Influence of Drawing Speed on Some Properties of Acrylic Fibers

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Synopsis

The effect of drawing speed on several properties of acrylic fibers has been examined. The acrylic fibers were prepared by the wet-spinning process. The coagulation bath contained 30–70% DMF and was held at a temperature varying from 10–45°C. From x-ray diffraction measurement, the orientation of finished fibers increased with an increase in drawing speed, and became constant when the drawing speed exceeded 40–50 m/min. The tenacity and stability to repetitive deformation also increased to a drawing speed of 40–50 m/min, but then decreased. The spinning conditions (spin-bath composition and temperature) influenced the most attainable properties of the finished fibers. The results are discussed from the point of view of structural changes in fibers during drawing.

INTRODUCTION

Drawing results in great improvement of microstructure,[1,2] mechanical properties, and orientation[3,4] of acrylic fibers. Several articles concerning the relation between drawing temperature,[2,3,5,6] draw ratio,[1–8] type of drawing[9] (in water or in the presence of live steam), and fiber structure and properties have been published. However, the influence of the drawing speed on fiber properties has been insufficiently investigated.[6,10] In the spinning of commercial fibers the drawing speed is directly related to the design of the process.

The investigations of Craig, Knudsen, and Holand[1] and Knudsen[11] show that the protofibers structure and properties are responsible for the finished fiber properties. Thus, there might be a relation between protofibers properties, drawing speed, and finished fiber properties.

In the present publication, we discuss the influence of drawing speed (in the region 30–61 m/min) on some properties of acrylic fibers obtained at different coagulation variables (composition and temperature of spinning bath).

EXPERIMENTAL

A series of experimental samples was prepared by spinning a 25% solution of the polymer dissolved in dimethylformamide (DMF) into a coagulation bath containing a mixture of DMF and water. The solvent remaining in the protofibers was removed by washing. Then the protofibers were stretched at 98–99°C (into water), treated in the presence of steam, and dried. The manufacturing fixed and variable conditions are shown in Table I. In all cases, the draw ratio was equal.

The density, porosity, and stability to repetitive deformation of the fibers were measured, as described previously.[12]

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TABLE I
Sample Preparation Conditions

Dope solids	25%
Coagulation bath composition (DMF:water)	30:70% to 70:30%
Coagulation bath temperature	10–45°C
PH of coagulation bath	3.0
Drawing water bath temperature	98–99°C
Draw ratio in hot water	3.8×
Drawing speed	30–61 m/min
Thermosetting temperature	100°C
Drying temperature	120–125°C

X-ray data were collected in transmission on a diffractometer using Ni-filtered CuK radiation with fixed-count techniques. A 2θ scan was made from 4 to 40°. The x-ray orientation was measured from the azimuthal scanning at $2\theta = 17°$. The width at half-maximum intensity ($H° = I_{1/2}$) was used as an index of orientation; it can be used to calculate the parallelism of the crystalline part of structure by the equation[3,13]:

$$P = \frac{90 - H/2}{90} \times 100\%$$

The tenacity was measured on a Fafegraph. All measurements were conducted in a laboratory maintained at 22°C and 65% RH. Specimens of filament (10 mm) were used and stretched at 12 mm/min.

Standardized techniques was used for optical microscopy studies of the fiber cross section.

RESULTS AND DISCUSSION

During the drawing process of fiber in water, the macromolecular chains and supermolecular structures orient in the direction of the external force. Simultaneously, at drawing conditions (water and high temperature), the mobility of the structure elements increases. This "stimulates" the disorientation of structure. The increase in drawing speed leads to an increase in the orientation (Fig. 1), i.e., the disorientation processes are kept.

Figure 1 shows that the degree of orientation depends on the coagulation temperature and coagulation bath composition. This result could be correlated with the properties of the undrawn filaments. At high temperature and low concentration of the solvent, the coagulation is rapid and the formation of the skin is faster.[11] In this case, the structure becomes more porous with larger voids (Fig. 2). The homogeneity of fibers is decreased and the density also decreases (Table II). Increasing the concentration of DMF and decreasing the bath temperature allows slower skin formation through hardening of the fibers.[14] The homogeneity of the structure is improved and the density is increased. The increase in solvent in bath in the range of 53–70%, and the decrease in temperature in the range of 22–10°C leads to a slight positive influence of the density (Table II). This small increase in density may be explained by the spinning conditions (for example, the value of jet stretch) and the tensile stress in the fibers.

Therefore, when the structure of protofibers is denser and more homogeneous,

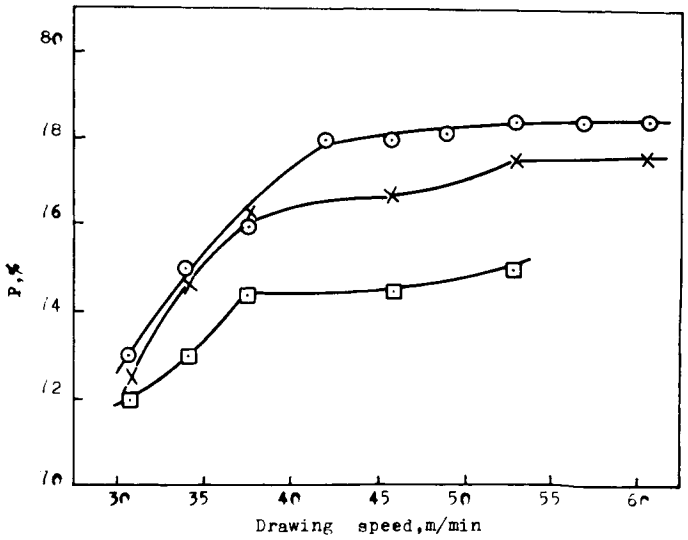

Fig. 1. Relationship between parallelism (orientation) and drawing speed for fibers coagulated at various bath composition and temperature: ×, DMF:H_2O = 70:30%, T = 10°C: ○, DMF:H_2O = 53:47%, T = 23°C, □, DMF:H_2O = 30:70%, T = 45°C.

the drawing speed influences the orientation to a high degree; and we may achieve higher orientation. These results, obtained by varying drawing speed, confirm the conclusion of Craig and Knudsen,[1,11] that the properties of the protofibers influence the effectiveness of the subsequent steps, and consequently the properties of the finished fibers.

The data in Figures 1, 3, and 4 indicate that the changes of orientation, tenacity, and stability to repetitive deformation depending on drawing speed are not identical. The changes in the tenacity and stability to repetitive deformation may be ascribed to the increase in orientation and the nonuniformity of the fibers

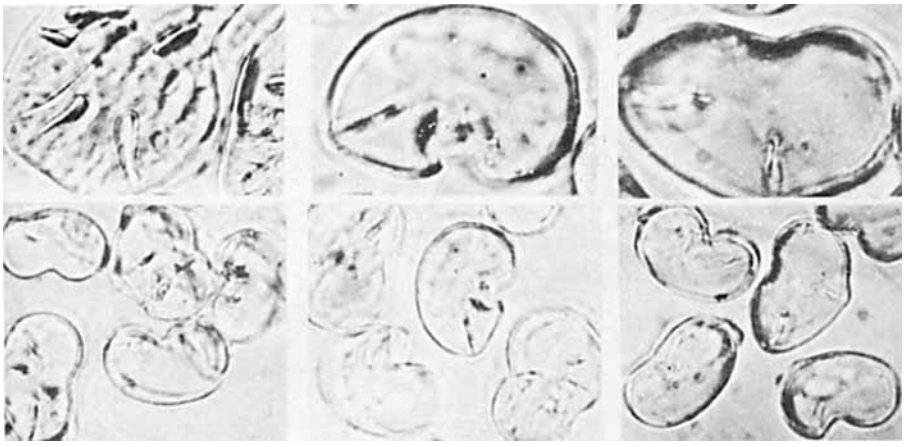

Fig. 2. Cross-section photographs of fibers after coagulation at different coagulation variables: (a) DMF:H_2O = 30:70%, T = 45°C, (b) DMF:H_2O = 53:47%, T = 23°C, (c) DMF:H_2O = 70:30%, T = 10°C.

TABLE II
Effect of Spin-Bath Composition and Coagulation Temperature on Protofiber Properties

Coagulation composition DMF:H_2O, %	Coagulation temperature °C	density g/cm^3,	Porosity, %	X-ray orientation H°
30:70	45	0.30	72	no
53 47	22	0.38	67	measurable
70:30	10	0.39	66	orientation

(mechanical and structural defects). At low drawing speed the orientation of the structure has a dominant influence. Upon increasing the drawing speed, the stress in fibers increases too (the relaxation processes are delayed). This leads to an increase in the probability of defects in fibers. Hence, the changes in variation coefficient of tenacity are not unexpected (Fig. 5). The increase of drawing speed leads to a decrease in the time during which the fibers remain in the zone for drawing (at same length of stretch bath). This fact decreases the effectiveness of the drawing process. Some experiments were conducted for compensating the duration of drawing through increasing the length of the stretch bath. However, the increase in the duration of drawing with approximately 30% for fibers spun under conditions of moderate bath concentration and moderate temperature (DMF:water ≈ I:I and T = 20°C) does not lead to changes in the structure and properties of fibers. The increase in the duration of drawing leads to a slightly positive influence on the properties of the fibers that were preparated at extremely low bath concentration and high temperature. The decrease in the duration of drawing by reduction of the length of the stretch bath leads to moving the maximum and minimum points on the curves (Figs. 3 and 4) to lower values of drawing speed.

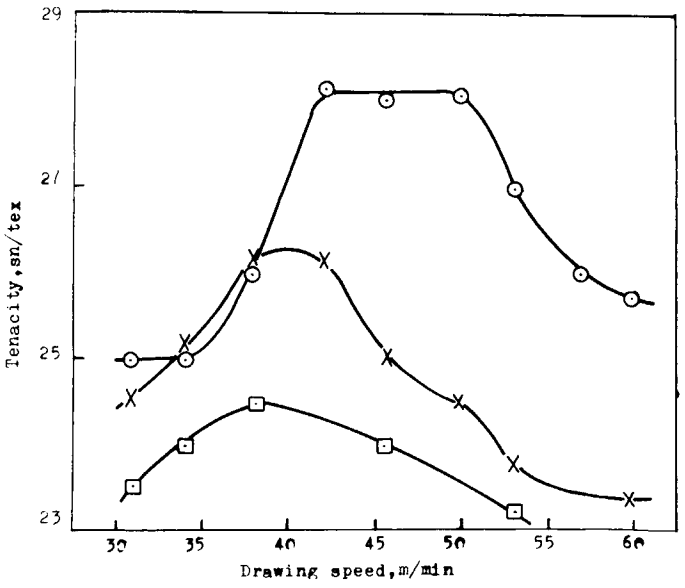

Fig. 3. Effect of drawing speed on tenacity of fibers coagulated at different coagulation variables: ×, DMF:H_2O = 70:30%, T = 10°C, ○, DMF:H_2O = 53:47%, T = 23°C, □, DMF:H_2O = 30:70%, T = 45°C.

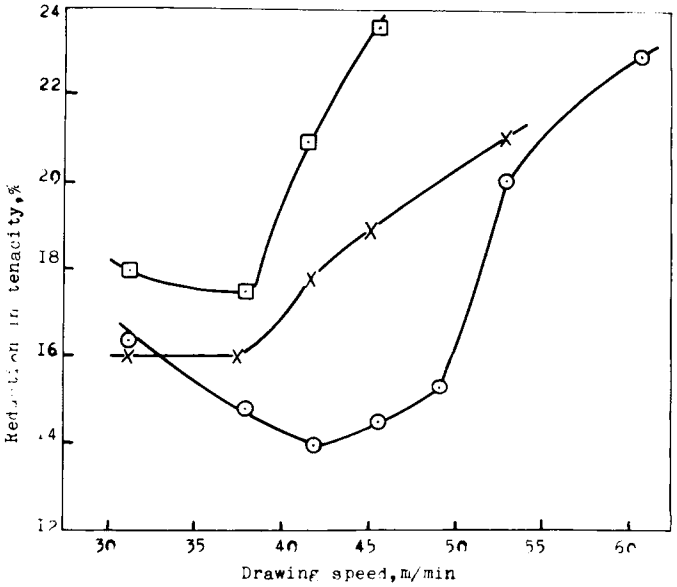

Fig. 4. Effect of drawing speed on reduction in tenacity in % after repetitive deformation of fibers coagulated at different coagulation variables: ×, DMF:H_2O = 70:30%, T = 10°C, ○, DMF:H_2O = 53:47%, T = 23°C, □, DMF:H_2O = 30:70%, T = 45°C.

From Figures 3 and 4, we see that the effect of protofiber properties (varied by spin-bath composition and temperature) on finished fiber properties is more marked at higher drawing speed. For example, the maximum difference between the tenacity of the fibers, prepared under different coagulation conditions, at drawing speed of 31 m/min, is approximately 7%. The same difference is approximately 20% at drawing speed of 50 m/min.

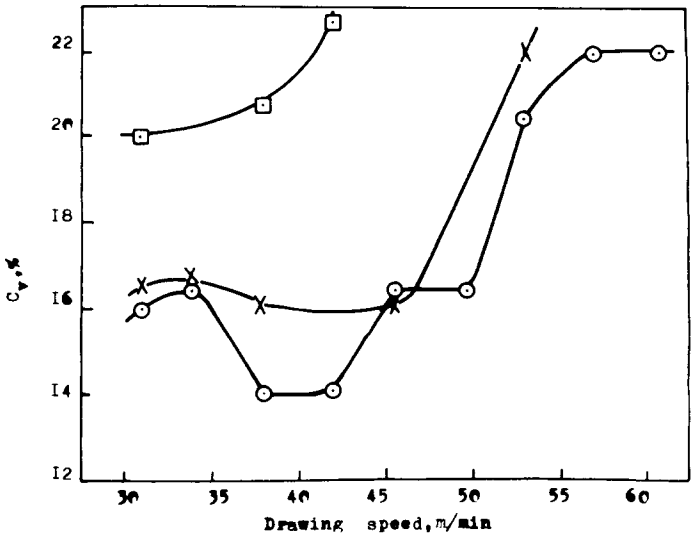

Fig. 5. Effect of drawing speed on variation coefficient of tenacity of fibers coagulated at different coagulation variables: ×, DMF:H_2O = 70:30%, T = 10°C, ○, DMF:H_2O = 53:47%, T = 23°C, □, DMF:H_2O = 30:70%, T = 45°C.

CONCLUSION

The influence of the drawing speed on the orientation, tenacity, and stability to repetitive deformation of acrylic fibers was discussed. The orientation increases with an increase in the drawing speed to $V = 40–50$ m/min. For tenacity and stability to repetitive deformation, extreme values appear. The positions of these extreme values depend on spin-bath composition and coagulation temperature.

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