Assessment of tensile properties of cotton yarns

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The influence of rate of extension on the tensile properties of cotton yarns has been studied. The relationship between different tensile parameters of cotton yarns obtained from Uster Tensorapid-3 and Uster Tensojet has been developed. It is observed that the results obtained from these two tensile testers show very good correlation. The average strength-time coefficient and breaking extension-time coefficient of cotton yarns of varying count have also been derived using the formula proposed by Meredith. The absolute value of both the time coefficients decreases with the increase in yarn fineness beyond 50s.

Keywords: Breaking extension, Cotton, Tenacity, Uster Tensorapid-3, Uster Tensojet, Work of rupture

1 Introduction

Among the measurable mechanical properties of a yarn, considerable attention has been paid on the evaluation of tensile strength and breaking extension as these properties of the spun yarns influence the efficiency of weaving and knitting machines and the quality of the fabric produced from them. However, the tensile strength and breaking extension of the yarns are not unique functions but they depend on the rate of extension. Uster Tensorapid-3 and Uster Tensojet are the two constant rate of extension (CRE) type tensile testers, manufactured by Zellweger Uster, which are very commonly used in the spinning mills to evaluate these properties of yarns. But their operating speeds are not same. The maximum possible speeds for Tensorapid-3 and Tensojet are 5m/min and 400m/min respectively. From the practical point of view, it is desirable that the effect of operating speed on the tensile properties of yarn should be known so that the results obtained from the instruments running at different speeds can be correlated and compared.

According to Midgley and Peirce, a rapid test produces a higher breaking load than a slow test. They have also established an empirical relationship between the strength values obtained and the breaking time. Meredith tested yarns over a millionfold range of rates of extension and found that the relationship between yarn tenacity and logarithm of rate of extension is approximately linear. For breaking times ranging between a second and an hour, the following formula was proposed by him:

\[ F_1 - F_2 = -K F_1 \log_{10}(t_2/t_1) \]

where \( F_1 \) is the breaking load in time \( t_1 \); \( F_2 \), the breaking load in time \( t_2 \) and \( K \), the strength-time coefficient.

George observed that at constant 'true' rates of extension, the strength-time coefficient is slightly higher than that obtained by Meredith. Some other researchers have also reported the effect of rate of extension on the tensile properties of yarns.

In the present work, an attempt has been made to find out the influence of rate of extension on the tensile properties of cotton yarns. The relationship between the results obtained from Uster Tensorapid-3 and Uster Tensojet has been derived and the effect of yarn count on strength-time coefficient and breaking extension-time coefficient of cotton yarns investigated.

2 Materials and Methods

Eight yarn samples, made of 100% cotton of varying count, were collected from spinning mills. Each yarn sample was consisting of 5 full cones.

2.1 Measurement of Tenacity, Breaking Extension and Work of Rupture

All the yarn samples were conditioned for 24 h in a standard atmosphere (20°C ± 2°C and 65 ± 2% R H) and then tested for tenacity, breaking extension and work of rupture using Uster Tensorapid-3 and Uster Tensojet.

2.1.1 Uster Tensorapid-3

This instrument is very commonly used in the spinning industries for tensile testing of yarns, industrial
threads and fabrics. It is sometimes referred to as a dynamometer, equipped with devices for removing broken ends so that a large number of tests can be performed without requiring assistance of an operator. Breaking load is measured by two pairs of frequency determining element which are connected with two oscillators and breaking extension is monitored by a rotational movement transducer. The test report provides information about breaking load, tenacity, breaking extension, work of rupture and their variability. The testing parameters used for the study were as follows:

- Specimen length: 500 mm
- Rate of extension: 5 m/min
- Pretension of yarn: 0.5 cN/tex
- No. of readings per sample: 1000

2.1.2 Uster Tensojet

This is the most advanced tensile tester, developed by Zellweger Uster, which can perform 30,000 tensile tests per hour at a test speed of 400 m/min. Working principle of Tensojet differs from that of normal tensile testers. In this tester, yarn is continuously drawn off the package by transportation rollers and is then suctioned into pneumatic yarn storage unit by an air nozzle. Yarn is injected into the measuring zone by a jet of compressed air as the recess in the continuously rotating metal roller opens the air channel. The feed yarn control rollers are opened at this stage. Once the air channel is again closed by the further rotation of the two pairs of drafting rollers, the yarn is clamped tightly between the metal and rubber rollers of the upper and lower drafting roller pairs and extended to rupture by counter rotating rollers. Pressure transducers are used to determine the breaking load and extension values. Tensojet can effectively be used to measure the frequency of weak spots in the spun yarn. The testing parameters used for the study were as follows:

- Specimen length: 500 mm
- Rate of extension: 400 m/min
- Pretension of yarn: 0.5 cN/tex
- No. of readings per sample: 10,000

3 Results and Discussion

3.1 Single Yarn Tenacity

Table 1 shows the influence of rate of extension on the tenacity of cotton yarns. It may be seen that the higher rate of extension causes higher yarn tenacity and vice versa. Although the actual values of tenacity are not equal for Tensorapid-3 and Tensojet, there is a very good correlation between the two values ($r = 0.99$). The regression equation used to calculate the correlation is as follows:

$$ T_I = 1.06 T_R + 1.80 $$

where $T_I$ is the yarn tenacity reported by Tensojet and $T_R$ the corresponding tenacity reported by Tensorapid-3.

The tenacity value shown by the Tensorapid-3 is always lower than the corresponding value shown by the Tensojet. This can be attributed to the relaxation of stress. The average yarn breaking times for Tensorapid-3 and Tensojet are 0.335s and 0.004s respectively, which may have allowed more relaxation of stress in the case of Tensorapid-3, causing lower yarn tenacity.

3.2 Breaking Extension

The breaking extension values of cotton yarns obtained from Tensorapid-3 and Tensojet are shown in Table 1. It is observed that the higher rate of extension causes lower breaking extension for all types of cotton yarn. When the breaking extension values reported by the two testers are compared, the correlation

<table>
<thead>
<tr>
<th>Count</th>
<th>Tenacity cN/tex</th>
<th>Breaking extension %</th>
<th>Work of rupture CN cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UTR</td>
<td>UTJ</td>
<td>UTR</td>
</tr>
<tr>
<td>16 KW</td>
<td>17.13</td>
<td>19.99</td>
<td>6.20</td>
</tr>
<tr>
<td>20 KW</td>
<td>16.21</td>
<td>19.05</td>
<td>6.01</td>
</tr>
<tr>
<td>30 KW</td>
<td>15.80</td>
<td>18.33</td>
<td>5.76</td>
</tr>
<tr>
<td>40 CBW</td>
<td>16.53</td>
<td>19.23</td>
<td>5.48</td>
</tr>
<tr>
<td>50 CBW</td>
<td>17.50</td>
<td>20.51</td>
<td>5.33</td>
</tr>
<tr>
<td>60 CBW</td>
<td>16.70</td>
<td>19.35</td>
<td>4.93</td>
</tr>
<tr>
<td>70 CBW</td>
<td>20.66</td>
<td>23.90</td>
<td>5.60</td>
</tr>
<tr>
<td>80 CBW</td>
<td>20.56</td>
<td>23.14</td>
<td>5.42</td>
</tr>
</tbody>
</table>

UTR—Uster Tensorapid-3, UTJ—Uster Tensojet, KW—Carded warp, CBW—Combed warp.
coefficient is found to be very good \((r = 0.95)\). A simple expression, as given below, has been proposed to find out the relationship between the two testers:

\[
E_J = 0.86 E_R + 0.09
\]

where \(E_J\) is the breaking extension reported by Tensorjet and \(E_R\), the breaking extension reported by Tensorapid-3.

The yarn breaking time reduces with the increase in rate of extension. Hence, there is less time for creep (time dependent extension) to occur. As a result, the overall breaking extension reduces at higher rate of extension.

### 3.3 Work of Rupture

The work of rupture, sometimes called the toughness, is defined as the energy needed to break the specimen. It is observed from Table 1 that the value of work of rupture reduces as the yarn becomes finer. The values of work of rupture obtained from the two testers are found to be very close to each other, although the Tensorjet shows slightly higher values than the Tensorapid-3, except in the case of 40s yarn. There is a very good correlation between the values of work of rupture obtained from Tensorapid-3 and Tensorjet \((r = 0.99)\). The regression equation used to calculate the correlation is as follows:

\[
W_J = 1.04 W_R - 2.25
\]

where \(W_J\) is the work of rupture reported by Tensorjet and \(W_R\), the work of rupture reported by Tensorapid-3.

As the yarn becomes finer the number of fibres in yarn cross-section reduces. As a result, the force required to break the yarn also reduces, causing lower value of work of rupture. As the work of rupture is a function of breaking force and breaking extension, the lower yarn breaking force obtained from Tensorapid-3 is almost compensated by the corresponding higher breaking extension. This ultimately leads to the work of rupture values closer to that of Tensorjet.

### 3.4 Time Coefficients

The strength-time coefficient and breaking extension-time coefficient are defined as the fractional increase in strength and breaking extension respectively for a tenfold increase in breaking time. The strength-time coefficient is negative because an increase in strength is produced by a decrease in breaking time.

The time coefficients of cotton yarns are calculated using the equation proposed by Meredith. It can be observed from Table 2 that, except in the case of 80s yarn, the strength-time coefficient of cotton yarns lies between \(-0.069\) and \(-0.076\). However, the absolute value of both the time coefficients shows a decreasing trend with the increase in yarn fineness beyond 50s. The average time coefficients of cotton yarns are \(-0.07\) and \(0.063\) for strength and breaking extension respectively. Hence, the effect of rate of extension on breaking extension is smaller than its effect on strength. In case of viscose rayon yarns, this phenomenon was also observed by Meredith.

Finer yarns are generally spun from longer and finer fibres. Moreover, the packing density of finer yarns is also higher than that of coarser yarns. In other words, the structure of finer yarns is relatively rigid than that of coarser yarns, which does not allow the fibres to exhibit time-dependent behaviours (stress-relaxation and creep) in the case of the finer yarns. Hence, the values of time coefficients reduce with the increase in yarn fineness beyond 50s.

### 4 Conclusions

4.1 The higher rate of extension, apparently, produces higher breaking strength and lower breaking extension for all the cotton yarns.
4.2 There is a very good correlation between the tenacity, breaking extension and work of rupture values reported by Uster Tensorapid-3 and Uster Tensor-jet.

4.3 The average strength-time coefficient and breaking extension-time coefficient of cotton yarns are \(-0.070\) and \(0.063\) respectively, based on the testing speed of 400 m/min.

4.4 The absolute value of both the time coefficients shows a decreasing trend with the increase in yarn fineness beyond 50s.

References