CHAPTER 8

FATIGUE LIFE

8.1 INTRODUCTION

Textile scientists all over the world are showing a lot of interest in investigating the fatigue properties of fibres because a number of new types of fibres have been introduced which are used not only for apparel but also for industrial purposes. An in-depth study on this property has been made possible by the advent of instruments like the scanning electron microscope.

Fatigue testing can be defined as the subjection of specimens to cyclical varying stress or strain leading ultimately to breakage. This definition eliminates the inclusion of dynamic tests which do not cause break, and also eliminates the failure of a specimen under a constant load.

Repeated tensile loading up to levels considerably below the simple tensile strength can lead to failure in most solids. Failure by fatigue has been recognized in metals for many years. The mechanism for failure, involves rearrangement of the crystalline structure around defects, which create regions of high stress. Damage from this crystalline rearrangement cumulates with cycling. Eventually failure results.

For textile fibres, the situation is different because they do not have a real elastic region. Attempts to investigate the fatigue properties have concentrated on determining changes at the molecular level during cycling, interpreting results of fatigue tests via a statistical approach and looking for effects directly linked with cyclic loading that lead to failure.
8.2 LITERATURE REVIEW

8.2.1 Some Aspects of Fatigue Testing

Fibre failure can be measured by various methods. To classify them in a simple manner, they can be divided into four groups:

i) Cyclic tensile loading from zero to about half of the normal breaking load
ii) Flex fatigue by backward and forward oscillation over a pin causing breakdown of fibres
iii) Direct surface rubbing over a pin, and
iv) Biaxial rotation over a pin.

8.2.1.1 Cyclic Tensile Loading

Cyclic tensile loading technique for measuring fibre fatigue was first used by Booth and Hearle (1963). The specimen is held between two clamps and one of them is subjected to a cycle of change of position. The disadvantage of this method is that slack develops in the specimen due to imperfect recovery and the specimen ceases to be subjected to tension during a large part of each cycle. Failure is observed only when the imposed extension is very large.

To overcome the above problem, several researchers have adopted techniques of cumulative extension cycling which removes the slack at the end of each cycle and imposes a fixed extension on the specimens during the next cycle. This method enables it possible to cycle the fibre to failure. Nath (1967) and Hearle and Vaughn (1970) have followed this principle in their apparatus.

Bunsell et al (1971) and Bunsell and Hearle (1974) have also used this method. The fibre is gripped between two sets of jaws. One set is
connected to a vibrator capable of operating at frequencies between 0 and 10 kHz and having a movement of 3 mm at 50 kHz. The upper jaws are connected to a piezoelectric transducer and a cantilever beam onto which is glued a wheatstone bridge. In this way, electrical signals are obtained which are proportional to the cyclic and mean loads on the fibre. Anandjiwala and Goswami (1993) have studied the fatigue behaviour of staple yarns (warp) under cyclic elongation accompanied by abrasion action using a Sulzer-Ruti web tester on the basis of three criteria - failure, damage rate and visual appearance.

**8.2.1.2 Torsional Fatigue Tests**

Van der Vegt (1962) has used the torsional fatigue method in which the fibre specimen is subjected to alternative positive and negative torsional strains. Greer (1969) subjected a fibre length of 10 cm to torsion under a constant tension to determine the fibre fracture. Goswami et al (1980) have improved on this method and here the fibre is mounted between a movable and a fixed jaw.

**8.2.1.3 Axial Rotation**

The fibre is subjected to a cyclic axial rotation with a variable torsional strain. The fibre is fatigued under a combination of torsional and tensile mode.

Dunlop and Barker (1973) have described an apparatus designed for testing of fibre fatigue under compressive flexing. The mode of action involves gripping the fibre at both ends, and causing it to buckle under a compressive axial load.
8.2.1.4 Flexural Bending

A number of research workers has employed the flexural bending technique for studying the fatigue behaviour. The Abrafil apparatus described by Barella (1965) works on this principle. Lang and Campbell (1966) have reported a method which works on this principle. Miller et al (1983) have developed an apparatus that imposes an adjustable constant axial tensile load on filaments, yarns or fabric strips, during cyclic rubbing over pins in various configurations under controlled temperature and specific chemical environments. The action is intended to simulate the combinations of tensile, bending and abrasive stresses experienced by fibrous materials during processing and end-use.

Jariwala (1974) has used this technique wherein, one end of the specimen is fixed in a jaw mounted on the shaft of a vibrator. The fibre is flexed with an oscillation amplitude of approximately 2mm. Lincoln (1952) and Chauhan et al (1980) have also employed this method.

8.2.1.5 Biaxial Rotation Over a Pin

Hearle and Vaughn (1970) have used the above technique for coarse monofilament, wherein the fibre is bent freely and clamped so that both ends are rotated together. This method, which leads to the desired alteration of tension and compression, is not suitable for fine filaments with diameters of the order of 10μm.

In order to overcome this problem, Goswami and Hearle (1976) suggested that an alternative method would be to hang the fibre over a wire and then rotate one end. The drive is at only one end of the fibre in this case.
Calil and Hearle (1977) have further developed this technique. The salient feature of their method is that the ends of a fibre specimen are clamped in two jaws directed at 90° to each other. The fibre is bent over a pin, and placed under constant tension by allowing one of the jaw shafts to move in its axial direction under tension from a hanging weight. Hearle and Hasnain (1979) developed an improved apparatus in which the tension on the fibre is controlled more conveniently by a pin which is connected to a cantilever fitted with a strain gauge.

Clark and Hearle (1979) have designed an apparatus in which the angle of wrap over the pin can be varied between 70° and 170° by altering the distance between the pin and jaws. The ends of the fibre sample are attached to two jaw shafts. The tension on the fibre can be varied by adding weights to a light perspex beam on which the pin rests and the beam is free to move vertically on bearings along two parallel shafts. The fibre which is in contact with the pin goes alternately into tension and compression resulting in damage to the fibre. This damage reveals a fracture morphology similar to that encountered in use.

Goksoy (1988) incorporated a novel "free rise and fall" self adjusting specimen tensioning system in his multistation fatigue tester. Ellison and Lundgren (1978) have described a method in which the breaking twist angle of fibres is measured. Briefly, a length of the fibre is taken and twisted until rupture and the number of turns is noted down. This parameter has been exploited by Zeronian et al (1989, 1990, 1994a) as an alternative measure of fatigue.

### 8.2.3 Fatigue Parameters

Since there are different procedures for measuring fibre fatigue, it is only logical that this property should be expressed in different ways.
The most common parameter is the number of cycles required to cause a rupture in the fibre. Van der Vegt (1962) has used the median fatigue life for representing the fatigue behaviour. Hearle and Wong (1977b) have also considered the median life for representing the fatigue life in their method of rotation over a pin.

A summary of the principles applied by various research workers to study the fatigue properties of fibres and yarns is presented in Table 8.1.

8.2.4 Factors Affecting the Fatigue Life

8.2.4.1 Tenacity

Lyons (1962), while carrying out study on two types of polyester fibres, has found that fibres possessing a higher tenacity display a higher fatigue life. Hearle and Wong (1977) have demonstrated that among nylon, polyester, and polypropylene, the polypropylene fibres have an exceptionally high resistance to fatigue. Chauhan et al (1980) have reported that the cell wall thickness of cotton fibres affect flexural fatigue significantly.

8.2.4.2 Effect of Temperature

Hearle and Wong (1977) have found that as the temperature increases, the fatigue life of nylon shows a decline. Clark et al (1980) have also drawn a similar conclusion on the fatigue life of polyester and nylon monofilament as the temperature increases. Similar findings have also been reported by Miller et al (1983).

8.2.4.3 Effect of Relative Humidity

Clark and Hearle (1979) and Clark et al (1980) have demonstrated considerable differences in the fatigue life of polyester and nylon monofilament when subjected to varying levels of relative humidity.
Table 8.1 Summary of Principles Used in Fatigue Testing

<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Principle applied</th>
<th>Measured Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lincoln</td>
<td>1952</td>
<td>Bending fatigue</td>
<td>Flex cycles</td>
</tr>
<tr>
<td>Lyons</td>
<td>1962</td>
<td>Biaxial rotation</td>
<td>No.of cycles</td>
</tr>
<tr>
<td>Van der Vegt</td>
<td>1962</td>
<td>Torsional</td>
<td>Median cycles</td>
</tr>
<tr>
<td>Booth and Hearle</td>
<td>1963</td>
<td>Cumulative tension</td>
<td>No.of cycles</td>
</tr>
<tr>
<td>Lang and Campbell</td>
<td>1966</td>
<td>Flexing</td>
<td>Flex cycles</td>
</tr>
<tr>
<td>Bunsell et al</td>
<td>1971</td>
<td>Load cycling</td>
<td>No.of cycles</td>
</tr>
<tr>
<td>Hearle and Wong</td>
<td>1977</td>
<td>Rotation over a pin</td>
<td>Mean and median cycles</td>
</tr>
<tr>
<td>Veer</td>
<td>1977</td>
<td>Bending abrasion</td>
<td>No.of cycles</td>
</tr>
<tr>
<td>Calil and Hearle</td>
<td>1977</td>
<td>Biaxial rotation over a pin</td>
<td>No.of cycles</td>
</tr>
<tr>
<td>Clark and Hearle</td>
<td>1979</td>
<td>Biaxial rotation over a pin</td>
<td>No.of cycles</td>
</tr>
<tr>
<td>Ellison et al</td>
<td>1982</td>
<td>Flexural fatigue</td>
<td>Flex cycles</td>
</tr>
<tr>
<td>Miller et al</td>
<td>1983</td>
<td>Cyclic rubbing</td>
<td>No.of cycles</td>
</tr>
<tr>
<td>Goksoy and Hearle</td>
<td>1986</td>
<td>Biaxial rotation with rise and fall mechanism</td>
<td>No.of cycles</td>
</tr>
<tr>
<td>Anandjiwala and Goswami</td>
<td>1993</td>
<td>Cyclic elongation and abrasion</td>
<td>No.of cycles</td>
</tr>
</tbody>
</table>
Whereas the fatigue of polyester monofilament has remained constant at all levels of humidity, nylon filament exhibits a reduction in the fatigue cycles as the humidity increases from 50% to 100%, particularly at temperatures from 0° to 20° C.

### 8.2.4.4 Effect of pH

Hearle and Wong (1977) have performed experiments on nylon 6.6 fibres at pH varying from 0 to 14, and concluded that between 0 to 2 pH the fatigue life of nylon shows a significant increase.

Lincoln (1952), after a study on carbonized 46's wool samples, has inferred that carbonized fibres have less resistance to flexural fatigue than the untreated ones.

### 8.2.4.5 Effect of Mercerization and Resin Finishes

Hearle and Hasnain (1979) have demonstrated that mercerization treatment increases the fatigue life of cotton fibres. The same finding has been reported by Chauhan et al. (1980) who demonstrated that the flexural life of fibres increase as a result of slack mercerization.

Subramaniam et al. (1990) have reported that slack mercerization treatment improves the fatigue life of ring and rotor spun yams. Goksoy and Hearle (1986) have concluded that resin treatment markedly reduces the fatigue life of cotton fibres.

### 8.2.4.6 Effect of Water

Hearle and Wong (1977a), Hearle and Hasnain (1979) and Clark et al. (1980) have investigated the effect of water on the fatigue of nylon 6.6 fibres, cotton fibres, and polyester and nylon monofilaments respectively.
Clark et al (1980) have also studied the effect of tap and sea water on the fatigue life of polyester and nylon filaments. Hearle and Hasnain (1979) have shown that untreated cotton fibres have significantly longer lives in water than in air, and that the mercerised fibres have about twice the fatigue life of untreated ones although mercerised fibres have same fatigue life in air and in water. Clark et al (1980) have found that for both polyester and nylon filaments, the fatigue life in sea water is slightly less than that in tap water. As far as cotton yarns are concerned, open end yarns have a longer life compared to ring spun yarns in air, but in the wet condition they possess a shorter life [Subramaniam et al (1990)].

8.2.4.7 The Relation Between Dynamic Modulus and Fatigue Life

Charch and Moseley (1959) have found that a plot of sonic modulus as a function of strain in a mechanical stress-strain test of viscose rayon has exhibited differences between an unfatigued specimen and a partially fatigued specimen. Grover et al (1966) subjected nylon 6.6 and high-density polyethylene monofilaments to fatigue, and then determined their dynamic modulus using the pulse propagation meter. They demonstrated that one could differentiate between a normal and a fatigued specimen by comparing values of the dynamic modulus at an arbitrary elongation subsequent to fatiguing. Thus, sonic modulus measurements reflect the changes in fatigued and unfatigued filaments.

From the above, it is clear that studies on fatigue failure have been conducted on cotton, nylon, polyester, and polypropylene fibres; however, there is no information available on fatigue behaviour of silk fibres. This chapter deals with fatigue life of the untreated and the treated silk fibres. Since fatigue life of a material is more sensitive to changes in environment than the breaking strength, it would be a more efficient means of detecting any deterioration in physical properties due to external environment [Hearle
and Wong (1977)]. Hence, in addition to conducting fatigue test in air (65% RH) the test was also conducted in water.

In a free biaxial rotation [Figure 8.1(a)] when the curved fibre is rotated it experiences a cyclic tension and compression through the rotation of plane of bending. However, when the fibre is in contact with a pin [Figure 8.1(b)], the frictional resistance that is developed between the pin and fibre holds back the rotation (twist) in the material. Twist develops in both the arms of the fibre in the opposite directions, until sufficient torque develops in the fibre to overcome the frictional force. At one point of time, the accumulated twists in the arm starts flowing and the portion of the fibre in contact with the pin rotates undergoing repeated tension and compression. Since the specimen is in the bent configuration, for a given bending strain, it may be expected that the magnitude of the tension and compression developed in it would depend upon its bending rigidity. An attempt has been made in this study to examine the relationship between the fatigue life and bending rigidity.

Zeronian et al (1989, 1990, 1994a) have reported in their study conducted on cotton and synthetic fibres that higher fatigue life is associated with lower breaking twist angle. In order to verify this phenomenon experiments have been conducted on silk fibres.

8.3 MATERIALS AND METHODS

8.3.1 Materials

Fatigue and studies related to it were conducted on mulberry silk. Details of the samples have been given in section 3.3 of Chapter 3.
(a) Free biaxial rotation - shows free rotation of yarn.

(b) Biaxial rotation over a pin - shows accumulation of twist before flowing of the twist.

Figure 8.1 Biaxial rotation of yarn.
8.3.2 Methods

8.3.2.1 Fatigue Life

The instrument used is the modified form of Clark and Hearle's (1979) design which is constructed on the principle of biaxial rotation over a pin. A pin is fixed on the top of a rectangular (10 x 1 cm) hollow moving beam (Figure 8.2). This beam is allowed to move freely in a vertical direction. Another beam having a frictionless surface and somewhat less dimensions than the moving beam, is fixed at the centre of the two rotating jaws on the bottom circular plate. The moving beam is slided over this fixed beam when the specimen is tested. An extended end having threads is provided on both sides of the moving beam to facilitate addition of weights, if required. One end of the yarn is fixed in the rotating jaw, and the other free end is passed through the nichrome wire (80% nickel and 20% chromium alloy) pin which is at the centre of the moving beam. This free end is fixed in the other rotating jaw which rotates in the opposite direction. The contact angle already chosen, is maintained by fixing the length of the yarn to be tested. A fixed tension is imparted to the yarn by hanging weights on both sides of the moving beam. The angle of wrap, \( \Theta \), can be varied between approximately 70 and 170° by changing the length of the yarn sample.

For all the samples, the experiment was carried out both in air (65% RH) and in water. When the experiment was carried out in air, the beam along with the additional weights was kept completely immersed in water taken in a beaker, but the level of water in the beaker was such as to leave the test portion exposed to air [Figure 8.2(a)]. The wet tests were carried out by submerging the test portion also along with the load in water, [Figure 8.2(b)] and the test was commenced after conditioning the specimen in water for a minute. This method of loading the specimen was adopted to avoid the tension variation between the tests in air and in water.
1. Jaws
2. Specimen
3. Beaker
4. Pin
5. Rectangular hollow moving beam
6. Solid fixed beam
7. Weights
8. Water
9. Circular baseplate

(b) Specimen in water

Figure 8.2 Fatigue tester.

(a) Specimen in air
Tension, $T$, acting on the specimen is given by the formula,

$$T = \frac{(\text{Moving beam weight}/2 + W/2)}{\sec (90 - \Theta/2)}$$ \hspace{1cm} (8.1)

where, $W = \text{the additional weight added to the moving beam}$, and $\Theta = \text{the wrap angle}$.

In the present case, a tension of $10 \text{cN/tex}$ and a wrap angle of $106^\circ$ were maintained.

The apparent maximum bending strain experienced by the surface of the specimen, $\varepsilon$, is given to a close approximation by,

$$\varepsilon = \frac{R_f}{(R_f + R_p)}$$ \hspace{1cm} (8.2)

where, $R_f$ and $R_p$ are radii of the fibre and pin respectively. The apparent maximum bending strain was confined to $3.5 \pm 0.4\%$ with a pin diameter of $1.16 \text{ mm}$. The jaws were rotated at 360 rpm.

The following test procedure was adopted. The specimen was mounted on the fatigue tester as described earlier, and the digital counter was set to zero. The test was commenced and the number of cycles required to break the specimen was noted down. Jaw breaks were not taken into account. For each sample, thirty readings were taken for the tests conducted both in air and in water, and the mean fatigue life is reported.

### 8.3.2.2 Bending Rigidity

The ring loop method [Carlene (1950)] was used for the determination of the bending rigidity of the treated yarns. The yarn specimen was bent through $360^\circ$ to form a ring, giving a diameter of about 1.5 cm, by tying around a cylinder. The ends were secured with a reef knot.
to prevent undue distortion of the ring and then cut off close to the knot. To minimise the effect of the knot on the flexural rigidity, it was positioned at about 45° with respect to the top of the ring. The loop was supported on a hook and its undistorted diameter was determined using a travelling microscope. The hook was mounted on a black background and shielding was provided to prevent the specimen from draughts. A small weight prepared from short lengths of wire was added to the lowest part of the loop. After allowing a loading time of 60 sec, the deflection of the lower end of the ring was found using the travelling microscope.

The flexural rigidity, G, was calculated using the equation,

\[ G = kWL^2 \cos \theta / \tan \theta \ g \ m^2 \ (cN \ m^2) \]

where,  
\[ k = 0.0047 \]  
\[ W = \text{load (g)} \]  
\[ L = \text{circumferential length (m) of undistorted ring} \]  
\[ \theta = 493 \ (d/L), \text{ and} \]  
\[ d = \text{displacement of lower end of ring under the action of the applied load (m).} \]

The load, W, was so selected as to get \( \theta \) between 40° to 50°. For each sample, five specimens were tested and the average value is reported.

The statistical analysis of the results obtained in this study is given in Appendix.

8.3.2.3 Scanning Electron Microscopic Studies

The nature of fatigue fracture of silk yarn degummed with sodium silicate (D-SS) was examined in the scanning electron microscope (JEOL, type JSM 820, Japan) after gold coating by sputtering. The instrument was operated at 5 kV. The coating was done using Fine Coat Ion Sputter JFC-1100, Japan.
The technique suggested by Hearle et al (1974) was used to mount the fractured silk yarns in the specimen holder. The fractured yarns were placed, with the help of tweezers, on to the adhesive side of a piece of cellophane tape so that their ends were 1 mm or less above the edge of the tape. The tape then was folded so as to hold the yarns between the two adhesive sides. The edge of the tape was pressed well with tweezers so that the adhesive makes good contact with the yarns, thus giving good electrical contact after metal coating. The yarn-cellophane tape assembly was then mounted on the specimen holder having a thick base with a step, cut to half its thickness. The yarn tips were coated with gold by sputtering and then scanned.

8.4 RESULTS AND DISCUSSION

8.4.1 Fatigue Life - in Air

8.4.1.1 Effect of Partial Degumming

Figure 8.3 shows the effect of gum loss on fatigue life. The partially degummed yarns have a much higher fatigue life than the raw silk. But, among the partially degummed silk yarns, the fatigue life decreases with increasing gum loss.

During fatigue testing, the material initially develops a crack at its weakest point due to stress accumulation. This crack acts as a nucleus and propagates till the material ruptures [Chauhan et al (1980)]. The filaments present in the raw silk are well bound by the sericin gum and hence it has a consolidated structure. On removal of the gum from the raw silk, separation of filaments in the yarn occurs. So, in the degummed yarns, because of the individualisation of the filaments during fatigue testing, stress accumulation would be lower and the crack propagation would be slower, resulting in higher fatigue life.
Figure 8.3 Effect of Partial degumming on fatigue life.
The reduction in thickness caused by the removal of gum would decrease the distance through which the crack has to propagate during fatigue cycling. This may be the reason for the reduction in fatigue life in partially degummed samples as the gum loss in it increases.

As expected, raw silk yarn has a very high bending rigidity compared to the partially degummed yarns; among the partially degummed yarns, as the gum loss increases bending rigidity decrease (Sl.No.1 to 4 of Table 8.2). This behaviour is due to the lower resistance offered by the individualized degummed yarns compared to raw silk yarns.

8.4.1.2 Effect of Types of Degumming Agents

The differences in the fatigue life of silk treated with different types of degumming agents (Figure 8.4) are not significant, indicating that the action of these agents is same on the fatigue life of silk.

A similar trend is observed in the bending rigidity of these yarns (Sl.No. 5 to 7 of Table 8.2).

8.4.1.3 Effect of Reagents

Treatment of silk yarn with formic acid and zinc chloride lowers the fatigue life (Figure 8.5). The reduction is greater when the concentration of these agents is high, and in this respect zinc chloride has a very severe effect compared to formic acid. This behaviour suggests that the treatment would have caused certain imperfections in the silk fibre which in turn acted as nucleation centres for crack initiation followed by propagation and rupture.

The treatment with reagents increases the bending rigidity of the silk yarn (Sl. No. 8 to 12 of Table 8.2). However, the increase in
Table 8.2  Fatigue Life and Other Properties of Treated Silk Yarns

<table>
<thead>
<tr>
<th>Sl.No.</th>
<th>Samples</th>
<th>Fatigue life-in air (No. of cycles)</th>
<th>Bending Rigidity (x10^6) (cN m^2)</th>
<th>BTA (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Control - Raw</td>
<td>1453</td>
<td>24.93</td>
<td>44.8</td>
</tr>
<tr>
<td>2</td>
<td>D - 30</td>
<td>3525</td>
<td>12.61</td>
<td>43.2</td>
</tr>
<tr>
<td>3</td>
<td>D - 60</td>
<td>3100</td>
<td>7.88</td>
<td>43.0</td>
</tr>
<tr>
<td>4</td>
<td>D - 90</td>
<td>2696</td>
<td>2.10</td>
<td>42.8</td>
</tr>
<tr>
<td>5</td>
<td>D - SS</td>
<td>2542</td>
<td>1.32</td>
<td>43.2</td>
</tr>
<tr>
<td>6</td>
<td>D - SC</td>
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<td>7</td>
<td>D - SH</td>
<td>2583</td>
<td>1.36</td>
<td>42.6</td>
</tr>
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<td>5 - FA</td>
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<td>5 - ZC</td>
<td>1322</td>
<td>2.28</td>
<td>43.1</td>
</tr>
<tr>
<td>12</td>
<td>20 - ZC</td>
<td>678</td>
<td>2.01</td>
<td>47.4</td>
</tr>
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<td>Control - ST</td>
<td>2542</td>
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<td>14</td>
<td>3 - SD</td>
<td>2317</td>
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<td>44.8</td>
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<td>15</td>
<td>8 - SD</td>
<td>2121</td>
<td>1.74</td>
<td>44.6</td>
</tr>
<tr>
<td>16</td>
<td>13 - SD</td>
<td>2507</td>
<td>1.82</td>
<td>44.6</td>
</tr>
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<td>17</td>
<td>18 - SD</td>
<td>2122</td>
<td>1.76</td>
<td>44.5</td>
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<td>18</td>
<td>3 - TD</td>
<td>2159</td>
<td>2.36</td>
<td>45.0</td>
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<td>19</td>
<td>8 - TD</td>
<td>2092</td>
<td>2.56</td>
<td>44.5</td>
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<td>20</td>
<td>13 - TD</td>
<td>2377</td>
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<td>18 - TD</td>
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<td>Control - SF</td>
<td>1453</td>
<td>24.93</td>
<td>44.8</td>
</tr>
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<td>23</td>
<td>1G-3T(D)</td>
<td>1957</td>
<td>13.83</td>
<td>39.7</td>
</tr>
<tr>
<td>24</td>
<td>3G-1T(D)</td>
<td>1918</td>
<td>13.21</td>
<td>39.2</td>
</tr>
<tr>
<td>25</td>
<td>3G-3T(D)</td>
<td>2195</td>
<td>14.45</td>
<td>39.5</td>
</tr>
</tbody>
</table>
Degumming agents

SS = Sodium Silicate
SC = Sodium Carbonate
SH = Sodium Hydroxide

in Air  in Water

Figure 8.4 Effect of Degumming agents on fatigue life.
Figure 8.5 Effect of Reagent concentration on fatigue life.

- Formic acid
- Zinc chloride

○ in Air
x in Water

Reagent concentration (% w/v)

Fatigue life (cycles)
concentration results in lowering of the bending rigidity. Treatment with zinc chloride has led to a significant increase in bending rigidity compared to that of formic acid.

8.4.1.4 Effect of Stretching Treatment

The fatigue life of stretched silk yarns is slightly lower than that of the unstretched ones (Figure 8.6); however, the drop is insignificant. The difference in fatigue lives within and between the slack and tension dried yarns of various stretch levels is also insignificant.

The stretching treatments increase the bending rigidity of silk yarns (Sl.No.11-21 of Table 8.2). The bending rigidity of tension dried yarns is found to be higher than that of slack dried yarns. However, for a given drying method, among the stretch levels, the difference in bending rigidity is insignificant.

8.4.1.5 Effect of Sericin Fixation

The effect of various combinations of sericin fixing agents on the fatigue life of silk yarn is shown in Figure 8.7. The fixation treatment improves the fatigue life of silk. However, the difference in the fatigue life of silk yarns treated with various combinations of fixing agents is insignificant.

The fixation treatment reduces the bending rigidity of the silk yarns significantly. However, among the sericin fixed yarns, the difference in bending rigidity is not significant (Sl. No. 22 to 25 of Table 8.2).
Figure 8.6 Effect of Stretching on fatigue life.
Figure 8.7 Effect of Sericin fixation on fatigue life.

Fatigue life (cycles)

Samples

C = Control, 1 = 1% w/v, 3 = 3% w/v,
D = Degummed, G = Glutaraldehyde, T = Tannic acid.

in Air  in Water

in Air  in Water
8.4.1.6 Relationship of Fatigue Life with Bending Rigidity and Breaking Twist Angle

In order to assess the relationship of the fatigue life with bending rigidity and breaking twist angle (BTA), the correlation co-efficients were computed. The values of all the three properties are given in Table 8.2. The results of the correlation co-efficients obtained for the silk yarns subjected to various treatments are given in Table 8.3. The r-values indicate that the fatigue life has good (negative) correlation with bending rigidity and BTA, except for stretching treatment, where the correlation is poor. The relationship that exists between the fatigue life and BTA is in agreement with the findings of Zeronian et al (1989, 1990, 1994a).

8.4.1.7 Nature of Fatigue Fracture

The scanning electron micrographs of fatigue fracture of silk yarns degummed with sodium silicate (D-SS) are shown in Figure 8.8. The Micrograph (a) shows the ruptured end of the filaments in a yarn whereas the other micrographs (b-g) show a single filament in the ruptured end of a few broken yarns. It is clear from the micrographs that the filaments do not split into fibrils as in the case of cotton, which is reported by Goksoy and Hearle (1986). This shows that the cohesion between the fibrils in the silk fibre is quite good. The nature of the fatigue fracture resemble that of nylon 6.6 and polyester fibres. [Bunsel and Hearle (1974)]. In some cases, the crack propagation does not take place completely across the filament (micrographs e-g), which shows that after the initial fatigue fracture, the fibre has broken due to tensile fracture.

8.4.2 Fatigue Life - in Water

Fatigue life in water of the untreated and the treated samples are shown in Figures 8.3 to 8.7, along with fatigue life in air. It reveals that in
Table 8.3 Correlation Co-efficients (r) of Fatigue Life with Bending Rigidity (BR) and Breaking Twist Angle (BTA)

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Treatments</th>
<th>Between fatigue life and BR</th>
<th>Between fatigue life and BTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Partial degumming</td>
<td>-0.662</td>
<td>-0.843</td>
</tr>
<tr>
<td>2.</td>
<td>Formic acid treatment</td>
<td>-0.710</td>
<td>-0.627</td>
</tr>
<tr>
<td>3.</td>
<td>Zinc chloride treatment</td>
<td>-0.812</td>
<td>-0.752</td>
</tr>
<tr>
<td>4.</td>
<td>Stretching and slack drying</td>
<td>-0.480</td>
<td>-0.554</td>
</tr>
<tr>
<td>5.</td>
<td>Stretching and tension drying</td>
<td>-0.534</td>
<td>-0.440</td>
</tr>
<tr>
<td>6.</td>
<td>Sericin fixation</td>
<td>-0.873</td>
<td>-0.909</td>
</tr>
</tbody>
</table>
FIGURE 8.8 Scanning Electron Micrographs of Fatigue Fractured Silk Specimens

(a) Fractured Filaments in the Yarn

(b)-(g) Individual Fractured Filaments
all the cases the fatigue life in water is lower than that in air. A similar trend was observed by Hearle and Wong (1977a) for nylon 6.6 fibres. They have attributed the reduction in fatigue life to the slippage of long chain molecules in the fibre upon absorption of water by CO-NH groups present in it. Since silk also contains CO-NH groups, it is also expected to behave in a similar manner, which is evident from the results obtained.

8.5 CONCLUSIONS

The fatigue life of silk yarn with various gum loss levels is higher than that of the raw silk yarn; however, the fatigue life drops with increasing gum loss. The different types of degumming agents used have a similar effect on fatigue life of silk yarn.

Treatment of silk yarn with formic acid and zinc chloride has generally led to a decrease in their fatigue life. The reduction is greater at a higher concentration, and the rate of reduction is higher with zinc chloride.

Stretching treatment followed by drying in slack or taut conditions does not have significant on the fatigue life.

Fixation of sericin in raw silk results in an enhancement of the fatigue life of silk yarn.

The fatigue life of treated silk yarns is found to have good (negative) correlation with the bending rigidity and BTA, except for the stretching treatment, which gives a poor correlation.

The fatigue life of silk and treated silk yarns in water is lower than that in air.

The mode of fatigue fracture of silk fibres resembles that of nylon 6.6 and polyester fibres.