Studies on Stuffer-Box Crimer: Part IV—Crimping of Polyethylene Terephthalate Multifilament Yarns and Their Crimp Characteristics

R K SINGH & R C D KAUSHIK
Technological Institute of Textiles, Bhiwani 125 022
&
A K SENGUPTA
Indian Institute of Technology, New Delhi 110 016

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The processing of polyethylene terephthalate (PET) multifilament yarns through the stuffer-box crimper does not require special changes, except ensuring controlled rates of heating and cooling. The characteristics of 2-ply and single PET yarns differ only when processing is done at low temperatures. The processing of PET yarns yields the best results in the temperature range 200-220°C of the preheater tube.

In the latest versions1-3 of the stuffer-box crimping technique, the preheated multifilament yarn is impelled into a cooled tube where the yarn buckles, collapses and simultaneously sets into a new matrix. A regular 'V' shaped crimp free from dyeing problems and with negligible crimp loss due to the withdrawal tension are the advantages claimed for the modified processes. For better results, the choice of variables and other processing conditions is made on the basis of physical parameters of the yarn and the mechano-thermal behaviour of the polymer. Thermal shrinkage4 in most of the thermoplastic yarns (polyethylene, polypropylene, nylon-6 and nylon-66) occurs over a relatively narrow temperature range near \( T_m \), while in PET yarns, it follows over a wide range of temperature above \( T_g \). Heat capacity and thermal conductivity values of PET yarns are lower compared to those of nylon-6 and as a result, the heating and cooling conditions would have to be chosen carefully while processing these yarns through the stuffer-box crimper. The processing conditions for nylon-6 yarns have been explained earlier5. The present paper reports the conditions of crimping favourable to PET yarns and explains the crimp characteristics of PET yarns.

**Experimental Procedure**

The modified stuffer-box crimper6 was set to run at the impelling speed of 80 m/min and 0.2 g/den tension in the region of preheater tube of sufficient length to have a yarn residence period of 0.9 sec and 0.6 sec for 2-ply (150 tpm) and single (200 tpm) PET multifilament yarns of 76 den/24 fil. The processing of yarn was carried out over a wide range of preheater temperature (80-220°C). Beyond 220°C, the processing was not possible due to sticking of filaments at the roller nip.

A specially designed brass stuffing tube of 73 mm length and 4.5 mm inner diameter was used with the egress tube of 65 mm length and 3.2 mm inner diameter. The outer diameter of the egress tube was just enough to slide it inside the stuffing tube without friction. The egress tube weighed 28.2 g and it was used for both the yarns. The supply of chilled water to the cooling chamber was maintained at constant rate through the water cooler at 15°C. The yarn cooling period or the residence period inside the stuffing tube was 22-25 sec. The cooling rate was increased by increasing the water flow rate in the cooling chamber. The nip pressure was set approximately to 2 kg/cm and the post-setting temperature was maintained at 200°C for 1 and 0.5 min for 2-ply and single PET yarns respectively. The 2-ply yarns were separated into singles by the reeling process and later converted into cones.

The projection microscope was used for measuring the buckling length and the crimp angle by a method reported earlier2.

The crimped yarns were laid on a glass plate graduated length-wise in centimetres. A pre-tension was applied to keep the yarns straight along the scale, but the tension was not allowed to increase to the extent of causing any alterations in the crimp angles. The number of crimps was counted with the help of a microscope in several 10 cm length pieces of each sample and their average values were calculated in terms of crimp/cm as \( c \).
The crimped yarn denier was measured as reported earlier. The yarn collapse values were measured by the method used for Banlon yarns. The crimp rigidity was measured by the HATRA method. All the samples were tested in an atmosphere of 62% RH and 26°C temperature.

Results and Discussion

The nip pressure applied to the filaments causes an axial deformation which changes their cross-sectional shape. These changes are effected gradually from the contact point of the filament with the roller surface to the axis of stress symmetry. The filaments contain a greater proportion of induced deformations which are accelerated due to the thermal activation energy of the polymer. PET yarns are sensitive to thermal energy even at low temperatures, which is evidenced by the gradual shrinkage experiments as well as by the losses in the tensile modulus. Therefore, while processing the preheated PET yarns through the crimper, the magnitude of deformations should be amplified considerably by imposing axial deformations at the roller nip.

The crimp characteristics of the yarn are the resultant effect of the above axial deformations as well as axial compression which induces a major molecular disorder in the structural matrix of the filament and is followed by the cooling process, stabilizing a new filament matrix of crimped yarn. Distortions in PET yarns are expected to be considerably higher than in polyamides and, therefore, they would buckle instantaneously, straining the outer matrix and compressing the inner one, either side of the neutral plane. When PET molecules are strained at a higher temperature, crystallization is induced and, therefore, the outer matrix under strain is likely to be crystallized and some crystallization might also be induced in the compressive zone, improving the crimp stability. The outer matrix would resist the straining forces, whereas the inner matrix would yield to the applied strains.

An interesting phenomenon observed was that PET yarns were difficult to process beyond 220°C due to sticking at the roller nip and the crimps produced with preheater temperature 220°C were almost jammed in such a way that after release of strain the recovery was not possible in a few segments of the yarns. The feel of the yarn was also harsh and spiky.

Effect of processing conditions on the appearance of crimp—The crimps were regular in both the yarns produced above 180°C, as seen through the projection microscope. Both the yarns contained a large proportion of spatial crimp, a few segments of uniplanar crimp and crimp discontinuity (Fig. 1). The yarns produced below 180°C showed major crimp irregularities in respect of buckling length and crimp angle, particularly in single yarn processing. The 2-ply yarns showed more structural compactness than the singles, although the processing conditions were the same for both the yarns except the duration of heating the yarns. The 2-ply yarns, being thicker, were more distorted and the yarn plug density, being quite uniform, in combination resulted in a regular spatial crimp of compact nature.

During the segregation process, the filaments occupying extreme positions probably escaped large axial deformations at the point of stress symmetry of the roller nip. Axial compression, causing tangential buckling of the escaped segments resulted in discontinuity of crimp in the yarns. Another probable reason reported earlier is associated with the

![Fig. 1—Crimp discontinuity due to crawling of crimped segments inside the stuffing tube](image1)

![Fig. 2—Temperature versus buckling length of crimped yarn ([0-0-0] single of 2-ply yarn; and [x-x-x] single yarn)](image2)

![Fig. 3—Temperature versus crimp angle of crimped yarn ([0-0-0] single of 2-ply yarn; and [x-x-x] single yarn)](image3)
Effect of processing conditions on crimp geometry of crimped yarn—The buckling length and crimp angles decrease with increase in the preheater temperature for both the yarns (Figs 2 and 3). There is a sudden drop in the above geometrical parameters of the crimp in the temperature range 200-220°C. Although these parameters in both the yarns appear different, they do not have much effect on yarn characteristics. At the higher temperatures, there is no significant difference between the crimp characteristics of both the yarns. The difference between the crimp characteristics at lower temperatures may be explained by the fact that the nip pressure in 2-ply yarn would be applied much before reaching the axis of stress symmetry and, therefore, the imposition of axial deformations would also be earlier, resulting in large changes in cross-sectional shape of the individual filament and considerable distortion of the molecular matrix of the filament which might have effected some changes even in the fine structure matrix. At elevated temperatures, the filament gets softened and the induced axial deformation might cause considerable damage to the filament matrix and also cause dislocation of the stable elements of fine structure. Around 200°C, the relaxation rate of PET changes abruptly, resulting in gradual collapse of the filament and homogenization of the structural matrix of both the yarns. Thus, both the yarns start giving identical response to axial deformations at the roller nip and to the axial compression inside the tube. Therefore, the difference between the crimp characteristics of both the yarns would become narrow around 220°C processing temperature.

Effect of processing conditions on crimp frequency of crimped yarn—The structure of crimp in the stuffer-box yarn is constituted by a bend and two straight segments (legs). The mechanism of the formation of this structure has been explained above, but it is not clear whether the buckling phenomenon involves face to face folding of the constituent segments or the buckling segments are sheared during the collapsing process. The face to face collapsing of the buckle would produce uniplanar crimp, but if the segments shear up, due to the asymmetricity of the filament structure and dislocation of its mass about its axis resulting from axial deformations at roller nip, the crimp conformation would be of spatial nature. Generally, spatial crimp is produced by most of the stuffer-box crimpers.

The induced compressive stresses during bend collapsing push the mass towards the straight segments which induces a new asymmetric state that drifts the other segment at a certain angle, resulting in increase in width and stability of the bend. Crimps with such bend exhibit low crimp angle and large number of crimps per unit length of the crimped yarn are observed (Figs 3 and 4).

Effect of processing conditions on collapse of crimped yarn—The yarn bulk is the result of yarn collapse from its straightened state. It has been reported that the stability of the stuffer-box crimped yarns is poor due to the longitudinal strains. Both the yarns in the present case exhibit a rising trend in the values of percentage yarn collapse with increase in the preheater temperature. The difference between the values of yarn collapse reduces with rise in temperature and around 200-220°C, there is no significant difference between the yarn collapse values of the two yarns (Fig. 5). The reasons for this are the same as given for crimp geometry and crimp frequency changes with the induced structural changes in the filament due to the changes in the mechano-thermal treatment.

The values of crimp rigidity also exhibit a similar trend as in the case of percentage yarn collapse with rise in temperature (Fig. 6).

It is interesting to note from Figs 5 and 6 that there exists a limiting value for both the yarn characteristics and beyond 220°C, both the characteristics may show a decreasing trend. This trend is similar to that in the
Effect of processing conditions on denier of crimped yarn—Fig. 7 shows a rising trend in the percentage increase in denier of both the crimped yarns. A well known behaviour of synthetic fibres is to shrink longitudinally at elevated temperatures in relaxed state. In the present case, the mode of deformation of filaments and the axial compression in combination facilitated the process of shrinkage with rise in temperature of the filament. In the yarn produced at and beyond 220°C, full decrimping could not be possible during length measurements, so the percentage increase in denier is abrupt in both the yarns.

Conclusions

In general, PET yarn processing through the modified crimper does not require drastic changes in the conditions of working, except the temperature at the preheater tube and the residence period there and the cooling rate of the stuffing tube. The distortion of PET yarns in the process is considerably large and the crimp stability is better. The processing of PET yarn is possible up to 220°C in the preheater tube. Beyond this temperature, processing is difficult due to sticking of the filaments. The best results for PET crimped yarns can be obtained in the temperature range 200-220°C of the preheater tube.

References

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