Influence of Yarn and Fabric Properties on Tearing Strength of Woven Fabrics

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The effect of different yarn and fabric parameters on the tearing strength of fabrics having plain, 2/2 twill, 3/1 twill and 4-thread satin weaves and woven using 52" reed and 2/40" polyester-viscose (15/85) warp has been studied. Weft count, weft twist multiplier and pick level were varied in the plain woven fabrics. It was observed that with increase in yarn fineness, twist multiplier and pick level, there is a decrease in tearing strength. The effect of yarn withdrawal force, crimp level elongation, weight/m² and cover factor has also been studied. Increase in float length increases tearing strength, which is minimum in the case of plain weave and maximum in the case of 4-thread satin.

Generally, tensile strength is taken as the criterion for predicting the serviceability of a cloth. Taylor disagreed with this view and observed that in contrast to tensile strength, tearing strength is directly involved in the assessment of serviceability. Tearing is much more a common mode of failure than fall in tensile strength in actual wear. Tear strength indicates the ability of a fabric structure to utilize the properties of component yarns. The results are dependent on those very factors which differentiate a fabric from its component yarn, the geometry of woven fabric making the greatest contribution to the stress pattern. In other words, tear strength is more characteristic of the material in fabric form than in yarn form and cannot be determined if any of the sets of threads, namely warp and weft, is removed. Tear strength refers to a response to non-uniform tensile stresses, causing a progressive tensile failure of cross yarns along a line, thread by thread or in small groups of threads.

Krook and Fox studied the effect of fabric count (both warp and weft ways) on the frequency of waves in the chart and on the tear strength of fabrics. They observed that increase in fabric count in the test direction has little effect on tear strength; any reduction in the number of yarns in the del resulting from the decreased del size is almost compensated by increase in the number of threads/in. However, they suggested that the strength of a fabric could be improved through (i) decrease in fabric count, (ii) increase in yarn strength, (iii) use of smoother yarn, and (iv) use of open weave.

According to Millard, the factors affecting the tear strength are: (i) strength of yarn, (ii) smoothness of yarn, (iii) number of thick places, and (iv) number of yarn slubs. O'Brien and Weiner pointed out the advantage of plying in that the use of two-fold yarns gives higher tearing strength than that when single yarns of the same equivalent count are used. He further stated that tear strength is directly proportional to yarn strength.

Morton and Turner observed that increase in the twist factor of component threads increases the tear strength of fabrics because of increase in thread strength and decrease in yarn diameter, the latter allowing a greater degree of freedom to the yarn. Backer and Tanenhaus and O'Brien and Weiner showed that tear strength increases with increase in weave factor, which they defined as the number of threads per repeat divided by the number of interlacements in the same repeat. Taylor introduced a similar factor in his theoretical treatment of rip strength.

Materials and Methods

Thirteen samples were prepared from a 15/18 polyester viscose blended yarn. Out of these, three samples were of 2/32, 2/36 and 2/40 counts, three of 3.1, 3.4 and 3.7 twist multipliers (TM) and four of 2/36 weft count with 3.1 TM but different weaves, viz. plain, 2/2 twill, 3/1 twill and 4-thread satin. In the remaining three samples, three different pick levels, viz. 44, 50 and 55, were chosen keeping the other three parameters constant. The warp count of 2/40 and 3.4 TM was kept constant in all the cases.

Prior to testing, all the samples were conditioned in a standard atmosphere (RH, 65% and temp. 27±2°C) for 48 hr. Standard test methods as per Indian Standard specifications were used to determine the yarn and fabric characteristics. For yarn testing, skeins of 120 yd were prepared and the average count was tested on Knowle's balance. For fabric testing, a test length of 20 cm on Eureka crimp tester, Type FY-07, applying 10 g tension. Single yarn strength and elongation at break
were measured on Instron tensile tester. The crosshead speed and the ratio between cross-head speed and chart speed were kept as 110 mm/min and 1.1:1 respectively. Clamping length of 100 mm was used and the full scale load was adjusted to 10 kg on Instron tensile tester.

The single rip test method was used for determining the tearing strength of the fabric. The rip test consists in making an initial longitudinal cut part way down the centre of a strip and then pulling apart the two tails thus formed, so that the tear proceeds through the uncut portion of the specimen. The testing machine used for this purpose may be an inertialess (CRE) machine or a pendulum type (CRT) instrument. Various dimensions have been used by different workers. We have, however, accepted the ASTM specifications as shown in Fig. 1.

In CRE/CRT machine, one tail of the specimen should be clamped in the upper jaw and the other one in the lower jaw (Fig. 1b) in such a manner that the cut edge of the tail is in a straight line joining the centres of the clamps, the two tails presenting opposite faces to the operator. The autographic device attached to the instrument indicates a succession of peak values of tensions corresponding to the successive rupture of yarn in the course of tear.

Instron tensile tester was used for the single rip tear test. The cross-head speed and the ratio between cross-head speed and chart speed were kept as 100 mm/min and 2:1 respectively. Clamping length of 100 mm was used and the full scale load was kept as 10 kg. The average tear strength of each sample was found from five observations for each sample.

For determining the yarn withdrawal force, keeping parity with Taylor's experiment, a strip of fabric (5 in long and 3 in wide) was taken. Leaving 2 in from one end of the longer sides to allow the specimen to be gripped by the fabric jaws, and another 0.5 in for a clearance from the jaw line, a transverse cut was made across the width of the specimen. The specimen was then marked across its width at a distance of 1 in from the transverse cut and all the crossing threads in the remaining portion of the specimen were unravelled, so that the length of each of the freed longitudinal yarns from the marked line was 1.5 in, the rear end of the specimen in the fabric form being already gripped by a pair of fabric jaws. The yarn clamp, initially being separated from the jaws by a distance of 2 in, was then moved apart until the said yarn was completely withdrawn from the strip, the force required to remove the yarn was recorded in the autographic device. The average values for all the tests were calculated from 10 observations made for both warp and weft directions.

Results and Discussion

Effect of weft count on tearing strength—The effect of weft count on tearing strength was studied for three plain woven fabrics having weft counts 2/365, 2/325 and 2/405. Data on the tearing strength and count (Fig. 2) indicate that when the fabric is ruptured in the weft direction, its tearing strength decreases with increase in weft count. This may be attributed to the strength of the thread, because with increase in the fineness of the yarn, the number of fibres in the cross-section decreases and this contributes to lowering of the breaking strength of the yarn. Thus, with increase in counts, a corresponding decrease in weft breaking strength is observed and this ultimately results in decrease in the tearing strength of the fabric in weftwise direction. The statistical relation derived for this action gives the value of correlation factor as 0.885, indicating that the observations made are true and the weft count is closely related to fabric tearing strength.

The value of warp-wise tearing strength, on the other hand, increases with increase in weft count, because the breaking strength of the weft in all the three cases is greater than that of the warp due to the coarser weft count having more number of fibres in its cross-section.

The above finding is in agreement with that of Turner, who found that the higher single thread strength, usually brought about by the use of coarser
yarn, causes increase in tearing strength. He also pointed out that even a slight increase in coarseness might produce a large increase in the rip test, because the breakage occurs thread by thread in this test.

Increase in the coarseness of the weft count increases the tearing strength of the fabric in the warp-wise direction, because the thread breaking strength of the weft is comparatively higher than that of the warp due to the greater number of fibres in weft cross-section, whereas increase in weft count decreases the tearing strength of the fabric in the weft-wise direction due to the decrease in the number of fibres in weft cross-section.

It is observed from Fig. 2 that with increase in weft count, weft elongation decreases and this relationship is linear. Also, the relationship is statistically significant, having the value of coefficient of correlation \( r \) as 0.81. The effect of weft TM on the elongation of the threads is shown in Fig. 3. It is observed that with increase in weft TM, weft elongation decreases. The values of weft elongation are 38, 37, and 36 mm for weft TM of 3.1, 3.4 and 3.7 respectively. The magnitude of extensibility depends upon the compactness of threads. With increase in the compactness of thread, the elongation of the thread decreases. Since the TM changes from 3.1 to 3.7, the compactness of weft threads increases and consequently the extensibility of threads decreases. The correlation between TM and elongation has been found to be linear and statistically significant, the value of coefficient of correlation being \(-0.99\). These results are in agreement with the findings of Weiner\(^3\).

**Effect of weft TM on tearing strength**—To study the effect of twist multiplier on the tearing strength of the fabric, three different TMs were selected. It is observed from Fig. 3 that increase in weft TM decreases the weft-wise tearing strength of the fabric when the warp particulars are kept constant. Hamburger\(^9\) also reported that the most important factor which influences the tearing strength of the fabric is its surface or yarn-to-fabric friction. Increase in TM causes a corresponding decrease in the elongation of the yarn (Fig. 3) and this results in decrease in the thread breaking strength. As observed earlier, increase in the thread breaking strength increases the fabric tearing strength and consequently decrease in the thread breaking strength (with increase in TM) causes a corresponding decrease in the tearing strength of the fabric.

Secondly, increase in TM decreases the area of cross-section of the yarn and thus increases the yarn-to-fabric friction. Due to this, the force needed for the withdrawal of yarn from the fabric is increased and this results in decrease in the tearing strength of the fabric.

Considering all the facts, it may be concluded that decrease in tearing strength (with increase in TM) is due to decrease in elongation and yarn breaking strength and increase in the yarn-to-fabric friction. Fig. 3 shows a close relationship between TM and tearing strength with the value of coefficient of correlation as \(-0.842\).

**Effect of yarn extensibility**—Yarn extensibility plays an important role in determining the tear behaviour of a fabric. The number of yarns in the ladder of a del at the tear locus depends upon the extent of yarn extension. With increase in elongation of the yarn, the active number of threads in del increases and hence contributes more to the system in supporting a higher load. To better understand the matter, we focus our attention on Fig. 4 to mark out three values of weft tearing strength for three different weft counts, viz. 2/32\(^{*}\), 2/36\(^{*}\) and 2/40\(^{*}\), while warp count is constant (2/40). The values of tearing strength are 7.29, 7.16 and 6.56 kg for weft elongation of 40, 37 and 34 mm respectively. In the first case, the weft thread count was 2/32\(^{*}\), which led to higher extensibility of weft threads. Consequently, the number of threads in del increased and hence contributed more to the system in supporting the higher load. In the second case, where the weft count was increased to the level of 2/36\(^{*}\), the
extensibility of weft threads decreased, which resulted in a lower value of tearing strength. In the third case, the weft count was further increased to 2/40s, which led to further decrease in the extensibility of weft threads. This further decrease in weft thread extensibility reduced the number of threads in the del, which in turn reduced the tearing strength. Hence, it may be concluded that with increase in the extensibility of threads, tearing strength increases.

**Effect of withdrawal force on thread strength**—Data on the tearing strength and the ratio between the breaking strength of weft \(f_i\) and the withdrawal force of weft \(f_i\) are presented in Fig. 5. It is observed that tearing strength increases as the ratio of \(f_i/f_i\) increases. This is in agreement with the finding of O’Brien and Weiner\(^3\), that breaking strength divided by the pull-out force for the opposite set of thread is directly proportional to the tearing strength, because with ultimate increase in the yarn withdrawal force, the del limits itself within a smaller area and depth, bringing fewer yarns into action. Obviously, the supporting capacity of the del system is reduced and a lower tearing strength is recorded.

**Effect of crimp on tearing strength**—It is observed from Fig. 6 that the crimp has a linear relationship with the tearing strength of the fabric with the value of coefficient of correlation as \(-0.99\). This is in agreement with the finding of Weiner\(^3\), who reported that the crimp of the threads in a cloth causes a reduction in the case of slippage that arises from a higher crimp because of the yarn bent to a greater extent. With a lower crimp, the area of contact among the threads would be smaller and the frictional resistance to the movement would be less.

Increase in pick level increases the crimp level (Fig. 7) and thereby the elongation also increases. Increase in elongation becomes the root cause of decrease in tearing strength, as stated earlier. Another factor influencing the crimp is the weave. The number of times the weft changes its face in 1 in also affects the crimp level. The weft in a plain woven fabric changes its face for the maximum number of times and thus has the highest value of crimp, while reverse is the case with 4-thread satin. Due to this, the withdrawal force of thread, or the thread pulling out force, is maximum in the case of plain weave and this results in a lower value of fabric tearing strength compared that for 4-thread satin. It may be concluded that the tearing strength of fabric has a linear relationship with the crimp level.

**Effect of fabric density**—The effect of change in fabric density (pick/in) on the warp tear strength is also shown in Fig. 7. The pick levels used were 46, 50 and 55, while the ends/in was constant (52) in all the three cases. It is observed that increase in fabric density along the tear direction increases the number of crossing points or frictional points per unit area of the fabric. With increase in pick level, cloth cover increases and thus the fabric ahead of del jams earlier in the direction of tear and the extent of yarn movement in that direction is lesser. This causes the del to comprise fewer yarns, resulting in a fall in the tearing strength.

This effect may also be explained on the basis of the cover factor. As the pick level increases in a woven fabric, its cover factor increases (Fig. 8). The computed value of coefficient of correlation between tear strength and fabric density across the direction of tear...
is negative. This finding is in agreement with that of Backer\textsuperscript{10}, who reported that the tearing strength of a fabric is closely related to the reciprocal of the cover factor.

Effect of weight on tearing strength—The relationship between weight/m\textsuperscript{2} (warp-way and weft-way) and tearing strength is shown in Fig. 9. The relationship is seen to be linear. It may be concluded that with increase in weight/m\textsuperscript{2} or weight per unit area of the fabric, there is a corresponding increase in the tearing strength of the fabric as well as in the weft direction. This finding is in agreement with that of Ganatra and Munshi\textsuperscript{11}.

Effect of weave on tearing strength—While studying the effect of various weaves, it was observed that the tearing strength of the fabric increases with increase in float length. This is in conformity with the findings of Hamburger\textsuperscript{9}, who found that a fabric having longer floats generally has a higher tearing strength than the one having shorter floats. He also observed that plain woven fabrics exhibit the minimum tearing strength due to the greater number of intersections in the weave. Apparently, the plain intersection provides better binding than that obtained by the passage of yarn merely from one end of the cloth to the other; the result is presumably due to the greater mutual yarn pressure which must exist at the plain intersection.

In a weave with many crossovers/in, the gripping section between the warp and weft threads has been found to be high and thus increases the ratio between the yarn withdrawal force and the yarn breaking strength in opposite direction over what it would have been for a fabric with longer floats. This increase in the pullout force resulting from the weave reduces considerably the tear strength of the fabric (for a given yarn strength and texture). Thus, the plain weave has been found to be weaker than 2/2 twill, 3/1 twill and 4-thread satin. A looser weave with longer floats also allowed a greater trellis type distortion. The magnitude of the tearing strength also depends upon the type of material used, yarn construction and other cloth parameters, as discussed earlier. The 2/2 twill has higher tearing strength than 3/1 twill, because it has lower value for the pullout force. The weave affects the tearing strength of the fabric, because it is closely related to the float length and the pullout force, which have direct influence on the tearing strength of a fabric (Table I).

Conclusions

(1) Increase in weft count causes a corresponding decrease in the weft-wise tearing strength due to the less number of fibres in the cross-section. Increase in weft twist multiplier decreases proportionately the weft-wise tearing strength of the fabric. Increase in elongation is followed by increase in the weft-wise tearing strength of the fabric.

(2) With increase in pick level, there is a corresponding decrease in the warp-wise tearing strength.

(3) The tearing strength is directly proportional to the thread breaking strength.

(4) The tearing strength increases with decrease in the thread pulling out force.

(5) Increase in float length increases the tearing strength, thus giving a high value of tearing strength in the case of 4-thread satin as compared to plain or twill

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Weave</th>
<th>Warp pullout force (g)</th>
<th>Weft pullout force (g)</th>
<th>Warp tearing strength (kg)</th>
<th>Weft tearing strength (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1/1 Plain</td>
<td>36</td>
<td>50</td>
<td>6.88</td>
<td>7.16</td>
</tr>
<tr>
<td>2</td>
<td>3/1 Right hand twill</td>
<td>12</td>
<td>18</td>
<td>7.93</td>
<td>8.34</td>
</tr>
<tr>
<td>3</td>
<td>2/2 Right hand twill</td>
<td>10</td>
<td>16</td>
<td>8.41</td>
<td>8.54</td>
</tr>
<tr>
<td>4</td>
<td>4-Thread satin</td>
<td>8</td>
<td>14</td>
<td>8.78</td>
<td>9.35</td>
</tr>
</tbody>
</table>
The tearing strength of 2/2 twill is higher than that of 3/1 twill, as the withdrawal force for 3/1 twill is higher.

(6) Increase in crimp decreases the tearing strength of the fabric.

(7) The tearing strength of the fabric is dependent upon the inter-yarn spacing or cover factor.

(8) With increase in wt/m² of a fabric, tearing strength increases in both warp and weft directions.

(9) The ratio of single thread strength to the pullout force for the opposite set of threads is directly related to the tearing strength.

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