# Structural and Performance Changes in Polyester Yarn Brought About by Simultaneous Draw Texturing Processes

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## Synopsis

A partially oriented yarn of polyester has been subjected to the simultaneous draw texturing process and also drawn on the same machine without false twist. The effect of the variation of the applied draw ratio, the temperature of the first heater, the speed of the yarn, and (for textured yarn) the twist on the properties of the processed yarns was investigated. It was shown that the main factor affecting the properties is the applied draw ratio, the other factors having only a secondary influence, which is different from the findings with conventionally textured yarn. A tentative model for the polyesters based on fibrillar units with extended chains is proposed to account for the observed changes.

## INTRODUCTION

The most widely used conventional bulking process is to texture by the false-twist process preoriented yarn of the type that can be used for other textile processes. To speed up this method of texturing, it is possible to eliminate the drawing process required to produce standard yarn by incorporating it into the texturing process. Originally, unoriented yarn was used as the starting material; but as this is highly unstable, a partially oriented yarn (POY) is now used as a starting material. Such PO yarn can be produced at relatively high speeds with a consequent economic saving, and it is stable enough to be used in the simultaneous draw texturing (SDT) process within a few months of manufacture. The SDT process is thus one in which drawing is applied at the same time as the false twist while the yarn is passing over the heater of a texturing machine at a controlled temperature. The structural changes brought about during such a process will thus be different from those taking place in a conventional texturing process with preoriented yarn.

In the work about to be described, yarn was treated in a texturing machine with and without false twist being applied under SDT conditions, so that the structural consequences of the false-twist process could be assessed. Previous work on the variation of machine settings to bring about changes in the textured yarn characteristics has been studied extensively by Lunenschloss,[1,2] Backer,[3] Thwaites,[4,5] Egbers,[6,7] and Morris and Barnes.[8] Backer[3] furthermore has studied structural features and has advanced some speculation into the structural reasons for some of the changes in properties observed. The present work is an attempt to understand further the properties of SDT processes from a structural standpoint and to relate this to the performance of the textured yarns.

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TABLE I
Sample Variations[a]

| Applied draw ratio | Temperature of first heater, °C | Twist turns/in. (turns/m) | Speed, m/min |
|---|---|---|---|
| 1.508 | 210 | 61 (2402) | 200 |
| 1.569 | 210 | 61 (2402) | 200 |
| 1.620 | 210 | 61 (2402) | 200 |
| 1.650 | 210 | 65 (2559) | 200 |
| 1.717 | 210 | 61 (2402) | 200 |
| 1.717 | 210 | 61 (2402) | 200 |
| 1.717 | 210 | 65 (2559) | 200 |
| 1.717 | 210 | 69 (2717) | 200 |
| 1.717 | 210 | 73 (2374) | 200 |
| 1.620 | 195 | 61 (2402) | 200 |
| 1.620 | 200 | 65 (2559) | 200 |
| 1.620 | 205 | 61 (2402) | 200 |
| 1.620 | 210 | 61 (2402) | 200 |
| 1.620 | 210 | 61 (2402) | 150 |
| 1.620 | 210 | 61 (2402) | 175 |
| 1.620 | 210 | 61 (2402) | 200 |
| 1.620 | 210 | 61 (2402) | 213 |

[a] Flat and textured yarns were prepared under each given condition. Second heater kept at 180°C. No second heater was used when flat yarns were prepared.

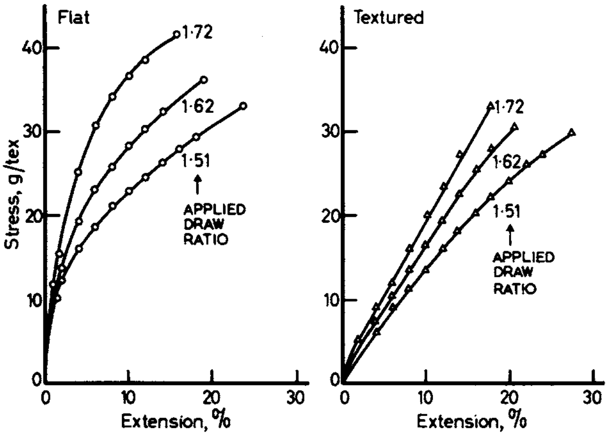

Fig. 1. Stress–strain curves of flat and textured yarns.

## EXPERIMENTAL •

### Basic Material

Experimental partially oriented yarn (POY) of Viscosuisse was used. The yarn has been wound at 3500 m/min; the initial decitex was 268, the final decitex was 167, and the residual draw ratio was 1.62. If textured under SDT conditions, the textured yarn was expected to have an extension of about 25%.

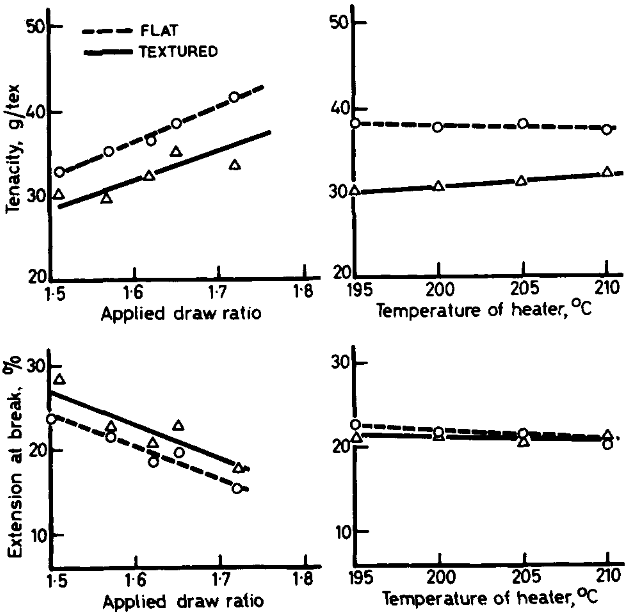

Fig. 2. Variation of tenacity and extension at break of flat and textured yarns with applied draw ratio and temperature of the first heater.

## Simultaneous Draw Texturing Process

Samples of yarn were processed on a laboratory single-unit double-heater simultaneous draw-texturing machine based on the dimensions of the Scragg Super-Draw Set II machine under the following conditions: Saphhire spindle; first heater 210°C; second heater 180°C; applied draw ratio 1.62; twist 61 turns/in.; yarn speed 200 m/min. These conditions are for a standard textured yarn, but these were varied as shown in Table I to give a series of samples with and without the false-twist process being applied. When no false twist was applied, the second heater was not used.

## Mechanical Properties

The mechanical properties of the yarns were measured on an Instron testing machine with a test length of 50 cm in the range of 0–1000 g and with a cross-head and chart-speed of 5.0 cm/min. The yarn was pretensioned before extension, and ten specimens were used for each sample. Results are given in the form of graphs in Figures 1–4. No variation in tenacity and extension at break was found when the yarn speed or twist was varied, the work of rupture did not vary with twist, and the value of tex was not altered by variations in the temperature of the first heater, the speed of yarns, or the twist. These observations were true for both flat and textured yarns (those involving twist for textured yarns only, of course).

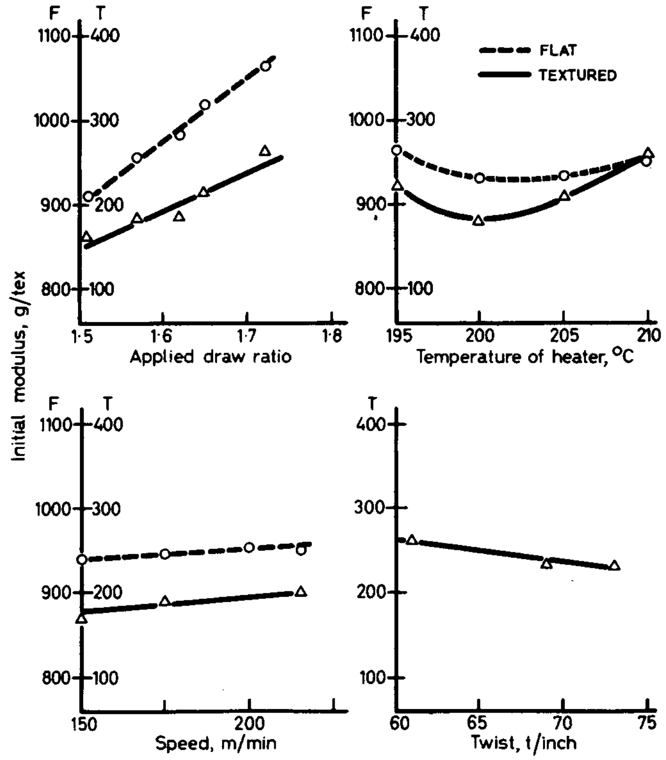

Fig. 3. Variation of initial modulus of flat and textured yarns with applied draw ratio, temperature of the first heater, speed of the yarns, and, for textured yarns, applied twist.

## Dyeing Experiments

As in previous work,[9] Duranol Blue (now renamed Dispersol Blue B-G) was used to detect structural differences in polyester. The dyebath was 0.5 g Dispersol Blue B-G, 0.75 g Atexal DA-AC (7.5% solution), and 10 ml 30% acetic acid made up to 1 liter with water. When carrier was used, 3 cc Palanil A was added to this dyebath.

Dyeing was carried out at 95° and 130°C. For the lower temperature, the conditions were those as described previously.[9] At 130°C, the dyebath was divided into two portions, one without dye and the other with dye alone. These two portions were held in the dye containers of a Pretema Multicolor machine, the portion without dye in the lower chamber containing the samples and that containing the dye, in an upper pressure head. When both portions were at 130°C, the dye solution was injected into the lower portion and the experiment timed from that moment. At the end of the given time, the dye liquor was ejected, the sample washed, and subsequent procedures carried out as before. In winding the samples onto the frames used for dyeing, a tension of 10 g was used during winding. After dyeing, the dyed yarn was cut from the frames, extracted in dimethylformamide, and estimated spectrophotometrically as previously described.[9]

The amount of dye (g/100 g of yarn) was plotted against the time of dyeing, giving a typical kinetics curve. At 95 °C, there was no sign of this curve reaching a steady equilibrium value within the experimental times studied. A plot of

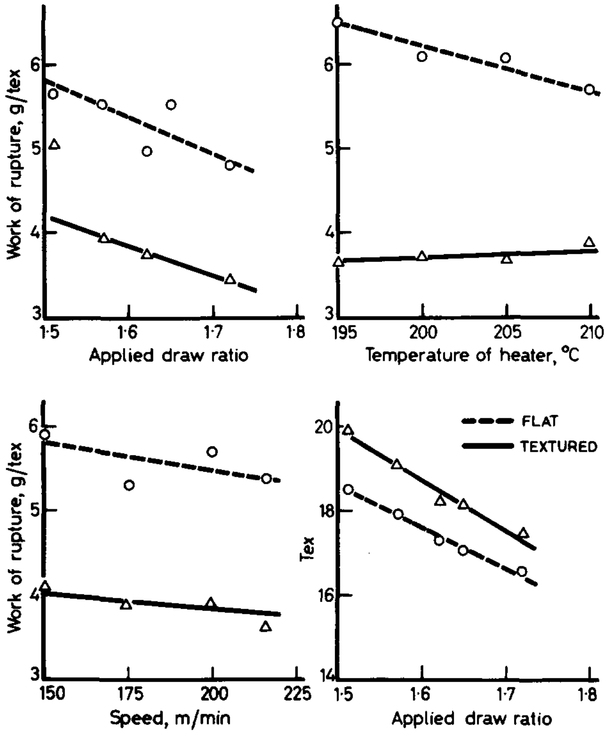

Fig. 4. Variation of work of rupture for flat and textured yarns with applied draw ratio, temperature of the first heater, and speed of the yarns; and variation of the tex value with applied draw ratio.

uptake ($A$) against the square root of the time ($\sqrt{t}$) gave a straight line through the origin, the slope of which ($A/\sqrt{t}$) was a convenient parameter for representing the speed of dyeing. For results at 130°C, the kinetics curve showed that equilibrium had been effectively attained after 30 min of dyeing so that the value of uptake after 30 min was taken as the equilibrium absorption value ($A_\infty$). By reading off from the kinetics curves values of uptake for each minute of dyeing over the first 5 min, uptake values were provided that, plotted against the square root of the time, gave a straight line passing through the origin. This line provided the speed of dyeing parameter ($A/\sqrt{t}$) for dyeings at 130°C.

The results at 95°C showed that the yarn speed both for flat and textured yarn did not affect the rate of dyeing, whether or not carrier was present in the dyebath. Twist had only a small effect, and that mainly when carrier was present (Fig. 5). The main factors of the SDT process subsequently influencing the rate of dyeing at 95°C were the applied draw ratio and, to much less effect, the temperature of the first heater.

At 130°C, the rate of dyeing was still largely governed by the applied draw ratio, to a much less extent by the temperature of the first heater, and only to small amounts by the speed of yarn and the twist (Fig. 6). The equilibrium absorption values for dyeing at 130°C were only influenced by the applied draw ratio (A.D.R.) as shown in Table II; the temperature of the first heater, the yarn speed, and the twist had only a negligible effect.

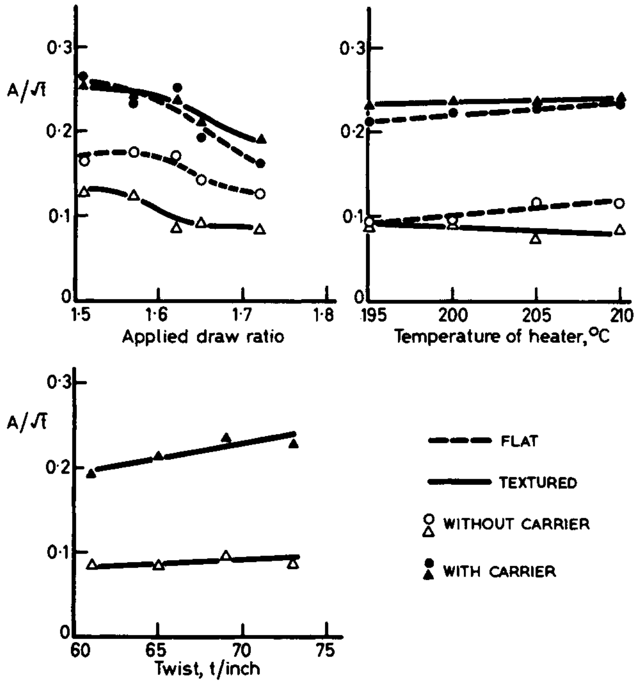

Fig. 5. Variation of rate of dyeing $A/\sqrt{t}$ (with and without carrier at 95°C) with applied draw ratio, flat and textured yarns; with first heater temperature, flat and textured yarns; and with twist, textured yarns.

## Density

Densities were measured with a density gradient column containing a mixture of carbon tetrachloride and *n*-heptane. For flat yarns, the applied draw ratio had a negligible effect on density. The variation in the temperature of the first heater and the speed of the yarn also had virtually no effect, and the mean density observed was 1.390 g/cc. The density for textured yarns was slightly lower, with a mean value of 1.386 g/cc. A slight tendency to rise from 1.384 to 1.386 g/cc as the temperature of the heater varied from 195° to 210°C was found, but no variation was found with the applied draw ratio or with twist. The yarn speed also affected the density only slightly, the density falling from 1.389 to 1.386 as the speed increased from 150 to 200 m/min. It should be noted that the temperature attained by the yarn would decrease slightly as the speeds increased.

## X-Ray Orientation

For reasons given in the discussion, the x-ray orientation factor was related to the orientation of the normal to the (100) plane. This factor ($1/\phi_{1/2}$) was measured by the method described previously,[9,10] where $\phi_{1/2}$ is the half-breadth at half the maximum intensity of the azimuthal scan round the (100) reflection on the x-ray diagram taken with a flat-plate camera.

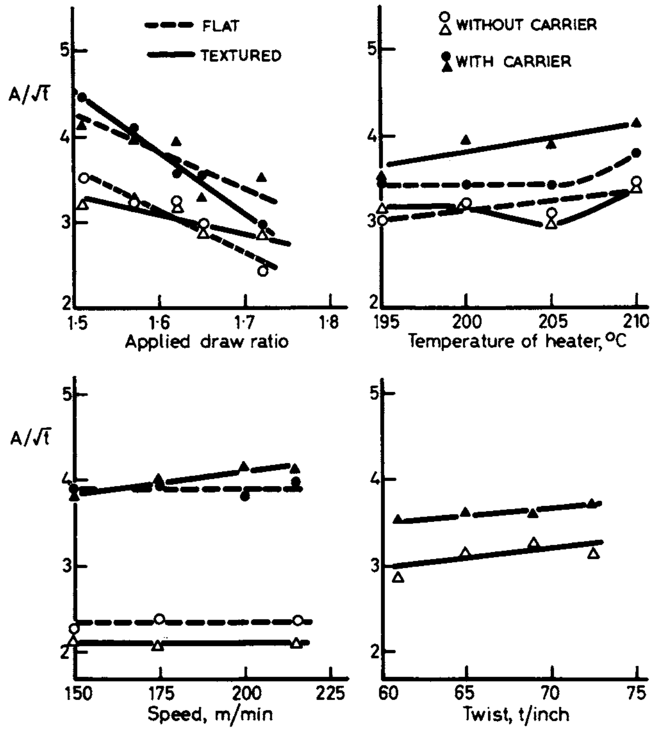

Fig. 6. Variation of the rate of dyeing $A/\sqrt{t}$ (with and without carrier at 130°C) with applied draw ratio, flat and textured yarns; with the temperature of the first heater, flat and textured yarns; with the speed of yarns, flat and textured yarns; and with twist, textured yarns.

TABLE II
Equilibrium Dye Absorption Values at 130°C of Textured Yarn

| A.D.R. | Without carrier | With carrier |
|---|---|---|
| 1.51 | 1.74 | 1.88 |
| 1.57 | 1.68 | 1.82 |
| 1.62 | 1.60 | 1.82 |
| 1.65 | 1.60 | 1.72 |
| 1.72 | 1.57 | 1.63 |

## X-Ray Lateral Order

The x-ray lateral order ($K$) was measured by the method already described previously[9] for the 010, $\bar{1}10$, and 100 reflections. No significant change in value was found with any machine variable. The mean values of $K$ were as follows:

Flat yarns

$$K = 1.01\ (010);\ 0.89\ (\bar{1}10);\ 0.80\ (100)$$

Textured yarns

$$K = 0.79\ (010);\ 0.68\ (\bar{1}10);\ 0.67\ (100)$$

The Bragg angles for the (010) and (100) planes are 8.77° and 12.85°, respectively, so that the extension of the morphologic units in the direction to the normals to these planes is[10] $D = 39.76K/\cos\theta$, where $\theta$ is the Bragg angle:

Flat yarns

$$D(010) = 40.6\ \text{Å};\ D(100) = 32.6\ \text{Å}$$

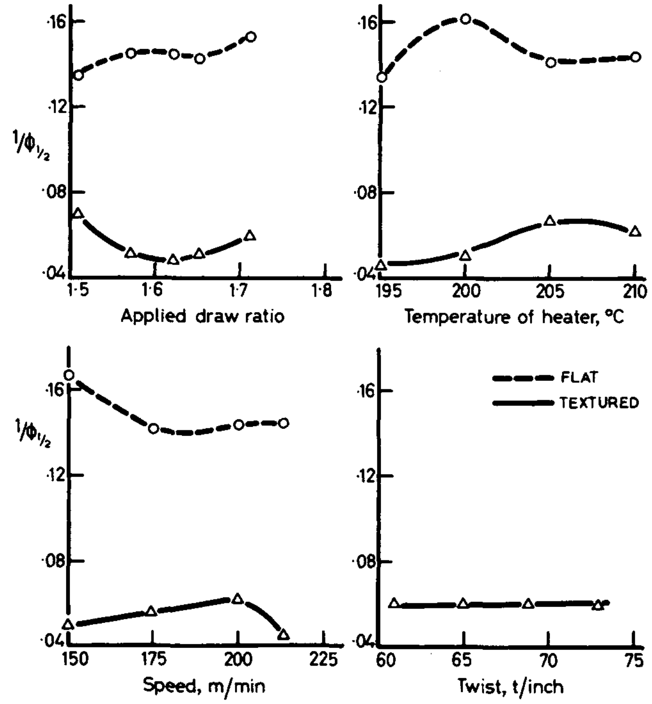

Fig. 7. Variation of x-ray orientation of flat and textured yarns with applied draw ratio, temperature of the first heater, speed of yarns, and, for textured yarns, applied twist.

Textured yarns

$$D(010) = 31.8\ \text{Å};\ D(100) = 27.3\ \text{Å}$$

These values are derived on the assumption that the breadth of the equatorial reflections is dependent only on the size of the units; and since there is also disorder between the planes affecting the $K$ value, these values must be taken only as indicative of possible sizes in the given directions.

## X-Ray Small-Angle Scatter

The x-ray small-angle scattering diagrams were taken with a Warhurst camera fitted with a cassette (A) at a film–specimen distance of 5 cm used simultaneously with a cassette (B) at a film–specimen distance of 17 cm used to record the x-ray small-angle pattern. The use of the wide-angle pattern recorded with cassette A was for calibration purposes as previously described.[11] The collimator of the Warhurst camera was round, with 0.5-mm pinholes; and nickel-filtered copper $K\alpha$ radiation was used.

The results all appeared to be diffuse four-point diagrams, although owing to the diffuseness of the reflections, they might also be described as meridional streaks. The intensity of the meridional reflections was obtained with a microdensitometer as previously described.[11] The spacing was derived by application of Bragg's law to the distance apart of the meridional streaks.

The results of the effect on the meridional intensity of the applied draw ratio, the temperature of the first heater, and, where appropriate, twist are shown in Figure 9. The spacing of the meridional reflection was found to vary only for

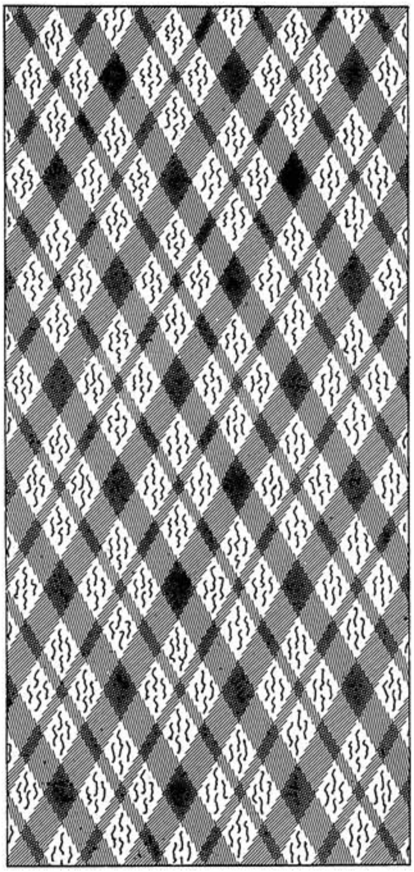

Fig. 8. Proposed idealized structure of polyester.

the flat yarns and these results are shown in Figure 10. The textured yarns showed no variation of the spacing with the machine variables, and a spacing of 107 Å was found for these yarns.

## DISCUSSION

The type of stress–strain curves given by flat and textured yarns is shown in Figure 1. Although the flat yarns have higher initial moduli than the textured yarns, the stress–strain curve shows more curvature for the flat yarns. The flat yarns must therefore have more viscous flow character than the textured yarns, at least above an extension of 5% or so, and from this it would be expected that movement of morphologic units past each other above a certain minimum stress must be more probable in flat yarns than in textured yarns. As the applied draw ratio increases, the stress–strain curves for textured yarns become straighter, but the flat yarns retain the element of flow even for the sample prepared with the highest applied draw ratio.

To understand the structural reasons for these different mechanical properties of the flat and textured yarns, it is helpful to try to visualize the changes in morphology involved in the simultaneous draw texturing (SDT) process. The PO yarn is initially noncrystalline and does not give a crystalline x-ray diagram.

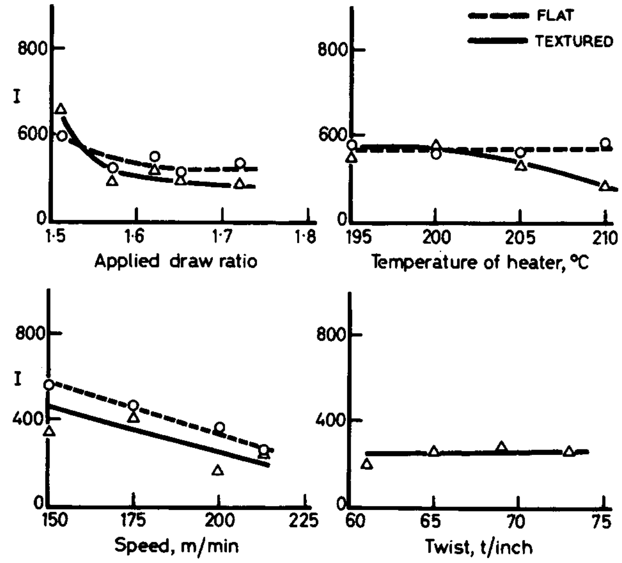

Fig. 9. Variation of meridional intensity of the x-ray small-angle scattering diagram for flat and textured yarns with applied draw ratio, temperature of the first heater, speed of yarns, and, for textured yarns, applied twist.

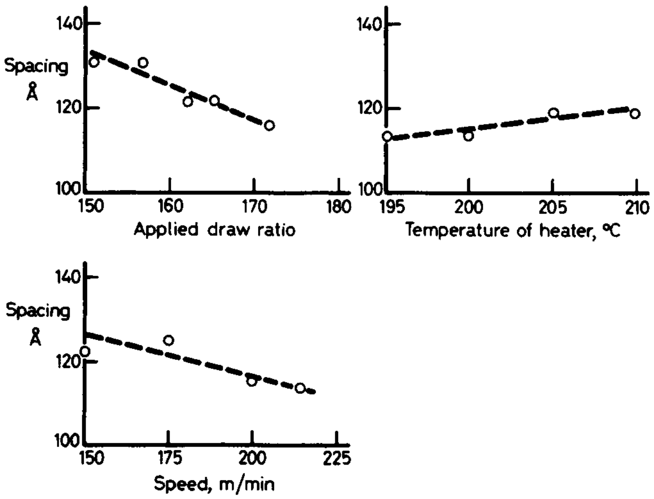

Fig. 10. Variation of meridional spacing of the x-ray small-angle scattering diagram for flat yarns with applied draw ratio, temperature of the first heater, and speed of the yarns.

After the SDT process, and also for flat yarns after passage over the heater, the yarn is highly crystalline and gives an oriented crystalline x-ray diagram. All the changes from a random noncrystalline state to an oriented crystalline state therefore take place on the heater of the texturing machine.

On heating the PO yarn above the glass transition point (i.e., above about 70°C), the first tendency is for shrinkage consistent with the rubber-like nature of the yarn above the glass transition temperature. The chains therefore will tend to coil or fold in a random way as in rubber and set up a complex network of chains that, because of weak $\pi$-bonding or owing to steric factors, will adhere randomly to each other at places. Such an equilibrium position of the structure is opposed by the drawing and twisting forces of the SDT process as well as by crystallization forces brought into play by the tension and the heat of the system.

Many elements of structure are therefore involved. There is the basic random rubber-like network superimposed on which are also the random locking points and the crystallized morphologic units which can adhere to themselves or to the rubber-like matrix. The adhesion points of whatever nature in this complex network will be opposed by the twisting action of the false-twist process, but when no false twist is applied, as with flat yarns, the probability of a higher number of locking points of all types will thus be higher than in textured yarns.

The difference in the stress–strain curves (Fig. 1) can be explained in terms of such a network. The yarn with the greater number of internal adhesion points should be a stiffer yarn, and this is consistent with the much higher values of initial moduli of the flat yarns compared with the textured yarns (Fig. 3). With increasing stress, the weaker internal locking points will break, allowing some flow in the system either by stretching the randomly coiled network or by slippage between crystalline units (or both), thus accounting for the flow character of the stress–strain curves for flat yarns (Fig. 2). With textured yarns, on the other hand, there will be fewer internal locking points to break, and the load will be taken up earlier in the deformation process by the complex network as a whole, leading to less flow character in the stress–strain curves as found. However, in consequence of having fewer internal adhesion points in the textured yarn, it might be expected that the tenacity would be lower and the extension at break higher for textured yarns than for flat yarns. This was in fact found to be the case (Fig. 2). The values of the work of rupture are determined from these considerations (Fig. 4) since they are related to the area under the stress–strain curves.

The type of complex network envisaged also allows an explanation of the dyeing results if a void content is included in the concept. Such voids will be situated in the rubber-like network of chains and also between crystallized morphologic units. As crystallization increases, the void structure will be increasing between morphologic units, and this is where it is thought the dye penetrates. By the nature of the system, the voids are thought of as accessible parts of a dynamically changing structure and not as rigid holes.

At 95°C, the rate of dyeing ($A/\sqrt{t}$) is chiefly influenced by the applied draw ratio (Fig. 5) which, as it increases, reduces the rate of dyeing. This is a well-known effect of drawing and comes about by the aligning and compacting of units reducing the space accessible for dye. The lower rate of dyeing for textured yarns where more accessible space would be expected has been attributed to tortuosity[9] of the channels causing steric hindrance to the penetrating dye molecule. This explanation seems justified since carrier in the dyebath causes the rate of dyeing of textured yarns to be higher than that for flat yarns. This implies that more accessible space is in fact potentially available in textured yarns than in flat yarns and that a carrier makes this extra space accessible. The function of the carrier in thus overcoming tortuosity lies partly in the fact that it lowers the glass transition temperature of the polyester, promoting more internal motion that aids dye penetration. The size of the penetrating dye molecule is therefore critical, and different results might be expected by the use of different dyes.

The effect of increases in the heater temperature is similarly explained. Whereas without carrier the flat yarns show a slight increase in the rate of dyeing, the dyeing of textured yarns hardly varies with an increase in heater temperature. Thus, the increase in void volume expected because of the increase of lateral order in the morphologic units is offset by the increase in tortuosity introduced by the false-twist process for textured yarns. However, the potential accessible space is made available by the use of carrier, and little difference is then found between flat and textured yarns. It should be noted that contrary to the findings for conventionally textured yarns,[9] the heater temperature variation has little effect on the rate of dyeing for simultaneous-draw textured yarns. However, the changes of dyeing characteristics found, although small from a structural standpoint, can be perceived by the eye and are therefore commercially important in terms of barre dyeing. Morris and Barnes[8] have shown in fact that with the same yarns, when dyed under commercial conditions, detectable differences in shade can be observed on knitted fabrics made from the yarns.

Dwell time as related to the yarn speed was found to have little effect on rates of dyeing over the range studied. Twist for textured yarns has little effect without carrier in the dyebath; but with carrier present, increasing the twist produces a higher rate of dyeing. Presumably without carrier, the increased tortuosity offsets any increased accessibility, which is then made accessible by the use of carrier.

Results (Fig. 6) of dyeing at 130°C are in many respects very similar to those of dyeing at 95°C with carrier, except for the obviously higher dyeing rates at 130°C compared with those at 95°C. In general, there is a tendency even without carrier for the textured yarns to dye at a higher rate than the flat yarns, especially at the higher applied draw ratios. This then tends to confirm that potentially there is more available internal space in textured yarns than in corresponding flat yarns, but it is not always accessible because of tortuosity and other factors. The higher temperature of dyeing, especially with carrier present, tends to optimize the accessible space, and therefore variations in morphology tend to show up under these conditions. This implies that the use of carrier or high-temperature dyeing does not eliminate the effect of differences in morphology brought about by false-twist texturing variations: it is therefore not a means of eliminating all barre effects. The main variable affecting the dye rate at 130°C is thus the applied draw ratio.

The 30-min dyeings at 130°C are taken to be indicative of equilibrium dyeings (Table II). These results for textured yarns are also mainly influenced by the applied draw ratio.

In an attempt to provide more support for the morphologic ideas developed to explain the mechanical and dyeing properties, other structural parameters were measured. The density as measured by a density gradient column was found to be essentially constant for all the samples of a given type, the value for flat yarns, however, being marginally greater than for textured yarns. Such a fact would be consistent with greater adhesion in flat yarns than in textured yarns. Since, however, there are distinct differences in dyeing rates caused by changes in the applied draw ratio, which imply changes in internal accessibility, it is therefore unwise to attempt to base accessibility measurements on density values. Thus, estimates of crystalline/noncrystalline ratios based on density measurements are highly suspect even in other materials, since the evidence deduced here shows the possibility that there is no correlation between density and accessibility or noncrystallinity.

X-Ray lateral order measurements were also made, and it was found that no significant change was found in samples processed under varying conditions. This means that the arguments based on lateral order changes producing void size changes have to be modified. Since density does not change either, it would imply that the distribution of packing or orientation of units must account for the variations in yarn properties found with variations in applied draw ratio. The fact that only small changes in dye rate and dye absorption are caused by the variation of the heater temperature is also consistent with these lateral order results. The method is somewhat insensitive to small changes so that it can be said that lateral order changes take place, but that such changes are small. If the lateral order measurements are taken as measurements of size, it was shown earlier that the morphologic units would approximate a mean diameter of 30–40 Å if circular. Such a measurement in relation to units made from long chains could imply long fibrillar units, although not being proof of them.

In making the lateral order measurements, the x-ray diagrams, the microdensitometer scans from them, and the computer analysis of these scans gave no evidence for any appreciable quantities of noncrystalline matter being present. The analysis, however, does imply that there is a distribution of size and/or order of the morphologic units; but as all contribute to the crystalline x-ray diffraction pattern, the rubber-like matrix in the highly crystalline processed yarns must be only a small portion.

The examination of the x-ray diagram of polyester shows that orientation processes are complex; and therefore to measure a meaningful orientation parameter required definition of this parameter. Daubeny, Bunn, and Brown[12] pointed out that there was a preferred orientation of selected planes, and Liska[13] has published x-ray photographs that clearly show the biaxial nature of the orientation process. The (100) plane is probably the most sensitive plane to these orientation processes, and its diffraction arc can sometimes be located on the meridian whereas if the polyester is properly oriented with its $C$-axis along the fiber axis, the (100) diffraction arc should be on the equator. All the x-ray diagrams of the specimens investigated had the (100) arc on the equator, and this implied that reasonable axial orientation had been achieved since the orientation around the second axis had already been virtually attained. The orientation of the normal to the (100) plane in these circumstances would indicate a relation with the orientation of the molecular axis. Since other equatorial arcs can be displaced off the equator in some orientations, the fact that they were also located on the equator supports the assumptions made. The orientation parameter was therefore the orientation of the normal to the (100) plane derived from the azimuthal scan around that particular arc. As in other papers,[10] the reciprocal of the half-breadth at half the maximum intensity of the azimuthal scan ($1/\phi_{1/2}$) was taken as the orientation parameter. This parameter increases for flat yarns as the applied draw ratio increases (Fig. 7) and is consistent with the alignment with morphologic units under the influence of drawing, as well as some adhesion of units. The false-twist process would be expected to tend to counteract this process so that the minimum found for textured yarns suggests that the aligning forces are predominant only for the higher values of the applied draw ratio. Heat can speed up crystallization rates and tend to make the units stiffer, but any alignment due to this cause would be opposed by thermal agitation, possibly explaining the maximum in the orientation parameter variation with heater temperature variation and the effect of dwell time; the total changes, however, are small. Twist over the range studied has apparently no effect upon the orientation parameter.

The final morphologic picture that emerges from this discussion of the observed properties is one mainly of long fibrillar units forming a complex mesh with adhesive areas between units tending to bind them together. There probably is also a residual random matrix originating from the PO yarns. A random distribution of tortuous voids between the units allows for penetration of dye. The mean orientation parameter suggests that the units are dispersed at an angle to the fiber axis. Therefore, any projection along the length of the fiber will appear as if the units spiral or crisscross each other along the length of the fiber. Furthermore, each unit, because of the dispersion of lateral order, will not necessarily have the same electron density as its neighbor. If now a conglomerate of units with voids between them is visualized, it is not hard to imagine volumes of high and low electron density distributed in the fiber. The drawing process will bring these units into some statistical order so that it is possible for high electron density regions to alternate with lower electron density regions in the way shown in Figure 8. This diagram is highly idealized and must be treated as a convenient abstraction, the actual structure being less precisely defined in shape and much more complex; but nevertheless it summarizes a morphology that could explain the properties discussed.

X-Ray small-angle scattering photographs showed that the diffraction pattern was that of a hazy four-point diagram the integrated meridional intensity of which varied as shown in Figure 9. This meridional intensity decreases and then tends to a constant value as the applied draw ratio increases. These results suggest that the best statistical structure is reached for an applied draw ratio around 1.6., i.e., around the natural draw ratio for these yarns; thereafter, little change takes place. Flat yarns have higher intensities, which implies higher electron differences than for textured yarns, and this could be consistent with the expected higher content of adhesion points in these yarns. Little variation of the meridional intensity with increase in heater temperature is found for flat yarns, but a decrease in intensity is found at the higher temperatures for textured yarns. The combined effect of thermal agitation and the mechanical action of the false-twist process might be expected to make the morphology a little more uniform for textured yarns than for flat yarns and hence electron density differences less, which would perhaps explain this result. Short dwell times (i.e., high yarn speeds) also tend to give low meridional intensities so that more prolonged heat must allow some type of annealing to take place to counteract the effects of thermal motion. Twist variation has little or no effect.

The meridional spacing of the x-ray small-angle diagrams for textured yarns does not change with any variable, which seems consistent with the view that a statistically more uniform structure is set up for textured yarns than for flat yarns. With flat yarns, there is a decrease of spacing with increase in the applied draw ratio (Fig. 10), an increase with increase in the heater temperature, and a decrease with decrease in dwell time (i.e., with increase in yarn speed). This is consistent with adhesion areas being reduced by drawing but increased by heating, which fits with the proposed model and its properties as discussed above.

The model proposed should also be consistent with x-ray small-angle scattering properties. The hazy four-point diagram can result from the alternate high and lower electron density regions arranged statistically in the way proposed. It is a mistaken belief that the meridional intensity of such a diagram must necessarily be caused by regularly folded chains in the morphologic units. A recent thesis by Miller[14] on the optical analogues of morphologic systems in polymers carried out under the direction of Professor C. Taylor at the Cardiff University College has dealt with the x-ray small-angle diffraction effects expected from various models of structure put forward for polymers. It showed that the four- or two-point diagram can be given by models involving folded chains, but they can equally be given by systems involving extended chains. It is therefore no criteria of folded chains to have an x-ray small-angle scattering diagram of this type, nor is the meridional intensity of such a diagram necessarily a measure of the degree of folding as suggested by some authors.[15]

In the light of this recent research, therefore, the morphologic units in the specimens need not necessarily involve regularly folded chains. Since the units do not exist in the partially oriented yarn and are formed under stress, it is very probable that they contain extended chains. Furthermore, although irregular folding can be visualized in the partially oriented yarn, it is hard to conceive of regular chain folding being promoted under high tensions. It is concluded therefore that the morphologic units contain extended chains; and if the units are arranged in the way proposed by the model, the x-ray small angle scattering phenomena can be explained. It is hoped that this model can be tested by optical analogue techniques to substantiate the claim for its validity.

It has become clear during this discussion that the main factor in modifying the properties and performance of simultaneously draw-textured (SDT) polyester yarn is the applied draw ratio. Other factors such as the variations in the temperature of the heater, the dwell time (inversely proportional to the speed of the yarn), and a twist have secondary influences on some properties. The false-twist action appears to act toward making the yarn more uniform in properties and to some extent less influenced by the other factors of the SDT process than the flat yarn. The properties of the flat yarn, however, may be relevant to other heat-setting processes where false twist is not applied. A tentative morphologic structure has been proposed that appears to summarize the properties of the performance observed, but only further tests can show if such a model has general validity.

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