Effects of Fiber Crimp Configurations on the Face Texture of Knitted Fabrics Made with PTT/PET Bicomponent Fibers

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ABSTRACT

PTT (Polytrimethylene terephthalate)/PET (Polyethylene terephthalate) bicomponent filament is a new type of polyester fiber with excellent elasticity and other desirable fiber properties. It is used extensively in woven fabrics, however, when used in knitted fabrics it has a tendency of showing severe random uneven surfaces. The causes of this problem and ways to overcome it were investigated. Fabric surfaces and yarn crimp configurations of several knitted fabrics made with PTT/PET bicomponent filaments were studied by optical microscopy. Attempts to adjust the tensions and yarn speeds during knitting could not eliminate the unevenness entirely, especially when the fabrics were wet-heat treated. From microscopy and heat-treatment studies, the major cause for this unevenness was found to be due to the development of tight crimp configurations, which produced reversal points and changed the helical crimp directions after heat-treatment. They caused light to reflect differently, and the random tight crimps caused fabric to protrude and, therefore, the unevenness. This problem was mitigated by using PTT/PET filaments made by a new yarn manufacturing method, which controlled the development of crimp configurations and prevented the formation of reversal points and helical crimp direction changes.

INTRODUCTION

PTT/PET side-by-side bicomponent filament is a new type of self-crimping conjugated polyester fiber with excellent elastic properties. At 20% strain the fiber recovery was reported to be >92%, and woven fabrics made with these fibers have a stretch ratio of as high as 25%[1]. Invista's T400 and Huvis's ESS are two of the more well known commercial PTT/PET bicomponent fibers. These fibers consist of side-by-side PTT and PET components with 30/70, 40/60 or 50/50 proportions by weight, respectively, and are melting spun by a conjugated fiber spinning process. There are two reasons why the PTT/PET bicomponent fibers develop crimps: (1) because of the asymmetric distribution of the two components in the fiber cross-section, and (2) the differential shrinkages of the PTT and PET components when the fibers are heat-treated. These cause the bicomponent fiber to develop high frequency spatial helical crimp geometries similar to the appearance of a telephone wire. These crimps offer exceptional good stretch and wrinkle recoveries, and bulk to the yarns and fabrics.

In recent years, a significantly large volume of PTT/PET bicomponent fiber elastic woven fabrics were used in sportswear, elastic suede, high-temperature printing fabric, worsted woven fabric, shirt fabric, etc. These fabrics possess good permanent stretch and elastic recovery, and they are also quite resistant to high temperature and acid or alkali exposures. Although PTT/PET bicomponent knitted fabrics are known to have even much better elastic recovery and stretch ratio than woven fabrics, their development lags behind those of the woven fabrics.[2, 3, 4]

The main reason that PTT/PET bicomponent filaments are not used in knitted fabric is that the fabric surface tends to develop severe uneven appearance. It would be regretful if the good elastic properties and hand of the PTT/PET bicomponent fibers could not be successfully exploited for knitted fabrics. Fortunately, a newly developed filament manufacturing process had purportedly solved this problem. In this paper, we compared knitted fabrics made with PTT/PET bicomponent and PTT fibers to show the underlying problem; experimented with controlled knitting process parameters to solve the problem, and showed that bicomponent fiber crimp development after heat treatment was the main cause of fabric surface unevenness, and how to improve them.

EXPERIMENTAL

Knitted Fabrics Used for Surface Unevenness Study

Four seemless knitted fabrics made with a SANTONI (Italy) SM8-TOP2 circular electronic seamless wear machine[5] were used for comparing the effects of PTT/PET bicomponent and PTT fibers on fabric surface unevenness.

TABLE I. Specifications of the Seemless Fabrics for Surface Appearance Analysis

Fabric number		Material Specifications				
		Fabric texture	Ground yarn	Color	Face yarn	Color
Set 1	1	Plain	83.3dtex/32filament PTT/PET FDY	purple	77.8dtex/48f Nylon DTY	purple
	2	Plain		brown	83.3dtex/36f PET DTY	brown
Set 2	3	Plain	83.3dtex/32filament PTT DTY	jacinth	77.8dtex/48f Nylon DTY	jacinth
	4	Plain		orange	83.3dtex/36f PET DTY	orange

TABLE II. Knitting Technical Parameters

Index		Technical Parameter
Machine size		14' (11.2 needles/cm)
Fabric texture		Plain planting
Material	Ground yarn	83.3dtex/32f PTT/PET FDY
	Face yarn	77.8dtex/48f Nylon DTY

Table 1 shows their specifications. The fabrics could be divided into two sets. The first set consisted of fabrics 1 and 2, which used 83.3 dtex/32f filament PTT/PET bicomponent fibers as ground yarns; the second set, fabrics 3 and 4, used PTT fibers as the ground yarns. The face yarns for the two sets of fabrics were either nylon or PET DTY as shown in *Table I.*

Knitting Parameters for Adjusting Fabric Surface Flatness

During knitting tensions and speeds of the feed yarns are the two main factors affecting surface evenness and tightness of a knitted fabric. To improve surface flatness, tensions and yarn speeds in this study were adjusted by the following two methods:

The first method used instrumentations to detect (or control) the yarn tensions and speeds. During knitting the dynamic tensions of the feed yarns were measured with a tension monitor (tension meter) to keep each yarn's tension consistent throughout the process. At the same time, speeds of the feed yarns were measured with a velocity monitor and were controlled by the press motors to maintain equal speeds for all the feed yarns.

The second method needs the technical expertise of the operating technician. The technician marked one of the yarns to distinguish the needle track on the fabric surface. A trial knitting was carried out, the tightness of each yarn route in the fabric was compared, then the tension and press motor were adjusted to regulate the feed yarns' speeds to obtain a fabric with good surface appearance. The parameters used are shown in *Table II.*

Fiber and Fabric Images

Photographs of the PTT/PET knitted fabric surface textures were acquired using a Samsung Digimax i5 digital camera with a 3X optical zoom in close-up mode.

The image resolution was 5.0 mega pixels. Images of the PTT/PET filament crimp configurations were obtained using a digital three-dimensional video microscope (HI SCOPE Model KH-1000) with magnifications in the range of 50-400.

Wet-Heat Treatment

To simulate the bicomponent fiber crimp configurations of the final fabric, PTT/PET fibers and their fabrics were heat-treated at 90℃ for 20 minutes[6] in a XMT-6000(Shanghai Laboratory Instrument Co., Ltd. China) hot water bath. Individual filaments were immersed in the hot water bath separately to avoid them from sticking to each other and to prevent fiber damages. The heat-treated filaments and fabrics were then conditioned in a controlled laboratory conditions with a constant temperature of 20±2℃ and a relative humidity of 65±3% for at least 16 hours.

ANALYSIS ON CAUSES OF THE UNEVEN SURFACES

Fabric Surfaces

Bicomponent filaments are often used as ground yarns in knitting with PET, nylon, cotton, wool or spandex fibers as the face yarns. *Figure 1* shows the photographs of fabrics 1 and 2's surfaces. These fabrics used PTT/PET bicomponent fibers as the ground yarns while the face yarns were either nylon or PET as indicated in *Table I.* The surfaces of fabrics 1 and 2 showed distinct and very obvious random unevenness. *Figure 2* shows the photographs of the control fabrics 3 and 4 using PTT filaments as the ground yarns, the corresponding face yarns were the same as those of fabrics 1 and 2, respectively. None of the control fabrics shows any random unevenness in the surfaces like those of the first set of fabrics using PTT/PET bicomponent fibers.

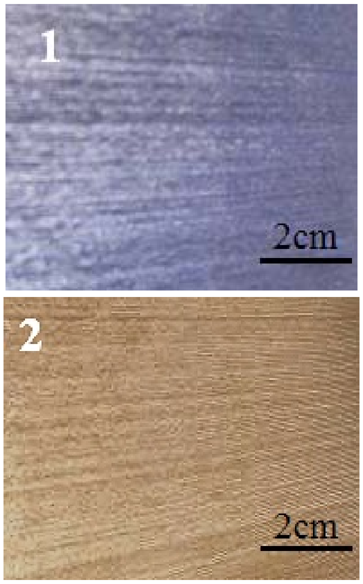


FIGURE 1. Surfaces of knitted fabrics using PTT/PET ground yarns.

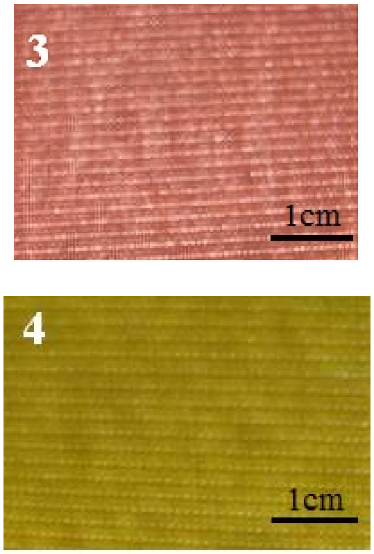


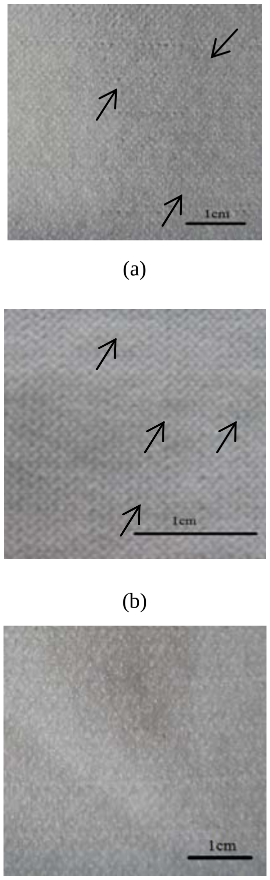
FIGURE 2. Surfaces of knitted fabrics using PTT ground yarns.

Since the two sets of fabrics used the same nylon and PET DTY face yarns, respectively, and had the same knitting constructions, we concluded that the unevenness had to be caused by the PTT/PET bicomponent ground yarns.

Surface of Fabrics from Adjustments of Knitting Parameters

We also experimented with adjusting the speeds and tensions of the feed yarns by using a combination of instrumentations and by leveraging the technician's experience, as described in Section Knitting Parameters for Adjusting Fabric Surface Flatness, to make fabrics with even surfaces. *Figure* 3 shows the surface textures of the PTT/PET knitted fabrics made by the above adjustments.

Figure 3(a) is the surface of a greige fabric knitted by a normal process without any special adjustments for flatness, and *Figure 3*(b) is the greige fabric surface in which the yarn speeds and tensions were adjusted through a combination of the above two methods. Comparing these two photographs, the surface of the fabric without any adjustment shows serious random unevenness which was denoted by arrow marks in the picture, however, the unevenness disappeared in the fabric with tension and yarn speed adjustments, *Figure 3*(b). However, when the fabric of *Figure 3*(b) was wet-heat treated distinct unevenness appeared, *Figure 3*(c). We repeated the experiments several times with different knitting adjustments, although the fabric's face textures could be improved to some extents, unevenness could not be completely eliminated after wet-heat treatment. We have showed that fabrics made with PTT ground yarns did not have surface unevenness regardless of whether nylon or PET face yarns were used, and with this study we concluded that fabric textures and knitting parameters were not the causes of surface unevenness. The unevenness has to come from some fundamental properties of the starting materials used in making the fabrics. We, therefore, focused our study on the properties of the PTT/PET bi-component filaments as a likely cause of the unevenness.



(a)

(b)

(c)

FIGURE 3. Surfaces of the PTT/PET Knitted Greige Fabrics:(a) without adjustment, (b) with adjustments, and (c) fabric after wet-heat treatment.

Crimp Configuration of PTT/PET Filaments

The PTT/PET bicomponent fiber used in this study had an evenness coefficient of variance, CV %, of about 1%. Yarns with such a CV% value are considered as very uniform and are acceptable for textile use in the industry. Therefore, bicomponent filament evenness CV% was not likely a source causing the fabric's surface unevenness. Since fabric unevenness occurred only after the wet-heat treatment of an even greige fabric, we focused our study on the development of crimp configurations of the PTT/PET bi-component filaments before and after heat treatments. *Figure 4* shows a typical helical configuration of a PTT/PET filament in an unstrained state. Such a configuration is typical and could be found all along the filament.

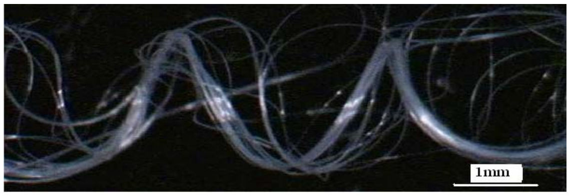


FIGURE 4. Crimp configuration of a PTT/PET bicomponent filament.

When the PET/PTT knitted fabrics were examined, the directions and arrangements of the stitches were found to change randomly in areas where surface unevenness occurred. This observation was similar to features found in the shadow stripes of fabrics made by using alternate S- and Z-twist yarns with different twist directions. We, therefore, speculated that the unevenness surface could have come from the unusual PTT/PET crimp configurations after heat treatment.

To simulate the finishing process of a fabric, normal PTT/PET filaments were coated with a piece of absorbent gauze and then heat-treated in a hot water bath. *Figure 5* shows a random segment of the treated filaments; the crimp configuration formed a tight helix with very high frequency of turns. Compared to *Figure 4*, the crimp configuration changed dramatically after wet-heat treatment; crimp loop sizes became more compact and smaller than those of the untreated filaments. Instead of a uni-direction spatial helix along the length of the filament, the treated filament developed left- and right-hand helices separated by a reversal point.

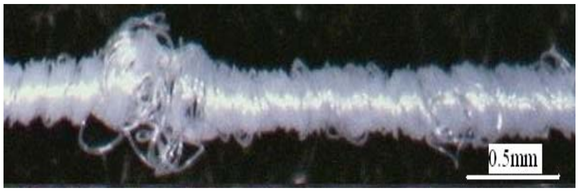


FIGURE 5. Crimp configuration of PTT/PET filament after wet-heat treatment.

The reversal points were found to occur irregularly along the PTT/PET filament. *Figure 6* shows a close-up image of the reversal point; distinct opposite direction spirals forming right- and left-handed helices could be clearly seen on both sides of the reversal point. The formation of reversal points had been attributed to the bicomponent fibers trying to eliminate torsional forces generated by the high spatial crimps in the axial direction in prior studies[7, 8]. Although reversal points also occur in the untreated filament, they are difficult to observe, because they are too small and few frequent. They are, however, easily observed in the treated filaments. Unlike the crimp geometries shown in *Figure* 5, helical crimps of a heat-treated filament were rather disordered in some segments of the filament. Since it is very hard for all filaments in the skeins to co-operatively curve in unison; variations in the crimped loop sizes and the adjacent left- and right- hand helices caused light to reflect differently at different parts of the yarns, as a result, the PTT/PET knitted fabric surface appeared uneven. The effects are analogous to the traditional shadow-stripes fabric obtained by the use of alternating S and Z twist yarns. The difference between these two kinds of fabrics is that the direction of twist changes within a single PTT/PET yarn, whereas in the shadow- stripes fabrics the twist direction changes for the two interlaced yarns.

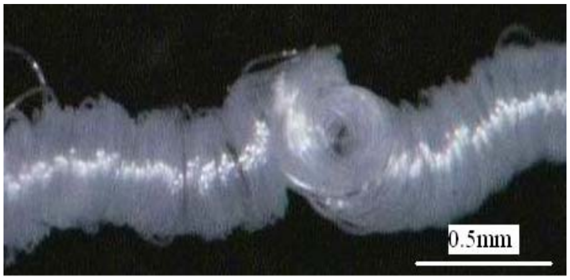


FIGURE 6. Reversal point of a heat-treated PTT/PET filament.

This deduction was further confirmed by a further careful examination of *Figure 1*. In the finished PTT/PET knitted fabric, crimps of the PTT/PET filaments in the fabric contracted by a lesser extent than that of an unconstrained single PTT/PET filament as shown in *Figure* 5 because of the constraints imposed by stitches of the knitted fabric. Crimp configurations of the adjacent left- and right-hand helices, and the reversal points in the fabric result in protuberant or sunken parts to appear discontinuously in the same course direction, that is to say loop sizes in some wale directions are not always the same as those of the sideway routes. Therefore, the PTT/PET knitted fabric surface appeared uneven. However, such a phenomenon does not readily occur in PTT/PET woven fabrics because of the tighter fabric structure, which does not allow development of excessive high crimps during the finishing process.

IMPROVED FABRIC SURFACE KNITTED WITH THE NEW PTT/PET FILAMENTS

Based on the above analysis, a new improved process for making PTT/PET bicomponent fiber to control the crimp configurations after heat treatment was developed; details of the process were described in the patent application.[9] In the new process, the PTT/PET bicomponent fibers were first twisted and pre-set to reduce the torsional forces and high crimps, which caused reversal points and changes in the helical directions after heat-treatment. There are four steps needed to obtain the new PTT/PET filament. Firstly, it is necessary to undergo the twisting process for PTT/PET filament. Secondly, the twisted filament should be set via twist setter by steaming or heating at 70~100^{o}C for 20~60 minutes. Finally, during the knitting process, the PTT/PET filaments with S and Z twist directions are alternate to knit, especially for the knitted fabric easy to produce bias. Furthermore, the important parameter for the process is twist number, which has been explained in our former paper [10]. We have invested the crimp configurations of PTT/PET filaments with different cross-section shapes. The results showed that there was a linear relation between the optimum needed twist number and fiber linear density.

Figure 7 shows the helical crimp configuration of a PTT/PET filament made by the improved process, the helices were uniform and the turns were in one direction only. After heat treatment, the filaments did not develop reversal points along the length of the fiber, as shown in *Figure* 8.

When these new PTT/PET bicomponent filaments were knitted, it was much easier to adjust the machine parameters to control the fabric's flatness and tightness than those of the normal PTT/PET filaments. Thus an even surface PTT/PET knitted fabric could be obtained and maintained its evenness after finishing. Such an improvement allowed the potential development of a distinctive PTT/PET knitted fabric product line.

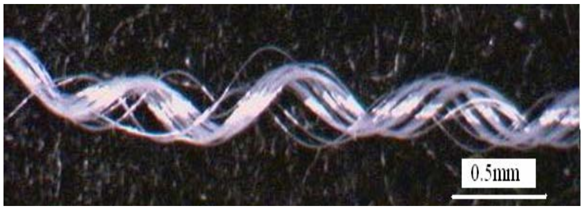
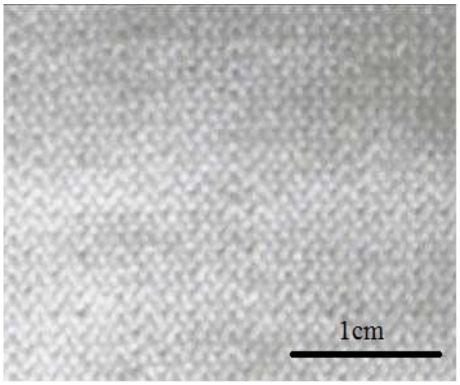


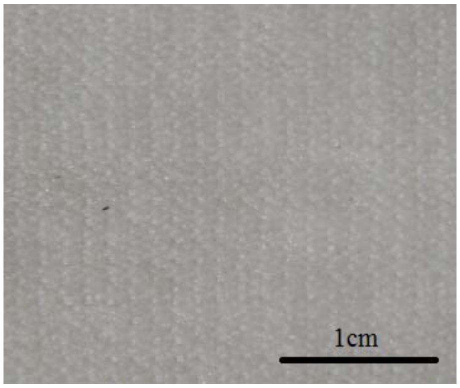
FIGURE 7 Configuration of the new PTT/PET filament.

FIGURE 8. Configuration of new PTT/PET after wet-heat treatment

*Figure*s 9(a) and (b) are the face textures of knitted fabrics with the new PTT/PET bicomponent filaments. Random unevenness no longer occurred, and the fabric surfaces are much tighter and evener. Therefore, knitted fabric unevenness from irregular crimp configurations of the PTT/PET bi-component filaments after heat treatment was eliminated. This study shows that the development of regular crimp configurations is very important for obtaining a knitted fabric with even surface.



(a)



(b)

FIGURE 9. Surfaces of knitted fabrics made with the new PTT/PET filaments: (a) before and (b) after wet-heat treatment.

CONCLUSIONS

Comparisons of knitted fabrics made with PTT/PET bicomponent and PTT filaments showed that surface unevenness occurred only in fabrics made with the bicomponent filaments. Heat treatment studies showed that the PTT/PET filaments developed random reversal points along the filaments. On each side of the reversal point, the helical twist directions changed; because of differences in light reflections they caused fabrics to have uneven appearances. This problem could not be eliminated by the typical methods used in adjusting and controlling the feed yarns' tensions and speeds for fabric flatness. Even in greige fabrics that appeared flat, unevenness occurred once the fabric was heat-treated. Using a new type of PTT/PET filaments pre-twisted to control the development of a more uniform crimps during finishing, occurrence of reversal points and different helical hands were eliminated, random unevenness in the PTT/PET knitted fabrics were eliminated entirely.

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