Development of an instrument to study shrinkage properties of air-jet textured yarns

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An instrument has been fabricated to study the shrinkage behaviour of yarns. The effect of various process parameters, namely speed, overfeed and air pressure, on the shrinkage behaviour of air-jet textured polyester yarns has been investigated. Samples were prepared using factorial design for three variables and then tested for shrinkage, bulk and instability. Three response surface equations were calculated for shrinkage, bulk and instability in terms of process parameters. The results show that the shrinkage value decreases with the increase in overfeed, air pressure and speed. The use of water during the air-jet texturing process is found to increase the shrinkage in the resultant air-jet textured yarns.

Keywords: Air-jet texturing, Partially oriented yarn, Polyester

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1 Introduction

Among the various techniques for testing yarn shrinkage, there is a method in which twisted skeins are put in boiling water and subsequently their shrinkage is determined. This method has a major disadvantage that the shrinkage value is affected by frictional forces between the neighbouring yarns. Ideally, a yarn should be free to shrink during the heat treatment. It has been found that the yarn in a single loop form is better for testing its shrinkage, because it behaves in the same way as a single yarn and does not hinder shrinkage.

Shrinkage is an important property because it determines the fabric behaviour during the apparel end use. The uniqueness of the air-jet texturing process lies in its capability to produce textured yarns of different configurations, like single component yarns, blended yarns and yarns with fancy effects. According to Wray & Sen, the physical characteristics of single end air-jet textured yarns are affected by both the properties of supplied yarn (type of yarn, linear density of individual filament, number of filaments and geometry of filament cross-section) and the process parameters (overfeed, air pressure, speed, wet or dry processing and heater temperature). The yarn overfeed promotes the development of texturing effect, but reduces the tenacity of textured yarn. Kerenyl studied the effect of overfeed on the stability of loops, keeping the other parameters constant. He concluded that with increasing overfeed, the instability and the yarn shrinkage increase.

Holden observed that the instability decreases with air pressure, but at the same air pressure, the yarns with a higher denier per filament show much lower instability. He found that the instability and boiling water shrinkage reduce with the increase in heater temperature and are the function of yarn speed. Sengupta et al. have reported the decrease in instability, as measured by Du Pont method, with the increase in air pressure. Demir et al., however, claimed the increase in instability with increasing air pressure. Acar et al. claimed that the wetting reduces the inter-filament friction, which enhances the filaments’ longitudinal displacement relative to each other, facilitates loop and entanglement formation, and thus produces improved textured yarns.

Shrinkage behaviour of fibres, textured filament yarns and textile fabrics can be characterised by the shrinkage value and the shrinkage force. Stein & Wallas found that the measured shrinkage force gives information about the ‘inner’ structure of the fibre which is marked by the molecular chain orientation and fibre crystallinity. It also gives indication about the yarn’s dyeing behaviour. According to Piller, the yarn shrinkage value can generally be expressed as a function of several parameters...
parameters, like chemical and physical properties of the polymer, fibre geometry in yarn, history of yarn production and physical parameters of thermal treatment (temperature, shrinkage, type of treating medium, shrinkage time and yarn tension during shrinkage). A number of methods have been developed for the measurement of shrinkage properties of textile materials.\textsuperscript{16-23}

Testing of yarn shrinkage can be carried out in either lea (skein) or single yarn form. In a lea test, the yarn is made into a lea, folded and then put into boiling water. After a predetermined time, the lea is taken out from the water and length is measured. In a similar test where a lea is replaced by a single loop, it is found that the lea shrinkage is less than the single loop shrinkage. This is due to the yarn-to-yarn friction in the lea, which constrains movement of the yarn and ultimately reduces shrinkage of the lea. In the case of single yarn shrinkage testing, a twisted yarn may untwist. Measuring exact length of the yarn after it has shrunk is sometimes difficult since a lot of proper care is involved while removing folds of the shrunk yarn, which may cause undue stretching. Refinement of this method is necessary to get reliable and reproducible values of yarn shrinkage. The present study is aimed at developing an instrument to determine single yarn shrinkage and then studying the effect of various texturing process parameters on the shrinkage behaviour of polyester air-jet textured yarns.

2 Materials and Methods

A new and improved method of accurately measuring yarn shrinkage has been developed, considering the following points in the design of the instrument:

- Neighbouring yarns should not hinder shrinkage of one another
- Yarns should remain straight throughout the testing to prevent entanglements
- Yarn should not untwist during the test
- Temperature of bath should be controlled automatically within a close tolerance
- Loss of heat should be minimised
- Testing of multiple samples at the same time should be possible
- The instrument should not be too costly and should be easy to operate.

The instrument, as shown in Fig. 1, consists of a removable frame and a water bath tube. Removable frame has two sets of nails which are arranged in a row. Nails in each set are 30 mm apart and the distance between the sets can be adjusted depending upon the yarn shrinkage. Yarn samples in the form a loop having one meter girth are hung from the nails in the top set. Lower sets of nails pass through the loops, thereby keeping them separate and prevent any self-twisting tendency. To keep the yarns sufficiently taut, a load of 0.005 gf/den is hung from the test yarn throughout the test. Water bath tube is 200 mm in diameter and 750 mm in height having two electrical powered heaters of 1.5 kW at a height of 40 mm and 70 mm respectively from the bottom of tube. Temperature of the bath is maintained in a range of ± 0.5°C with the help of a thermostat connected in series with the heaters connected in parallel.
The test material used was a 50 denier 24 filaments polyester fully drawn yarn (FDY), having residual shrinkage of 5.4%. Textured yarns were produced by parallel-end texturing on Eltex AT-HS air-jet texturing machine using following fixed parameters:

- Texturing nozzle type: Hemajet with T-100 core
- Water application: 1 litre/h/head at 1 bar water pressure
- Mechanical stretch: 4.7%
- Winding underfeed: 0.7%

Fifteen textured yarn samples were produced according to Box-Behnken factorial design (Table 1). The actual values of the three variables corresponding to the coded levels are given in Table 2.

In another set, 12 samples were produced by parallel-end air-jet texturing of 74 denier 36 filaments polyester partially oriented yarn (POY) with the parameters as shown in Table 3. Drawing of POY was carried out at a hot-pin temperature and draw ratio of 120°C and 1.52 respectively. Texturing speed was fixed at 300 m/min. Shrinkage of the drawn polyester POY before texturing was 8.3%.

Preliminary studies have shown that the yarn shrinkage remained constant after 10 min of testing. Therefore, a time period of 15 min was used for testing shrinkage. Tension of 0.005 gpd was applied on the yarn during the test through a ‘U’ pin. Yarns were put into boiling water for 15 min and then conditioned in a standard atmosphere for at least 3 h before measuring the shrunken length. Shrinkage was calculated using the following equation:

\[
\text{Shrinkage, } \% = \frac{\text{Initial length} - \text{Final length}}{\text{Initial length}} \times 100
\]

### 3 Results and Discussion

#### 3.1 Regression Equation of Yarn Shrinkage

Shrinkage in thermoplastic filaments takes place to reduce the stresses developed in the molecular chains during processing. When heated, the structure tries to achieve maximum entropy by going into random chain structure to the extent possible, which releases the stresses in the structure and the filaments shrink longitudinally. Filament shrinkage leads to the yarn shrinkage.

The transformed equation for the responses in terms of yarn property, i.e. textured yarn shrinkage in relation to the process variables, namely speed (SP), overfeed (OF) and air pressure (AP), after successively eliminating the insignificant terms to obtain the minimum error is:

\[
\text{Shrinkage, } \% = 0.477 + 0.00337 \times \text{SP} + 0.23852 \times \text{OF} + 0.296 \times \text{AP} - 0.00304 \times \text{OF}^2 - 0.011 \times \text{OF} \times \text{AP} - 0.00033 \times \text{SP} \times \text{AP}
\]

Here, the range of values for speed, overfeed and air pressure is 300 - 500 m/min, 20 - 30% and 7 - 9 bar respectively. The correlation coefficient between the experimental values and the calculated values

<table>
<thead>
<tr>
<th>Variable</th>
<th>Level</th>
<th>Speed, m/min</th>
<th>Overfeed, %</th>
<th>Air pressure, bar</th>
</tr>
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<tr>
<td>Speed, m/min</td>
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<td>300</td>
<td>20</td>
<td>7</td>
</tr>
<tr>
<td>Overfeed, %</td>
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<td>400</td>
<td>25</td>
<td>8</td>
</tr>
<tr>
<td>Air pressure, bar</td>
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<td>500</td>
<td>30</td>
<td>9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of texturing</th>
<th>Temperature, °C</th>
<th>Air pressure, kgf/cm²</th>
<th>Shrinkage, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet</td>
<td>170</td>
<td>8</td>
<td>6.65</td>
</tr>
<tr>
<td>Wet</td>
<td>170</td>
<td>9</td>
<td>6.48</td>
</tr>
<tr>
<td>Dry</td>
<td>190</td>
<td>8</td>
<td>1.55</td>
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<td>190</td>
<td>9</td>
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<tr>
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<td>190</td>
<td>9</td>
<td>0.11</td>
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</table>
obtained from the response surface equation is 0.96 and the standard error is 0.048. The high correlation coefficient indicates that the experimental data agree with the response surface equation.

3.2 Effect of Stabilising Heater Temperature on Yarn Shrinkage

Table 3 shows that the textured yarns, stabilized at higher heater temperature, exhibit lower shrinkage than those stabilized at lower heater temperature. Also, the shrinkage reduces if heaters are used compared to when heaters are not used. This can be seen from the lower shrinkage values of yarns textured at a heater temperature of 170°C and 190°C. As the temperature is increased, the filament shrinkage inside the heater increases and greater stress relaxation in individual filaments takes place during the texturing process. Hence, the boiling water shrinkage of individual filament decreases, which, in turn, causes lower shrinkage in the yarn.

3.3 Inter-relationship of Process Variables and Yarn Shrinkage

Figs 2-4 show the response surface equations in the form of 3-D graphs. Interactive effects of the overfeed and air pressure show that the shrinkage decreases with the increase in both overfeed and air pressure, whereas interactive effect of the speed and overfeed on shrinkage is less. The same effect is observed with the speed and air pressure.

If the overfeed is increased, the yarn shrinkage reduces slightly for constant values of speed and air pressure. An increase in overfeed is associated with the increase in number of loops, loop size and lesser compactness of the yarn core. This leads to higher instability and bulk in the yarn. During the shrinkage...
test, when individual filaments start to shrink they have relatively greater freedom, leading to higher slippage among the filaments. As a result, the individual filaments shrink rather than the yarn in totality.

On increasing air pressure, the degree of entanglement in the yarn increases, the loops become smaller, and the yarn becomes more compact. This could be associated with the increase in shrinkage of filament. But, the experimental data show decrease in shrinkage with the increase in air pressure, possibly due to higher obliquity of the filaments in the yarn structure produced with higher air pressure. This causes yarn compactness to increase as the individual filaments shrink, resulting in the lower yarn shrinkage.

Shrinkage of air-jet textured yarns increases with speed for constant values of yarn overfeed and air pressure. It is known that the texturing at lower speeds produces relatively compact and bulkier yarns compared to those textured at higher speed. As the texturing speed increases, yarn structure becomes less compact, loop frequency reduces and, therefore, inter-filament friction can be expected to reduce, leading to higher yarn shrinkage.

3.4 Effect of Water Application on Yarn Shrinkage

Use of water during the air-jet texturing leads to higher shrinkage. This is reflected by the higher shrinkage values of wet textured yarns compared to dry textured yarns (Table 3). This is due to the fact that during air-jet texturing there is more entanglement in the wet textured yarn, which increases the average angle of filaments in the yarn core, leading to higher yarn shrinkage.

4 Conclusions

An instrument to determine single yarn shrinkage has been developed and used to study the shrinkage properties of textured yarns produced with different processing parameters. The shrinkage value of air-jet textured yarns depends on the texturing process parameters, such as speed, overfeed, air pressure, heater temperature and application of water prior to texturing. In case of yarns textured at higher overfeed, the slippage between the filaments is more and the yarn shrinkage is low. With the increase in texturing speed, the texturing effect in the yarn decreases but the shrinkage in the yarn increases. With the use of a stabilizing heater and increasing the heater temperature, there is reduction in yarn shrinkage due to stress relaxation. Increasing the temperature can further reduce yarn shrinkage. Use of water before texturing increases the yarn boiling-water shrinkage, as there are increased number of entanglements and higher average filament obliquity.

References