Influence of Draw Ratio and Drawing Temperature on False Twist Textured Nylon 6 Multifilament Yarns

A K SENGUPTA, M L GULRAJANI & S A N SETTY
Department of Textile Technology, Indian Institute of Technology, New Delhi 110029
Received 15 April 1979; accepted 18 May 1979

A 413/24 undrawn nylon 6 yarn was drawn to draw ratios of 3.0, 3.4 and 3.6 at drawing temperatures of 30°, 100° and 150°C and at a constant drawing speed of 100 m/min. It is observed that increase in the draw ratio brings about a decrease in the crimp rigidity and dye uptake, while the yarn tenacity and initial modulus increase. Increase in the drawing temperature reduces the crimp rigidity, while the yarn tenacity and initial modulus increase. The dye uptake decreases at first and then increases as the drawing temperature increases. The properties of the textured yarn are greatly influenced by the feeder yarn characteristics, and the memory of the drawing history is retained even after texturing.

The texturization process involves mechanical deformation of a filament or a bundle of filaments and dissipation of internal strains induced by mechanical stressing to obtain a permanent or a quasi-permanent stress-free distorted configuration. For thermoplastic yarns, the process employed is a thermomechanical one in which the stability of the distorted configuration is obtained through thermosetting. The events that occur in a thermosetting process may be summarized in the following three stages: (a) weakening the intermolecular links in the fibre and increasing the mobility of its structural elements by raising its temperature; (b) formation of a more even structure as a result of thermal relaxation and reduction of internal stresses; and (c) stabilization of the even structure by reformation of bonds in an energetically favourable configuration.

Within a nylon fibre, there is a range of states of order and associated inter-chain bond energy levels. These inter-chain bonds hold the molecular chains in an extended form along the fibre axis in the drawn yarn. When torsional, bending and tensile stresses occur, they supersede the stresses originally present in the matrix and hence in order to stabilize the yarn in its new form, this condition of inner stress must be eliminated. This can happen through a partial loosening of the valency connections by the supply of heat energy. The molecules begin to oscillate and perform rotary motions, resulting in loosening of some of the hydrogen bonds. Parisot and Bouriot, from their infrared spectroscopic investigations, observed that when polyamide is brought up to a sufficiently high temperature, the energy of hydrogen interaction, C=O···HN, decreases owing to the spacing out of macromolecular chains and some hydrogen interactions disappear with the formation of free NH groups. It is, thus, to be anticipated that if the inter-chain bond energies are initially of a lower magnitude, the conditions are likely to be more favourable for thermostabilization. Some experimental evidences towards this are available.

In the present investigation, the characteristics of nylon 6 feeder yarn have been changed by altering both the drawing temperature and the draw ratio, and the influence of the drawing conditions on the properties of textured yarns has been studied.

Materials and Methods

The basic raw material used was undrawn 413/24 denier nylon 6 yarn supplied by Modipon Ltd.

Drawing and texturing—Both drawing and texturing were done on a Scragg CS12 Minibulk machine. For drawing, the feed unit drive was modified to accommodate the necessary draw ratios. The texturing conditions used were the same for all the yarns and are as follows: Heater temperature, 180°C; twist level, 75 tpi; contact period, 1 sec; and overfeed, −2%.

Crimp rigidity—The HATRA crimp rigidity test was performed in air after relaxing the yarn in hank form in water at 80°C for 15 min.

Tensile properties—The Instron tensile tester was used for obtaining the load-elongation curves for the specimen. A gauge length of 5 cm and jaw and chart speeds of 5 and 30 cm/min respectively were used. The stress-strain curves were plotted from the averages of 25 load-elongation curves for each sample. The crimped deniers, needed for the computation of stress values, were measured by pretensioning the samples to a load of 0.00536 g/d. The initial modulus values were
computed from the slopes of the stress-strain curves following decrimping extension.

**Dyeing**—Durazol Blue 2R (C.I. Direct Blue-71) was used. This dye is very sensitive to physical structural variations and is relatively insensitive to variations in chemical structure. The dye was purified by dissolving it in DMF followed by filtration and precipitation in acetone. A beaker dyeing machine was used for dyeing 50 mg samples of fibre in 35 ml of dye liquor of 1% concentration. The pH of the dye solution was adjusted to 4.2 and dyeing was carried out for 2 hr at 80°C. Dyed samples were thoroughly washed with cold distilled water and dried. The amount of dye on the fibre was determined spectrophotometrically by dissolving a known amount of the dyed fibre in formic acid.

**X-ray studies**—X-ray photographs of yarn samples were obtained on Norreco Type 170-112-02 machine with exposure period of 4 hr. The azimuthal scan of the spot darker in intensity was obtained on a Joyce-Lobel double beam microdensitometer. The reciprocal of the azimuthal breadth (after normalization) at half maximum intensity was used as a measure of crystalline orientation. The percentage crystallinity index was computed from the equatorial scans and the area under the crystalline curve was expressed as percentage of the total area to obtain the crystallinity index (%). A standard amorphous curve of nylon 6 was used to compute the area under the crystalline curve.

**Results and Discussion**

**Crimp Rigidity**

Data pertaining to the effects of drawing temperature and draw ratio on the crimp rigidity (%) of the textured samples are presented in Fig. 1. It is observed that increase in either (in the ranges studied) decreases crimp rigidity.

**Effect of drawing temperature**—Increase in the drawing temperature increases the mobility of molecular chains, resulting in a better molecular packing and, hence, increase in the intermolecular cohesive force. Data on consolidation of the structure with the drawing temperature, as evidenced from the X-ray studies, are presented in Table 1. It is observed that increase in the drawing temperature increases the crystallinity and crystallite orientation of the drawn material. Increase in crystallinity is sharper between 100 and 150°C than between 30 and 100°C. This is presumably because of the enhanced rate of crystallization at 150°C; the most suitable temperature for crystallization of nylon 6 is reported to be around 140°C. Texturization enhances crystallinity, but reduces orientation. The degree of crystallinity and crystallite orientation of the textured samples are dependent on the crystallinity and orientation of the parent samples.

Smith et al. have observed that for good crimpability, a feeder yarn should have low crystallinity, as this allows the texturing process to set more easily the coil structure into the yarn. This is presumably because of the fact that the mechanism of permanent set involves crystal melting, particularly of the smaller and imperfect crystals. With the very low residence period in the heater during texturing, this process is likely to be hindered if the parent yarn crystallinity is high. Thus, it is observed that the crimp rigidity is lowered as the parent yarn crystallinity is increased. The crystallinity of textured yarn is dependent on the crystallinity of the parent yarn. The higher the parent yarn crystallinity, the higher is the crystallinity of the textured yarn.

**Effect of draw ratio**—In cold drawn nylon 6, the draw ratio does not have a pronounced effect on crystallinity. It is, however, observed that increase in the draw ratio reduces the crimp rigidity. The crimp
rigidity of the yarn drawn to a draw ratio of 3.0 is considerably higher than the crimp rigidities of the yarns drawn to draw ratios of 3.4 and 3.6. The effect of draw ratio is similar for all the drawing temperatures. There may be two reasons for this:

(i) Nylon 6 is known to appear in two crystalline forms, α and γ. The γ form is less stable, as its hydrogen bond density is much less. In undrawn nylon 6, both the crystalline forms are present but with orientation stretching, γ-α conversion takes place. The γ content depends on the draw ratio and is higher for a lower draw ratio. By altering the γ content of nylon 6 yarn using draw ratio as the variable, Martin showed a maximum in the crimp rigidity for nylon 6 at a draw ratio of 2.9. The present results are in close agreement with Martin’s results.

(ii) Increase in the draw ratio increases the overall intermolecular cohesive force. The residence period in the heater is a combination of the yarn heating period and the molecular relaxation period. Yarn with higher molecular packing and, hence, greater cohesive force, would need a higher relaxation period to attain the same level of stress relaxation. When the heater temperature and residence period in the heater are kept constant, the yarn with high draw ratio would give a poor crimp rigidity value due to inadequate stress relaxation.

Tensile Properties

The tenacities of the drawn yarns and their corresponding textured yarns are presented in Fig. 2. It is observed that increase in both the draw ratio and the drawing temperature increases the tenacity of the parent yarn. This is due to the better molecular alignment leading to improved orientation of the molecular chains along the fibre axis. Texturization is a disorienting process. The strength of the textured yarn is lower than that of its parent yarn and is dependent on the orientation stretching history of the parent yarn. The strongest yarn has the highest strength after texturing. The % strength retained after texturing is, however, similar for all the samples.

The initial modulus values of the parent and textured yarns (Fig. 3) show more or less similar trends with process variables as the tenacity values.

Dye Uptake

The dye uptake values for drawn and textured yarns are plotted in Fig. 4. It is observed that the dye uptake values for both drawn and textured yarns show similar trends in relation to draw ratio and drawing temperature. The dye uptake by the textured yarn is always higher than that by its corresponding parent yarn. This is due to the higher disorientation in the textured yarn, which facilitates penetration of the dye molecules. Increase in the draw ratio decreases dye uptake by the parent yarn. Subsequently, on texturing, a similar trend is maintained. This is presumably because of the fact that the memory of the drawn state is retained to a considerable extent even after texturing. This is further supported by the results of experiments in which the drawing temperature was varied. As the drawing temperature is increased from 30°C to 100°C, the dye uptake is reduced for both parent and textured yarns for all the draw ratios. The yarns drawn at 100°C are more oriented and crystalline than those drawn at
and recrystallization takes place, with the probable result that a planar extended configuration gives way to a chain folded one and a more discrete separation between the crystalline and the amorphous phases takes place. With the suppression or elimination of the intermediate phase, greater segmental mobility in the non-crystalline phase is now possible, so that the diffusion of dye molecules into the matrix becomes easier, resulting in a higher dye uptake.

Conclusions
(1) The properties of the textured yarn are dependent on the characteristics of the feeder yarn.
(2) Although texturization involves destabilization of a set and imposition of a new set, the memory of the previous set is largely retained even after texturing.
(3) Use of a feeder yarn with low draw ratio improves the crimp rigidity and dye uptake by the textured yarn, but the tensile properties deteriorate.

References