Influence of false-twist texturing parameters on the structural properties of polyester yarn

H Canbaz Karakaş & H Dayoğlu
Textile Engineering Department, Faculty of Mechanical Engineering, Istanbul Technical University, 34439 Istanbul, Turkey

Received 2 May 2003; revised received and accepted 6 May 2004

Structural changes of polyester yarn with false-twist draw texturing parameters have been studied using a high-temperature heater, high texturing speeds, short residence time in the heater and a short yarn path. The dependence of three structural parameters, viz. crystalline orientation, crystal size and birefringence, on texturing temperature, yarn residence time in the heater and draw ratio has also been studied. At high texturing speeds, the crystalline orientation and crystal size decrease due to low thermal input. Crystalline orientation tends to increase at high texturing temperatures and draw ratios.

Keywords: Birefringence, Crystal size, Crystalline orientation, False-twist texturing, Polyester, X-ray diffraction

IPC Code: Int. Cl. D01D1/00; D02G3/22

1 Introduction

The most recent developments in false-twist texturing have shown that there is still a considerable potential in this process. The production speed could be increased by the use of high-temperature heaters that reduce the residence time of the yarn in the heater to achieve the setting temperature of the polymer. As the texturing zones are shortened, the yarn path improves and the desired yarn temperature could be obtained in a very short time.

As the false-twist draw texturing involves close interactions between machine working parameters and textured yarn properties, the effect of process parameters has been widely investigated. The extent of reduction in residence time in the high-temperature heater is an important aspect for the studies. Therefore, the structural changes due to false-twist draw texturing parameters at high process speeds and very short residence time need to be investigated. The effect of process variables on the mechanical and crimp properties of polyester yarn has already been investigated. This paper deals with the study of the effect of setting variables, such as yarn temperature, texturing speed and draw ratio, on yarn structural parameters of polyester using a false-twist draw texturing machine and a high-temperature heater.

2 Materials and Methods

All the texturing processes were carried out on a laboratory-type false-twist draw texturing machine with Positotor friction head twisting assembly. A schematic diagram of texturing machine is shown in Fig. 1. The machine is able to run at mechanical working speeds of up to 1500 m/min. The thread path is linear. A high-temperature heater with a one meter length was used. The heater works on the convection principle. For cooling of yarns, a cooling plate having 0.8 m length was used. Polyester POY with the linear densities of 304 dtex/30f and 120 dtex/24 f were textured and the textured yarns with the linear densities of 167 dtex/30f and 76 dtex/24f were obtained respectively.

2.1 Texturing Variables

2.1.1 Yarn Temperature

The texturing trials were performed by taking the actual yarn temperature at the exit of the heater into consideration. The yarn temperature at the exit of the heater was measured using a Luxtron Transmet...
temperature measurement system. The temperature measurement is based on heat exchange by convection between the running thread and the measuring head. The measuring head consists of two sensors. The yarn temperature was calculated by using the relationship among the heat input, heat output and temperatures of two sensors. The heater temperature was varied accordingly to achieve the desired yarn temperature. The temperature range for polyester yarn was 155-185 °C. The D/Y ratio was kept at 2.2. Polyurethane discs were used and the draw ratio was kept at 1.81 for 304 dtex/30f POY and at 1.57 for 120 dtex/24f yarn.

2.1.2 Texturing Speed

The texturing speed was changed between 1000 m/min and 1400 m/min. The texturing trial at 1500 m/min was not considered due to the occurrence of surging at this speed.

2.1.3 Draw Ratio

Three different draw ratios (1.57, 1.63 and 1.81) were used for the study. The temperature was kept at 175°C and the texturing speed at 1000 m/min.

2.2 Yarn Properties

The crystalline orientation function and crystal size on different planes were measured.

2.2.1 X-ray Diffraction Measurements

The crystalline orientation function and the crystal size were measured using Rigaku Dmax III model X-ray diffractometer. CuKα radiations were used along with a nickel filter for monochromation of X-rays and an alternating voltage of 35 kV with an anode current of 20 mA. For polyester, the scanning range (2θ) was 13°-32° with 0.05° step for equatorial scan and the (100) plane was used for azimuthal scanning.

The crystal size was measured using the following Scherrer equation:

\[ \text{Crystal size} = \frac{K\lambda}{\beta \cos \theta} \]  

(1)

where \( K \) is the Scherrer constant (0.9); \( \lambda \), the wavelength of CuKα X-ray (1.54 Å); \( \beta \), the FWHM (Full width at half maximum); and \( \theta \), the Bragg angle.

Crystalline orientation function \( f_c \) was measured using the following equation:

\[ f_c = \frac{(180° - \text{FWHM})}{180°} \]  

(2)

2.2.2 Birefringence

The birefringence was measured using a Leitz polarizing microscope and a Berek compensator. The number of readings was adjusted so that the accuracy was within ±0.003.

The refractive indices parallel and perpendicular to the fibre axis were measured and the difference between these values \( (\Delta n) \) was taken as a measure of birefringence. This value also gives an idea of the degree of orientation in the fibre. The birefringence was measured using the following relationship:

\[ \Delta n = \frac{2\delta}{d} \]

where \( d \) is the diameter of the yarn.

3 Results and Discussion

Fig. 2 shows that the crystalline orientation function of the yarn increases with the increase in yarn temperature. The temperature was varied between 155°C and 185°C, while the texturing speed was kept constant at 1000 m/min.

With the increase in temperature for any contact time in the heater, the heat input in the yarn increases and the mobility of the macromolecular chains is facilitated. As the temperature increases, the intermolecular forces become weak. Therefore, the flexibility of the macromolecules and the motion of structural elements increase. As the stiffness of the filaments becomes lower, the crystallites align more easily. These results also correlate well with the tenacity values of the textured samples. Also, POY is subjected to externally applied forces and internal stress during draw texturizing process. The externally applied forces are drawing tensile force and yarn twisting forces, namely torsional, bending and
tangential ones. Drawing and twisting press the yarn filaments together and cause their migration and mutual friction. The internal stresses are the contraction stresses, which result from the relaxation processes and are due to the elevated molecular motion with increasing temperature. The ability of the yarn to resist these forces depends on changes in the threadline temperature. The increasing temperature interrupts more and more molecular interactions and softens the material; as a consequence, the yarn stress diminishes.\(^\text{10}\)

The change in crystal size for textured polyester yarn is shown in Fig. 3. Crystal size increases in all the planes (010, 110, 100) as the temperature increases to 160°C from 155°C and then to 165°C from 160°C. As it reaches 170°C, the crystal size decreases in (010) and (100) planes, but increases in (110) plane. There is a very slight decrease in crystal size at 175°C in all the planes, but it shows increase in all the planes at 180°C. At 185°C, the crystal size decreases in (010) plane, but increases in other planes. When the results at temperature increase of 10°C are compared, the crystal size tends to increase. As the texturing speed is high, there is not much time for the formation of bigger crystals. Therefore, a bigger range of temperature increase is needed for crystal size growth. When the results with 15°C temperature increase (155°C, 170°C and 185°C) are compared, it can be seen that the crystal growth is more significant.

The reason that the bigger crystals are obtained at higher temperatures is that the smaller and imperfect crystals melt and the growth of bigger crystals is facilitated at higher temperatures.\(^\text{11}\) From these results, it is found that the crystalline orientation function and crystal size increase as the temperature increases.

Crystalline orientation was reported to decrease by the increase in texturing temperature on friction-twisted texturing without drawing.\(^\text{2}\) In this process, the torsional and bending forces are included which have a disorienting influence at and above the temperature at which crystals become mobile. However, in draw texturing, the drawing forces will be more effective at high temperatures due to more freedom of motion of macromolecules and the crystallites will be aligned. Also, as the crystals become more mobile, they can improve their orientation.

The birefringence values of polyester yarns are shown in Fig. 4. It can be seen that the birefringence values increase as the temperature increases. Birefringence is a measure of orientation and the increase in birefringence value shows that the orientation also increases.

Table 1 shows heater temperature at various texturing speeds when the yarn temperature is kept at 175°C for 167 dtex/30f textured PET yarn. For these trials, the configuration of discs is changed from 1-5-1 to 1-6-1. The change in crystalline orientation function and crystal size with texturing speed is shown in Figs 5 and 6 respectively. It is observed that the \(f_c\) decreases as the texturing speed increases. Crystal sizes decrease in (010) plane as texturing speed is increased. When the \(f_c\) values for 1000 m/min and 1400 m/min texturing speeds are compared, a

![Figure 3](image1.png)

**Fig. 3—Change in crystal size of 167 dtex/30f textured polyester yarn with yarn temperature**

![Figure 4](image2.png)

**Fig. 4—Change in birefringence of textured polyester yarn with the yarn temperature**

<table>
<thead>
<tr>
<th>Texturing speed m/min</th>
<th>Yarn residence time in heater s</th>
<th>Heater temperature °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>0.06</td>
<td>447</td>
</tr>
<tr>
<td>1100</td>
<td>0.054</td>
<td>459</td>
</tr>
<tr>
<td>1200</td>
<td>0.05</td>
<td>470</td>
</tr>
<tr>
<td>1300</td>
<td>0.046</td>
<td>486</td>
</tr>
<tr>
<td>1400</td>
<td>0.042</td>
<td>503</td>
</tr>
</tbody>
</table>
The draw ratio is increased, the macromolecules and crystallites get more parallel along the fibre axis, and hence the crystalline orientation is increased. Also, the application of drawing reduces the possible degree of disorientation. Thus the higher the draw ratio, the greater is the orientation of the crystallites.

The results were analyzed statistically to determine whether the parameters are effective on the properties. The variance analysis shows that the yarn texturing temperature and texturing speed affect the crystalline orientation function and crystal size with an error ratio of 5%.

4 Conclusions

As the temperature of the yarn increases, the crystalline orientation function and crystal size for polyester also increase. The texturing speed determines the dwell time of the yarn in the heater and the yarn residence time in the heater decreases as texturing speed increases. This leads to a decrease in crystalline orientation function and crystal size for polyester yarn due to the fact that the time of heat setting is decreased.

Acknowledgement

The authors are thankful to the Institüt für Textiltechnik, Aachen, for allowing them to use the laboratory-type false-twist texturing machine for the trials.

References


