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Stretching of Polypropylene Hollow Fibers in Continuous Drawing Process

- Kinetics of Deformation -

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1. INTRODUCTION

Melt spinning is a kind of technique to manufacture hollow fibers[1] and it is usually followed by drawing process in a consecutive operation or separated one. In drawing of hollow fibers, not only are the drawing force and stress distribution along the drawing path which affect the microstructure of fibers of particular interest, but also the profile development and hollowness of final drawn fiber are of significant value. The cold stretching of melt-spun polypropylene hollow fiber is particularly important due to its special end use such as membranes.[2]

There have been relatively few studies aimed at modeling of large plastic deformation in continuous drawing process in spite of its industrial significance. The main factor which makes such an analysis more difficult than in the case of melt spinning is that there has been no satisfactory constitutive relation which describes the rheological behavior of the solid polymers.

In the present work, in order to find out optimum process conditions for the manufacture of polypropylene hollow fibers, simple model describing continuous drawing process was presented. A constitutive relation for solid semicrystalline polymers was used in this model, of which parameters can be determined by tensile tests.[3-4] Calculations were carried out to predict the trends of strain localization as a function of the drawing conditions under isothermal condition. The effects of drawing conditions on hollowness and drawing force were also discussed from these results.

2. EXPERIMENTAL

For the preparation of undrawn hollow fiber, PP was melt spun through the spinneret that consists of four segmented arcs. Melt-spinning system manufactured by Uenoyama Kiko Co. was used for laboratory-scale experiment and water quenching box was set for quenching condition. The drawing apparatus consists of feed roll, water bath, take-up roll and tensiometer. Drawing experiments were carried out in this work under various conditions. To estimate the relative quantity of hollow portion of fiber, hollowness defined as the ratio of area of the hollow portion to the total cross-sectional area was measured.

3. FORMULATION AND CALCULATION

In order to develop a mathematical model for the deformation in the continuous drawing system, some assumptions were made. Combining governing equations and some relations gives displacement, x from feed roll as a function of local true strain:

$$x = \frac{v_0}{\dot{\varepsilon}_0}\left(\frac{k}{\sigma_0}\right)^{1/m} \int_0^{\varepsilon} R(\varepsilon)d\varepsilon \qquad (1)$$

where

$$R(\varepsilon) = \exp(\varepsilon)\left[\exp\left(h\varepsilon^2 - \varepsilon\right) - \exp\left(h\varepsilon^2 - (\omega+1)\varepsilon\right)\right]^{1/m} \qquad (2)$$

where v_0, σ_0 and $\dot{\varepsilon}_0$ denote the initial velocity, initial true stress and reference strain rate, respectively ; k, h, ω and m are the rheological parameters at a given temperature, each denoting the scaling factor, strain hardening factor, viscoelastic coefficient and strain-rate sensitivity coefficient respectively. From equation (1) with boundary conditions, a plot of ε against x can be obtained by numerical integration. The range of strain from zero to maximum value, ε_L which corresponds to the applied draw ratio must be sectioned into fine elements for numerical integration of equation (1). By some relations, other variables along the axial distance can also be computed.

4. RESULTS AND DISCUSSION

To understand the deformation history of filaments during their transfer from the feed roll to the take-up roll in continuos drawing, we can consider the filament elements along the axial distance which are under different deformation state. Since each element is considered to follow the governing equations and constitutive relation, we can obtain the local variables at each position along the drawing line by solving the equations. The results are shown in Figure 1 and from these, the characteristics of continuous drawing can be found. Overall features of profiles are similar to those in melt spinning. However, the strain in drawing process is localized more intensively and neck appears by drastic reduction of diameter that cannot, in general, be found in melt spinning. In order to investigate the effects of drawing temperature, calculation was performed for two drawing temperatures in which noticeable differences in deformation behavior could be observed. Such differences with respect to drawing temperatures result from the dependence of rheological parameters on temperature and they determine the true $\sigma - \varepsilon - \dot{\varepsilon}$ surface that affects the drawing behaviors. From Figures 1(a) and (b), it can be seen that the deformation localization at lower drawing temperature is more remarkable than at higher temperature. It should be noted that the deformation at 80 °C seems to be almost homogeneous if it is plotted in a practical aspect ratio (i.e. *x* axis of curves in Figure 1 is enlarged) but at lower drawing temperature plastic instability obviously appears.

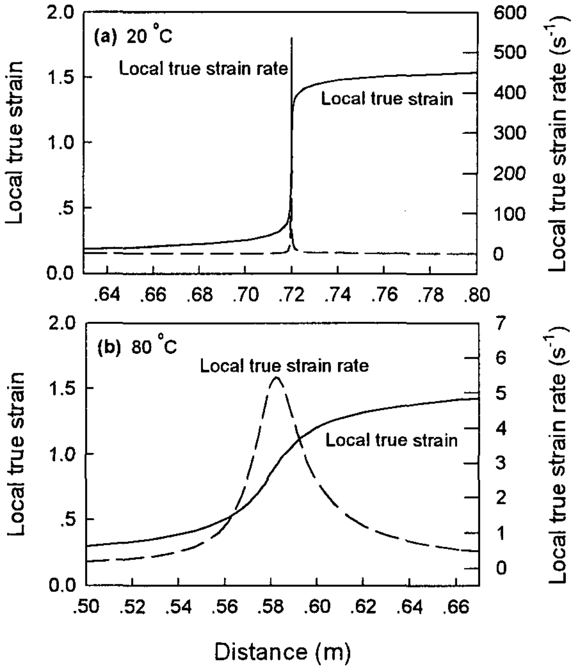

Fig. 1. Predicted local true strain and strain rate distribution along drawing line for continuous drawing of PP hollow fibers at two drawing temperatures (DR=5) :
(a) T = 20 °C ; (b) T = 80 °C

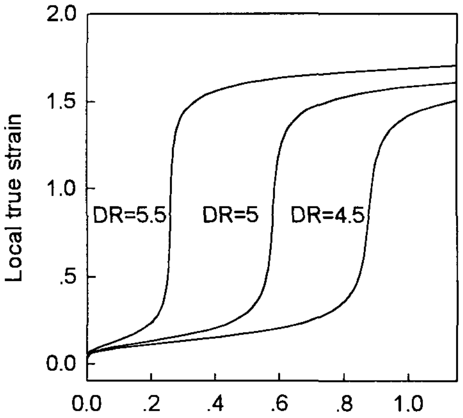

Fig. 2. Calculated local true strain profile along drawing line for continuous drawing of PP hollow fibers at various applied draw ratio (T=80 °C).

The applied draw ratio is determined by the ratio of initial to final velocity of the filament. It is illustrated in Figures 2 that the applied draw ratio affects the local history of deformation, which results in the change in deformation kinetics. The position of strain localization (i.e. position of steep increase of local true strain in Figure 2) shifts towards the lower strain region with increasing draw ratio. It may be also understood that the intensity of strain localization increases with draw ratio by noticing the increase in slope of curve at strain localization region.

The change of hollowness of drawn fibers was investigated by experiments. It can be found from these results that the process conditions have influence on not only the deformation kinetics but also the profile development of hollow fibers.

5. CONCLUSIONS

It has been shown that the combination of some governing equations with the constitutive relation for solid polymers that can describe the true (stress-strain-strain rate) surface makes it possible to express the deformation behavior of continuous drawing. It has been shown that the increasing applied draw ratio and decreasing drawing temperature result in the increment in intensity of strain localization and drawing force, but drawing velocity has less effect. The manner of deformation according to drawing temperature affects the evolution of hollowness during stretching in continuous drawing process. The drawing of hollow fibers at 30 °C results in higher hollowness but lower than that of undrawn fibers above this temperature.

6. REFERENCES

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