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Effect of Heat-treatment on Stretch of Poly(trimethylene terephthalate) Woven Fabric

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Abstract: The properties of a woven fabric made of poly(trimethylene terephthalate) (PTT) were investigated. The PTT fabric of draw textured yarn (DTY) showed excellent stretch as good as a fabric containing spandex. However, the unique stretch of the PTT fabric reduced dramatically by simple heat-treatment even at as low as 80 °C. To understand the phenomenon, the crimp rigidity of the DTY was observed by SEM. It was found that the drastic reduction of stretch was caused by irreversible uncrimping of PTT DTY after heat-treatment. Conclusively, it is of importance to optimize the texturing conditions for PTT DTY to make the crimp more stable.

Keywords: PTT, Woven fabric, Stretch, Heat-treatment, DTY

Introduction

Poly(trimethylene terephthalate) (PTT) was first synthesized by Whinfield and Dickson of Caligo Printing Ink.[1,2]. Further commercialization was slowed by a lack of readily available, inexpensive 1,3-propanediol (PDO), one of the starting materials for the synthesis of PTT. Shell Chemicals has recently commercialized a route based on the hydroformylation of ethylene oxide. PTT is synthesized through polycondensation of terephthalic acid and PDO, which is chemically obtained by the Shell Group and that is biochemically obtained by DuPont.

Shell, which introduced PTT fiber in the name of Corterra in 1996, has given its license to produce textile fibers from the polymer to some operators of different geographic areas including Hubis, Hyosung and Hankook Synthetics Inc. in Korea. The companies have launched PTT yarns and fabrics under their commercial brands of Espol® (1998), Neopol® (1999) and Zispan® (2000), respectively through joint development with Shell.

PTT is a synthetic fiber that has peculiar physical and chemical properties, different from those of PET[3,4]. It has superior characteristics such as good color fastness, outstanding softness, dry touch and excellent elastic-recovery due to it's molecular shape of a helix (spring structure), which is far more elastic than the normal polyester fiber and has low Young's modulus. Thus, PTT fiber is considered to be the most important fiber of the after-polyester period. The developing technology surrounding PTT appears to offer the promise of opportunities in the carpet[4], textiles[5], film and packaging and other market places.

Warmth, handle, natural texture, and appearance are considered to be desirable properties of most textile yarns. Flat continuous synthetic filament yarns do not possess such qualities, though they offer some superior properties, such as high strength, good elasticity, stretch, and abrasion resistance. One of methods achieving these desirable properties is the method of texturing which is the modification process of regular structure of synthetic filaments into somewhat random structures.

POY, which stands for partially oriented yarn, is now the standard feed yarn for the texturing process. It is a continuous filament yarn spun at a speed, which is for example with polyester around 3200 m/min. And through drawing and twisting of POY, drawn textured yarn can be gained. Textured yarn is known in the industry as DTY which can impart bulkiness and extensibility to fabrics. Only synthetic filament yarns can be false twist textured because of their thermoplastic properties.

Stretch is the ability of a textile to extend when a pulling force is applied and then to recover relatively quickly and fully to its original dimensions when that pulling force is removed. Generally, fabrics with $\geq$ 15 % elongation are referred to as stretch fabrics; fabrics with <15 % elongation are rigid fabrics. Most woven fabrics are rigid fabrics because the interlacement of yarns allows little extension to occur under a tensile force. However, stretch woven fabrics can be structured from elastic fibers and yarns such as spandex. Comfort stretch fabrics exhibit 15-30 % elongation. These fabrics provide closer-fitting garments by reducing resistance to body movements. Some woven fabrics made of DTY or containing as little as 2-3 % of spandex may exhibit comfort stretch. On the other hand, the power stretch fabrics which shows 30-200 % stretch are normally gained by knit structure with more amount of spandex is needed.

It is very interesting that the PTT woven fabric made of DTY in this study, showed an excellent stretch up to 40 % as good as a power stretch fabric containing spandex. In this paper the effect of heat-treatment on the stretch of PTT fabric was studied by investigating crimp properties of DTY before and after heat-treatment.

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Experimental

PTT POY and DTY were supplied by Hankook Synthetic Co. The DTY was texturized by false twist method at 160 °C. The PTT greige fabric used in the study was a twilled fabric woven with 75/24 and 150/48 DTY yarns for warp and weft, respectively. The yarns and fabrics were heat treated in a liquid medium (PEG 400) at temperatures, 80 °C, 120 °C, and 160 °C at a constant length condition or in free state for one minute.

Mechanical properties of PTT filament yarns and fabrics were measured using a universal testing machine (Instron 4456). For the mechanical test of DTY yarns, specimens were prepared at a free state with a length of 5 cm and a test speed at 25 mm/min. Fabric were cut to 5 mm × 50 mm in width and length to test at a speed of 25 mm/min.

Thermal properties of PTT fibers were analyzed using DuPont DSC 910 at a heating rate of 20 °C/min. The change of crimp of DTY yarns and texture of twill fabrics were observed using a scanning electron microscope (Hitachi S-2400).

Results and Discussion

The purpose of texturing is to set the filament into crimped shapes so that the yarn and fabric produced by such filaments have a substantial degree of stretch and bulkiness. Figure 1 represents typical tensile curves for PTT-POY and DTY. The PTT-DTY made from POY exhibits an uncrimping region up to 40-50 % elongation which is not seen in the case of POY. Although the PTT-POY used in the study was manufactured at the same spinning speed, 3200 m/min as that of PET-POY. The PTT-POY showed around 80 % elongation much lower than 130 % which is generally known in PET-POY[6].

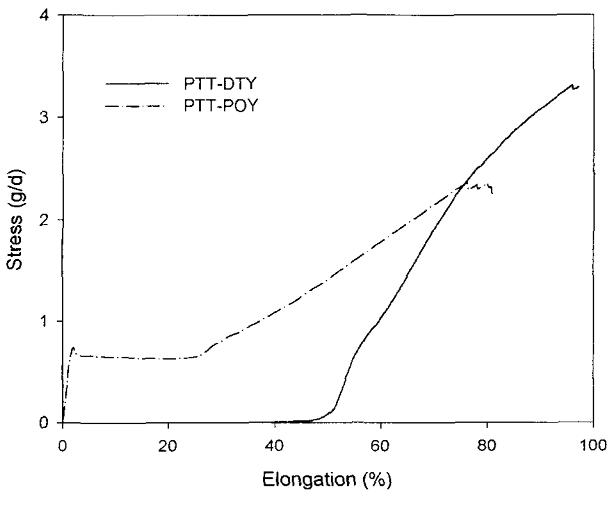


Figure 1. Typical tensile curves of PTT-POY and PTT-DTY.

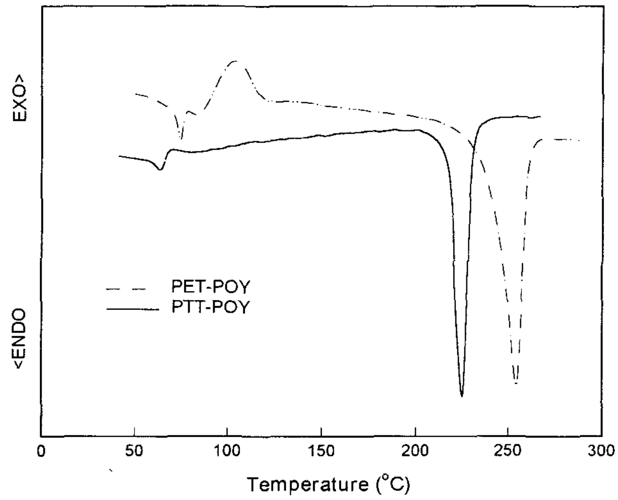


Figure 2. DSC heating curves of PET-POY and PTT-POY.

In order to investigate this difference, thermal properties of the two POYs were analyzed using DSC. It has been reported that PTT crystallizes faster than PET while slower than poly(butylenes terephthalate)[7-10]. As shown in Figure 2, PTT-POY exhibits little trace of cold crystallization which is clearly seen in the PET-POY just above glass transition temperature (T_g). This implies that PTT-POY has already crystallized fully during spinning process while PET-POY did partially at the same condition due to slower crystallization rate of PET than that of PTT. Moreover, PTT shows T_g and melting point (T_m) at 50 °C and 225 °C, respectively, which are lower than those at 80 °C and 255 °C of PET. This inferior thermal properties of PTT considered to be caused by longer methylene groups in propanediol than in ethylene glycol. Thus, PTT is more flexible than that of PET.

Conclusively, it is considered that the faster crystallization rate of PTT resulted in higher crystallinity to PTT-POY during spinning process which caused again the lower elongation of PTT-POY than that of PET-POY manufactured at the same condition.

Textured yarns can be divided into two broad groups, stretch textured yarns and spun-like textured yarns[11]. Stretch textured yarns are characterized by their high extensibility and good recovery, but possess moderate bulk compared with spun-like textured yarns. Because the zigzag or helical forms are a function of molecular rearrangement, when the loads are removed the filament recovers and attains the original crimped shape. Stretch yarns are produced by the thermo-mechanical texturing processes such as false-twist or stuffer-box method. The PTT-DTY used in the study is a kind of stretch yarn by a false twist method for the use in stretch-to-fit garments in which extensibility and recovery from stretch are of primary importance.

The woven fabric made of the PTT-DTY in this study showed an extraordinary degree of extensibility and recovery compared to the fabric made of PET-DTY. The degree of stretch in the PTT fabric was comparable to that of a fabric containing elastic fiber, spandex. The company which supplied this material was interested in the excellent stretch of the PTT-DTY fabric. That is why it named the fabric as Zispan by combining 21 (21st century) and spandex. The excellent elastic recovery of PTT fibers are related to the unique structure of PTT molecules. It is well known that PTT molecules have an extended zigzag chain conformation by using *n*-methylene glycol with odd-number, propandiol, while PET molecules exhibit a fully extended chain conformation[7]. This PTT conformation induces a kind of spring-like structure to molecules resulting in excellent elastic recovery, stretch, and resiliance of fibers and yarns. However, this molecular conformation is not enough to explain the extraordinary stretch of the fabric while it is enough for the excellent elastic recovery which is of importance for the use in carpet.

In general, when the stretch textured yarn is heated in a relaxed state, the degree of stretch decreases while the bulk of the yarn is improved. The PTT fabric was heat treated at a constant length or in free state in order to investigate the effect of heat-treatment on the stretch of the fabric. Figure 3 and 4 shows the tensile curves of the PTT fabric before and after heat-treatment at a constant length and in free state, respectively. The unique uncrimping region for the untreated DTY fabric was clearly seen. However, it is notable that the uncrimping region decreases with increasing treatment temperature, which implies that the stretch of the PTT fabric reduces by heat treatment. The reduction of stretch was more severe in the taut condition than in free tension, as represented

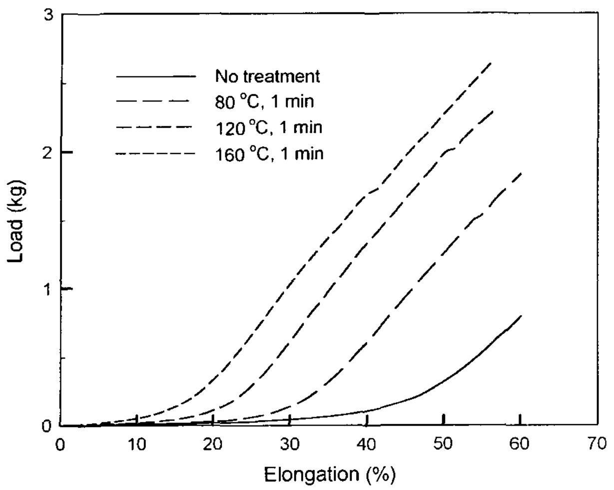


Figure 3. Stretch change of PTT woven fabrics with heat-treatment at various temperatures in constant length for 1 min.

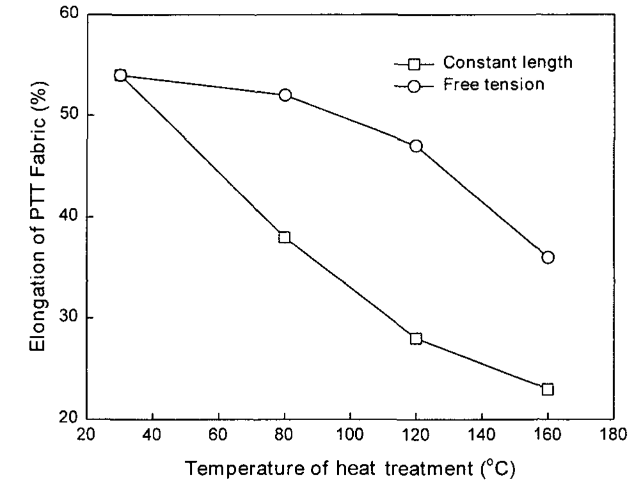


Figure 5. Change of elongation of the PTT fabric with heat-treatment temperature (0.5 kg load to 5 mm-wide specimen).

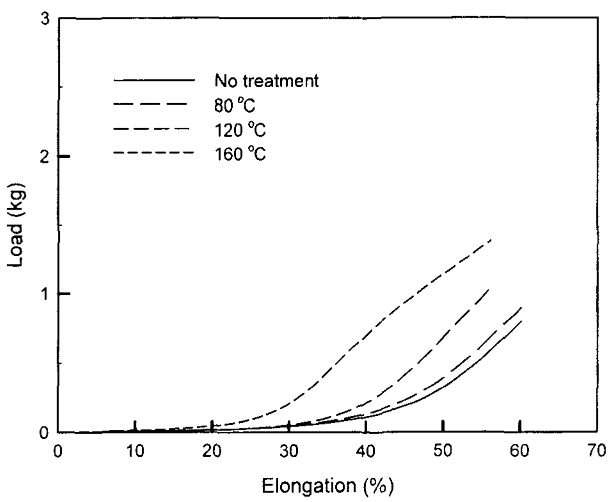


Figure 4. Stretch change of PTT woven fabrics with heat-treatment at various temperatures in free state for 1 min.

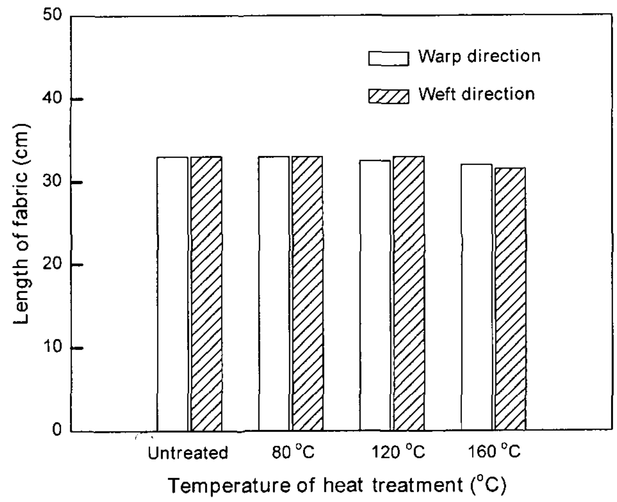
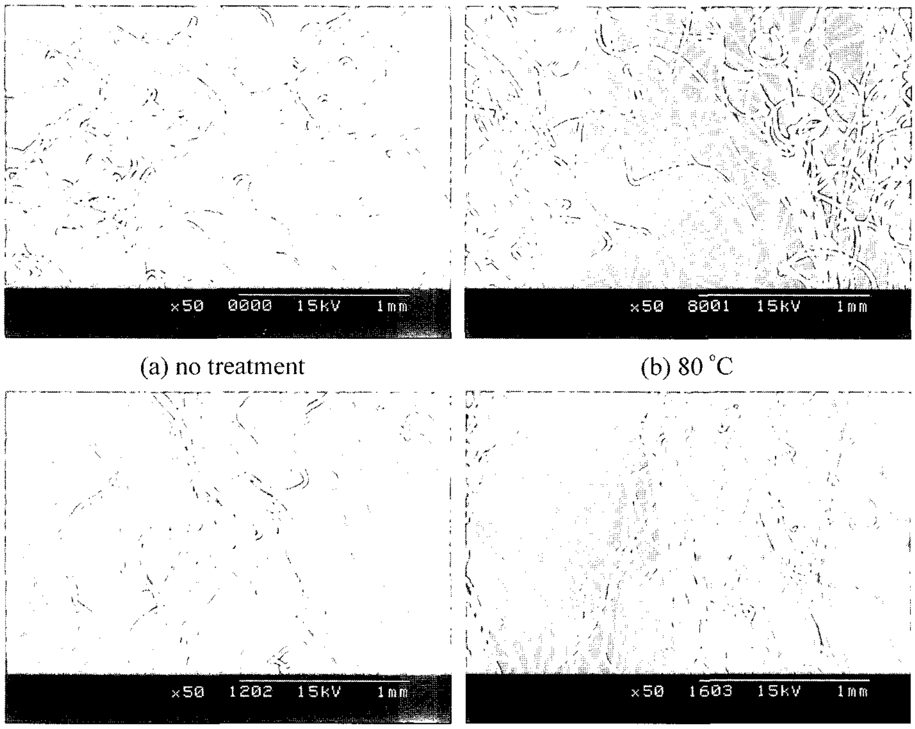


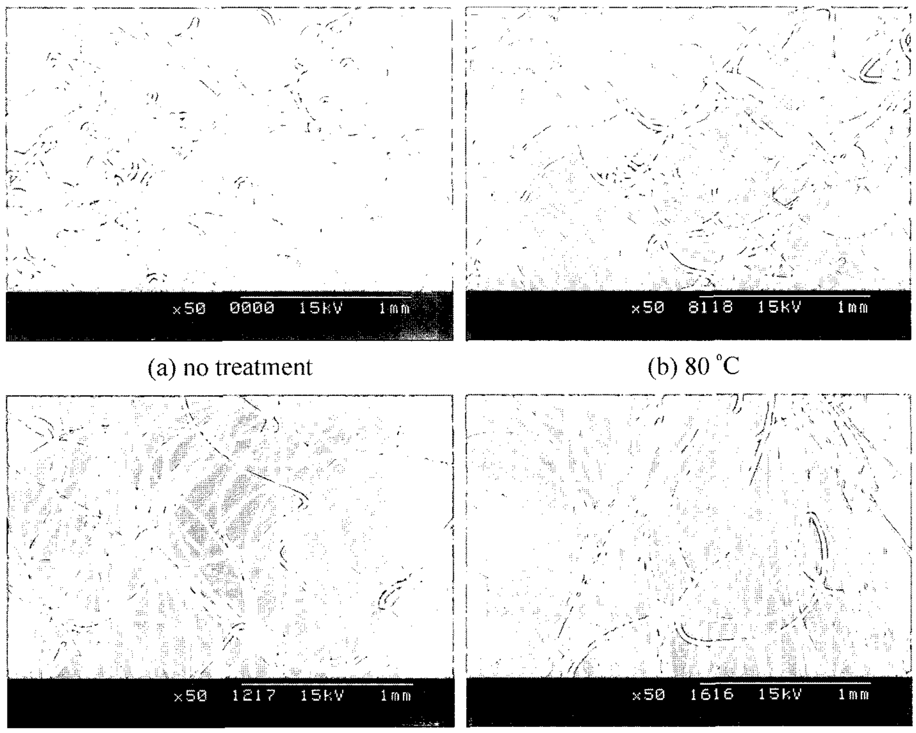
Figure 6. Effect of heat treatment on dimensional change of PTT woven fabric in free state.



(a) no treatment (b) 80 °C

(c) 120 °C (d) 160 °C

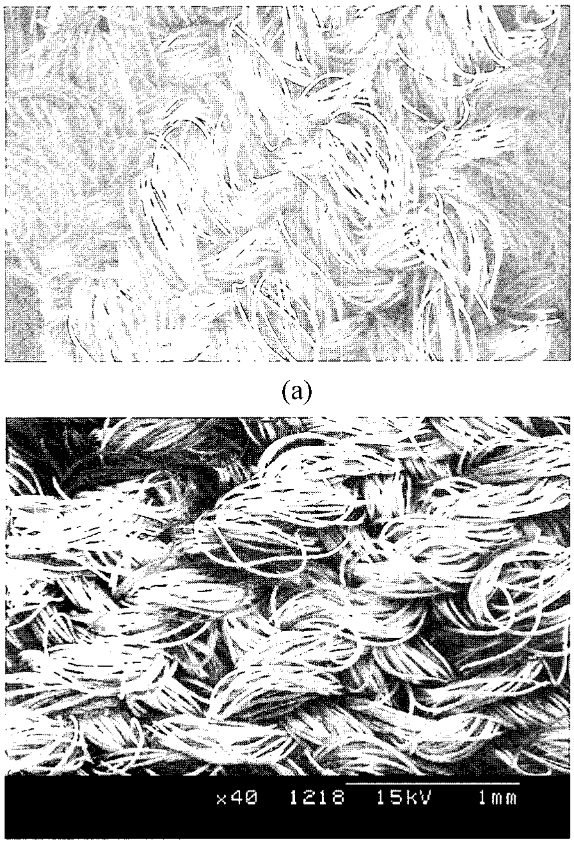
Figure 7. SEM photographs of PTT-DTY before (a) and after heat-treatment at various temperatures (b-d) for 1 min. without tension.



(a) no treatment (b) 80 °C

(c) 120 °C (d) 160 °C

Figure 8. SEM photographs of PTT-DTY before (a) and after heat-treatment at various temperatures (b-d) for 1 min. with tension.of 0.03 g/d.



(a)

(b)

Figure 9. SEM photographs of PTT fabric before (a) and after (b) heat-treatment at 160 °C for 1 min.

in Figure 5. This reduction in stretch of the fabric after heat-treatment was enough to be felt by hand.

On the other hand, there was little change in dimension of the fabric after heat-treatment regardless of tension during the treatment, as shown in Figure 6. As the stretch of the fabric was mainly a result of crimp rigidity of DTY, it is considered that the crimp property has changed after heat-treatment.

The SEM microphotographs in Figure 7 and 8 show the shape change in crimp of the DTY by heat-treatment at taut and free conditions, respectively. The crimps produced by false twist texturing process are considered as three-dimensional crimps, which consists of a helices twisted in the S and Z directions and connected by a reversal zone[12], as shown in Figures. It is clearly seen that considerable amount of the crimp was relaxed with increasing treatment temperature. The images also show that there occurred more severe uncrimping in taut condition than in free condition. Figure 9 exhibits the change in the surface texture of the fabric before and after heat-treatment at taut condition. The surface seems to be flatter after the treatment. Thus, it is concluded that the drastic reduction of stretch in the PTT-DTY fabric after heat-treatment was originated from the irreversible uncrimping of the DTY used in the fabric.

Conclusions

The fabric made of PTT-DTY fabric showed excellent stretch up to a level of power stretch fabric. However, the unique stretch of the PTT fabric reduced severely by simple heat-treatment even at 80 °C. It was found that the drastic reduction of stretch was caused by irreversible uncrimping of PTT-DTY after heat-treatment. In general, crimp rigidity of the DTY is proportional to the temperature of draw-texturing[13]. Lower T_g and T_m of PTT prohibit to increase the texturing temperature up to that of PET. Since it seems to be clear, however, that PTT-DTY fabric exhibits better stretch than PET-DTY fabric, it is of importance to research on the optimization of texturing conditions for PTT-DTY.

Acknowledgement

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