. G. Cazzaro, *Synthetic Fiber Supplement*, **20,** 12 (1971).
3. W. Suity, *J. Soc. Fiber Sci. and Technol. Jpn.*, **22,** 421 (1966).
4. M. Mejirov, V. Jabin, and E. Pakshver, *Collect. Synth. Fibers, Chemistry*, Moscow, 1969, p. 99.
5. M. Takahashi and M. Watanabe, *J. Soc. Text. Cellulose Indr. Jpn.*, **34,** 951 (1959).
6. V. Grobe and J. Heyer, *Faserfersch. Textiltech.*, **19,** 313 (1968).
7. J. Knudsen, *Text. Res. J.*, **33,** 13 (1963).
8. A. Stoyanov and V. Krustev, *J. Appl. Polym. Sci.*, **24,** 583 (1979).
9. D. Paul, *J. Appl. Polym. Sci.*, **12,** 383 (1968).
10. D. Paùl, *J. Appl. Polym. Sci.*, **12,** 2273 (1968).
11. C. D. Han and L. Segal, *J. Appl. Polym. Sci.*, **14,** 2999 (1970).

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