Stress-Strain Characteristics of White and Canary Coloured Chokla Wool Fibres in Air and Water

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The stress-strain characteristics of white and canary coloured Chokla wool fibres and their thioglycollate-reduced fibres were studied in air (65 ± 5% RH and 27 ± 2°C) and in water (27 ± 2°C). The data were analyzed by taking the regression of the curve parameters on the tex value of the fibre and the interaction of colour and treatment. The effect of thioglycollate treatment differs in white and canary coloured wools. The regression is significant in air test for stresses at 2% extension and post-yield slope and in wet test for stresses at 30% extension, yield and post-yield slopes and breaking stress. The interaction is significant in air test for stresses at 15 and 30% extensions, yield and post-yield slopes and breaking stress and in wet test for all the cases except post-yield slope. The canary colouration modifies both the matrix and the microfibril, the extent of modification depending on the intensity of yellowness.

Keywords: Chokla wool, Stress-strain characteristics, Wool fibres

The modification of disulphide bond due to canary colouration in the autumn clips of Indian wools is well documented. The action of thioglycollate to reduce the disulphide bond is also known. To explain the modification in the structure on canary colouration the stress-strain characteristics of white and canary coloured Chokla wool fibres and their thioglycollate-reduced fibres were studied in air (65 ± 5% RH; 27 ± 2°C) and in water (27 ± 2°C). This paper deals only with non-medullated fibres.

Materials and Methods

Three groups of wool fibres — white, yellow and light yellow (C1, C2 and C3 respectively) — of Chokla breed of sheep were collected from the flocks being maintained at CSWRI, Avikanagar, in the autumn clip of 1982. The shades yellow and light yellow were visibly distinguished. The samples were cleaned with petroleum ether. One part of each of the samples was treated with an alkaline thioglycollate solution (pH 10.5) with a wool-to-liquor ratio of 1:15. The mixture was kept at 0°C for 18 h, and the fibres were washed repeatedly with distilled water and dried in air. The true fibres were selected and tex/linear density was determined on a vibroscope. Fibres of 2 cm length were fixed on aluminium tags. One set each of control and treated samples was stretched on an Instron tester in air (65 ± 5% RH and 27 ± 2°C) and the other set in water (27 ± 2°C). For the wet test the fibres were soaked in water overnight and during the test the fibres were completely immersed in water throughout. The ratio of crosshead-to-chart speed was 1:10 with an extension rate of 25% per minute. The data were analyzed statistically by considering the regression of curve parameters on the tex value of the fibre and also the interaction between colour and treatment (untreated T1 and reduced fibres T2). Wherever the regression was not significant the analysis was done without considering the covariate.

Results

The raw means and standard errors (SE) of the fibre characteristics in air and water are given in Tables 1 and 2 respectively. The adjusted means and SE are given in Table 3. In these tables the curve parameters are given the usual symbols, viz. $F_2$, $F_{15}$, $F_{30}$ and BS (stresses at 2, 15 and 30% extensions and at break); $H$, $Y$ and $PY$ (the hookean, yield and post-yield slopes); and $BE$ (extension at break). The analysis of variance with Duncan's multiple range test for the air and wet tests is given in Tables 4 and 5 respectively. The stress-strain curves are shown in Figs 1-3 based on the results of individual treatments given in Tables 1 and 2. The different curve parameters are indicated in Fig. 3.

Discussion

The dependence of the stress-strain parameters on the dimension of the fibre is known. The visco-elastic properties of crosslinked polymers depend on the crosslinks in them, which may quantitatively vary with the dimension. The trend of dependence may vary with the medium used for testing the fibre, the coarseness of the fibre and the type of fibre. However, this regression cannot be ignored since it can help in a better comparison of results.

Air test — $F_2$ depends significantly on tex and varies with colour and treatment. The canary coloured samples do not differ among themselves; and C2 and
### Table 1 — Mean and SE of Fibre Characteristics in Air (65 ± 5% RH and 27 ± 2°C)

| Type of fibre | No. of fibres tested | Tex | $F_2$ | $F_{15}$ | $F_{30}$ | H | Y | FY | BS | BE
<table>
<thead>
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</tr>
</thead>
<tbody>
<tr>
<td>m</td>
<td>73</td>
<td>1.267± 0.045± 4.355± 0.14</td>
<td>5.657± 0.201</td>
<td>7.645± 0.229</td>
<td>240.785± 8.555</td>
<td>5.593± 0.3</td>
<td>17.134± 0.587</td>
<td>9.774± 0.291</td>
<td>43.39± 0.525</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>26</td>
<td>1.118± 0.067± 4.921± 0.153</td>
<td>7.06± 0.132</td>
<td>8.17± 0.136</td>
<td>261.265± 12.007</td>
<td>5.826± 0.63</td>
<td>17.606± 0.923</td>
<td>10.66± 0.143</td>
<td>44.51± 0.903</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>26</td>
<td>1.29± 0.083± 4.27± 0.203</td>
<td>5.402± 0.122</td>
<td>7.37± 0.127</td>
<td>247.881± 10.777</td>
<td>5.667± 0.376</td>
<td>18.999± 0.991</td>
<td>8.907± 0.245</td>
<td>43.6± 0.819</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>16</td>
<td>1.42± 0.06± 7.642± 0.397</td>
<td>6.137± 0.493</td>
<td>7.32± 0.493</td>
<td>202.306± 23.83</td>
<td>5.167± 0.586</td>
<td>17.388± 1.166</td>
<td>8.51± 0.79</td>
<td>42.28± 1.036</td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>42</td>
<td>1.25± 0.06± 7.047± 0.176</td>
<td>6.617± 0.216</td>
<td>8.074± 0.239</td>
<td>219.449± 11.249</td>
<td>6.936± 0.466</td>
<td>20.15± 0.708</td>
<td>10.13± 0.436</td>
<td>40.37± 0.555</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>15</td>
<td>0.89± 0.05± 4.97± 0.181</td>
<td>7.202± 0.203</td>
<td>9.32± 0.193</td>
<td>260.46± 12.515</td>
<td>8.56± 1.049</td>
<td>23.606± 0.149</td>
<td>12.09± 0.699</td>
<td>41.97± 0.919</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>11</td>
<td>1.42± 0.109± 4.916± 0.262</td>
<td>6.183± 0.175</td>
<td>6.603± 0.239</td>
<td>262.35± 22.789</td>
<td>2.095± 0.492</td>
<td>9.42± 1.529</td>
<td>8.703± 0.424</td>
<td>47.79± 1.781</td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>16</td>
<td>1.19± 0.12± 3.93± 0.246</td>
<td>5.344± 0.134</td>
<td>6.904± 0.178</td>
<td>215.07± 18.25</td>
<td>6.36± 0.526</td>
<td>21.93± 0.526</td>
<td>10.18± 0.398</td>
<td>40.32± 0.792</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>12</td>
<td>1.42± 0.09± 7.508± 0.337</td>
<td>6.213± 0.195</td>
<td>6.12± 0.185</td>
<td>291.625± 18.47</td>
<td>4.532± 0.512</td>
<td>15.14± 0.512</td>
<td>9.305± 0.397</td>
<td>48.07± 1.399</td>
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</tr>
<tr>
<td>C</td>
<td>11</td>
<td>1.83± 0.14± 3.0± 0.101</td>
<td>5.24± 0.14</td>
<td>7.92± 0.216</td>
<td>169.38± 35.295</td>
<td>5.95± 0.749</td>
<td>12.89± 1.213</td>
<td>7.37± 0.945</td>
<td>38.27± 1.056</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>8</td>
<td>0.87± 0.03± 4.47± 0.18</td>
<td>7.36± 0.216</td>
<td>8.055± 0.239</td>
<td>246.69± 27.205</td>
<td>4.6± 0.67</td>
<td>14.89± 2.255</td>
<td>10.08± 1.084</td>
<td>45.42± 2.109</td>
<td></td>
</tr>
</tbody>
</table>

* m — General mean: C1 — White fibres; C2 — Yellow fibres; C3 — Light yellow fibres; T1 — Control fibres (C1 + C2 + C3 + T1); T2 — Treated fibres (C1 + C2 + C3 + T1); C1 — White untreated fibres; C2 — Yellow untreated fibres; C3 — Light yellow untreated fibres; C1 + C2 — Yellow treated fibres; C1 — Yellow fibres; C2 — Yellow treated fibres; C1 + C2 — Light yellow fibres; C1 + C2 + C3 — Light yellow treated fibres

Note: $F_2$, $F_{15}$, $F_{30}$, H, Y, FY and BS are in g/tex

### Table 2 — Mean and SE of Fibre Characteristics in Water (27 ± 2°C)

| Type of fibre | No. of fibres tested | Tex | $F_2$ | $F_{15}$ | $F_{30}$ | H | Y | FY | BS | BE
<table>
<thead>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>m</td>
<td>117</td>
<td>1.14± 0.03± 1.14± 0.02</td>
<td>1.86± 0.04</td>
<td>2.37± 0.05</td>
<td>64.44± 3.23</td>
<td>14.59± 0.59</td>
<td>5.81± 0.16</td>
<td>53.02± 0.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>46</td>
<td>1.27± 0.05± 1.01± 0.06</td>
<td>1.58± 0.06</td>
<td>2.03± 0.06</td>
<td>54.49± 3.25</td>
<td>6.97± 0.68</td>
<td>0.46± 0.02</td>
<td>54.07± 1.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>36</td>
<td>1.2± 0.06± 1.25± 0.06</td>
<td>2.23± 0.05</td>
<td>2.9± 0.05</td>
<td>67.85± 4.1</td>
<td>14.0± 0.42</td>
<td>1.24± 0.43</td>
<td>53.64± 0.98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>35</td>
<td>0.9± 0.04± 1.28± 0.05</td>
<td>1.91± 0.05</td>
<td>2.27± 0.05</td>
<td>65.49± 3.42</td>
<td>17.48± 0.23</td>
<td>1.22± 0.23</td>
<td>51.36± 0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>57</td>
<td>0.9± 0.04± 1.71± 0.07</td>
<td>2.57± 0.06</td>
<td>3.24± 0.06</td>
<td>94.59± 3.98</td>
<td>19.8± 0.25</td>
<td>7.32± 0.66</td>
<td>30.87± 0.62</td>
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</tr>
<tr>
<td>T</td>
<td>60</td>
<td>1.29± 0.04± 0.61± 0.05</td>
<td>1.19± 0.06</td>
<td>1.52± 0.06</td>
<td>30.5± 0.25</td>
<td>9.6± 0.25</td>
<td>8.99± 0.35</td>
<td>55.28± 0.86</td>
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<td></td>
</tr>
<tr>
<td>C</td>
<td>16</td>
<td>0.8± 0.04± 0.12± 0.05</td>
<td>1.28± 0.06</td>
<td>2.26± 0.05</td>
<td>81.1± 1.21</td>
<td>19.0± 0.25</td>
<td>8.99± 0.35</td>
<td>55.28± 0.86</td>
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<tr>
<td>C</td>
<td>19</td>
<td>0.8± 0.04± 0.12± 0.05</td>
<td>1.28± 0.06</td>
<td>2.26± 0.05</td>
<td>81.1± 1.21</td>
<td>19.0± 0.25</td>
<td>8.99± 0.35</td>
<td>55.28± 0.86</td>
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</tr>
<tr>
<td>C</td>
<td>22</td>
<td>0.8± 0.04± 0.12± 0.05</td>
<td>1.28± 0.06</td>
<td>2.26± 0.05</td>
<td>81.1± 1.21</td>
<td>19.0± 0.25</td>
<td>8.99± 0.35</td>
<td>55.28± 0.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>23</td>
<td>0.8± 0.04± 0.12± 0.05</td>
<td>1.28± 0.06</td>
<td>2.26± 0.05</td>
<td>81.1± 1.21</td>
<td>19.0± 0.25</td>
<td>8.99± 0.35</td>
<td>55.28± 0.86</td>
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</tbody>
</table>

Note: $F_2$, $F_{15}$, $F_{30}$, H, Y, FY and BS are in g/tex
C1 group together. After adjustment, reduced samples show higher values than untreated ones. This may be because, for a low stretching of 2% the disulphide bond is less important than the other structural components of the wool to hold the stress at 65% RH.

For F15 and F30, as the interactions are significant the fibres in untreated condition behave differently from reduced samples. For the control fibres, F15 is the lowest in C3 followed by C2 and C1; C1 and C2 group together. This means that the microfibril is free from matrix and the opening of the helices takes place at a lower stress in C3 than in C1 and C2. The colours do not differ among themselves after reduction and C1 has the lowest value. This may be because initially white wool (C1) had more disulphide bonds than canary wools and the reduction was more effective. F15 is not significantly lowered owing to reduction except in C2 and C3 wherein probably there were fewer disulphide bonds. The trend is similar in F30 except that C1 is significantly different from C2 and C3, which group
Table 5—Effect of Colour, Treatment and Their Interaction with and without Regression on Tex of Curve Parameters in Water Test

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Degrees of freedom</th>
<th>Mean sum of squares</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$F_2$</td>
<td>$F_{15}$</td>
</tr>
<tr>
<td>Colour</td>
<td>2</td>
<td>0.333</td>
</tr>
<tr>
<td>Treatment</td>
<td>1</td>
<td>32.2247$^b$</td>
</tr>
<tr>
<td>Interaction</td>
<td>2</td>
<td>18.516$^b$</td>
</tr>
<tr>
<td>Regression</td>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td>Error</td>
<td>110/111$^c$</td>
<td>0.1572</td>
</tr>
</tbody>
</table>

Results of Duncan’s multiple range test

- $T_1$  
  - $(C_2C_3)(C_1)$  
  - $(C_2C_2)(C_2)$  
  - $(C_2C_1)(C_2)$  
  - $(C_2C_1)(C_2)$  
  - $(C_1C_2)(C_2)$  
  - $(C_2C_1)(C_2)$  
  - $(C_1C_1)(C_2)$

- $T_2$  
  - $(C_2C_3)(C_2)$  
  - $(C_2C_2)(C_2)$  
  - $(C_2C_1)(C_2)$  
  - $(C_2C_1)(C_2)$  
  - $(C_1C_2)(C_2)$  
  - $(C_2C_1)(C_2)$  
  - $(C_1C_1)(C_2)$

- $C_1$  
  - $(T_2)(T_1)$  
  - $(T_2)(T_1)$  
  - $(T_2)(T_1)$  
  - $(T_2)(T_1)$  
  - $(T_2)(T_1)$  
  - $(T_2)(T_1)$  
  - $(T_2)(T_1)$

- $C_2$  
  - $(T_2)(T_1)$  
  - $(T_2)(T_1)$  
  - $(T_2)(T_1)$  
  - $(T_2)(T_1)$  
  - $(T_2)(T_1)$  
  - $(T_2)(T_1)$  
  - $(T_2)(T_1)$

- $C_3$  
  - $(T_2)(T_1)$  
  - $(T_2)(T_1)$  
  - $(T_2)(T_1)$  
  - $(T_2)(T_1)$  
  - $(T_2)(T_1)$  
  - $(T_2)(T_1)$  
  - $(T_2)(T_1)$

*Significant at 5% level; *Significant at 1% level; *Error degrees of freedom is 110 for the cases with regression and 111 for the cases without regression

Note: $F_2$, $F_{15}$, $F_{30}$, $H$, $Y$, $PY$ and $BS$ are in g/tex

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Fig. 1—Stress-strain curves for white Chokla wool fibres [A — untreated fibres (air test); B — treated fibres (air test); C — untreated fibres (wet test); and D — treated fibres (wet test)].

Fig. 2—Stress-strain curves for yellow Chokla wool fibres [A — untreated fibres (air test); B — treated fibres (air test); C — untreated fibres (wet test); and D — treated fibres (wet test)].

Fig. 3—Stress-strain curves for light yellow Chokla wool fibres [A — untreated fibres (air test); B — treated fibres (air test); C — untreated fibres (wet test); and D — treated fibres (wet test)].

together in the untreated state. The treatments group together in the canary samples.

The hookean slopes differ significantly both colour-wise and treatment-wise. $C_2$ and $C_1$ group together and $C_3$ is lowest. The trend is similar to that of $F_2$.

The yield slopes indicate that in canary wool, the low sulphur region, in particular the matrix adjoining the microfibril, has been affected, resulting in a significant reduction of the slope in them compared to white wool ($C_1$). The yield slope of $C_1$ significantly falls owing to reduction, confirming the same results. The treatment is less effective in $C_2$ and $C_3$.

The disulphide bond is broken at post-yield and all the effects are significant. The colour and treatments change in groupings owing to regression. The post-yield slope of untreated fibres of $C_3$ is less than that of
treated ones, which is clearly an effect of tex, because the adjusted means follow the same trend \(T_1 > T_2\) in all the colours.

The breaking stress is in the order \(C_3 < C_2 < C_1\) and the values differ significantly among coloured samples. The values fall in \(C_1\) and \(C_2\) owing to reduction, but not in \(C_3\). This may be due to difference in types and degree of crosslinks in \(C_3\) and \(C_5\).

Reduction results in better plasticizing of the fibres, which show increased extensions. However, there is no significant difference among the colour samples.

The curves show that, in general, the characteristics diminish owing to reduction. However, in \(C_3\), the trend is different for the air test. This may be due either to the fewer number of samples tested or to the fact that the modification of structure varies with respect to the intensity of canopy colouration. The differences in \(F_2\) (air test) are clear in Figs 2 and 3.

Wet test — More parameters (Tables 2, 3 and 5) show dependence on tex, and interaction is significant in more cases than in air test. Though the trends of \(F_2\) and \(H\) are similar to the trends in air test, \(F_2\) is lowered because of treatment \((T_3)\). The white control fibres differ significantly from canary-stained fibres. The canopy colouration weakens the microfibrils such that they have less stress than white fibres. The matrix and its structural modification due to canopy colouration seem to be different from the modification of the microfibril.

\(F_{15}\) in \(C_3\) and \(C_2\) is significantly different from that in \(C_1\), indicating the modified structure of \(C_2\) and \(C_3\). \(C_1\) loses more than \(C_2\) and \(C_3\) on reduction \((T_3)\). In particular, \(C_2\) prevents much loss due to the reducing agent, which may in turn be due to additional or different types of crosslinks in it.

\(C_1\) and \(C_2\) show more \(F_{30}\) than \(C_3\) in the control, which means that \(C_2\) takes more load in spite of structural modification. This is also shown by the reduction treatment. The structural difference between \(C_2\) and \(C_3\) may be due to the fact that \(C_2\) contains both lanthionine and lysinoalanyl crosslinks, whereas \(C_3\) contains only lanthionine crosslink. The additional crosslink in \(C_2\) probably prevents the penetration of the reducing agent to low sulphur region.

The yield slopes of the control sample do not differ significantly whereas in the regression \(C_1\) differs significantly from \(C_2\). The orderly polypeptides of \(C_1\) and \(C_2\) are stiffer because the yield slope of \(C_1\) and \(C_2\) are greater than that of \(C_3\). The reduction is less effective in \(C_2\), which scores a higher value than the rest in \(T_2\). In \(C_2\), the treatments group together.

The post-yield slopes of canary wools are significantly higher than those of white wool, which is only an effect of tex. Otherwise only \(C_2\) differs significantly from \(C_1\). The trend is similar both in the control and the treated fibres. This indicates that the crosslinks of \(C_2\) effectively contribute in the stress stiffening region and not so in \(C_3\). Owing to treatment the slope falls significantly.

Though the breaking stresses of \(C_2\) and \(C_1\) are significantly higher than that of \(C_3\) in the untreated sample, the reducing agent fails to reduce the stress of \(C_2\) compared to \(C_1\) and \(C_3\), which group together.

In general, the extension increases owing to treatment and the colours do not differ significantly among themselves. However, in the control, \(C_5\) differs significantly from the rest but is less extensible.

**Conclusions**

The effect of thioglycollate treatment is different in white and canary coloured Chokla wools. Some of the curve parameters depend on the tex of the fibre and such cases are more in the wet test. The interaction is also significant in many cases in both the tests, indicating that the fibres of different colours behave differently in the control and treated conditions.

The canopy colouration modifies the structure of fibre both in matrix and microfibril, the modification taking place in the matrix adjoining the microfibril in the low sulphur region adjacent to \(\alpha\)-helices. This results in a low yield slope of canary wools. The structural modification depends on the intensity of canopy colouration. The deeper the yellowness, the greater the modification such that the reducing agent is less effective.

**References**

4. Harvey W R, Least square analysis of data with unequal sub-class numbers (ARS-USDA, Maryland 20705) 1966.