Pretreatment dependence of mechanical and surface properties of cotton ring- and OE rotor-spun yarns

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The variations in the mechanical and surface properties of cotton ring- and OE rotor-spun yarns on exposure to different chemicals during wet processing have been studied. It is observed that the structure and yarn twist are the dominant parameters in determining the accessibility of chemicals during wet processing. The most distinct outcome of alkaline scouring of cotton yarns, in comparison to enzyme scoured ones, is the resulting yarn characteristics, i.e. more tensile strength, no change in breaking extension, more dye pick-up, more residual shrinkage, and more resistance to abrasion. Dramatic increase in residual shrinkage and dye uptake and decrease in abrasion resistance of alkaline scoured yarns after hydrogen peroxide bleaching are consistent with the effect of twist on the yarn during bleaching. The enzyme softening is effective in reducing the hairiness of the bleached yarn. While the absorbency change due to enzyme softening is small, the reduction in tenacity, abrasion resistance and hairiness is relatively large. Interestingly, however, there is no apparent change in the breaking extension and residual shrinkage of hydrogen peroxide bleached yarns.

Keywords: Biopolishing, Draw-off nozzle, Enzymatic scouring, Hydrogen peroxide bleaching, Ring-spin yarn, Rotor-spin yarn

1 Introduction
Cotton holds its own place as a textile material because it has properties very different to those of other fibres. Fabrics containing cotton are comfortable to wear and have an aesthetic appearance. The hydrophilic character of cotton coupled with high fibre tenacity, easy care and rapid moisture absorption and desorption properties are some other factors that have led to the development of a wide variety of characteristic textiles ranging from apparel fabric through household furnishings to artist’s canvas. Such substrates need to be subjected to various chemical treatments for value addition. Typical treatments, such as scouring, bleaching and biopolishing, aim at improving the absorbency, level of whiteness and surface properties of the aforesaid products. Conventional method of scouring cotton textiles under high temperature alkaline conditions is associated with number of problems. Another approach used to produce specific finishing effect on cellulose textiles is enzymatic scouring. In comparison with alkali scouring, it offers significant advantages in respect of lower effluent generation, water pollution and quite good soft action. Hydrogen peroxide is a strong bleaching agent that destroys natural colouring pigments and imparts degree of whiteness. In recent years, biopolishing has gained increasing importance in the textile industry. Cotton and cotton blend fabrics possess rather stiff handle. Fibre ends protruding from the material surface are the common cause of this problem. Biopolishing is the core technology developed for the removal of protruding fibres from cotton materials, and it is an effective way to improve material softness, smoothness and fashionable appearance. ¹⁻⁹ Detailed studies exist on the effect of enzymatic softening on fabric softness and surface properties that affect aesthetic comfort, but there has been no systematic study of the relationship between enzymatic softening and yarn properties. The present study aims at investigating the changes imparted to cotton ring- and OE rotor-spun yarns with different wet processing routes.

2 Materials and Methods
2.1 Preparation of Yarn Samples
J-34 cotton, having specifications as given in Table 1, was used for spinning 29.5 tex yarns on ring and rotor spinning machines. Laps were made on Lakshmi Rieters’ blowroom line and carded on MMC card. The conversion to drawn sliver was carried out using Lakshmi Rieters’ draw frame DO/2S. Two drawing passages were given to carded slivers to

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produce a finisher sliver of 0.13 Ne. The drawn sliver was spun into yarns on Ingolstadt rotor spinner RU11/80(4602). The machine parameters used for spinning rotor yarns included a 48mm rotor running at 833.33 rps, a saw-tooth opening roller type of clothing (OS/21; teeth/cm², 24; and face angle, 100°), an opening roller speed of 100 rps; two draw-off nozzles—notched (exterior diam. 15.5 mm and interior diam. 3 mm) and plain (exterior diam. 15.5 mm and interior diam. 3 mm); and twist factors of 43.07, 47.85 and 52.64. For ring spinning, the drawn sliver was converted into a suitable roving and then spun on a Lakshmi Rieters’ ring frame G5/1.

2.2 Treatments
All the yarns were scoured in skein form in a laboratory winch machine. The yarns were divided into two lots. One was scoured with enzyme and the other was subjected to simulated sodium hydroxide scouring, bleaching and biopolishing.

2.2.1 Scouring
Scouring with Bactosol.co.ip enzyme (2mL/L) was carried out at 90°C for 1 h maintaining the pH at 8.0 and liquor ratio at 30:1, followed by deactivation in cold water for 5 min. Resiwet EECW (0.5g/L) was added to the scouring bath to improve the absorbency of the samples. The yarns were thoroughly washed in cold water and then air dried. For alkaline scouring, 4% aqueous sodium hydroxide was prepared and the yarns were treated at a liquor ratio of 30:1 for 2.5 h at 95°C. After scouring, the yarns were thoroughly washed with hot water followed by cold water twice, and finally dried under atmospheric conditions.

2.2.2 Bleaching and Biopolishing
The bleaching was carried out with 1.5 % (owf) commercial H₂O₂ at 85°C for 1 h maintaining 30:1 liquor ratio. The bleached solution was then neutralized in 10% acetic acid and rinsed with distilled water. Biopolishing of alkaline scoured-bleached sample with G-Zyme VGB (1.5%) was carried out at 55°C for 1 h at pH 4.5, in the presence of Kleenox PSF (0.5%). The yarn samples were thoroughly washed, air dried and conditioned.

2.3 Tests
All the yarns were tested according to standard ASTM procedures. Tensile properties of all the yarns were measured on an Instron using 500 mm test specimen and 200mm/min cross-head speed. The mean yarn tenacity and breaking extension were averaged from 50 observations for each yarn sample. Zweigles hairiness meter (Model G 565) was used to record yarn hairiness and a spectrophotometer to assess dye absorbency of the yarns. Residual shrinkage of yarns was estimated according to the method mentioned in BSI handbook and flat abrasion resistance on CSI abrasion tester.

3 Results and Discussion
The influence of seven experimental factors, viz. yarn type, twist factor, draw-off nozzle and chemical treatments, on the yarn properties was assessed with the help of ANOVA analysis (Table 2); the confidence level used was 99%.

3.1 Tensile Properties
Table 3 shows the results of tensile test. In general, cotton ring-spun yarns record substantially higher values of tenacity than their rotor-spun counterparts. The tenacity of enzymatic scoured ring-spun yarns does not change significantly. However, for rotor-spun yarns, the tenacity slightly decreases on enzymatic scouring. The trend is consistent in all yarns, though the magnitudes of changes are different between ring- and rotor-spun yarns. The observed changes are principally associated with the weight loss due to various treatments, which would undoubtly govern the yarn strength. The values of average weight loss for rotor yarns treated with 4% NaOH for 60 min at 95°C and 2 mL/L Bactosol.co.ip for 60 min at 90°C are found to be 2.38% and 3.30% respectively. On the other hand, both types of yarns exhibit exceptionally high levels of tenacity after caustic scouring. Since the pretreatment of cotton
fibre with different chemicals under identical conditions does not show significant change in bundle strength (Table 1), it appears that the increased inter-fibre friction as a consequence of removal of natural oil and waxy substances leads to an increased yarn strength.

Moreover, the sequential treatment of yarns with sodium hydroxide for 1h at 90°C followed by 1.5%(owm) hydrogen peroxide for 1 h at 85°C shows a greater loss in tenacity, which according to Buschle-Diller et al.2, can be attributed to the reduced degree of polymerization. When a comparison of the tenacity indices of the caustic scoured-bleached-biopolished yarns is made, there is a further reduction in tenacity as a consequence of biopolishing treatment; the decrease being more in rotor yarns. It is a known fact that the cellulase enzyme causes hydrolysis of cellulose by reacting to the beta-1, 4-glucoside bond of the cellulose which results in appreciable weight loss and consequently lowers strength.11 A lesser decrease in yarn tenacity occurs at higher twist factor due to reduced accessibility of liquor to axial fibres that contribute most to the yarn tenacity.

For the rotor yarns, statistical analysis of the data shows that the draw-off nozzle profile does have an effect with the notched nozzle, producing stronger yarns; Table 1, however, suggests that the difference is marginal.

The breaking extension of cotton ring yarn varies between 4% and 4.9%, depending upon the pretreatment used. In rotor yarns, the breaking extension varies from 4.8% to 5.6% and from 5.3% to 5.7% for the enzyme and caustic scoured yarns respectively. In the case of caustic scoured-hydrogen peroxide bleached and caustic scoured-hydrogen peroxide bleached-biopolished yarns, it varies from 5.1% to 5.5% and from 4.7% to 5.2% respectively, indicating that the yarn elongation does not alter with the different pretreatment procedures.
comparison of the results of the yarns treated with sodium hydroxide followed by hydrogen peroxide bleaching and biopolishing is made, it can be observed that here again the extent of reduction in breaking extension is slightly higher for rotor-spun yarns, and it further increases with the decrease in twist factor. Although notched nozzle has little impact on the breaking extension of untreated yarns, there is a lesser decrease in breaking extension of the pretreated yarns produced with notched nozzle due to increased false twist, which ultimately makes the yarn more compact. This compactness causes insufficient penetration of liquor to axial fibres and consequently decrease in the swelling of core fibres, resulting in lesser decrease in yarn breaking extension.

### 3.2 Abrasion Resistance

Table 3 shows that the caustic and enzymatic scouring can seriously affect the abrasion resistance of cotton ring- and OE rotor-spun yarns. Generally, the abrasion resistance shows a marked increase after caustic scouring regardless of the yarn structure. This can be partially ascribed to the compactness from fibres swelling, and to the increased inter-fibre friction during alkaline scouring. The fibre-to-fibre friction is found to be 0.52 in caustic scoured as compared to 0.31 and 0.44 in unscoured and enzyme scoured cotton fibres. However, both ring- and rotor-spun yarns show different responses in their abrasion resistance to enzymatic scouring. After enzymatic scouring, the abrasion resistance of rotor yarns generally decreases, while for the ring yarns it increases. The results show that the conventional alkaline scouring followed by bleaching with hydrogen peroxide can cause marginal reduction in yarn abrasion resistance comparable to that of alkaline scoured yarns. However, the abrasion resistance of the yarns decreases when treated with G-Zyme VGB enzyme. This phenomenon may be due to the mechanical action during enzyme application as well as due to the removal of surface wax, fats and other naturally accompanying substances during biopolishing treatment. For all the yarns, increasing twist factor generally improves abrasion resistance. Nevertheless, the yarns produced with a notched nozzle withstand fewer abrasion cycles than the yarns spun with a plain nozzle.

### 3.3 Hairiness

The hairiness differences between ring and rotor yarns of identical count determined on the Zweigles hairiness meter are clearly apparent in Table 4. Invariably, rotor-spun yarns exhibit less hairiness than the ring- spun yarns. Also, the change in hairiness related to twist factor is evident in both types of yarns; the lower the twist factor, the higher is the hairiness. Change in draw-off nozzle also reduces rotor yarn hairiness. The notched nozzle produces fewer hairs at constant machine twist. The higher proportion of fibre wrappings associated with notched nozzle prevents the formation of hairs. It is intriguing that while the hairiness of ring yarn is hardly changed

<table>
<thead>
<tr>
<th>Treated with</th>
<th>Twist factor</th>
<th>Ring yarn Residual shrinkage , %</th>
<th>Absorbency K/S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>43.07</td>
<td>4.07</td>
<td>1.34 1.49 1.39</td>
</tr>
<tr>
<td>Bactosol.co.ip</td>
<td>43.07</td>
<td>4.07</td>
<td>1.38 1.52 1.43</td>
</tr>
<tr>
<td>NaOH</td>
<td>43.07</td>
<td>4.07</td>
<td>1.42 1.58 1.51</td>
</tr>
<tr>
<td>NaOH + H₂O₂</td>
<td>43.07</td>
<td>4.07</td>
<td>1.45 1.63 1.54</td>
</tr>
<tr>
<td>NaOH+H₂O₂+G-Zyme</td>
<td>43.07</td>
<td>4.07</td>
<td>1.47 1.65 1.57</td>
</tr>
</tbody>
</table>
by scouring treatments, rotor yarn hairiness increases appreciably with enzyme scouring. Significantly, however, the hairiness of either yarn remains unaffected by bleaching treatment. The hairiness data for the biopolished yarns show a marked decrease in hairiness regardless of the yarn structure. This is because cellulase enzyme hydrolyzes cellulose by reacting to the beta-1,4-glucoside bond of the cellulose.\textsuperscript{11} As a result, the yarn surface becomes smooth with the loss of surface fibres. However, no consistent trend between hairiness of the treated yarns and the process variables has been observed.

3.4 Residual Shrinkage

As can be seen from Table 4, both ring- and rotor-spun yarns undergo shrinkage when treated with chemicals. This behaviour is related to the release of stress and strains which are imposed on fibres during yarn formation and also to swelling of fibres. The results in Table 3, although obviously affected by all above-mentioned pretreatments, confirm the expected effectiveness of the alkaline scouring. The residual shrinkage is generally more for the yarns scoured with sodium hydroxide than that for enzyme scoured yarns. This can be ascribed to the swelling of fibres, which, in turn, leads to a reduction in their length. Bleaching of the caustic scoured yarns increases the residual shrinkage presumably as a consequence of the development of porosity in the form of voids created following the removal of waxes.\textsuperscript{12} Very remarkably, no striking changes in the residual shrinkage values of alkali scoured-bleached ring-and rotor-spun yarns are observed after biopolishing treatment. It is well known that the cellulase treatments are restricted to fibre surface with minimal degradation, and previous studies\textsuperscript{13} have shown that the molecular size of any cellulase enzyme is in the range of 20-80 k Da, which prevents their diffusion inside the fibres. Furthermore, the residual shrinkage of cotton rotor yarns is relatively more than that of ring yarns on account of the lower spinning tension used during spinning on a rotor frame. In each case, the trends are identical with respect to twist factor. There is a minimum level of residual shrinkage at the lowest twist levels. The use of notched nozzle leads to higher residual shrinkage regardless of the pretreatment.

3.5 Dye Uptake

The assessment of the response of pretreated cotton yarns towards reactive dye (Cibacron Red HD-2%) was made in terms of $K/S$ values. The pretreatment methods show significant difference in dye uptake of cotton ring- and rotor- spun yarns. Enzymatic scouring slightly improves the dye uptake (Table 4). The alkaline scouring significantly improves the dye uptake of the cotton yarns obviously due to the improved absorption brought out by the removal of non-cellulosic substances during caustic scouring. Conventional alkaline scouring followed by bleaching with hydrogen peroxide causes a significant increase in dye uptake of both types of yarns. The increased absorbency as a consequence of the creation of pores when the yarn undergos bleaching treatment\textsuperscript{14} is strictly associated with a higher dye uptake. Alkaline scoured-hydrogen peroxide bleached yarns treated with cellulase enzyme, on the other hand, absorb slightly more dye as compared to the yarns treated with sodium hydroxide and hydrogen peroxide alone. A possible explanation for the small increase in dye uptake is that the cellulase enzyme treatment makes the fibre surface smooth, thus making it easier for the substantive dye to attach to them.\textsuperscript{14} The dye uptake values, however, are markedly lower for ring-spun yarns, indicating less accessibility of the liquor to the fibre surfaces in the ring yarn. Moreover, the dye uptake is appreciably higher for the yarns made with a plain nozzle but shows no specific trend with change in twist factor.

4 Conclusions

4.1 The mechanical and hairiness characteristics of cotton ring- and OE rotor-spun yarns change dramatically as a consequence of scouring treatments. Generally, the yarns scoured with sodium hydroxide show higher tenacity, enhanced abrasion resistance, reasonably higher residual shrinkage with increasing dye uptake, while those scoured with Bactosol. co.ip enzyme show lower tensile strength but improved abrasion resistance for almost all experimental combinations. The extent of change in these characteristics is more marked in rotor-spun yarns and it decreases with increasing twist. In particular, dye uptake is greatly reduced and abrasion resistance is greatly increased with increasing twist factor.

4.2 Bleaching with hydrogen peroxide yields a material with reduced abrasion resistance, higher residual shrinkage, and similar or marginally lower tenacity coupled with significantly higher dye uptake.

4.3 While the absorbency change due to softening with G-Zyme VGB enzyme is small, the reduction in tenacity, abrasion resistance and hairiness is relatively large. There is essentially no difference in the
breaking extension and residual shrinkage of hydrogen peroxide bleached and biopolished yarns.

**Industrial Importance:** Enzymatic treatment has several advantages from the aspects of energy saving, pollution control and safety. Besides, it also modifies the tensile and surface characteristics of cotton textiles and their behaviour during weaving. The study suggests that yarn formation mode also plays a dominant role in the ease of penetration of the chemicals, especially in the case of the enzymatic scouring process. Due to their high absorbency and more openness, rotor-spun yarns offer easier access to the enzyme systems than ring-spun yarns. Such a study would be useful for establishing the optimal experimental conditions of an enzyme necessary for improving surface characteristics of cotton substrates, for better results.

**References**