OPTIMAL SPINNERET SIZE FOR IMPROVEMENT OF FIBER'S MECHANICAL PROPERTY

by

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The effect of spinneret size and place on diameter and tensile property of cellulose acetate fibers is studied, and a criterion for the maximal breaking energy is obtained, and the spinneret distribution can be optimized for each spinning condition.

Key words: *tensile property, spinneret, distribution, design, non-linear strain-stress relationship*

Introduction

Spinneret is the starting position where the spinning dope begins to form tow, which is the key part for forming tow, and the initial spinning conditions will greatly affect fiber geometrically and mechanically. To optimize a spinneret, we should consider the spinning process for fabrication of chemical fibers. There are dry spinning, wet spinning, melting spinning, composite spinning, and others. The spinneret should be specially designed to match the requirement of different fibers such as long and staple fibers of polyester, nylon, acrylic, rayon, and cellulose acetate. Recently much attention was paid on spinneret design due to rapid development of industrial fabrics, however, there is, so far, no report on optimal spinneret distribution and its effect on fiber's tensile properties. He & Khan first studied theoretically the effect of spinning speed on the diameter and mechanical properties of dragline during the spider-spinning procedure[1]. Stylianopoulos, *et al.*[2] gave a computational prediction of the tensile properties of electrospunfiber meshes, but the impact ofspinning conditions on the tensile properties has not been rigorously characterized.

Relationship between the spinning speed and the fiber size

Assume that spinning procedure is steady, according to the mass conversation[3,4], we have:

$$\pi r_0^2 u_0 \rho_0 = Q_0 \tag{1}$$

where Q_0 is the initial flow rate, u_0– the spinning speed, r_0– the equivalent radius of fiber at feeding roller, and ρ_0– the fiber density at feeding roller. The initial flow rate might be changed due to environment change from Q to $Q + \Delta Q$, mass conversation equation becomes:

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$$\pi r^2 u\rho = Q = Q_0 + \Delta Q = \pi r_0^2 u_0 \rho_0 + \Delta Q \tag{2}$$

where Q is the flow rate of dope at spinneret, ΔQ– the flow rate of solvent evaporation, r– the spinneret hole equivalent radius, ρ– the dope density, and u – the dope jet speed at spinneret hole.

From eq.(2), we can obtain the following relationship between the spinneret size and the dope jet speed at spinneret hole, which reads:

$$r = \sqrt{\frac{1}{u}\left(a_1 r_0^2 + a\right)} \tag{3}$$

where a is a constant for a fixed spinning condition.

We assume that the velocity distribution is parabola, that is:

$$u = u_0 - bR^2 \tag{4}$$

where u_0 is the jet speed in spinneret center, and$R$– the distance between spinneret hole and spinneret center.

Substituting eq.(4) into eq.(3), we have:

$$r = \sqrt{\frac{a_1 r_0^2 + a}{u_0 - bR^2}} \tag{5}$$

Stress-strain relationship of fiber

Generally the stress-strain relationship for cellulose diacetate fiber can be expressed in the form[1]:

$$\varepsilon = \alpha\sigma + \beta\sigma^k \tag{6}$$

where ε is the strain, σ– the stress, andα, β, and k are constants.

We obtained typical stress-stain curve of cellulose diacetate fiber as illustrated in fig.1. Using the data, α, β, and k can be determined.

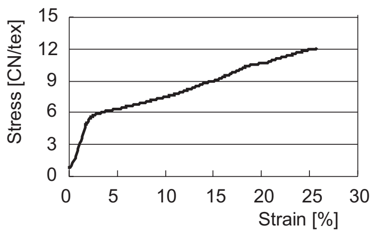

Figure 1. Stress-strain relationship for cellulose diacetate fiber

Optimal spinneret position for the best tensile property

During the fiber tensile test, breaking energy, A,can be expressed as[1]:

$$A = \int_0^{\varepsilon_0} \sigma \mathrm{d}\varepsilon \tag{7}$$

Substituting eq.(6) into eq.(7), we have:

$$A = \int_0^{\varepsilon_0} \sigma \mathrm{d}\varepsilon = \frac{1}{2}\alpha\varepsilon_0^2 + \frac{1}{k+1}\beta\varepsilon_0^{k+1} \tag{8}$$

where σ_0 is the yield strain, which mainly depends upon the section area and elastic modulus of the cellulose diacetate fiber. It was assumed that the elastic modulus is a constant, that indicates:

$$\varepsilon_0 \propto r^2 \propto \frac{1}{u_0 - bR^2} \tag{9}$$

or we write the scaling relationship, eq.(9), in an equation form:

$$\varepsilon_0 = \frac{C}{u_0 - bR^2} \tag{10}$$

where C is a constant.

Substituting eq.(10) into eq.(8), we have:

$$A = \int_0^{\varepsilon_0} \sigma \mathrm{d}\varepsilon = \frac{1}{2}\alpha\left[\frac{C}{u_0 - bR^2}\right]^2 + \frac{1}{k+1}\beta\left(\frac{C}{u_0 - bR^2}\right)^{k+1} \tag{11}$$

We find that breaking energy depends upon the distance between spinneret hole and spinneret center, it reaches its maximum when:

$$\frac{\mathrm{d}A}{\mathrm{d}R} = 0 \tag{12}$$

Solving R from eq.(12) yields:

$$\overline{R} = \sqrt{\frac{u_0 - \left(\frac{-\alpha C^2}{\beta}\right)^{1/(1-k)}}{b}} \tag{13}$$

The breaking energy arrives at maximum at $R = \overline{R}$. The parameters in eq.(13) can be determined experimentally for a fixed spinning condition.

Conclusions

The spinneret size and distribution are of crucial importance for fiber's mechanical properties. The paper shows that the breaking energyis controllable by adjusting the spinning condition, and it reaches its maximum when the criterion, eq.(13), is satisfied.

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