Mechanics of Latent Crimp in False Twist Textured Yarn

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The factors contributing to temporary set in textured polyethylene terephthalate yarn, rendering the crimp latent, are discussed. It is postulated that temporary set can be attributed to internal structural factors and interfilament contact forces.

TEXTURED polyethylene terephthalate (PET) yarn which has not been given any post-texturing treatment shows little bulk when carefully taken off the package. This apparent lack of bulk has been attributed to temporary set achieved on the wind-up. The mechanism of temporary set has not yet been elucidated, but is believed to be related to internal molecular arrangement. According to Denton, one of the limitations of the theories explaining crimp retraction of textured yarns is that it is not possible at present to make a reasonable estimate of the effects of interfilament frictional forces and entanglements which are extremely important.

This paper reports the results of a detailed investigation on the phenomenon of latent crimp. An attempt has also been made to elucidate the mechanisms by which temporary set can come into play.

The effect of winding tension in rendering crimp latent has been reported recently. The data presented in Fig. 1 show that in the as-textured sample, the higher the winding tension, the greater is the latent crimp till a critical winding tension is reached at which there is maximum suppression of crimp. A similar effect was observed by Familant for nylon 66 textured yarn. Obviously, the effect of holding the filaments of a yarn under tension below the critical limit on a wound package was the suppression of torsional and bending stresses which would normally cause the yarn to develop crimp contraction. Above the critical limit, higher winding tensions can result in the stretching of some of the filaments and the potential energy due to this can release the latent crimp when the yarn is unwound.

The latent crimp was released by giving two types of post-texturing treatments to the yarn; the first by subjecting it to mechanical conditioning and the second by boiling it in water for 2 hr. In both the cases, the yarn develops bulk and, as shown in Fig. 1 for the case of water-boiled samples only, the crimp retraction values register an appreciable increase. The effects of these post-texturing treatments on the structural geometry of the yarn and on their internal structure are discussed in this paper. It is suggested that in the case of as-textured PET yarn, residual forces can lead to the development of potential energy in the non-crystalline regions of the fibre or to the surface contact forces between the filaments; these residual forces can render the crimp latent until they are released.

It has been appreciated for quite some time that a free state fibre curvature resulting from heat-setting of twisted yarn is perhaps the main driving force behind the self-crimping process, while the residual torque plays a somewhat parasitic role and the friction between the fibres restricts crimp formation. Starting from this premise, the present investigation attempts to identify, in more precise terms, the roles of some of these factors, and to understand better the part played by other factors like changes in the fine structure of the fibre in the suppression of crimp in the as-textured yarn and its release by post-texturing treatments.

Structural Geometry of Textured PET Yarn

The false-twist textured PET yarn used in the present investigation is of the conventional type based on flat commercial yarn 76/240, i.e. 76 denier, 24 filaments and zero twist. The yarn was textured on a Barmag spindle false-twisting machine at a heater temperature of 230°C, heater contact period of 0.55 sec, twist level of 80 tpi and underfeed in the texturing zone of 3%. No second heater was used.

The as-textured yarn had very low crimp retraction, viz. in the region of 5%. The crimp was released by giving two types of post-texturing treatments; the
first by mechanical conditioning and the second by relaxing the yarn in boiling water. The mechanical conditioning was achieved by subjecting the freely moving yarn to a dead load of 100 g for 2 min, removing the load and allowing the yarn to relax under no load for 20 min. This loading/unloading cycle was repeated four times. Relaxation in water was achieved by immersing the yarn in a relaxed state in boiling water for 90 min, drying it and then storing it for 24 hr under temperature and humidity controlled conditions. The crimp retraction was found by taking a single yarn about 1 m long and measuring the changes in length using 0.002 gpd as the low load and 0.1 gpd as the high load. The periods of deformation and the expression used to calculate crimp retraction were the same as used in the HATRA crimp rigidity test described elsewhere.

Shadowgraphs of the three samples held at a pretension of 0.002 gpd are shown in Fig. 3. It is seen from Figs. 2 and 3 that both crimp retraction and bulk are low for the as-textured sample, but their values are relatively high in the case of post-textured samples. The high crimp retraction of the water-boiled sample arises obviously because of its improved set on account of the thermal treatment.

The shadowgraphs indicate that the post-textured samples have a more open structure compared to the as-textured yarn and the surface contact between the filaments is, therefore, higher in the case of as-textured yarn. Scanning electron micrographs, not reproduced here, confirm this observation. The high latent crimp shown by the as-textured yarn could, therefore, partly arise from the increased number of contact points in the filaments of the yarn.

It was noticed that the as-textured yarn had a considerable amount of residual torque and it had a strong tendency to form snarls when the tension in the yarn, held at two ends, was released. If the yarn was held at one end and the other end allowed to hang freely under gravity, the free end was seen to rotate, apparently due to the flow of twist through the free end. The snarling tendency was also lost after the twist had been allowed to flow out. The shadowgraphs (Fig. 4a) for textured PET made on a Superset Scragg machine show the differences between these two; the yarn with residual torque appears to be more compact than the one in which twist has been allowed to flow out. The crimp retraction of the yarn with residual torque was found to be 4% and it increased to 5% after the twist had been allowed to flow out. This increase in crimp retraction could at least partly be due to the lower number of contact points, which results in less interference between adjacent filaments during the crimp retraction test.

If the two yarns shown in Fig. 4(a) are subjected to a sudden longitudinal pull (while being held by hand) which is quickly released, there is development of bulk, as the corresponding shadowgraphs in Fig. 4(b) show. It is interesting to note that the yarn in which twist has not been allowed to flow out shows much higher bulk. Since the process of bulk formation arises due to the redistribution of forces and the consequential change in configuration of the filaments and since the as-textured sample with residual torque has a more compact structure with larger number of contact points, it would appear that interfilament contacts could provide possible sites for the location of residual forces.

Structural Changes as a Result of Post-texturizing Treatments

The structural changes which take place on relaxing the as-textured PET yarn in hot water have been reported recently. It was found that this post-texturing treatment can cause changes in the degree of crystallinity, crystallite orientation and amorphous orientation. However, since temporary set would be expected to be related to changes in the structure of the non-crystalline regions, we will consider only the amorphous orientation factor as a possible source of temporary set. The orientation of the molecules in the amorphous regions was found to decrease after the hot water treatment.

The time involved in the texturing process is in the region of 1 sec or less, and PET, due to its rigid chain structure and lack of strong intermolecular forces, will not be expected to attain its equilibrium position within such a short time interval. A subsequent treatment at a lower temperature may, therefore, allow the metastable system to move closer to its equilibrium position. Thus, the high orientation of the molecules in the non-crystalline regions in the as-textured yarn is a possible mechanism of temporary set which is released when the yarn is allowed to relax in hot water.

The PET yarns, which were mechanically conditioned by applying a longitudinal tension at room temperature, were studied similarly and the amorphous orientation factor was obtained by the method described earlier. It was interesting to note that the amorphous orientation increased on mechanical conditioning. To confirm this, infrared studies were undertaken using an IR spectrophotometer which had a
Fig. 3 — Shadowgraphs of textured PET yarns (Top, as-textured; middle, mechanically-conditioned; and bottom, water-boiled)

Fig. 4 — Shadowgraph of textured PET yarns (a) As-textured: top, with residual torque; bottom, with no residual torque; (b) impulse-loaded: top, corresponding to sample with residual torque; bottom, corresponding to sample with no residual torque
Conclusion

It has been shown that (i) post-texturing treatments affect amorphous orientation, (ii) removal of residual torque changes the latent crimp, and (iii) there is a semi-qualitative relation between curvature and entanglement forces.

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References

Appendix—Analysis of Forces on a Filament

This analysis is based on the general theory of bending and twisting of thin rods. The forces and couples acting on a thin rod are shown in Fig. 5. The equations of equilibrium of the thin rod are:

\[
\begin{align*}
\frac{dN}{ds} - N' \zeta + Tk' + X &= 0, \\
\frac{dN'}{ds} - Tk + N \zeta + Y &= 0, \\
\frac{dT}{ds} - Nk' + N'k + Z &= 0, \\
\frac{dG}{ds} - G' \zeta + Hk' - N &= 0, \\
\frac{dG'}{ds} - Hk + G \zeta + N &= 0, \\
\frac{dH}{ds} - Gk' + G'k &= 0,
\end{align*}
\]

where \(s\) is the length along the centre line of the deformed filament and \(N, N', T, G, \text{ etc.}\) are the components of the internal force and moment resultants in \(x, y,\) and \(z\) directions, respectively; \(X, Y\) and \(Z\) are the distributed external force components in \(x, y,\) and \(z\) directions; and \(k, k'\) and \(\zeta\) are the curvature and twist of the rod. The filament may be straight or curved initially. The determination of the directions \(x, y,\) and \(z\) initially and \(x, y,\) and \(z\) in the deformed configuration can be done according to the procedure given by Love. Here it suffices to say that the \(z\) direction is tangential to the centre line of the deformed filament and, therefore, the other two directions are transverse to the filament.

From Eqs. (3)-(6), we can obtain the following equation:

\[
\sum \frac{dT}{ds} + k' \frac{dG'}{ds} + k \frac{dG}{ds} + \zeta \frac{dH}{ds} + Z = 0,
\]
or

\[
T + \left( k' \frac{dG'}{ds} + k \frac{dG}{ds} + \zeta \frac{dH}{ds} \right) ds + \int Z ds = \text{constant.}
\]

Eq. (7) can be further simplified by incorporating the following constitutive relations:

\[
\begin{align*}
G &= G (k), \\
G' &= G (k'), \\
H &= H (\zeta)
\end{align*}
\]

Thus,

\[
\int k' \frac{dG'}{ds} ds = \int k' \frac{dG'}{ds} dk' ds = \int k' dG',
\]

and

\[
\sum = \text{constant.}
\]

Each of the first three integrals in Eq. (11) is a function of the mechanical state at a given point of the filament in equilibrium. This is a characteristic equation of the equilibrium of a filament. No assumption has been made about the shape of the filament. If the relations (8), (9) and (10) are linear, Eq. (11) takes the following form:

\[
T + \frac{1}{2} \left( A k^2 + Bk'^2 + C \zeta^2 \right) + \int Z ds = \text{constant.}
\]

where \(A\) and \(B\) represent the bending rigidity; and \(C,\) the torsional rigidity of the filament. The constant on the right side represents the state of the filament and can be changed only by some thermomechanical treatment; otherwise it is constant along the length of the filament.