Influence of annealing on the properties of air-jet and ring yarns

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The influence of heat treatment or annealing under tensioned and relaxed conditions on the properties of air-jet and ring yarns has been studied. Slack annealing reduces the flexural rigidity of air-jet yarn at the cost of tenacity. Tension annealing though increases tenacity, makes the yarn very stiff by enhancing flexural rigidity. Abrasion resistance and recovery properties have been found to improve with slack and tension annealing respectively.

Keywords: Air-jet yarn, Annealing, Ring yarn

1 Introduction

The air-jet spun yarns are well known for being stiffer than the equivalent ring- and rotor-spun yarns. The high bending rigidity of air-jet yarn is ascribed to its structure. The straight and parallel arrangement of core fibres wrapped by helically arranged binding fibres offers very little freedom of movement to the fibres within the core when the yarn is bent, thus enhancing stiffness. The high bending rigidity is one of the greatest weaknesses of air-jet yarns. There could be three possible ways to reduce rigidity. These are (i) to use finer fibres, (ii) to reduce linear density of fibre using sodium hydroxide treatment, and (iii) to reduce the tension level under which binding fibres are wrapped around core. All the methods mentioned above have some limitations. The use of fine fibres is limited by difficulties in processing them on card. Reduction in tension level of binding fibres will concomitantly decrease yarn strength. Denier reduction through sodium hydroxide treatment is an additional process that needs to be carried out under controlled conditions.

In the present work, a different approach has been adopted to reduce bending rigidity. Since straight and parallel arrangement of fibres facilitates clustering, any method that introduces disorder in the fibres will reduce clustering and hence bending rigidity. To introduce disorder, the fact that polyester fibre shrinks on heating has been used. Incidentally, polyester fibre, either 100% or in blend, is extensively used in air-jet spinning also.

In the present paper, the influence of heat treatment or annealing, under tensioned and relaxed conditions, on the properties of air-jet vis-a-vis ring yarns has been reported.

2 Materials and Methods

Air-jet spun yarns of 26.8 tex (22s Ne) and 9.8 tex (60s Ne) and ring yarns of 24.3 tex (24.3s Ne) and 9.8 tex (60s Ne) were produced from polyester fibre (1.4 denier and 51 mm).

The portions of air-jet and ring-spun yarns were annealed (by dry heat) at a constant temperature of 160°C for 5 min in a hot chamber under relaxed and tensioned (0.9 g/tex) conditions. The extent of shrinkage was measured by determining the contraction in length and increase in linear density.

The parent and the annealed yarn samples were tested for tensile property, structural integrity, abrasion resistance and flexural rigidity.

2.1 Tensile Property

The parent and the annealed yarn samples were tested on Instron tensile tester at a gauge length of 20 cm and cross-head speed of 2.5 cm/min. Tenacity, breaking extension, modulus and breaking energy values were computed from the load-extension curves.

2.2 Structural Integrity

Each type of yarn sample was subjected to repeated load cycling at gauge length of 20 cm and cross-head speed of 2.5 cm/min. Two upper load limits, fixed at levels equivalent to 10% and 50% of the total extension at break of the respective samples, were used in this study. It was found that concurrency of the hysteresis curve occurred at tenth and thirtieth load cycle for upper limit of load equivalent to 10% and 50% of breaking extension respectively. Areas of hysteresis curves were measured using a planimeter for the first, 10th and 30th load cycles.
The percentage decay, which was used as a measure of structural integrity, was found out as per the following formula:

$$\text{Decay} (\%) = \left( \frac{A_{1} - A_{n}}{A_{1}} \right) \times 100$$

where $A_{1}$ is the area of loading curve for first cycle; and $A_{n}$, the area of loading curve for 10th or 30th cycle.

After the completion of load cycling, each sample was further tested for tenacity and breaking extension. A minimum of 30 readings were taken for each sample.

2.3 Abrasion Resistance

A parallel array of yarn placed at an interval of 1 mm was tested for flex abrasion resistance on a universal wear test at a constant tension and head weight of 1 lb and 1/2 lb respectively. The number of cycles needed to rupture the strip of yarns was used as the measure of abrasion resistance.

2.4 Flexural Rigidity

This test was carried out on Shirley ring loop tester. The circumference of the loop was 7.75 cm. A weight was hung so as to deflect the bottom of the loop between 0.35 cm and 0.70 cm. A minimum of 10 tests were carried out for each sample. Flexural rigidity was determined using the following formula:

$$\text{Flexural rigidity} = \frac{981 M L \cdot}{Z \cdot} \text{dyn-cm}$$

where $M$ is the weight hung; $L$, the loop circumference; and $Z$, a parameter calculated from the deflection of loop and $L$.

3 Results and Discussion

3.1 Influence of Annealing on Length and Linear Density

It may be observed from Table 1 that slack annealing results in contraction of length with concomitant increase in linear density for both air-jet and ring yarns due to longitudinal shrinkage of individual fibres. Tensioned annealing set the fibres in an elongated state causing an increase in length and decrease in linear density. The ring yarn has a higher potentiality of shrinkage during slack annealing process, probably due to higher level of spinning tension at which the yarn is spun.

<table>
<thead>
<tr>
<th>Yarn</th>
<th>Linear density tex</th>
<th>Change in length, %</th>
<th>Change in linear density, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Slack annealed</td>
<td>Tension annealed</td>
</tr>
<tr>
<td>Air-jet</td>
<td>26.8</td>
<td>-5.7</td>
<td>+4.5</td>
</tr>
<tr>
<td></td>
<td>9.8</td>
<td>-6.6</td>
<td>+3.9</td>
</tr>
<tr>
<td>Ring</td>
<td>24.3</td>
<td>-8.4</td>
<td>+1.3</td>
</tr>
<tr>
<td></td>
<td>9.8</td>
<td>-7.4</td>
<td>+2.1</td>
</tr>
</tbody>
</table>

3.2 Influence of Annealing on Tensile Properties

It may be observed from Table 2 that for both air-jet and ring yarns, tenacity decreases and breaking extension increases after slack annealing. Tension annealing reduces breaking extension of both types of yarn. Tenacity, however, increases marginally for air-jet yarn and decreases for ring yarns. Tension annealing can be seen to increase modulus which is especially significant for air-jet yarn. Slack annealing, in general, decreases modulus except for 9.8 tex air-jet yarn.

During slack annealing, the shrinkage of fibres causes disorientation and loosening of the structure. As a result, one would expect a decrease in tenacity and an increase in extension. The extensibility of ring yarn improves more than that of air-jet yarn. This is mainly because fibres shrink more in ring yarn as they are subjected to higher strain levels during spinning. Also, the contraction of wrapped binding fibres in air-jet yarn has a restrictive influence on longitudinal shrinkage of the core fibres.

Tension annealing sets the core fibres in an elongated state in the air-jet yarn, thus reducing residual extensibility of core fibres. The wrapped fibres undergoing shrinkage reinforce the structure. As a result, breaking extension decreases and tenacity increases marginally. The reduction in breaking extension of ring yarn is also ascribed to setting of fibres in an elongated state. The reduction in tenacity of ring yarn following annealing may be associated with strain asymmetry in individual fibres which is enhanced as a consequence of constrained shrinkage.

The decrease in modulus for slack-annealed samples of both types of yarn is due to more open structure of slack-annealed yarns. The tension-annealed samples show an increase in modulus due to more compact structure. The reinforcing of core fibres
through shrinking of wrappers is very much predominant in air-jet yarns which exhibit a significant rise in modulus after tension annealing.

3.3 Flexural Rigidity

Flexural rigidity of both types of yarn decreases after slack annealing (Table 2) due to the opening up of the structure which favours easy inter-fibre movement during bending. The flexural rigidity increases after tension annealing. This can be ascribed to compaction of the structure which gives less freedom of fibre movement during bending. This is also manifested in the modulus values of the tension-annealed samples (Table 2).

3.4 Abrasion Resistance

Abrasion resistance of both types of yarn increases after slack annealing (Table 2). This is due to increase in compressibility of the yarn because of the opening up of the structure and extensibility of the yarn which reduces the intensity of abrading action. Tension annealing on the contrary reduces the
Table 4—Influence of load cycling on the tensile properties

<table>
<thead>
<tr>
<th>Yarn</th>
<th>Linear density tex</th>
<th>Annealing treatment</th>
<th>Tenacity (cN/tex) at load equivalent to 10% extn</th>
<th>Breaking extension (%) at load equivalent to 10% extn</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0% extn</td>
<td>50% extn</td>
</tr>
<tr>
<td>Air-jet</td>
<td>Nil</td>
<td>Nil</td>
<td>22.0</td>
<td>21.0</td>
</tr>
<tr>
<td></td>
<td>Slack</td>
<td>26.8</td>
<td>19.0</td>
<td>18.9</td>
</tr>
<tr>
<td></td>
<td>Tension</td>
<td></td>
<td>22.4</td>
<td>22.0</td>
</tr>
<tr>
<td></td>
<td>Slack</td>
<td>9.8</td>
<td>23.6</td>
<td>20.6</td>
</tr>
<tr>
<td></td>
<td>Tension</td>
<td></td>
<td>20.1</td>
<td>20.6</td>
</tr>
<tr>
<td></td>
<td>Slack</td>
<td>23.8</td>
<td>23.0</td>
<td>23.5</td>
</tr>
<tr>
<td></td>
<td>Tension</td>
<td></td>
<td>27.3</td>
<td>26.7</td>
</tr>
<tr>
<td>Ring</td>
<td>Nil</td>
<td>24.3</td>
<td>24.1</td>
<td>22.3</td>
</tr>
<tr>
<td></td>
<td>Slack</td>
<td></td>
<td>26.0</td>
<td>24.3</td>
</tr>
<tr>
<td></td>
<td>Tension</td>
<td>9.8</td>
<td>20.5</td>
<td>20.3</td>
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<tr>
<td></td>
<td>Slack</td>
<td></td>
<td>19.4</td>
<td>26.7</td>
</tr>
<tr>
<td></td>
<td>Tension</td>
<td></td>
<td>19.1</td>
<td>24.9</td>
</tr>
</tbody>
</table>

"No. of load cycles.

abrasion resistance for air-jet yarn and increases it for ring yarns. The reduction in abrasion resistance can be ascribed to stiffening of air-jet yarn (corroborated by higher modulus and flexural rigidity values) which develops more stress in the structure as it bends over the edge during flex abrasion.

The increase in abrasion resistance for tension-annealed ring yarn is a little difficult to explain. May be, there is less plucking by the abrading surface due to the compaction of the structure. This may be a distinct possibility as the yarn was spun at a low twist multiplier (3.1).

3.5 Structural Integrity

The recovery behaviour of tension-annealed samples is much better for both types of yarn in comparison to parent and slack-annealed yarns as may be seen from % decay values given in Table 3. This is mainly due to enhancement of structural integrity which restricts the possibility of fibre slippage during load cycling, resulting in lesser decay. The % decay generally increases for slack-annealed samples except for air-jet yarn subjected to a load equivalent to 10% extension. The increase in % decay can be attributed to the loosening of the structure following slack annealing which causes localized slippage of fibres.

It may be observed from Table 4 that repeated load cycling gradually reduced tenacity and breaking extension of both air-jet and ring yarns. This phenomenon is likely to be associated with the reduction in structural integrity due to fibre slippage and accumulation of stain as a result of repeated loading.

4 Conclusions

Slack annealing reduces tenacity and increases breaking extension of air-jet and ring yarns. Tension annealing reduces the breaking extension of both types of yarn and increases the tenacity of air-jet yarn.

While slack annealing reduces modulus with concomitant decrease in flexural rigidity, tension annealing reverses the trend and there is a high rise in the modulus of air-jet yarns following tension annealing.

Abrasion resistance improves with slack annealing.

Recovery property improves after tension annealing.

The results suggest that slack annealing of air-jet yarns may be a useful process for reducing stiffness and enhancing abrasion resistance.

References