Tensile Properties of the Large Diameter TPEE Monofilaments

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Abstract. The monofilaments were prepared by melt-spinning under different quench temperatures. The thermal properties were investigated by Differential scanning calorimetry (DSC) and the morphologies were observed using Scanning electron microscope(SEM). The effects of cooling temperature, stretching temperature, the stretching way, the stretching ratio, and heat-setting temperature on the structures and mechanical properties of the monofilaments were investigated. The result shows that: the rational process to produce high quality TPEE monofilaments is:Cooling water temperature:50 ℃, hot stretch temperature:170 ℃, hot-water stretching temperature:95 ℃ and heat-setting temperature: 190 ℃ .

Introduction

As a special representative of the thermoplastic elastomer,the thermoplastic polyester elastomer (TPEE) is a kind of linear block copolymer which have characteristics of both rubber and thermoplastics. The thermoplastic polyester elastomer monofilaments with large diameter exhibited balanced performances either at high or low temperature which can make up the shortcomings of traditional elastic fibers under small deformation,such as small stress, bad stretching mechanics and poor abrasion resistance. Its operating temperature range is very wide (-70 ~ 200 ℃), and can be widely used in automobile parts, bio-materials and industrial products, and other fields [1-5]. In this study,the TPEE monofilaments with the diameter of 0.2mm were prepared by melt spinning to improve the mechanical properties, and then the effects of the stretch ratio, stretching temperature, liquid cooling temperature and heat-set temperature on the structure and the mechanical properties of TPEE monofilament were investigated.

Experimental

Materials. TPEE chip was purchased from DU POUD MYTREL; Tg=93° C; Tm=210.2° C

Fabrication of Monofilaments. Monofilaments of TPEE were fabricated by a melt-spinning process. the temperature profile was as follows: 258℃, 262℃, 265℃, 265℃, 265℃; upper mould temperature:265℃, lower mould temperature:263℃;Immediately after the monofilament was extruded from the spinneret, it was quenched in water baths with different temperatures and passed through a set of rotating godet. In the drawing step, the following procedures were adopted: the first drawing treatment by hot water at 95℃ and the second drawing treatment by hot air at 170℃.Next, the monofilaments were heat treated at 190℃. Finally, a take-up machine was used to collect the monofilaments at the speed 120 m/min.The diameter of monofilament was 0.20 mm.

Characterization. Diferential scanning calorimetry (DSC) analyses were performed under nitrogen using a Netzsch 200 F3 instrument. Temperature calibration was performed using indium.

The specimens (10-20mg) were placed in sealed aluminum cups and then cyclically heated from 25C° to 280℃ at 10℃/min.Results from the second scan were reported.A scanning electron microscope (SEM, Hitachi S–550) was used to investigate the morphology. The cross-section and surface of the monofilaments were observed after being sputtered with gold.

Tensile tests were performed on a filament mightiness instrument (FMI, GY061, Laizhou Instruments Company) at a speed of 100 cm/min. Filament samples were 250mm long. All reported results were the average of at least five measurements. Among the tests, elongation at break (ε)was defined as following:

$$\varepsilon = (l - l_0)/l_0 \times 100\% \quad (1)$$

l_0 is the original length of the fiber and l is the length at break.

Results and Discussion

Stretching Ratios. Though the variations of structure and performance of different kinds of as-spun fibers in the process of drawing are different, the trend in any conditions is all from low-order state to high-order state. For example, the crystallization and orientation of macromolecules in amorphous regions of crystalline fiber-forming polymers are enhanced by stretch reasonably,the morphological structure changed with the increase of density. These are often accompanied by the increase of the dipole bond and hydrogen bond, the improvement of the breaking strength and initial modulus of the fiber, the strong enhancement of the wear and fatigue resistance and the decrease of elongation at break [4,6].

The tensile strength of TPEE monofilaments under one-stage stretching and two-stage stretching increased significantly with the increase of draw ratio which was due to the increasingly ordered polymer chains resulting from the draw,which improved the orientation degree and regularity as well as the crystallization degree of the monofilaments. Therefore, the mechanical properties were improved. However, when the draw ratio was too high, the mechanical properties degraded slightly.

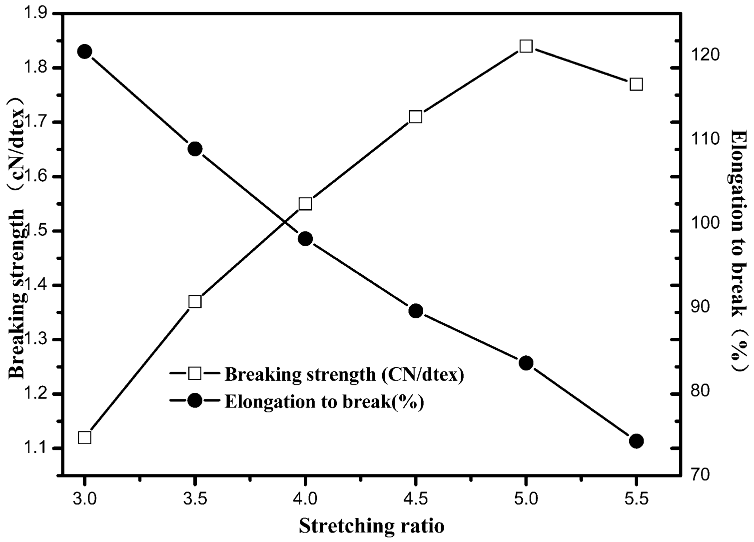


Figure 1. The Influence of the Different Stretching Ratios on the Mechanical Properties of the TPEE Monofilaments Under One-Stage Stretching(Stretch Temperature 95℃,170℃; Diameter: 2.0mm)

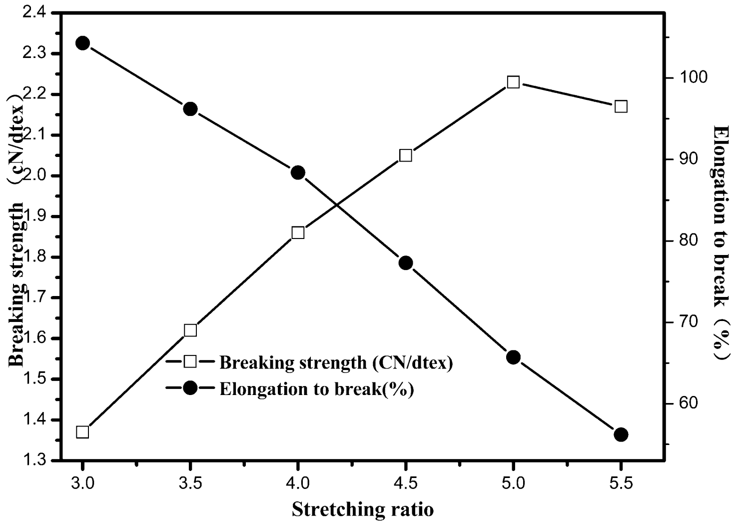


Figure 2. The Influence of the Different Stretching Ratios on the Mechanical Properties of the TPEE Monofilaments Under Two-Stage Stretching(Stretch Temperature 95℃,170℃; Diameter: 2.0mm)

Quench Temperature. We also investigated the effects of quench temperature on the mechanical strength of the monofilaments(Fig. 3). It is obvious that the water bath temperature strongly affects the mechanical properties of TPEE monofilament. In a certain range,with the increase of quench temperature, the tensile strength increased whereas the elongation at break decreased obviously,which could be attributed to the different crystallization processes and orientation structures induced by changing quench temperatures. The effects on the mechanical properties may be due to the change of crystallinity. High crystallinity lead to low thermal shrinkage by improve the thermal stability[7]. But above a certain temperature,the tensile strength will decrease. This is because, at lower temperatures, the as-spun fibers have higher degree of crystallization and lower orientation which is not conducive to afterdrawing; however excessively high temperatures is not conducive to the crystallization and the molding process. Therefore,the optimum quench temperature for the preparation of TPEE monofilament was around 60 ℃.

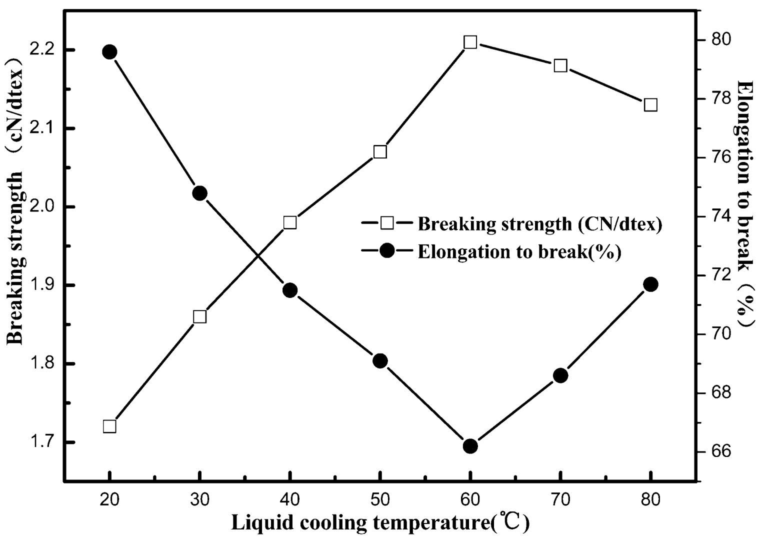
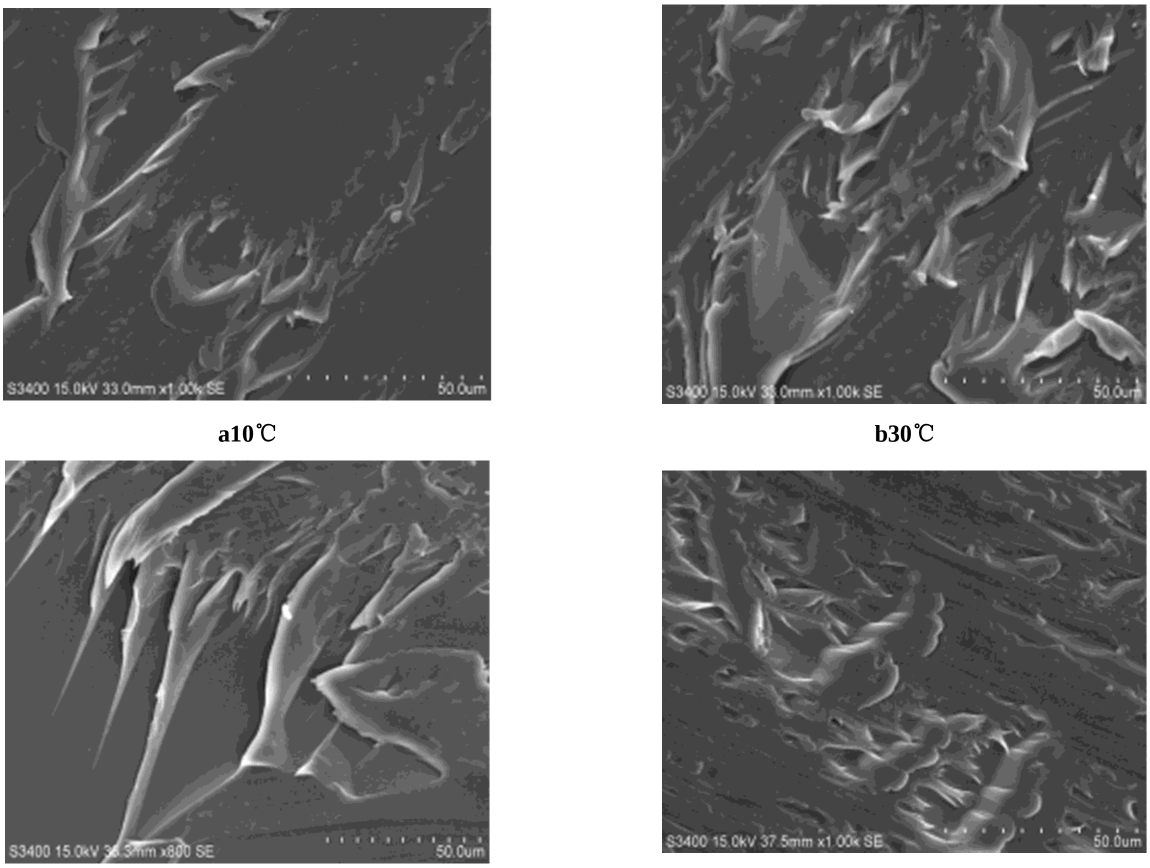


Figure 3. The Influence of the Liquid Cooling Temperature on the Mechanical Properties of the TPEE Monofilaments (Diameter 2. 0 mm)



a10℃ **b30℃** **c 50℃** **d 70℃**

Figure 4. SEM images of the Monofilaments under different liquid cooling temperature

SEM images of the TPEE monofilaments are shown in Fig. 4(a-d). Results indicate that with the increase of the liquid cooling temperature, the pore walls of TPEE monofilament become smoother. The distributionof dispersed phases are more uniform, the particle sizes are smaller, the boundaries are fuzzy, and a certain plastic deformations are founded [8].

Draw Temperature. The influence of the one stage stretching hotwater temperature and two stage stretching hot air temperature on the stability of the drawing and the mechanical properties of the TPEE Monofilaments were investigated.The results show that the fiber strength are improved significantly with the increase of temperature(Fig. 5,Fig. 6). This is because the relatively high temperature in hot water stretching make the plastic viscosity down. Water molecules acted as the plasticiser which make the plastic deformation easier; the fiber structure unit arrange along the axial direction further and the orientation degree of macromolecular increases which lead to the increase of fiber's breaking strength[9,10]. But at higher temperature,the strength along the orientation also increase but the degree is small and the original crystalline structure will be destroyed because of the excessive molecular thermal motion.Therefore, the optimum temperature of two stage stretching hot air for the TPEE monofilament was around 190 ℃,which could be attributed to the best properties and crystallization processes.

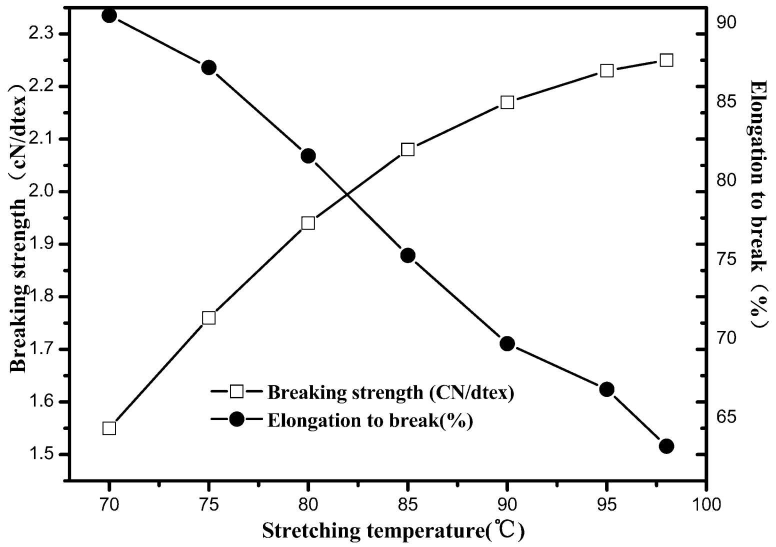


Figure 5. The Influence of the One Stage Stretching HotWater Temperature on the Mechanical Properties of the TPEE Monofilaments (Diameter 2. 0 mm)

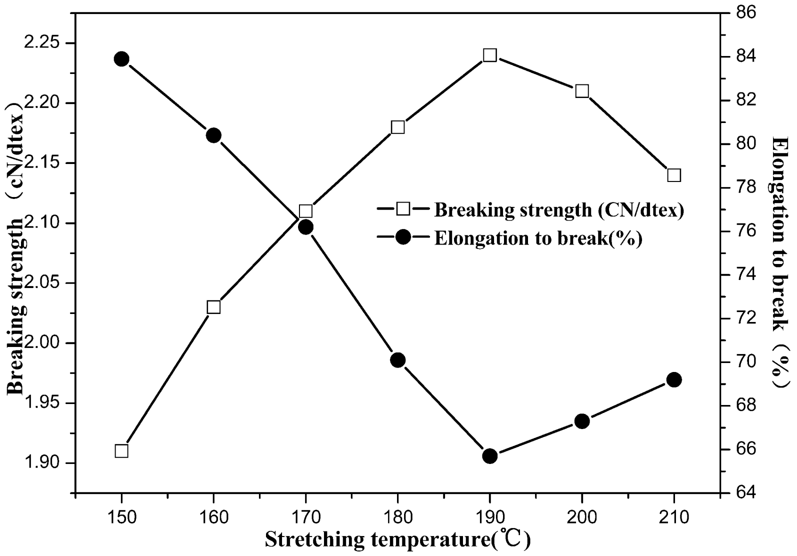


Figure 6.The Influence of the Two Stage Stretching Hot Air Temperature on the Mechanical Properties of the TPEE Monofilaments (Diameter 2. 0mm)

Heat Setting Temperature. We also investigated the effects of heat setting temperature on the mechanical properties of the monofilaments. As shown in Fig. 7, the fiber strength increases with the increase of temperature,and the fasten movement of molecular is favor of eliminate the internal stress of molecular chain. But when the temperature close to the softening point of various fibers, although the internal stress on the fiber eliminated, the strength of the fiber decreased because of the disorientation caused by the big changes of the fiber structure.So during the heat treatment, It is important to choose the optimal temperature.

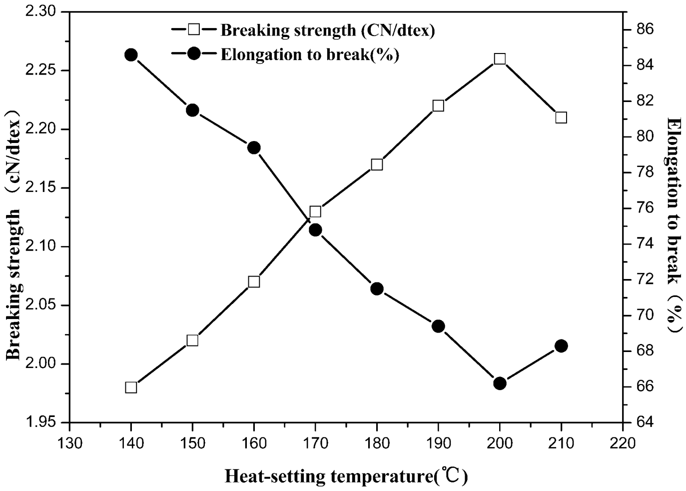


Figure 7. The Influence of the Heat-Setting Temperature on the Mechanical Properties of the TPEE Monofilaments (Diameter 2. 0 mm)

As shown in Fig. 8,the boiling water shrinkage decreased with the increase of heat setting temperature within the appropriate temperature range. This is because in a certain heat treatment time, the higher temperature is advantageous to fasten movement of molecular chain, and effectively eliminate internal stress. The fiber to better achieve stability, so the boiling water shrinkage rate decline.

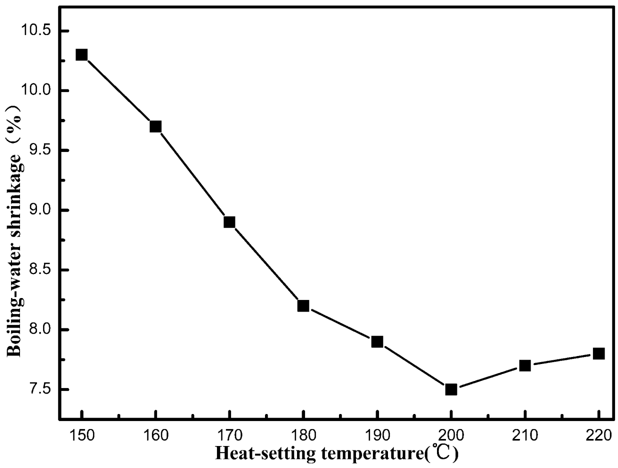


Figure 8. The Influence of the Heat-Setting Temperature on the Boiling-water shrinkage of the TPEE Monofilaments (Diameter 2. 0 mm)

Conclusions

The quench temperature, the stretching ratio ,the stretching temperature and heat setting temperature were the major factors, which influenced the mechanical properties of the TPEE monofilaments.

During the process of after-stretching,the tensile strength of the monofilaments under two-step stretching was higher than that under one-stage stretching.The quench temperature had strong effects on the structure and mechanical properties of the TPEE monofilaments. With the decrease of quench temperature, the tensile strength of the monofilaments increased obviously, which could be attributed to the different crystallization processes and orientation structures induced by changing quench temperatures. The optimum quench temperature for the preparation of TPEE monofilament was around 50 ℃.The stability of the drawing process and the structure of the TPEE monofilament were affected by stretching temperature.the temperature of hot water stretching is 95 ℃, and the temperature of hot air stretching is 170 ℃.In a certain range, higher heat setting temperature will help reduce the boiling water shrinkage. The optimum heat setting temperature of the TPEE monofilament is 190 ℃ which enables monofilament boiling water shrinkage to a minimum.

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