An attempt has been made to alter polyester fibre properties through physical modification using simple drawing and heat setting operations with a view to producing a compatible fibre with properly matched stress-strain curves for blending with cotton. It is observed that the cold-drawn and subsequently tension heat set polyester fibres give stress-strain curves matching those for some superior cottons and therefore these fibres can be better alternatives for commercial medium and high tenacity polyester fibres normally used in India for blending with cotton for getting apparel fabrics. The new anti-pill polyester fibres can also be used for blending with cotton, provided they are heat set under tension. When these fibres are stretched beyond their original length and heat set under tension, their stress-strain curves match those for most cotton fibres.

Of late, there appears to be an increase in consumer demand and consequently in the industrial production of blended textiles. Ford discussed the reasons for having fibre blends and reported the advantages and disadvantages of some blends of fibres. Parthasarathy et al. considered the blends of several Indian cottons with polyester and reported that there is good scope for blending cottons of good maturity and low trash content with polyester of appropriate denier and tenacity to get acceptable levels of yarn quality. Shah and Shah discussed the processing of polyester/cellulose blended fabrics and some fabric defects.

When binary blend fabrics were first introduced, the main considerations in selecting the blend components were some fibre characteristics, viz. length, fineness and tenacity. However, it was soon found that matching these parameters alone did not lead to optimum spinnability or maximum strength of yarn. It is now well recognized that the processing behaviour and the end properties of a blended yarn or fabric are dependent on all the properties of the constituent fibres. Therefore, while selecting the constituents of the blend, it is essential that the fibres in the blend are fully compatible to avoid certain undesirable side effects, which may arise during processing and consumer use. In particular, when synthetic fibres like polyester are blended with natural fibres like cotton, these problems become much more acute. Incompatibility of blended constituents may lead to low CSP, high yarn unevenness, and numerous imperfections during the spinning of the blended yarn. It can also enhance the pilling tendency of the blended yarn or fabric.

Seidel recently reviewed the field of intimate blends and observed that regular, commercial polyester (T-400 by Celanese) with a breaking tenacity of 4.8 g/den, though stronger than cotton (breaking tenacity, about 3.5 g/den), has a very high breaking elongation of 45-55%. Therefore, when blended with cotton, the polyester does not contribute its full strength to the blend in spun yarns, because it is still stretching when the cotton fibres are breaking. This is obvious from Fig. 1. High-modulus and high-tenacity fibres were, therefore, developed on commercial scale (T-300 by Celanese) to reinforce cotton in blends. It is observed from Fig. 1 that at an elongation of 10%, when cotton fibres are breaking, this polyester is contributing equal strength and sharing the burden with the cotton fibres, so that the blended yarns and fabrics are stronger. When softer yarns or fabrics are desired, the low-pill variant profile (T-460 by Celanese) with its lower breaking strength (3.5 g/den) and high elongation (48%) provides a low-pilling fibre for blending with cotton. The stress-strain curves for Kodel polyester fibres (from Eastman) of three variants, viz. high-tenacity (421), medium-tenacity (461) and regular (411) are presented in Fig. 2. At 10% elongation, these fibres
have a tenacity of 4.5, 2.5 and 1.5 g/den respectively and suggest that the high-tenacity type would be more compatible for blending with cotton on the basis of somewhat similar stress-strain curves.

It has been emphasized that the most important criterion for the selection of suitable partners in the blend is that they should have closely matching stress-strain response\(^5\) and that for blending into yarns with adequate strength, the two types of fibres selected must have compatible stress-strain characteristics\(^1\). It was reported recently by Rao et al.\(^6\) that by blending the fibres with matching elongation properties, CSP and yarn evenness can be improved, while reducing the number of imperfections. It was also shown that in many cases, negative correlation existed between fibre bundle strength and yarn strength where matching of elongation was not given due consideration. When the elongation properties of the blend components were matched, a positive and close relationship was observed together with the realization of highest strength and optimum spinning behaviour.

Of late, after the introduction of the multifibre policy, triple blend fabrics with polyester, cotton and viscose are also being produced. From a study\(^7\) on the performance of triple blend yarns and their properties, it was concluded that a high tenacity polyester fibre as a component in a triple blend gives better results than a medium tenacity polyester fibre. Better results were also obtained at a lower twist multiplier. Shreenivasa Murthy and Chaudhari\(^7\) suggested that the matchmakers of fibre blends should carefully consider the load-elongation characteristics of the polyester fibres before matching them with other fibres to achieve optimum results.

After a diagnostic approach to the wet processing of polyester-polynosic-cotton blend fabrics, some optimum conditions were suggested by Patel et al.\(^8\) for various wet processing operations for ternary blends to reduce strength losses. They also stressed that an important factor to be considered when blending is the load-elongation characteristics of the blend components.

A comparative evaluation\(^9\) of different blend levels of cotton and polyester in various types of blend fabrics revealed that the high modulus polyester staple offered significant improvements over regular polyester staple in fabric tensile and tearing strength, but no appreciable differences in other properties were apparent. A 65/35 cotton/high modulus polyester blend was found to provide a good balance with abrasion resistance deemed sufficient for satisfactory wear life.

The properties of yarns and fabrics of high cotton content binary blends with polyester fibres and similar ternary blends with polyester and Kevlar have been investigated\(^10,11\). Here again, the best overall performance with regard to fabric strength and abrasion resistance was obtained with the finest high tenacity polyester fibre. Fabrics with acceptable strength and abrasion resistance could be had from binary blends of 70-75\% cotton with fine, high tenacity polyester. Normal tenacity polyester offered little or no advantage in strength improvement when used in high cotton content resin-treated fabrics\(^10\). Ternary blends of cotton, polyester and Kevlar gave stronger yarns and fabrics compared to binary cotton-polyester blends of equivalent man-made fibre contents.

However, the improvement in strength imparted by Kevlar diminished as the percentage of polyester increased due to a considerable lack in fibre compatibility between the two man-made fibres with regard to modulus and elongation. This also resulted in reduced abrasion resistance and a greater tendency to pill in the case of ternary blends\(^11\). Thus, it is observed that fibre compatibility is an important criterion for satisfactory blending of fibres.

Pilling is another important problem affecting the quality of garments made out of synthetic and natural fibre blends\(^12\). The high tenacity and abrasion resistance of synthetic fibres are two important factors which contribute to the ease with which the fabric pills. The realizations that the high tensile strength of the polyester fibres is the major contributor to the pilling propensity and that there is incomplete utilization of the inherent strength and abrasion resistance of polyester fibres in apparel fabrics led to the development of polyester fibres with reduced tensile strength and greatly reduced tendency to pill.

Reduction in tensile strength can be achieved through suitable chemical treatments. However, many of these treatments, though promising, involve reactions which are difficult to control, and there is a risk of excessive degradation or poor uniformity of strength. Besides, these chemicals are expensive, create unpleasant working conditions and may lead to certain
undesirable side effects. Reduction in tensile strength can also result from reduction in the molecular weight of the polymer during the melt-spinning stage. Many references to such pill resistant, low molecular weight polyester fibres are found in literature.

All these methods of subsequent modification of fibre properties can be accepted only with reservations. Every additional treatment after spinning is liable to increase the manufacturing cost and to make the production itself more complicated. From this viewpoint it, therefore, seems more attractive to confer the required properties on the fibre during production. Since polyester continues to enjoy pride of place and is undoubtedly the 'big' blend fibre of the present and perhaps the future as well, an attempt has been made in this study on laboratory scale to alter polyester fibre properties through suitable physical modification using simple drawing and heat setting operations, so that a compatible fibre with properly matched stress-strain curves (over the entire extension range) can be produced for blending with cotton without increasing the production cost.

Materials and Methods

Two specially produced pill-resistant polymer fibre samples were examined. Commercially available medium and high tenacity polyester staple fibres were also examined for comparison. Amorphous as-spun tow was drawn at room temperature to 400% extension. All these fibres were subsequently heat set at a setting temperature of 200°C, both with and without allowing the fibres to shrink, in an air oven having an inert gas (nitrogen) atmosphere for 5 min. The samples were then quenched to room temperature in acetone.

Four different cottons, viz. Y₁ (Indian), 940 (American), 875 (American) and 888 (Iquitos), were chosen to examine the compatibility of the above-mentioned polyester fibres for blending with any of these cottons.

The load-elongation curves for all the samples were recorded using the same test length (1 cm) and extension rate (50%/min). Fifty to sixty single fibres were tested in each case, and the average tenacity and extension to break were calculated. The average stress-strain curves, representative of each sample, were plotted using five stress-strain curves having their breaking elongation and breaking load values close to the average values for the entire sample.

Results and Discussion

The stress-strain curves for medium tenacity, high tenacity and pill-resistant polyester staple fibre are shown in Fig. 3 and those for cotton fibres in Fig. 5. It is obvious that both tenacity and elongation are considerably higher for medium and high tenacity polyester fibres compared to those for cotton fibres. The low pilling fibres, on the other hand, show a tenacity comparable to that of cotton fibres, but their elongation is considerably higher than that of cotton fibres.

Heat setting under tension did not produce the expected reduction in elongation for the low and medium tenacity fibres so as to match with that of cotton. On the contrary, increase in tenacity also
occurred. On the other hand, heat setting of one of the pill-resistant fibres under tension (not allowed to shrink) reduced the elongation at break from 39 to 15% (Fig. 4), while the tenacity remained unaffected at 29 g/tex. When these fibres were stretched by 10%, over their initial length and then heat set under tension, the elongation fell to 8.6%, while the tenacity increased to 36 g/tex.

It is observed from these results that unmodified low-pilling fibres do not have stress-strain properties matching those of cotton fibres for blending. However, after subsequent heat treatments under a small tension, the elongation of these anti-pill fibres can be reduced to match that of cotton fibres.

Fig. 5 shows the stress-strain curves for cold-drawn untreated, cold-drawn and heat set under tension, and cold-drawn and heat set in free or slack condition polyester fibres along with those for some cotton fibres. The untreated cold-drawn fibres (tow drawn by 400% only) have a tenacity of 44 g/tex and an elongation of 22%. The tenacity of these fibres is slightly lower than that of the commercial medium tenacity polyester fibres (Fig. 3), while the elongation at break is much lower. Although this can be a better component for blending with cotton in view of its lower elongation at break, its poor dimensional stability due to low crystallinity will be a disadvantage.

The cold-drawn fibres heat set in free or slack condition show a tenacity of 33 g/tex and an elongation of 29% at break. These values are much lower than those for the normally used medium tenacity fibres. Also, due to high crystallinity, these fibres have good dimensional stability and can, therefore, be a better blending partner for cotton fibres in place of the medium tenacity commercial polyester fibres. The best results are, however, obtained in the case of cold-drawn fibres heat set under tension, where it has been found that

![Fig. 4—Stress-strain curves for non-pill polyester fibres with and without heat setting](image)

![Fig. 5—Stress-strain curves for cottons and laboratory drawn heat set polyester fibres (TQ, fibres heat set under tension for 5 min and quenched back to room temperature; and SQ, fibres heat set in free or slack state for 5 min and quenched back to room temperature)](image)

<table>
<thead>
<tr>
<th>Table 1—Tensile Properties of Cotton Fibres</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Gauge length, 1 cm, strain rate, 50%)</td>
</tr>
<tr>
<td>Cotton fibre</td>
</tr>
<tr>
<td>(Indian)</td>
</tr>
<tr>
<td>875</td>
</tr>
<tr>
<td>940</td>
</tr>
<tr>
<td>888</td>
</tr>
</tbody>
</table>

The elongation decreases from 22 to 9.5% at break and tenacity decreases from 44 to 40 g/tex. The tenacity, elongation and the overall stress-strain response of
Table 2—Tensile Properties of Polyester Fibres

<table>
<thead>
<tr>
<th>Polyester fibre</th>
<th>Range of tenacity</th>
<th>Range of extension</th>
<th>Average tenacity</th>
<th>Average extension</th>
</tr>
</thead>
<tbody>
<tr>
<td>High tenacity staple</td>
<td>37-57</td>
<td>22-38</td>
<td>53.1%</td>
<td>30%</td>
</tr>
<tr>
<td>Medium tenacity staple</td>
<td>33-53</td>
<td>28-52</td>
<td>44.1%</td>
<td>41%</td>
</tr>
<tr>
<td>Medium tenacity staple heat set at 200°C</td>
<td>36-49</td>
<td>30-46</td>
<td>42.3%</td>
<td>37%</td>
</tr>
<tr>
<td>Tow, 400% drawn</td>
<td>35-56</td>
<td>14-33</td>
<td>43.2%</td>
<td>24%</td>
</tr>
<tr>
<td>Tow, drawn to 400% and heat set at 200°C</td>
<td>28-42</td>
<td>11-19</td>
<td>33.3%</td>
<td>15%</td>
</tr>
<tr>
<td>Low pill staple</td>
<td>27-33</td>
<td>20-50</td>
<td>28.8%</td>
<td>15%</td>
</tr>
<tr>
<td>Low pill staple heat set at 200°C</td>
<td>27-36</td>
<td>9-24</td>
<td>31.5%</td>
<td>14.5%</td>
</tr>
<tr>
<td>Low pill staple, 10% stretched and heat set at 200°C</td>
<td>32-40</td>
<td>6-13</td>
<td>35.1%</td>
<td>8.7%</td>
</tr>
</tbody>
</table>

these fibres are found to match rather well with those of high maturity American cotton (875).

Since cold-drawing and heat-setting of the fibres do not involve any additional expenditure, it is felt that the cold-drawn and subsequently tension heat set polyester fibres can be suitably blended with cotton fibres. This would not only save the cost of import of new anti-pill fibres but would also provide better alternatives for the medium and high tenacity polyester fibres normally used in India for blending with cotton. This can be understood clearly by examining the stress-strain curves (Figs 1-5) and breaking elongation and tenacity data for all these fibres (Tables 1 and 2).

Conclusion

The conventional techniques such as cold-drawing and tension heat setting can be used effectively to obtain polyester fibres which will have reduced elongation at break and low tenacity. The cold-drawn and subsequently tension heat set polyester fibres are found to have stress-strain curves matching those of some superior cotton fibres. These fibres can be better alternatives to the commercial medium tenacity polyester fibres normally used in India for blending with cotton for blended apparel fabrics.

The new anti-pill polyester fibres can also be used for blending with cotton, provided they are at least heat set under tension. When these fibres are stretched beyond their original length and heat set under tension, their stress-strain curves match those of most cotton fibres.

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References