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The Influence of Heat Setting Conditions on Mechanical Properties of PTT Filaments

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Abstract

It is proposed that Poly(Trimethylene Terephthalate) (PTT) filaments are used for fabricating vascular prostheses instead of Poly(Ethylene Terephthalate) (PET) because of their lower Young's modulus and superior elastic recovery. The heat setting process is necessary to keep the stability of shape and mechanical properties as well as making the flattened tubular structures round. However, the best heat setting condition for keeping properties of lower Young's modulus and superior elastic recovery of PTT filaments is unknown. This paper studies the influence of different heat setting conditions to the change of Young's modulus and elastic recovery. The temperature range is chosen from 120 to 180 ℃ and time period is chosen from 30 s to 90 s. The heat setting of yarns is both done in the relaxation state and tension state. Results show that the best heat setting conditions to get lower modulus, higher elastic recovery and better creep property at the temperature of 160 ℃ under the tension state through 60 s. The tension or relaxation state has the biggest influence on elastic recovery and Young's modulus while time period has the least influence.

Keywords: Poly(Trimethylene Terephthalate); Heat Setting; Young's Modulus; Elastic Recovery; Temperature; Time Period

1 Introduction

PET is currently used for the fabrication of large and medium size woven arterial prostheses [1-4]. All grafts in general have lower compliance than those of host arteries and in particular the woven PET prosthesis has the lowest compliance [5]. To minimize compliance mismatch [1, 6, 7] between native artery and woven Dacron vascular prostheses and weave small diameter (<6 mm) [8] woven compliant prostheses, new polyester material Poly(Trimethylene Terephthalate) (PTT) have been used in manufacturing vascular prosthesis [9]. PTT which is manufactured with 1, 3-propanediol (PDO) and Terephthalic Acid (TPA) by polycondensation is a relatively novel thermoplastic polymer, and belongs to the aliphatic aromatic polyalkylene terephthalate family, which also includes the well-known and widely applied Poly(Ethylene Terephthalate) (PET) and

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Poly(Butyleneterephthalate) (PBT) [10]. It was the difference in the number of methylene groups that resulted in the difference in physical properties among these aromatic polyester filaments [11]. PTT fibers have the resiliency and softness of nylon fibers and the chemical stability and stain resistance of Poly(Ethylene Terephthalate) (PET) fibers [12]. Both the Young's modulus and the breaking strength of the PTT filament were lower than those of PET filaments, whereas the breaking elongation was higher than those of PET filaments. PTT filaments had a high instantaneous elastic recovery even at a high elongation of 20%. The outstanding instantaneous elastic recovery of PTT filaments resulted from its helical conformation in crystal lattice, which responded immediately to the applied stress and deformed as though it was a coiled spring [11, 13]. So compared to PET, PTT filaments have favorable mechanical properties to weave compliance vascular prosthesis [9].

As-manufactured polymeric fibers are oriented semi-crystalline structures in which the macromolecules are rarely in their equilibrium state. Further instabilities are imparted when the fibers are converted to yarns and the yarns to fabrics. Heat setting is an important industrial process, since it rids them of their instabilities [14]. The importance of heat setting as a means for optimizing the structure and performance of oriented films and fibers has been well recognized. The morphological changes underlying the heat-setting process in Poly(Ethy1ene Terephthalate) (PET) and other semicrystalline polymers have been studied extensively over the past three decades by means of X-ray diffraction, IR spectroscopy, calorimetry, rheology, and other characterization techniques [15]. As for woven vascular prosthesis, the heat setting process is necessary to make the flattened tubular structures round and get optimum mechanical properties [5]. Heat setting will affect such important properties as stress–strain and recovery behavior, dye-uptake, optical properties, and thermal properties [14]. Most studies conclude that the increase in the crystalline fraction and the size of the crystalline domains during heat setting signinga qualitative change in the superstructure and morphology of the oriented matrix [15].

There were few studies about the heat setting process of PTT fibers. Liu carried out the heat setting process under a relaxed state for 30 seconds at the temperature of 150 ℃, and results showed that PTT filaments shrunk, breaking strength decreased and breaking elongation increased [16]. Dong studied the heat setting condition of PTT fibers during the temperature of 120 to 190 ℃ for 90 seconds. Results show that with the higher temperature, the crystallinity of fibers increased [17]. The study of Yin et al. showed that under pressure state the temperature of 160 ℃ is the best condition for the highest elastic recovery [18]. Yuan's study showed that the best heat setting temperature is lower than 160 ℃ and time period is lower than 60 seconds for knitted fabric under pressure state [19]. Liu studied the influence of temperature during the heat setting process on the knitted fabric and showed that with the increase of temperature the elastic recovery increased but the hand characteristics became worse. The better temperature for heat setting is lower than 160 ℃ [20].

However, the best heat setting condition for keeping properties of lower Young's modulus and superior elastic recovery is unknown. This paper designed the experiments and studies the influence of different heat setting conditions on mechanical properties, and especially on the change of Young's modulus and elastic recovery.

2 Experimental

70D/72f PTT filaments were used as heat setting samples. Time period is chosen from 30 s to

90 s. The heat setting of yarns is both done in the relaxation state and tension state. From the previous study about the tensile properties of PTT filaments after heat setting, it can be seen that tensile and elastic properties were decreased after heat setting under lower temperatures because of stress concentration and the destruction of crystalline region [18]. The temperature was chosen from 120 to 180 ℃. Table 1 shows different heat setting conditions of PTT filaments with the sample serial numbers. Number 0 is the control samples that do not have heat setting treatment. YG061 Electronic Single Yarn Tensile Tester was used to test tensile properties, elastic recovery and creep of PTT filaments. The creep is under the certain tension of 70CN (the elongation is 10%) and the elongation is tested after 800 s.

Table 1: Heat setting conditions of PTT filaments (s)

Tension	Temperature (℃)	Time (s)	Sample serial number
Control	25	–	0
Relaxation state	120	30	1
		60	2
		90	3
	140	30	4
		60	5
		90	6
	160	30	7
		60	8
		90	9
	180	30	10
		60	1
		90	12
Tension state (the elongation is 5%)	120	30	13
		60	14
		90	15
	140	30	16
		60	17
		90	18
	160	30	19
		60	20
		90	21
	180	30	22
		60	23
		90	24

3 Results and Discussion

3.1 Tensile Properties

Fig. 1 shows the breaking strength of PTT filaments under different heat-setting conditions. It shows that the breaking strength is decreased after heat setting at the relaxation state except for the sample number 7, as while it is increased after heat setting at the tension state. The highest breaking strength is shown at the temperature of 160 ℃ at the tension state. Fig. 2 shows the breaking elongation of PTT filaments under different heat-setting conditions. It shows that the breaking elongation is increased after heat setting at all different conditions and it shows higher increase at the tension state. Fig. 3 shows that Young's modulus of PTT filaments under different heat setting conditions. It shows that the Young's modulus is decreased after heat setting at all different conditions. The change of breaking strength, breaking elongation and Young's modulus of PTT filaments do not have an obvious change trend with the change of time and temperature under both the relaxation and tension state. The tension applied on the filaments helps to form bigger crystals and make the structure in crystalline zone more complete. The more complete

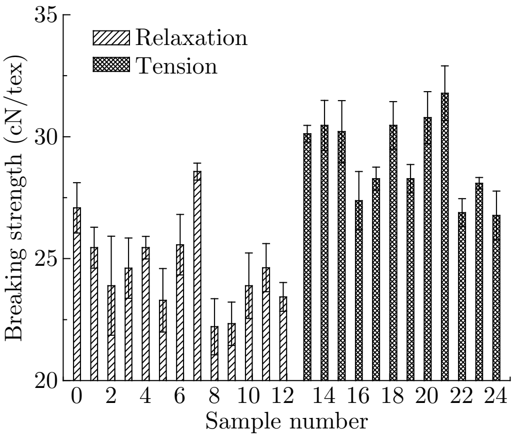

Fig. 1: The breaking strength of PTT filaments under different heat-setting conditions.

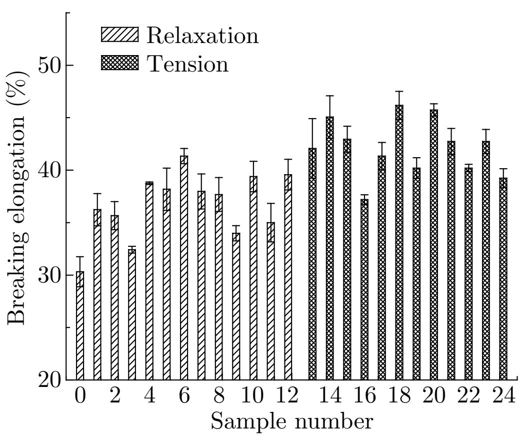

Fig. 2: The breaking elongation of PTT filaments under different heat-setting conditions.

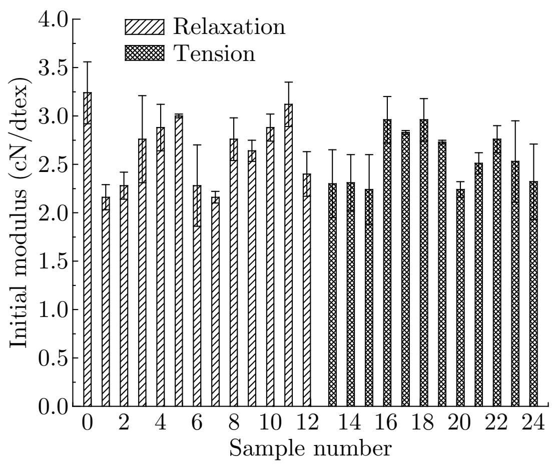

Fig. 3: Young's modulus of PTT filaments under different heat-setting conditions.

structure is helpful to prevent the relaxation of molecular chains in the amorphous zone and make the fiber stronger [18].

3.2 Elastic Recovery

Fig. 4 shows that elastic recovery of PTT filaments under different heat-setting conditions. It shows that the elastic recovery is decreased after heat setting at all different conditions. The decrease of elastic recovery is bigger under the relaxation state than that under tension state especially at the lower temperature. Under tension state, at the higher temperature, the elastic recovery decreased from the temperature of 160℃ to 180℃. The highest elastic recovery of PTT filaments after heat setting is got at 160℃ after 60 s treatment. There have been only a limited number of studies to gain an understanding of the structural features that could influence recovery. It shows that at the relaxation state, the recovery behaviors is dominated by the amorphous phase; at the tension state, both the crystalline and amorphous phases will influence the recovery behavior and this is mainly because of the parallel coupling between them [14].

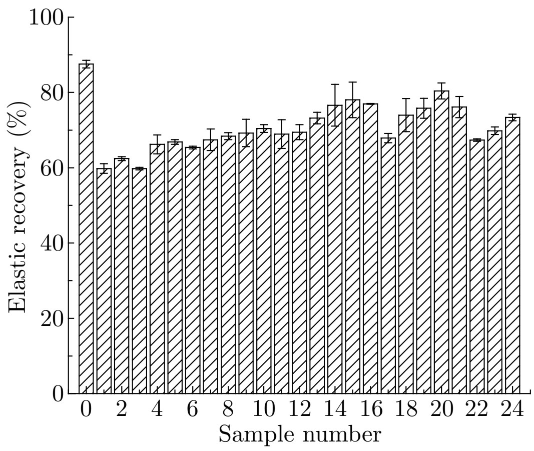

Fig. 4: The elastic recovery of PTT filaments under different heat-setting condition.

3.3 Creep

When stress is applied constantly, there is an increased extension with time in viscoelastic materials. This phenomenon is called creep. Almost all textile materials exhibit an appreciable amount of creep [16]. Fig. 5 shows the elongation of PTT filaments after creep test under different heat-setting conditions. It shows that the elongation after creep test is increased after heat setting at all different conditions. Compared samples 1, 2 and 3 with samples 13, 14 and 15, it shows that elongation increased more under the tension state than that under the relaxation state. Under the tension state, the elongation is increased with the increase of temperature and it gets the highest value at 160℃ after 60 s treatment. After heat setting at 180℃, the elongation is decreased. The increase of elongation after creep test shows that the ductility of PTT filaments is increased after heat setting and the tension loaded on the filaments helps to increase the ductility. This is also because the tension applied on the filaments helps to form bigger crystals and makes the structure in crystalline zone more complete [18].

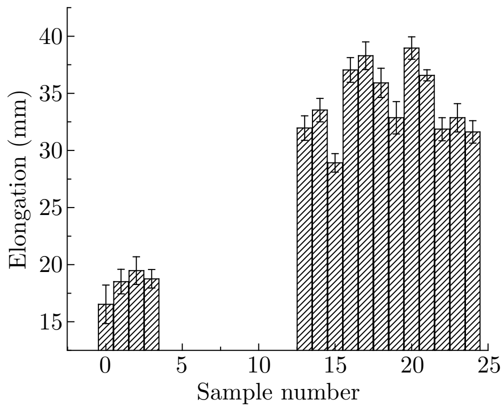

Fig. 5: The elongation of PTT filaments after creep test under different heat-setting conditions.

From the above results, it can be concluded that the best heat setting conditions to get lower modulus, higher elastic recovery and better creep property are at the temperature of 160℃ under the tension state through 60s. These conditions could be used as the recommended heat setting conditions for woven or knitted vascular prosthesis with PTT filaments as weft or warp yarns.

3.4 Factor Analysis

The results obtained were subjected to the analysis of variance (ANOVA) for identifying factors producing significant effects. Table 2 shows factors affecting the elastic recovery and Young's modulus. ANOVA on the results showed that all factors have significant effect on the properties of elastic recovery and Young's modulus at 5% level. The factor of tension state has the biggest F value which means that the tension or relaxation state has the biggest influence on elastic recovery and Young's modulus while time period has the least influence. The study of the effect of heat setting treatment on the microstructure and macroscopic properties of polyesters shows that these effects are manifested by notable changes in crystallinity, crystallite size, density, orientation, dimensional stability and other related properties. Raising the heat-set tension, temperature and time period should improve the overall high-temperature dimensional stability [15].

Table 2: Factors affecting the elastic recovery and Young's modulus

Properties	Factor	Tension	Temperature	Time period
Elastic recovery	F value	116.15	41.68	11.84
	Prob>F	$0.40*10^{-3}$	$3.85*10^{-8}$	$0.83*10^{-2}$
Young's modulus	F value	243.67	19.07	15.47
	Prob>F	$0.10*10^{-3}$	$0.25*10^{-2}$	$0.43*10^{-2}$

4 Conclusion

It is proposed that Poly(Trimethylene Terephthalate) (PTT) filaments are used for fabricating vascular prostheses instead of Poly(Ethylene Terephthalate) (PET) because of their lower Young's modulus and superior elastic recovery. The heat setting process is necessary to keep the stability of shape and mechanical properties as well as make the flattened tubular structures round. However, the best heat setting condition for keeping properties of lower Young's modulus and superior elastic recovery is unknown. The temperature range is chosen from 120 to 180℃ and time period was chosen from 30 s to 90 s. The heat setting of yarns is both done in the relaxed state and tension state. Results show that breaking strength is decreased after heat setting at the relaxation state while it is increased after heat setting at the tension state. Breaking elongation of PTT filaments is increased after heat setting at all different conditions and it shows higher increase at the tension state. Young's modulus is decreased after heat setting at all different conditions. The change of breaking strength, breaking elongation and Young's modulus of PTT filaments do not have an obvious change trend with the change of time and temperature both in the relaxation and tension states. The decrease of elastic recovery is bigger under the relaxation state than that under tension state especially at the lower temperature. Elongation after the creep test increases more under the tension state than that under the relaxation state which indicates that the ductility of PTT filaments increases after heat setting and the tension loaded on the filaments helps to increase the ductility.

The best heat setting conditions to get lower modulus, higher elastic recovery and better creep property are at the temperature of 160℃ under the tension state through 60 s. The tension or relaxation state has the biggest influence on elastic recovery and Young's modulus while the time period has the least influence. Further work is to study the change of microstructure and crystallinity to confirm the change of mechanical properties.

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