폴리에틸렌테레프탈레이트의 고속 In-Line 연신공정내에서의 섬유형성 메커니즘에 대한 연구 (I)

-On-Line 계측에 의한 네킹변형거동 해석-

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Mechanism of Fiber Structure Development in High-Speed In-Line Drawing Process of Poly(ethylene Terephthalate) (I)

-On-Line Measurement Studies on Filament Deformation and Orientation Development Behaviors-

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1. Introduction

High speed in-line drawing process, in which melt spinning and drawing processes are connected, is one of the most widely used process for the production of commodity fibers such as polyesters and polyamides. Development of fiber structure and characteristics of resultant fibers are affected both by the melt spinning and drawing conditions, however, number of research papers on the mechanism of fiber deformation and structure evolution in these processes is limited. In this study, on-line measurement studies in the in-line drawing process of poly(ethylene terephthalate) filament was conducted at various spinning and drawing conditions. The deformation behavior was measured using optical diameter monitors and a laser-Doppler velocimeter. On-line measurement of birefringence development was also conducted paying particular attention to the regions of neck-like deformation in the spinning process and necking deformation in the drawing process.

2. Experimental

The polymer material used was PET with intrinsic viscosity of 1.0 dl/g supplied by Toyobo Co. Ltd. The polymer was melted using a single screw extruder and extruded from a spinneret with a single hole of 1 mm diameter by a gear pump. The throughput rate and spinning temperature were controlled to 6.0 g/min and 300 ℃, respectively. High speed in-line drawing (Fig. 1) was conducted keeping the speed of the first roller at 2 km/min, and increasing the speed of the second roller from 3.5 to 4.5 km/min (D2035 ~ D2045). Temperatures of the first and second rollers were set to 85 and 135 ℃, respectively. For comparison, direct high-speed melt spinning was executed by operating the first and second rollers at the same speed. The velocity was varied from 2 to 5 km/min (S2 ~ S5).

Simultaneous on-line measurements of filament velocity and diameter were carried out both in the spinning and drawing processes using a laser-Doppler velocimeter and an optical diameter monitor. On the other hand, moving velocity of fluctuating necking position was measured using a pair of optical diameter monitors (Fig. 1). Birefringence of running filament was evaluated analyzing data from a pair of optical diameter monitors and an optical retardation measurement system (Fig. 2), which is composed of a He-Ne laser light source (543.5 nm), polarizing filters, quarter-wave plates, a rotating polarizing filter, photo detectors, etc.

3. Results and discussion

3.1 Overall diameter and velocity profiles

Overall diameter and velocity profiles of PET filament measured at various spinning and drawing conditions are summarized in Fig. 3. In the spinning line, neck-like deformation started to occur at 4 km/min (S4), whereas the filament in the drawing line showed a steep deformation immediately after passing through the first roller. Position of the neck-like deformation shifted to upstream with an increase in the take-up velocity. Even though the deformation in the drawing line became steeper with an increase in the draw ratio, the histogram for the time-course variation of velocity measured at a position in the necking deformation only showed a single peak with wide distribution. This result suggested that the deformation in the drawing process was milder than that in the neck-like deformation in the spinning process where bimodal velocity distributions were observed.

3.2 Detailed Diameter Profile of Necking

Detailed diameter profiles in the vicinity of necking deformation in the in-line drawing process was analyzed comparing the time-course variations of data simultaneously measured using two diameter monitors, which were placed close to each other. It was found that there was a change in the shape of necking depending on the direction of its movement along the drawing line: the deformation was steeper when the necking position was shifting to upstream. This tendency was confirmed through the simultaneous on-line measurements of filament diameter and velocity. It should be noted that the analyzed detailed shape of neck-like deformation in the spinning process was almost identical irrespective of the direction of its movement, i.e. toward upstream or down stream. When filament was drawn from 2 to 4 km/min, the moving velocity of necking position was broadly distributed from 1.3 to 6.8 m/s. The most frequently observed velocity was ca. 3.3 m/s. For the necking deformation shifting to upstream, the maximum strain rate obtained averaging the data for the region of ca. 6.8 mm along the drawing-line reached ca. 510 s^{-1}.

3.3 Birefringence Measurement

In the measurement of optical retardation of running filament, order of interference was successfully determined from the successive relationships between varying phase shift and filament diameter observed at each position in the spinning and drawing processes. Obtained birefringence profiles were plotted as a function of distance from the spinneret or the first roller as shown in Fig. 3. Birefringence increased steeply in the vicinity of the neck-like deformation in the high-speed spinning line and in the region near the first roller, where steep diameter reduction was observed in the in-line drawing process. Off-line measurement of resultant fibers revealed that the birefringence of the high-speed spun fibers obtained at 5 km/min (S5) was lower than that for the in-line draws fibers prepared at the first and second roller speeds of 2 and 4 km/min (D2040). The relationships between diameter and birefringence measured in the spinning and drawing processes showed that the birefringence started to increase remarkably when the filament diameter decreased to around 50 μm in the spinning line, whereas birefringence of the drawing line started to increase steeply at a higher diameter of around 60 μm, which corresponds to the diameter of filament running at 2 km/min. This difference is simply caused by the difference in temperature of the region of filament where significant deformation underwent.

3.4 Temporal diameter variation of short period observed in drawing process

Time-course changes of diameter and birefringence in the vicinity of neck-like deformation in the spinning line could be clearly analyzed in the present on-line measurement conditions. On the other hand, it was relatively difficult to analyze the time-course variation of birefringence near the necking deformation in the drawing line. This was caused by a relatively large diameter fluctuation of a short-period of around 8.0 ms, which was found only in the region of necking deformation as shown in Fig. 4. The maximum amplitude of the diameter fluctuation reached around 4.0 μm, i.e. around 13 % of the filament diameter. This short-period diameter fluctuation always moved toward downstream even during the downstream (a) and upstream (b) shifts of the necking deformation. It is also important to note that the moving velocity of the short-period diameter fluctuation was comparable to the velocity of running filament. These results suggested that the short-period diameter fluctuation was originated from the variation of material characteristics along the filament.

4. References

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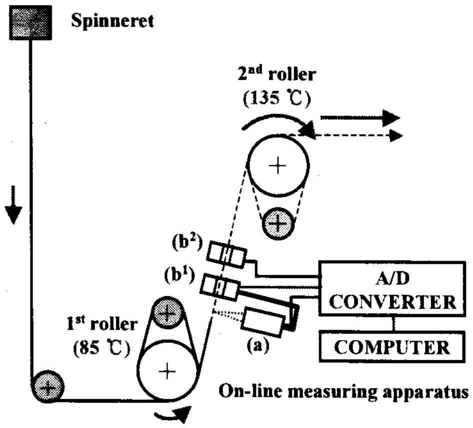

Figure. 1 Schematics of high speed in-line drawing process and on-line measurement apparatus of velocimeter (a) and diameters (b[1,2])

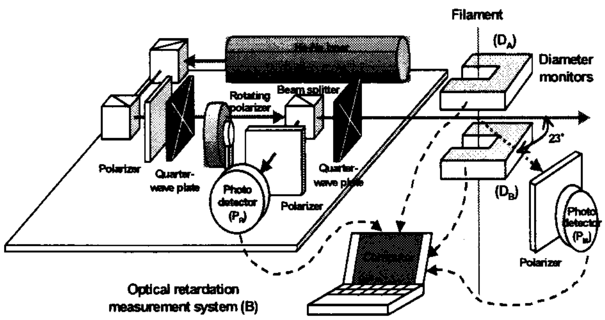

Figure. 2 Schematic of on-line birefringence measurement apparatus.

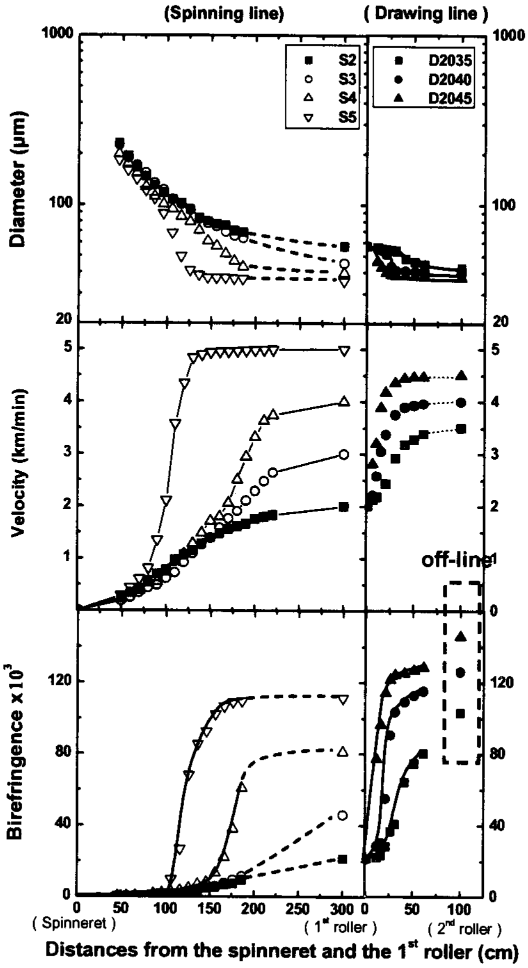

Figure. 3 Overall diameter, velocity and birefringence profiles of PET filaments in high speed in-line drawing process.

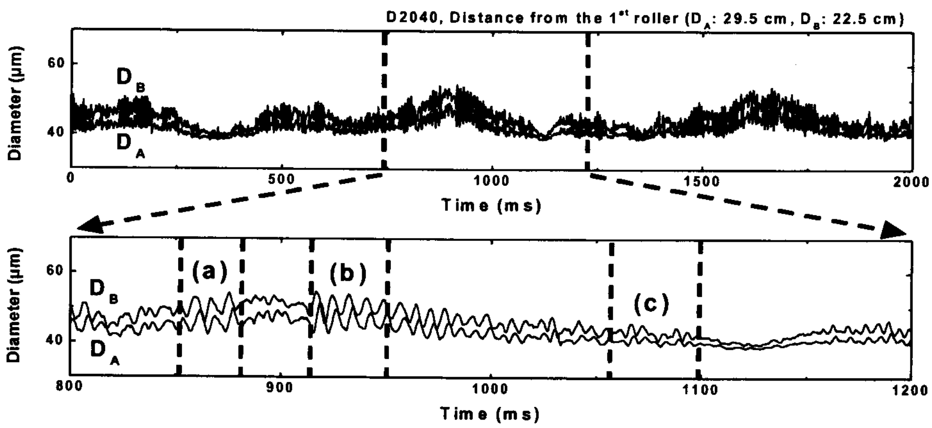

Figure. 4 Time-course variations of diameters in the vicinity of necking deformation in the high speed in-line drawing process of D2040.