Fibre Rupture during Tensile Failure of Ring and Rotor Yarns

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Received 27 January 1984; accepted 14 February 1984

Fibre rupture during tensile failure of ring and rotor yarns has been studied as a function of fibre length using the technique of optical isolation of tracers. It has been observed that as the fibre length increases, the percentage of fibre rupture increases almost linearly for the ring yarn and the core of the rotor yarn. The minimum length of fibre which ruptures and contributes to yarn tenacity is higher for rotor yarn than for ring yarn. Fibre rupture for rotor yarn is always much lower than that for ring yarn.

The tensile strength of a yarn depends, besides other things, on the strength of the constituent fibres in the rupture region and the extent to which this strength is utilized in the process of yarn breakage. Considerable work has been done to assess the influence of the above factors on yarn tenacity. It is generally accepted that a higher fibre strength leads to a yarn with higher tenacity, irrespective of the yarn structure. The extent of utilization of fibre strength depends on the percentage of fibre rupture, which, in turn, depends on the twist in the yarn and the rate at which the yarn is being tested.

For ring yarns, Gulati and Turner, using the Congo Red staining method to distinguish the ends of broken cotton fibres, observed that there is a very close relationship between the percentage of fibre rupture and the yarn strength, over 60% fibres breaking at high twist when the yarn strength is maximum and very few fibres breaking at low twist when the yarn strength is very low. They further observed that fibres below 0.5 in length do not contribute to yarn strength. Tallant et al. indicated a minimum length of 3/16 in at each end of the fibre as the gripping length. On the other hand, Köhler indicated a value of 8 mm for at least certain conditions of yarn size and twist. Singh and Sengupta used the technique of optical isolation of tracers to find out the percentage of fibre rupture and observed that except for very low strain rates, increase in tensile strength with strain rate is a direct contribution of increased strength utilization due to higher fibre rupture, the frictional contribution remaining essentially constant. In the above study, the percentage of fibre rupture was calculated on the assumed assumption that the probability of fibre rupture during yarn breakage is the same irrespective of the fibre length. However, Köhler pointed out the influence of fibre length on the number of fibres that break and on fibre strength utilization in the yarn.

Regarding rotor yarns, it is generally accepted that yarn failure occurs predominantly due to the slippage of fibres. The arguments advanced for this type of behaviour are purely qualitative, like breaking extension being high and the stress levelling off at the breaking point. No quantitative information is available to support this type of behaviour.

The present study was aimed at finding out (i) the percentage of fibre rupture, taking into consideration all lengths of fibres, for both ring and rotor yarns, and (ii) the minimum fibre length which breaks and thereby contributes to yarn tenacity. For all these studies, the technique of optical isolation of tracers was used.

Materials and Methods

American cotton (fibre fineness, 4.2 µg/in and mean fibre length, 18.1 mm) was used.

Preparation of yarn samples—Six different lengths of fibres, viz. 6, 8, 10, 15, 20 and 25 mm, were taken from the American cotton. To segregate the fibres of a particular length, a sliver of this cotton was prepared and clamped at A in the clamping device shown in Fig. 1. The fibres projecting to the right of A were combed to remove the unclamped fibres. Another clamp was then positioned at B, the distance from A to B being the length required. The parallel array of fibres was then cut at A and the clamp at A was removed. The fibres were then combed to the left of B to remove the unclamped fibres at B. The fibres were then cut at B. The fibres lying between A and B were collected. This procedure was repeated until sufficient fibres of each length were collected. These fibres were dyed with Congo Red dye (C.I. Direct Red 28).

About 0.30 g dyed fibres were mixed with 40 g undyed cotton, so that, on an average, only 1-2 tracers were observed in the yarn cross-section. It was processed twice on the Shirley miniature card. The laps obtained were given two passages of drawing on the
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Fig. 1—Clamping device

Shirley miniature drawframe. Yarn of 16' cotton count was spun on the Suessen OE spin tester using 5.0 twist multiplier. To prepare the corresponding ring yarn, the drawn sliver was first converted into a slubbing and then to an inter of 1.7 hank. The inter was fed to a ring frame equipped with PK 211 drafting system. The yarn was spun with 4.5 twist multiplier.

Tensile testing of yarns—The yarn samples were tested for tensile strength on an Instron universal strength tester at a strain rate of 10 cm/min. The gauge length was 25 cm. The broken ends were collected for observation of tracers.

Observation of tracers—The tracers were observed using the method followed by Singh and Sengupta. This method is based on optically dissolving the undyed fibres using tricresyl phosphate, so that the tracers dyed are clearly visible in the yarn. For each yarn sample, a minimum of 50 tracer fibres were observed.

Identification of broken fibre—A fibre was classified as a broken fibre if the following requirements were met: (i) Both the broken ends of yarn contained tracers, (ii) the length of each tracer was more than a certain minimum length, 4 mm for ring and 5 mm for rotor yarns, and (iii) the sum of the lengths of both the tracers was equal to or less than the original tracer length.

Fibre length analysis—The length frequency diagram of the American cotton was obtained using the Uster fibre staple.

Calculation of percentage of fibre rupture—It seems reasonable that the probability of fibre rupture during yarn breakage in a tensile test is dependent upon fibre length, as suggested by Köhler. This means that there is a certain minimum length of fibre that ruptures and contributes to yarn tenacity. This minimum length was determined for both ring and rotor yarns by taking progressively smaller tracer fibres. Using this minimum as base, the expected percentage of fibre rupture for any length was determined from the plot in Fig. 2, which depicts the relationship between the fibre length and the percentage of fibre rupture. For lengths > 25 mm, the expected percentage of fibre rupture was extrapolated from the above relationship, as shown in Fig. 2. This expected percentage of fibre rupture ($E_i$) multiplied by the corresponding class frequency gave the number of fibres that ruptured. The overall percentage of fibre rupture for a given yarn was calculated from the fibre length distribution curve. The number of fibres ($N_i$) in each class interval of 2 mm was found out. The percentage of fibre rupture ($P$) for the yarn was calculated using the following equation:

$$P = \frac{\sum_{i=1}^{n} N_i E_i}{\sum_{i=1}^{n} N_i}$$

where $n = \frac{L - 4}{2}$, $L$ being the maximum fibre length in mm.

Fig. 2—Relationship between fibre rupture and fibre length
Results and Discussion

Fibre rupture in ring yarn—The values of percentage of fibre rupture for various lengths of tracer fibres are given in Table 1. It is seen that only 4% fibres of 8 mm rupture at the time of yarn-break. At 6 mm fibre length, the rupture percentage is zero. Therefore, for ring yarns, 8 mm may be taken as the minimum length of fibre which ruptures. This means that in a ring yarn, the fibre should provide grip over at least 4 mm at each of its ends. Therefore, in a broken yarn, the minimum length of ruptured segment of fibres which could be expected is 4 mm. Hence, the minimum length of broken segment has been taken as 4 mm to ascertain whether a tracer fibre is broken or not. As the length of tracer fibre increases, the percentage of fibre rupture increases linearly (Fig. 2).

The calculated values of percentage of fibre rupture for various intervals of fibre lengths are given in Table 2. The overall calculated percentage of fibres that rupture when the yarn breaks comes to 34.14, which is in the range observed by Gulati and Turner using the Congo Red staining method.

Fibre rupture in rotor yarn—The values of percentage of fibre rupture for various lengths of tracers in the case of rotor yarn are also given in Table 1. Due to the unique bipartite structure of the rotor yarn, the percentage of fibre rupture has been given for both core and overall yarn (i.e. core and sheath combined). The value for the core has been computed as the percentage of fibre rupture that takes place only in the core of yarn, and that for the overall yarn, as the percentage for the core and sheath taken together.

It is interesting to note from Table 1 that the minimum length of fibre which ruptures in the tensile test is 10 mm for rotor yarns as compared to 8 mm for ring yarns. Hence, the minimum length of broken segment has been taken as 5 mm for rotor yarns to ascertain whether a fibre is broken or not. As the fibre length increases, the percentage of fibre rupture for the core yarn increases almost linearly. Up to a fibre length of 20 mm, the percentage of fibre rupture for core and overall yarn is the same. At 25 mm fibre length, the percentage of fibre rupture is 8.75% higher for the core yarn. This difference can be explained by considering the fact that rotor yarn has a bipartite structure with a core and a sheath. The core of the rotor yarn resembles the ring yarn. The sheath consists of loosely packed fibres twisted around the core lying at a low angle.

<table>
<thead>
<tr>
<th>Group fibre length mm</th>
<th>Frequency %</th>
<th>Expected fibre rupture %</th>
<th>Fibres ruptured %</th>
</tr>
</thead>
<tbody>
<tr>
<td>38-36</td>
<td>0.4</td>
<td>72.00 0.29</td>
<td>31.25 0.12</td>
</tr>
<tr>
<td>36-34</td>
<td>0.6</td>
<td>67.00 0.40</td>
<td>31.25 0.19</td>
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<tr>
<td>34-32</td>
<td>1.4</td>
<td>61.00 0.85</td>
<td>31.25 0.43</td>
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<tr>
<td>32-30</td>
<td>2.7</td>
<td>56.00 1.51</td>
<td>31.25 0.84</td>
</tr>
<tr>
<td>30-28</td>
<td>5.4</td>
<td>51.00 2.75</td>
<td>31.25 1.67</td>
</tr>
<tr>
<td>28-26</td>
<td>6.5</td>
<td>46.00 2.99</td>
<td>31.25 2.02</td>
</tr>
<tr>
<td>26-24</td>
<td>8.7</td>
<td>41.00 3.57</td>
<td>31.25 2.70</td>
</tr>
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<td>24-22</td>
<td>9.5</td>
<td>36.00 3.42</td>
<td>31.00 2.95</td>
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<td>8.0</td>
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<tr>
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<td>26.00 2.13</td>
<td>28.00 2.30</td>
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<td>8.2</td>
<td>20.00 1.72</td>
<td>20.50 1.68</td>
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<td>7.75 0.60</td>
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<td>6.00 0.38</td>
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<td>0 0</td>
<td>0 0</td>
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Fibre rupture for core, 24.66%. Overall fibre rupture, 19.31%.
angle to the yarn axis together with the fibres wrapped round the outside of the yarn having a very large inclination to the yarn axis. It has been found that longer fibres tend to predominate as belts or wrappers in rotor yarns\textsuperscript{12}. These belts rarely break during yarn breakage. Hence, the core shows a higher percentage of fibre rupture than the overall yarn.

The calculated values of percentage of fibre rupture for various intervals of fibre lengths are given in Table 3. The overall calculated percentage of fibres that rupture when the yarn breaks comes to 19.31.

Comparison of percentage of fibre rupture in ring and rotor yarns—It is seen from Table 1 that the percentage of fibre rupture for ring yarn is always higher than that for rotor yarn. The observed difference in fibre rupture can be explained on the basis of differences in their structures. The fibres in rotor yarn resemble open-packing and the yarn has a low packing density\textsuperscript{13}. In addition, fibre migration in rotor yarn is much lower than in ring yarn\textsuperscript{14}. On the other hand, the fibres in ring yarn show uniform migration and the packing density resembles close packing. When the ring yarn is subjected to tension, the helical geometry of the fibres in the outer layers causes inward pressure to develop from the outer layers to the inner layers. As the tension increases, the frictional contribution of the component increases until the fibres start breaking. On the other hand, in a rotor yarn, only the fibres in the core experience a similar consolidating effect. Even this consolidating effect is considerably lower because of poor migration in rotor yarns. This fact is borne out by the lower minimum length requirement of 8 mm for ring yarns, as compared to 10 mm for rotor yarns, for contribution to yarn tenacity. This argument holds good for all the other fibre lengths. When the sheath fibres are also taken into account, a still lower percentage of fibre rupture can obviously be expected for rotor yarn in comparison to ring yarn.

Conclusions

(1) The minimum length of fibre which ruptures in a tensile test is 8 mm for ring yarn and 10 mm for rotor yarn.
(2) The percentage of fibre rupture increases linearly with increase in fibre length for ring yarn and the core of rotor yarn.
(3) The percentage of fibre rupture for ring yarn is higher than that for rotor yarn for all the fibre lengths. The overall fibre rupture is 34.14\% for ring yarn and 19.31\% for rotor yarn.

Acknowledgement

The authors acknowledge the help rendered by Shri K.L. Renganathan during this work.

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