CHAPTER 6

ELASTIC SILK

YARNS AND FABRICS.
6.1 INTRODUCTION

Commercially used core-spun yarns are of two types, those with non-elastic cores and those with elastic cores. Non-elastic core yarns get their strength and toughness from the support material in the core and other properties such as softness, friction and texture from the covering materials.

Core-spun yarns with elastic core are finding more and more application in the textiles because of change in requirements of knitted garments. The consumers preference is for garments that is stylish, comfortable and also allow freedom of movement. With the growth of sporting activities people expect better quality in sportswear and associated fashion accessories in terms of easier to put on, softer fit and a smoother feel. Knitted fabrics containing elastic core have become very popular for sportswear in recent years. Stretch fabrics with elastic core-spun yarns can provide consistent shape, fit as well as comfort.

The yarns containing elastic core can be used in a fabric in several forms like bare (naked) yarn, core-spun yarns or plied yarns. Bare yarns are difficult to handle in knitting or weaving. In plied yarns, the presence of elastic core on the surface gives unpleasant skin contact and dye shade variations. Hence core-spun yarns are preferred, where the core is buried inside sheath fibres.

Presently fabrics made of 100% silk lack in some qualities like wrinkle recovery, ready to wear and freedom of body movement. These fabrics can be made skin-fit by introduction of elastic filament in the core of silk yarn. Although the cost of the fabric may increase but it is likely to be absorbed by fashion conscious, style and comfort demanding market which will accept silk as a luxurious component.

If spandex is used with silk fibres in yarns made by core spinning techniques, it can be knitted into fabrics for a variety of apparels where a limited degree of stretch may provide interesting comfort and fashion advantages. Spandex provides good wrinkle recovery and crease retention, making it the perfect complement to silk garments.
In this study, silk covered elastic core yarns using spandex has been produced and evaluated for use in apparel purpose. The present work compares the properties of single jersey knitted fabric made from silk covered elastic core-spun yarn with that of 100% silk and 100% cotton fabric under identical conditions.
6.2 EXPERIMENTAL PLAN

6.2.1 Properties of Raw-material

40 dtex (36 denier) Lycra® (spandex) having 5 coalesced filaments produced by DuPont and cut staple silk were selected as basic raw material for this study. Lycra is spandex elastomeric yarn with high stretch and recovery power. The silk fibres were obtained from mulberry silk hanks after cutting, degumming and drying. The stress-strain curve of the silk fibre has already been given in section 3.2.1. The properties of the silk fibre and spandex are shown in Table. 6.1. The stress-strain curves of 100% silk yarn and spandex are shown in Fig. 6.1 and Fig. 6.2 respectively.

Stress-strain curves of

Fig.6.1- 100%Silk yarn.  
Fig.6.2- Spandex (Lycra filament)

The stepwise rise of the stress is visible in the stress-strain curve of the spandex filament. The spandex filament contains long segments of flexible nature and short segments of hard nature alternately as mentioned earlier in section 2.5. As the stress in the spandex increases, it breaks the bonds.
present in the soft and hard segments gradually which is reflected from the stepwise rise in the stress-strain curve of the spandex filament.

This silk covered Lycra core-spun yarn and fabric is denoted by SLF. This new kind of yarn and fabric is also compared with pure silk as well as cotton yarn and fabric. The properties of the lycra filament, silk and cotton fibre used in this study are shown in Table 6.1.

Table 6.1 Properties of silk, cotton fibre and Lycra filament.

<table>
<thead>
<tr>
<th></th>
<th>Lycra filament</th>
<th>Silk fibre</th>
<th>H-4 Cotton</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tenacity (g/den)</strong></td>
<td>0.76</td>
<td>4.1</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>(12.0)</td>
<td>(12.4)</td>
<td></td>
</tr>
<tr>
<td><strong>Elongation (%)</strong></td>
<td>650</td>
<td>30.8</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>(13.3)</td>
<td>(15.4)</td>
<td></td>
</tr>
<tr>
<td><strong>Staple length (mm/2.5% span length)</strong></td>
<td>51</td>
<td>25.41</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(28.5)</td>
<td>(25.4)</td>
<td></td>
</tr>
<tr>
<td><strong>Fineness (den/micronaire)</strong></td>
<td>36</td>
<td>1.2</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>(17.4)</td>
<td>(20.4)</td>
<td></td>
</tr>
</tbody>
</table>

Figure in parenthesis represent C.V. %

6.2.2 Preparation of Yarn Samples

A core-spun yarn is a compound structure consisting of a readily separable core surrounded by fibre and suitable for use as a yarn. The manufacturing process consists of feeding a filament to the front drafting roll of a spinning frame where it is covered by staple fibres to produce a core yarn.

The basic requirement to produce an elastic core yarn is to stretch an elastomeric yarn before it enters the spinning frame. For this it is necessary to modify conventional ring-spinning machine to permit feeding of spandex under a uniform stretch. This action provides elasticity in final yarn by retraction of the elastomeric core when stress is removed, thus compacting and bulking the spun-yarn cover.
To produce elastic core-spun yarn, conventional spinning frame was modified. DuPont recommends 3.9 maximum total draft for 40 dtex Lycra spandex before it enters front roller nip [84]. Spandex core-spun yarn was produced on a “Super” ring frame fitted with special attachment for feeding spandex yarn into front roller nip after giving pre-draft of 2.5 to spandex as shown in Fig. 6.3. The yarn was spun in a regular manner except that 40 dtex spandex was delivered from positively driven feed rolls and guided into the nip of front roller.

Spandex core is surrounded by a sheath of staple silk fibres. The core is generally extended in spinning operation by a draft of 3.5-5.5 [156]. Hence the ratio of speeds of the “feed” and “front” rollers of ring-frame was kept 2.5. In this way the core was elongated to 250 percent before it was helically covered by
the drafted sheath of silk fibres. Thus the 36 denier spandex core was spun at a draft of 2.5 with a sheath of silk fibres into a composite yarn of 30s (19.68 tex) using a twist multiplier of 2.7 (14.8 twist per inch, Z). After giving a draft of 2.5 to 36 denier spandex, fineness of spandex comes out to be 14.4 denier in the core-spun yarn. Hence for 30s N_e (177.16 den.) core-spun yarn, the core : sheath ratio comes out to be 8 : 92 approx.

To ensure optimum covering of spandex, the spandex was directed to the left edge of the roving bobbin as shown in Fig. 6.5. The result is a shift in the center of twist for the aggregate structure that favours covering the core.

![Diagram showing position of core for core-spun yarn having Z and S twist.](image)

**Fig. 6.5 Position of core for core-spun yarn having Z and S twist.**

### 6.2.3 Preparation of Fabric Samples

The core-spun yarn can be knit at full extension like a hard yarn since the inelastic sheath supports the load [94].

Three types of fabric samples were prepared from silk covered lycra filament core-spun yarn (SLF), all silk and all cotton yarn on single jersy, 24 feeder circular knitting machine (Make : Sant knitting works, Ludhiana) having 12" dia., total number of needles 886 and 24 guage. All the three fabric samples were knitted at the same time with same cam setting. This was done to observe the change in properties of three fabrics (knitted under identical conditions) from three different yarns (spun under identical condition, same count, twist etc.).

To study the properties of this new fabric SLF, the properties of cotton knitted fabric were taken as reference. The tightness factor of cotton fabrics is generally around 15. Hence cam setting in knitting machine was done in such a
way so that a tightness factor of 15 is achieved in the cotton fabric. Now on the same cam setting and yarn tension, other two fabrics SLF and silk were knitted. SLF yarn was threaded through the needles of knitting machine in a normal way without any extra attachment. Normally the yarns are fed under tension during knitting. This tension ensured smooth feeding of the SLF yarn. Hence silk covered lycra core-spun yarn didn’t pause any problem during knitting. This was also evident from uniform appearance of the fabric. During knitting the SLF yarn was fed in extended form and it behaved like a conventional rigid yarn because the stretched inelastic component (silk) bears the load during knitting. Three single jersey knitted fabrics were prepared by, ensuring constant and uniform tension on all the feeders.

6.3 TEST METHODS

6.3.1 Yarn Testing

The samples were conditioned for 48 hr in the standard atmosphere of 65% R. H. and 27°C and then tested according to the standard procedures, already described in Section 3.3.

It was not possible to take stress strain curve of lycra filament at normal gauge length of 500 mm as it is having an elongation more than 600%. Standard methods are not available for checking the tensile properties of spandex. Hence a gauge length of 100 mm was taken on Instron Tensile Tester and the stress strain curve of spandex filament was taken. Rest of the procedure was same. Silk and cotton yarns were tested at a gauge length of 500 mm according to ASTM standards as mentioned earlier.

Spandex core-spun yarns do not have a constant and obvious stabilization point at which yarn number should be determined but an even and consistent tension must be chosen for measurement. Du pont [84] suggests that yarn length of 90 cm should be cut at standard tension for yarn number measurements as described below.

A pulley was attached to the end of a metre stick and fasten it to a table with a pulley extended over the edge. A standard weight of 40 gm (for yarn numbers upto 280 denier) was hung to the end of yarn so that its length is
under tension while hanging over the pulley. The yarn was held in position on
the metre stick while under tension and 90 cm specimen was cut.

The specimen was weighed individually on an appropriate balance and
yarn number was determined. Yarn number may also be determined by the
conventional skein method, but since it is difficult to maintain a consistent
tension on the yarn during winding, the short length method is preferred.

Standard test methods are not available for testing of yarns containing
elastic core. The testing of spandex core-spun yarn and fabric seems to be
difficult but this problem was sorted out by keeping constant tension
(0.5 g/tex) on the samples which we keep generally during testing of samples.
On this basis, it was possible to measure yarn tenacity, abrasion resistance and
knot strength.

Another interesting feature of spandex core-spun yarn is that if this yarn
is running at constant tension (which develops during normal running of yarn on
testing instruments), then also it is possible to test properties. On this basis
evenness, imperfections, hairiness and yarn metal friction was measured.

Yarn flexural rigidity and snarling tendency of spandex core-spun yarn
could not be measured because of highly retracting nature of this kind of yarn.

6.3.2 Fabric Testing

All the properties of fabrics were tested in dry relaxed state. During
testing of fabric samples, the tension on all fabrics (SLF, silk and cotton) was
kept same. The standard procedures have already been described in Section
3.3.

Hand values of all three fabrics SLF, silk and cotton fabrics were
evaluated on Kawabata set of instruments.

In this study an additional test for judging stretch and recovery properties
of knitted fabrics was performed as per British Standards [157]. For this
purpose a fabric specimen of 75 mm*75 mm was stretched on Instron tensile
tester 4465 at a guage length of 75 mm after putting reference marks on the
sample. Increase the load gradually on the specimen to 3 Kg±5g within 7.5
sec±2.5 sec. Maintain this load for10±2 sec and then reduce the load gradually
within 7.5±2.5 sec. Immediately reapply the load and measure the length of specimen \((L_2)\) one minute after application of full load. Within one minute of making the measurement, reduce the load. Remove the specimen and measure the distance between the reference marks \(L_3\) on flat surface.

In this test \(L_1=75\,mm\), then extension (%) and residual extension (%) was found in the following way

\[
\text{Extension (\%)} = \frac{L_2 - L_1 \times 100}{L_1}
\]

\[
\text{Residual Extension after 1 minute (\%)} = \frac{L_3 - L_1 \times 100}{L_1}
\]
6.4 RESULT AND DISCUSSION

6.4.1 Yarn properties

Table 6.2 in the appendix lists the properties of silk covered lycra core-spun yarn (SLF). The stress-strain curves of silk covered lycra core-spun yarn (SLF), silk and cotton yarn are shown in Fig. 6.6.

![Stress-strain curves](image)

Fig.6.6 Stress-strain curves of 100% silk yarn, silk covered lycra core-spun yarn (SLF) and 100% cotton yarn (C10).

The tenacity and elongation % at break of the yarns are also compared in Fig.6.7 and Fig. 6.8. It reveals that tenacity of silk covered lycra core-spun yarn (SLF) is lesser than 100% silk yarn. The silk yarn is breaking at 13.1%. It is clear from Table 6.1 in section 6.2.1 that tenacity of spandex is much lower than silk fibre, hence it is not able to bear the load when all the silk fibres are breaking. Hence addition of spandex has resulted in reduction in tenacity of the
core-spun yarn. Strain percent at break for SLF yarn is slightly greater than all silk yarn as shown in Fig. 6.6 and 6.8.

![Fig.6.7 Tenacity of lycra core yarn (SLF).](image1)

![Fig.6.8 Strain % at break of lycra core yarn (SLF).](image2)

It can be seen in from Fig. 6.9, 6.10 and 6.11 that irregularity (U%), total number of imperfections/250 m and hairiness/100m of SLF yarn is lesser than 100% silk. It implies good quality yarns can be produced by addition of spandex core in the silk yarn.

![Fig.6.9 Unevenness of lycra core yarn (SLF).](image3)

![Fig.6.10 Total imperfections of SLF yarn.](image4)

Due to highly retractive nature of SLF yarn, it was not possible to measure flexural rigidity of SLF yarn. Abrasion resistance of SLF yarn was found lesser in comparison to silk yarn (Fig. 6.12). Due to presence of the spandex filament in the core yarn SLF, the sheath fibres may not be as firmly...
bound to the body of the yarn as in case of normal ring-spun silk yarn. Hence it is comparatively easier to peel off the sheath fibres. A reduction in the abrasion resistance of SLF yarn is therefore observed. Diameter of SLF yarn was found to be slightly greater than silk and cotton yarn as shown in Fig. 6.13.

![Graph showing hairiness of lycra core yarn (SLF)](image1)

![Graph showing abrasion resistance of SLF yarn](image2)

![Graph showing diameter of lycra core yarn (SLF)](image3)

6.4.2 Yarn properties for Knitting

The properties of the yarn, which are important from knitting point of view, are shown in Table. 6.3 in the appendix. SLF yarn exhibits comparatively lower values of yarn metal friction in comparison to silk and cotton yarn as shown in Fig. 6.14.
It is clear from Fig. 6.15 that loop breaking load of SLF yarn is slightly lower than silk yarn. The trend observed is same as tenacity of the respective yarns.

Fig. 6.16 reveals that loop breaking extension of SLF yarn is slightly greater than silk yarn. This trend accords with elongation at break values of the yarns. Loop strength ratio (ratio of loop strength to twice single yarn strength measured under same conditions) of SLF yarn is maximum among three yarns studied (Fig. 6.17). Due to reduction in the value of the loop breaking load of SLF yarn, the value of loop strength ratio has increased.
Fig. 6.18 shows that knot breaking load of SLF yarn is slightly lesser than silk yarn whereas a slight increase in the value of knot breaking extension is observed from Fig. 6.19. The same trend was observed in the values of tenacity and elongation % value of the respective yarns. Knot strength ratio (ratio of knot breaking load and single yarn strength under same conditions) of SLF yarn is slightly greater than silk and cotton yarn, due to lower value of knot breaking load of SLF yarn observed earlier (Fig. 6.20).

It is clear from the results that loop breaking load and loop breaking extension values are much better than cotton yarn. Knot breaking load and knot breaking extension are also much greater than cotton yarn. Loop strength ratio and knot strength ratio are greater than 90%. These results indicate that SLF
yarn can be knitted easily along with silk and cotton yarn. This was found true practically also.

6.4.3 Fabric properties

The stretch and recovery properties of the silk covered spandex core-spun knitted fabric in comparison to silk and cotton fabric have been shown in Table 6.4.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Walewise Extension (%)</th>
<th>Coursewise Extension (%)</th>
<th>Walewise Residual Extension (%)</th>
<th>Coursewise Residual Extension (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLF</td>
<td>76.6</td>
<td>85.6</td>
<td>2.5</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>(5.2)</td>
<td>(6.7)</td>
<td>(4.2)</td>
<td>(6.1)</td>
</tr>
<tr>
<td>100% Silk</td>
<td>35.2</td>
<td>75.2</td>
<td>6.0</td>
<td>6.7</td>
</tr>
<tr>
<td></td>
<td>(4.8)</td>
<td>(4.5)</td>
<td>(5.3)</td>
<td>(4.8)</td>
</tr>
<tr>
<td>100% Cotton</td>
<td>48.2</td>
<td>80.5</td>
<td>13.3</td>
<td>22.7</td>
</tr>
<tr>
<td></td>
<td>(6.4)</td>
<td>(5.3)</td>
<td>(4.7)</td>
<td>(5.1)</td>
</tr>
</tbody>
</table>

(Figures in parenthesis represent CV %)

It is clear from Table 6.4 that extension of SLF fabric is greater than 100% silk and cotton fabric in both walewise and coursewise direction. Due to presence of spandex, the SLF fabric can be elongated to a much greater extent in both the directions. It is likely to provide wearing comfort from the point of view of easy limb movements in both directions.

The residual extension of the SLF fabric is also very low in comparison to silk and cotton fabric. It implies that recovery properties of the SLF fabric are much better than equivalent silk and cotton fabric in both directions (walewise and coursewise). This property is likely to ensure shape retention of the knitted garment.

Table 6.5 in the appendix shows the properties of knitted fabric made out of silk covered spandex core-spun yarn (SLF). The results have also been plotted in respective figures. It is clear from Fig. 6.21 that bursting strength of SLF fabric is maximum followed by silk and cotton fabric.

Bursting strength of a knitted fabric is a composite effect of various properties like yarn and fabric extension, freedom of loops in fabric and strength
of loop. If numbers of loops in a unit area are more, then consequently more strength will be required to burst all the loops. Contraction of the fabric has taken place after knitting and this kind of structure has more number of loops per unit area. Hence higher bursting strength of the SLF fabric may be attributed to more number of loops per unit area and higher elongation at break values of SLF yarn. In case of sportswear and skin fit garments the load is applied multidirectionally instead of in one direction, at various parts of the body during wear. For these kinds of applications bursting strength is very important. Results of bursting strength have clearly shown that SLF fabric is better than silk and cotton fabric for its application as skin fit garments. It can follow the contour of the body and withstand the development of pressure at bulged portions of the body.

![Bursting strength of SLF fabric](image1)

![Abrasion resistance of SLF fabric](image2)

SLF fabric also exhibits superior abrasion resistance than silk and cotton fabric (Fig. 6.22). As the fabric has contracted after knitting resulting in compact structure hence higher values of abrasion resistance are observed.

It is further noticed that air permeability of SLF fabric is lesser in comparison to silk and cotton fabric of similar construction (Fig. 6.23). During knitting the yarn was under tension. The retractive forces are higher in case of SLF yarn, resulting in contraction of the fabric after knitting. The contraction of the SLF fabric after knitting has resulted in denser and compact structure,
hence reduced air permeability of the SLF fabric. It is readily noted by visual inspection of the fabric also. This reduced air permeability may prove useful with improved fabric warmth.

The results presented in Fig. 6.24 reveal that moisture regain of SLF fabric is slightly lesser than silk and cotton fabric. This is due to hydrophobic nature of the spandex filament present in the SLF fabric.

The results of the pilling tests are shown in Table 6.5 in the appendix. It was noticed that SLF fabric display hairy surface when subjected to pilling tester but pills are not observed on it.
The results of thermal resistance are plotted in Fig. 6.25. Thermal resistance of SLF fabric is much superior to cotton and silk fabric. This result accords with air permeability results. Higher thermal resistance may be attributed to contraction of the fabric after knitting resulting in dense and compact structure of SLF fabric.

6.4.4 Relaxation Treatment

6.4.4.1 Dry Relaxed Fabric

The properties of dry relaxed knitted fabric made out of silk covered spandex core-spun yarn (SLF) are shown in Table 6.6 in the appendix. It shows that the width of the dry relaxed SLF fabric is considerably lower than 100% silk and cotton fabrics. This is due to contraction of the SLF fabric after knitting.

All three single jersey fabrics (SLF, silk and cotton) were knitted on the same machine, at same tension without any extra attachment. During knitting, tension on all the yarns on 24 feeders was also kept same. Yarn linear density of all three yarns was same (19.7 tex). SLF yarn contains inelastic silk sheath fibres wrapped around spandex. All the three yarns were threaded through the needles of knitting machine in extended form.

After knitting the yarn and the fabric tend to relax resulting in contraction of the fabric. But in case of SLF yarn contraction force was much higher due to presence of elastic spandex and hence contraction took place in SLF fabric.
Spandex provides compressive force and plays major role in retracting the fabric as it leaves the knitting machine. Hence due to contraction of the fabric after knitting, values of courses/cm and wales/cm are much different from silk and cotton fabrics. Fig. 6.26 and Fig. 6.27 reveal much higher values of course/cm and wales/cm for SLF fabric.

Stitch density of SLF fabric is also much greater than silk and cotton fabric due to higher values of courses and wales/cm (Fig. 6.28).

Stitch length of SLF fabric is least among the three fabric studied (Fig. 6.29). Retractive force exerted by spandex and contraction of the fabric after
knitting may be the factors responsible for lower value of stitch length in case of SLF fabric. Values of knitting constant Kc, Kw and Ks are also greater for SLF fabric due to more values of course/cm and wales/cm for SLF fabric as shown in Table. 6.6 in the appendix.

![Fig. 6.29 Stitch length of silk covered lycra core-spun (SLF) knitted fabric.](image1)

It can be observed from Fig. 6.30 that the value of loop shape factor of SLF fabric is greater than for all silk and cotton fabric. This is because of higher values of courses/cm of the SLF fabric.

![Fig. 6.30 Loop shape factor of silk covered lycra core-spun (SLF) knitted fabric.](image2)

Higher values of tightness factor are observed for SLF fabric from Fig. 6.31. This is due to lower value of the stitch length for SLF fabric as tightness factor is inversely proportional to stitch length of fabric. Thickness of the fabrics

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is shown in Fig. 6.32. Due to contraction of the SLF fabric, thickness of SLF fabric is much greater than silk and cotton fabric. These results further confirm tighter, thicker, denser and compact structure of the SLF fabric.

Fig. 6.31 Tightness factor of silk covered lycra core-spun (SLF) knitted fabric.

Fig. 6.32 Thickness of silk covered lycra core-spun (SLF) knitted fabric.

Skewness is an important property of knitted fabric. Lower values of skewness are observed for SLF fabric as shown in Fig. 6.33. Lower skewness implies ease in cutting, tailoring and garment manufacturing.

Weight/m² of SLF fabric is higher than silk and cotton fabric of equivalent construction as shown in Fig.6.34. This is due to contraction of the fabric after knitting in case of SLF fabric. It is clear from Fig.6.35 that bulk of SLF fabric is greater than silk fabric. Higher thickness of SLF fabric may be responsible for greater fabric bulk.
Fig. 6.33 Skewness of silk covered lycra core-spun (SLF) knitted fabric.

Fig. 6.34 Weight of silk covered lycra core-spun (SLF) knitted fabric.

Fig. 6.35 Fabric bulk of silk covered lycra core-spun (SLF) knitted fabric.
6.4.4.2 Wet Relaxed Fabric

The results of fabric properties after wet relaxation have been shown in Table 6.7 in the appendix. A greater value of shrinkage is observed in case of SLF fabric in comparison to silk fabric. During wet relaxation the strain imparted during fabric preparation is relieved to some extent. Hence the shrinkage takes place and the values of course/cm, wales/cm, stitch density has increased as displayed in Fig. 6.26, 6.27 and 6.28 respectively. Due to yarn swelling and change in the shape of the loops, the values of the stitch length has reduced.

Due to shrinkage of fabric, the shape of the loop has also changed. The change in value of loop shape factor has been shown in Fig 6.30. Loop shape factor is a measure of ratio of width to the length of the loop. This ratio is critically affected by any fabric distortion since such distortion causes an increase of one parameter together with a decrease in the other. Considerable increase in values of tightness factor and thickness can be noticed in Fig 6.31 and 6.32. The relaxation treatment increased the thickness because the process of shrinkage made the fabric structure compact.

During wet relaxation the yarn to yarn friction is reduced, resulting in increase in skewness of the fabric. Weight/m² and fabric bulk has also increased due to contraction of SLF fabric after wet relaxation as shown in Fig. 6.34 and 6.35.

6.4.4.3 Fully Relaxed Fabric

It is evident from Table 6.8 in the appendix that shrinkage is maximum in case of SLF fabric after full relaxation. The fully relaxed state of a plain knitted fabric is arrived only after through wetting and tumble drying at 70°C. After dry and wet relaxation fabric is not able to reach strain free state due to frictional force at interlocking points of the loops. But in full relaxation process water is acting as a lubricating agent, which reduces the frictional force at the interlocking points. The extra energy applied to overcome this frictional force is in the form of rotational motion of tumble drier. So ultimately loops attain state of minimum strain. After full relaxation the fabric has reached a strain free state and dimensionally stable state. Hence the values of course/cm, wales/cm and
stitch density have also increased. These values have been plotted earlier along with values of wet relaxed fabrics in the respective figures.

Due to decrease in values of stitch length, increase in values of loop shape factor and tightness factor is observed in Fig 6.30 and 6.31. Thickness of wet and fully relaxed SLF fabric is found to be same in Fig. 6.32. Due to tumble drying, the extent of lubrication was more, hence skewness has further increased slightly (Fig. 6.33). Weight/m² has increased after full relaxation due to contraction of the fabric after full relaxation (Fig. 6.34). Fabric bulk has also increased in comparison to dry relaxed fabric as shown in Fig. 6.35.

6.4.5 Comfort Properties

6.4.5.1 Moisture Transfer Properties

The moisture transfer properties of the silk covered lycra core knitted fabric in comparison to silk and cotton fabric are shown in Table 6.9. It is observed from Table 6.9 that water climbs up the surface of SLF fabric quickly in comparison to silk and cotton fabric. Wickability of the fabric takes into account increase in height of water as well as increase in weight of the fabric due to moisture absorption, hence wickability of the SLF fabric is marginally greater than silk and cotton fabric. It is further revealed from Table 6.9 that SLF fabric takes lesser time to transport the drop of water than silk fabric during spot test. This is due to good wicking properties of SLF fabric.

<table>
<thead>
<tr>
<th>Table 6.9 Moisture transport properties of silk covered lycra core-spun yarn fabrics.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLF</td>
</tr>
<tr>
<td>---------------------------------</td>
</tr>
<tr>
<td>1. Wicking test</td>
</tr>
<tr>
<td>(a) Wicking height (cm)</td>
</tr>
<tr>
<td>30 sec.</td>
</tr>
<tr>
<td>5 min</td>
</tr>
<tr>
<td>15 min</td>
</tr>
<tr>
<td>Wickability</td>
</tr>
<tr>
<td>(b) Spot Test (sec)</td>
</tr>
<tr>
<td>2. Water vapour transfer (g)</td>
</tr>
<tr>
<td>3. Total absorbency %</td>
</tr>
</tbody>
</table>

(Figures in parenthesis represent CV %)

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The results of the water vapour transfer indicate that SLF fabric has minimum water vapour transfer ability among the fabrics studied. The compact and dense structure of SLF fabric has resulted in reduced air permeability as already observed in Fig. 6.23 and hence lower water vapour transfer ability is observed for SLF fabric. Due to contraction of the fabric, stitch density and weight/sq.m of SLF fabric is greater than silk fabric, so a higher value of total absorbency is observed for SLF fabric.

6.4.5.2 Low Stress Mechanical Properties

Table 6.10 shows tensile properties at low stress levels of silk covered lycra core knitted outerwear fabric (SLF) in comparison to silk and cotton fabric.

6.4.5.2.1 Tensile properties

Table 6.10 shows that extensibility (EM) of SLF fabric is significantly greater than silk fabric in walewise and coursewise direction both. Higher value of EM implies better wearing comfort in both directions. This may be attributed to the presence of elastic spandex in the fabric.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Strain at 500 gf/cm²</th>
<th>Linearity of load-extension curve (LT)</th>
<th>Tensile energy (WT)</th>
<th>Tensile resilience (RT)%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wale</td>
<td>Course</td>
<td>Mean</td>
<td>Wale</td>
</tr>
<tr>
<td>SLF</td>
<td>59.4</td>
<td>77.3</td>
<td>68.4</td>
<td>0.81</td>
</tr>
<tr>
<td>Silk</td>
<td>21.5</td>
<td>33.8</td>
<td>27.6</td>
<td>0.67</td>
</tr>
<tr>
<td>Cotton</td>
<td>30.9</td>
<td>45.8</td>
<td>38.3</td>
<td>0.67</td>
</tr>
</tbody>
</table>

From Table 6.10 higher values of linearity (LT) are observed for SLF fabric. Tensile linearity depends upon the ease of crimp removal and elasticity of the yarn. It represents the resistance offered by the fabric in the initial strain region. Hence higher value of LT for SLF fabric may be due to higher value of tightness factor for SLF fabric (16.43) as compared to silk (14.55) and cotton (14.83).
From Table 6.10 much higher values of the tensile energy (WT) are observed in case of SLF fabric. WT represents tensile energy per unit area. Due to higher tightness factor of SLF fabric, more energy is required for its tensile deformation. From Table 6.10 higher values of tensile resilience (RT) are observed for SLF fabric. This is showing good recovery properties due to presence of elastic spandex in the fabric.

### 6.4.5.2.2 Bending Properties

From Table 6.11 it is clear that bending stiffness of SLF fabric is lesser than silk fabric in walewise and coursewise direction. The mean bending stiffness of the SLF fabric is also lesser than pure silk fabric. It implies introduction of the elastic spandex in the silk fabric has reduced the bending stiffness of the SLF fabric.

From Table 6.11 higher values of hysteresis of bending moment (2HB) are observed for SLF fabric. Hysteresis of bending moment is related to recovery from bending deformation. As the number of loops and number of cross-over points per unit area are more in comparison to silk and cotton fabric, hence a greater resistance is offered after removal of bending forces and a higher value of hysteresis is observed.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Bending rigidity (B)</th>
<th>Hysteresis of bending moment (2HB)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wale/cm²/cm</td>
<td>Course/cm</td>
</tr>
<tr>
<td>SLF</td>
<td>0.0679</td>
<td>0.0898</td>
</tr>
<tr>
<td>Silk</td>
<td>0.0693</td>
<td>0.0967</td>
</tr>
<tr>
<td>Cotton</td>
<td>0.0998</td>
<td>0.0214</td>
</tr>
</tbody>
</table>

### 6.4.5.2.3 Shear Properties

From Table 6.12 higher values of shear stiffness (G) are observed for SLF fabric in walewise and coursewise direction. This may be due to higher tightness factor of SLF fabric resulting in compact structure and hence lesser mobility of the threads within the fabric.
Table 6.12 - Shear properties

<table>
<thead>
<tr>
<th>Sample</th>
<th>Shear stiffness (G) gf/cm/deg</th>
<th>Hysteresis of shear force at 0.5° shear angle (2HG), gf/cm</th>
<th>Hysteresis of shear force at 5° shear angle (2HG5), gf/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wale</td>
<td>Course</td>
<td>Mean</td>
</tr>
<tr>
<td>SLF</td>
<td>0.0679</td>
<td>0.0898</td>
<td>0.0789</td>
</tr>
<tr>
<td>Silk</td>
<td>0.6003</td>
<td>0.6934</td>
<td>0.6468</td>
</tr>
<tr>
<td>Cotton</td>
<td>0.6542</td>
<td>0.6174</td>
<td>0.6358</td>
</tr>
</tbody>
</table>

Higher values of hysteresis of shear force (2HG5) are observed for SLF fabric in Table 6.12. This may be due to denser structure of SLF fabric as compared to silk and cotton fabrics. It has been observed earlier that values of course/cm, wales/cm and stitch density are higher as compared to silk and cotton fabric. It implies that number of cross-over points are much higher in SLF which causes more resistance to the fabric to acquire its original position, after removal of shear deformation.

6.4.5.2.4 Surface properties

From Table 6.13 it is observed that coefficient of friction (MIU) of SLF fabric is slightly greater than silk fabric but lesser than cotton fabric. The coefficient of friction depends upon contact area of the contactor with the fabric during testing. The greater the area of contact, the higher is the coefficient of friction. The slightly higher value of coefficient of friction for SLF fabric in comparison to silk fabric may be attributed to higher contraction observed in case of SLF fabric after knitting resulting in greater area of contact and higher MIU value.

Table 6.13 - Surface Properties

<table>
<thead>
<tr>
<th>Sample</th>
<th>Coefficient of friction (MIU)</th>
<th>Mean deviation of MIU (MMD)</th>
<th>Geometrical roughness (SMD), μm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wale</td>
<td>Course</td>
<td>Mean</td>
</tr>
<tr>
<td>SLF</td>
<td>0.2852</td>
<td>0.2509</td>
<td>0.2681</td>
</tr>
<tr>
<td>Silk</td>
<td>0.2220</td>
<td>0.2509</td>
<td>0.2364</td>
</tr>
<tr>
<td>Cotton</td>
<td>0.3685</td>
<td>0.2862</td>
<td>0.3274</td>
</tr>
</tbody>
</table>

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All three fabrics represent similar values of mean deviation of MIU (MMD) in Table 6.13. MMD is a measure of variation of MIU. Table 6.13 reveals that the mean value of geometrical roughness is least for SLF fabric among the three fabrics studied. It implies a smoother surface of the SLF fabric in comparison to silk and cotton fabric.

6.4.5.2.5 Compression properties

From Table 6.14 higher values of linearity of compression (LC) and compression energy (WC) are observed for SLF fabric as compared to silk and cotton fabric. LC depends upon the slope of compression thickness curve. Hence this may be due to denser and compact structure of the SLF fabric. A compact fabric is supposed to offer more resistance during compression and more energy is required to compress it resulting in higher values of LC and WC.

From Table 6.14 lower value of compressional resilience (RC) is observed for SLF fabric. The contraction of the fabric after knitting has resulted in compact structure of SLF fabric. The compact structure is supposed to exhibit lower values of compressional resilience RC.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Linearity of compression (LC)</th>
<th>Compressional energy (WC) (g/cm²)</th>
<th>Compressional resilience (RC) (%)</th>
<th>Fabric thickness (T) (mm)</th>
<th>Fabric weight (W) (mg/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLF</td>
<td>0.341</td>
<td>0.598</td>
<td>47.98</td>
<td>1.54</td>
<td>21.40</td>
</tr>
<tr>
<td>Silk</td>
<td>0.259</td>
<td>0.376</td>
<td>66.34</td>
<td>1.13</td>
<td>13.82</td>
</tr>
<tr>
<td>Cotton</td>
<td>0.291</td>
<td>0.466</td>
<td>52.75</td>
<td>1.31</td>
<td>14.32</td>
</tr>
</tbody>
</table>

6.4.5.2.6 Thickness and weight

Due to higher contraction of SLF fabric after knitting, a much higher value of thickness and weight is observed for SLF fabric in comparison to silk and cotton fabric.
6.4.5.2.7 Fabric Hand

For knitted outerwear fabric, the three selected primary hand (Koshi, Numeri and Fukrami) and total hand value are shown in Table 6.15. These values are also plotted in Fig. 6.36.

Table 6.15 Total hand value of single jersey knitted outerwear SLF fabric

<table>
<thead>
<tr>
<th>Material</th>
<th>Koshi (Stiffness)</th>
<th>Numeri (Smoothness)</th>
<th>Fukurami (Fullness and softness)</th>
<th>Total Hand Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLF</td>
<td>4.55</td>
<td>6.14</td>
<td>6.92</td>
<td>3.70</td>
</tr>
<tr>
<td>Silk</td>
<td>1.56</td>
<td>7.37</td>
<td>6.22</td>
<td>3.47</td>
</tr>
<tr>
<td>Cotton</td>
<td>0.14</td>
<td>7.23</td>
<td>5.33</td>
<td>2.61</td>
</tr>
</tbody>
</table>

Fig. 3.36 Hand values for single jersey knitted outerwear silk covered lycra-core fabric (SLF), 100% silk and cotton fabric.

From Table 6.15 it is observed that Koshi value for SLF fabric is much higher than silk and cotton fabrics. Koshi is a stiff feeling related to bending property. Springy property promotes this kind of feeling. High-density fabrics
made by springy and elastic yarn usually possess this feeling strongly. Hence presence of elastic filament in the fabric may be held responsible for higher value of Koshi in case of SLF fabric.

Smoothness (Numeri) of SLF fabric is slightly lesser than cotton and silk fabrics whereas it exhibits higher values of fullness (Fukurami). Fukurami is a bulky, rich and well-formed feeling and is mainly governed by fabric bulk and compressional behaviour. It depends upon bending and shear properties as well.

Total hand value (THV) is a measure of tactile comfort. Among three fabrics studied SLF has the highest THV followed by silk and cotton. The addition of elastic filament in the core of silk yarn has resulted in increase of total hand value (THV) of the fabric. Hence there are more chances that customer would prefer to choose SLF fabric in comparison to silk and cotton fabric.
6.5 CONCLUSION

Silk fibres can be used efficiently in the manufacture of stretch knitted fabrics. A slight reduction in the tenacity of silk covered lycra core-spun yarn was observed after incorporation of spandex core but still this yarn can be knitted easily on circular knitting machine. The abrasion resistance and bursting strength of lycra core-spun fabric is also better than 100% silk and cotton fabric. The stretch and recovery properties are better than 100% silk and cotton fabric of equivalent construction. Total hand value of silk covered spandex core knitted fabric is much better than equivalent 100% silk and cotton fabric.

Hence silk covered lycra core-spun yarns has a good scope in sportswear, activewear, shapewear and body contouring garments. The combination of silk and spandex can be used in knitted sportswear, blouses, casual wear, socks, stockings, T-shirts, apparel fabrics, slacks, creepers and leisure wear.