CHAPTER 3

SILK AND SILK BLENDED
YARNS AND FABRICS.
3.1 INTRODUCTION

Silk is the most cherished of all the textile fibres as it has elegance, lusture, fineness and strength. It has pleasing lusture and softer handle. However the prohibiting cost of silk fabrics does not permit low-income group to possess them as easily as the affluent section of the society can.

The increased price of raw silk calls for a serious consideration of blending silk with man made fibre. One of the developments in recent times is the wide use of silk in apparels in pure as well as in blended forms. Investigations have been made on blending man-made fibres like polyester, viscose and acrylic with silk waste on various spinning systems [19, 20, 23]. However very good quality yarns and fabrics couldn’t be prepared because of taking waste silk or coarse denier silk fibre as a blend partner in most of the studies [18, 20 23]. Fine denier silk fibres can be obtained after cutting the filaments in the tow form and then degumming the staple cut silk fibres. The silk fibre is then blended with man-made fibres in staple form to produce yarn on cotton spinning system.

Polyester fibre has excellent properties such as high strength, abrasion resistance, wash and wear and wrinkle free characteristics but it is hydrophobic and hence fabrics made out of it are not as comfortable as natural fibre fabrics. Polyester does not absorb moisture and perspiration as it does not have moisture retention property. These drawbacks may not manifest much if a blend of polyester and silk is prepared.

Viscose fibre is though weak and limpy in comparison to silk, has moisture regain greater than silk. So addition of viscose fibre in silk is not supposed to affect the comfort properties at all, while the aesthetic aspects of silk will be complemented.

Silk has traditionally been used in woven fabrics. In order to bring in much needed awareness about the alternate end products for silk on the one hand and include the luxury of silk, development of weft knitted structures from silk and silk blended fabrics has been initiated.
The present work explores the possibility of producing polyester and viscose rayon silk blended yarns on cotton spinning system and to study the influence of blend proportion on yarn properties including those which are relevant for knitting. The effect of blend proportion on the quality of knitted fabrics made from these yarns and the comfort properties of these fabrics have also been assessed and compared with equivalent cotton fabric.
3.2 EXPERIMENTAL PLAN

3.2.1 Properties of Raw-material

Mulberry silk in hank form (denier 24 to 26) were cut to a length of 51 mm staple by scissors. Degumming was carried out by boiling off in soap solution under following conditions:

- **Soap**: 6 g/litre
- **Sodium carbonate**: 1 g/litre
- **Temperature**: 90°C
- **Time**: 90 minutes
- **Material : Liquor ratio**: 1:40

After degumming the fibres were washed in soft water and dried at room temperature for 48 hours. While squeezing water from the silk some crimp effect was observed in the fibres (Fig.3.1). This crimp is likely to facilitate carding. The conversion stages of silk hanks to fibres is shown in Fig.3.2.

![Fig.3.1 Crimp effect in silk fibres.](image-url)
Fig. 3.2 Conversion of silk hanks to silk fibres.

The silk staple fibres thus obtained were used for blending with polyester and viscose fibre. The properties of polyester, viscose, silk and cotton fibres are shown in Table 3.1 and stress strain curves are depicted in Fig.3.3.

Table 3.1 - Properties of polyester, viscose, silk and cotton fibre.

<table>
<thead>
<tr>
<th></th>
<th>Polyester</th>
<th>Viscose rayon</th>
<th>Silk</th>
<th>H-4 Cotton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tenacity (g/den)</td>
<td>2.8</td>
<td>2.6</td>
<td>4.1</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>(8.1)</td>
<td>(21.9)</td>
<td>(12.0)</td>
<td>(12.4)</td>
</tr>
<tr>
<td>Elongation (%)</td>
<td>50.1</td>
<td>16.8</td>
<td>30.8</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>(14.1)</td>
<td>(11.5)</td>
<td>(13.3)</td>
<td>(15.4)</td>
</tr>
<tr>
<td>Staple length</td>
<td>51</td>
<td>51</td>
<td>51</td>
<td>25.4</td>
</tr>
<tr>
<td>(mm/2.5% span length)</td>
<td>(28.2)</td>
<td>(20.4)</td>
<td>(28.5)</td>
<td>(25.4)</td>
</tr>
<tr>
<td>Fineness (den/micronaire)</td>
<td>1.58</td>
<td>1.52</td>
<td>1.2</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>(5.5)</td>
<td>(10.1)</td>
<td>(17.4)</td>
<td>(20.4)</td>
</tr>
</tbody>
</table>

(Figures in parenthesis represent CV %)
3.2.2 Preparation of Yarn Samples

Blend levels chosen to spin silk-polyester blended yarns of 30\textsuperscript{s} Ne (19.7 tex) were 0:100, 20:80, 40:60, 60:40, 80:20 and 100:0 denoted as Polyester, S2P8, S4P6, S6P4, S8P2 and Silk respectively. The same blend levels were also chosen for silk-viscose blended yarns, denoted as Viscose, V8S2, V6S4, V4S6, V2S8 and Silk. The staple cut silk fibres after degumming were thoroughly opened by hand. A mixture of 5% water and LV-40, P-2152, both 0.5% each was sprayed on both fibres by a spray gun. The material was allowed to condition for 24 hours. The blends were prepared on stack mixing principle, and after conditioning two topplings were given. The blended fibres were then processed on a card. A low production rate (10 kg/hr) was maintained in order to ensure thorough opening of fibres and avoid static generation related problems.

The slivers were then given two passages of the drawframe, each having draft and doubling of 8. The drawframe speed was kept low (100m/min) so as to
avoid roller lapping. This was also controlled to some extent by reducing the width of slivers, entering at the back of the drafting zone.

The drawn slivers were subsequently processed on speedframe keeping draft of 10, so as to produce roving of $1.4 \text{ N}_e$ (421.7 tex). Twist multiplier was 0.7 and the spindle speed was maintained at 900 rpm. Roller lapping was controlled by choosing a suitable condensor.

The rovings were processed on a ring frame to produce yarn of $30^\circ \text{ N}_e$ (19.7 tex). Spindle speed and twist multiplier were 10000 rpm and 2.7 respectively. The roller settings were fixed according to fibre length. All the yarn samples were prepared by this method.

Cotton knitted fabric is commercially very successful. Hence to provide a reference point for the assessment of silk/polyester and silk/viscose fabrics, cotton fabric was chosen for investigation at the same time. For this purpose a cotton roving was procured from an industry manufacturing export quality yarn for knitting purpose. The combed roving was produced from H-4 cotton. From this roving $30^\circ$ cotton yarn was prepared with the same twist level (TM 2.7).

3.2.2.1 Yarn Winding and Clearing

The yarn prepared on ring-frame was wound on to cones, on a RJK High speed cone/cheese winding machine running at 600m/min. This machine was also attached with Keisokki Classifault 2. The yarn was electronically cleared simultaneously so as to ensure smooth working of the yarn at knitting machine and good quality fabric.

3.2.2.2 Yarn Steaming

Spirality affects both the aesthetic and functional performance of the weft knitted fabrics. Fabric spirality is a complex phenomenon arising from many factors influencing the nature and degree of loop distortion in single jersey knitted fabric. Twist setting induces a permanent set in fibres, reduces yarn residual torque and minimises the degree of spirality in weft knitted fabrics [106]. Unrelieved torque plays an important role in determining the dimensions and behavior of single jersey knitted fabric and once the torque is overcome, the yarns knit well and produce very acceptable fabric. Auto-claving the yarns is
the best way of reducing twist liveliness and the associated difficulties in manufacturing the fabrics.

All the yarn samples were kept in autoclave for 20 minutes at a temperature 100°C and pressure of 1.0 Kg/cm² to set the twist. All the tests related to yarns were performed after steaming operation.

3.2.3 Preparation of Fabric Samples

After steaming of all the yarns, knitted fabric samples were prepared on single jersey circular knitting machine. The specifications of the knitting machine are given below:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make of the machine</td>
<td>Sant Knitting Works, Ludhiana (Punjab).</td>
</tr>
<tr>
<td>Gauge of the machine</td>
<td>24</td>
</tr>
<tr>
<td>Diameter of the machine</td>
<td>12 inches</td>
</tr>
<tr>
<td>Number of feeders</td>
<td>24</td>
</tr>
<tr>
<td>Speed of machine</td>
<td>36 rpm</td>
</tr>
<tr>
<td>Total no. of needles</td>
<td>886</td>
</tr>
</tbody>
</table>

The tightness factor of cotton knitted fabric is generally around 15. It was confirmed actually by finding the loop length and count of the yarn of the commercial single-jersey cotton knitted fabric. Hence the cam in the knitting machine was set such a way that a tightness factor of 15 is achieved in cotton fabric. Now at the same cam setting all other samples were prepared. Yarn tension and fabric take down tension during knitting process, were kept constant for all the samples. This was done to observe the change in the properties of the fabric (knitted under identical condition) from the yarns having different blend ratio (spun under identical conditions, same count and twist level).

The yarn tension on all the feeders was kept constant. For this a black spot of oil was marked on the yarn in each feeder. Then the machine was rotated by hand till the mark reached the knitted fabric. In an ideal case, a circle of the marks should be formed in the fabric. In case of any variation, the stitch cam was raised or lowered depending upon the level of mark. This was
repeated many times till uniform yarn feed was achieved on all the feeders. Then the machine was run by power to get continuous knitted fabric.

3.3 TEST METHODS

3.3.1 Fibre and Yarn Testing

All the fibre and yarn samples were conditioned in the standard atmospheric test conditions of 65% ± 2% RH and 27°C ± 2°C and then tested for the following properties according to the standard test methods as described below.

Fibre fineness was tested on Vibroskop [107] and fibre tenacity was assessed on Vibrodyn according to ASTM standards [108].

Yarn tensile properties were evaluated on Instron Tensile Tester 4465 following ASTM standards [109]. The gauge length and crosshead speed was kept 500 mm and 200 mm/min respectively so that breakage time is 20±3 sec. The pre-tension was adjusted at 0.5±0.05 g/tex. Yarn evenness and imperfections were evaluated on Keisokki evenness tester 80 [110]. Settings for thin places, thick places and neps were kept at -50%, +50% and +200% respectively. Yarn hairiness was tested on Zweigle G 566 hairiness tester [111]. To compare the hairiness of different yarns, the S3 value was chosen (number of hairs longer than 3 mm). Yarn flexural rigidity was tested on the Shirley weighted ring yarn stiffness tester [112,113].

Yarn appearance boards were prepared and grading was given as per ASTM standards [114]. Flex yarn abrasion resistance was tested on Custom Scientific Instruments abrasion tester following ASTM standards [115].

The fibre strength realisation percentage is a ratio of actual yarn strength and fibre strength expressed as a percentage. In the case of binary blends where the two components have different elongation at break and proportion, it is the ratio of actual and expected yarn strength. Expected yarn strength can be calculated by the method suggested by Hamburger [116] described below.

According to this method when a blended yarn of two components A and B is extended by an applied load, the fibres of least extensible component A
are strained to the breaking point first. The yarn tenacity $S$, at this first breaking point is given by

$$S_1 = \frac{aS_A + bS'_B}{100}$$

where $a$ and $b$ are percentage of fibre A and B in the blend. $S_A$ and $S'_B$ are tenacity of fibre A and B at $x_1$ (elongation percentage of fibre A).

All fibres of component A will break and for second rupture point at $x_2$ when all the fibres of B break, is given by

$$S_2 = \frac{bS_B}{100}$$

where $S_B$ is tenacity of fibres B at $x_2$.

After finding out the expected yarn strength, the ratio of actual yarn strength and expected yarn strength was calculated to get fibre strength realization percentage at various blend levels.

The yarn diameter was measured on a projection microscope at 100 randomly selected places along the length of the yarn so as to take care of any variations.

### 3.3.2 Evaluation of Knitting Relevant Yarn properties

The properties of yarn for knitting differ from those required for weaving [117,118]. Some special characteristics of yarn are to be checked, if it is meant for knitting [119] and their importance is stated below.

**Elongation at break** -- The yarn should have high elongation at break values. A yarn with low elongation at break will not knit properly as it can’t survive the loop forming action during knitting.

**Tenacity** -- High tenacity doesn’t always give good knitting quality. Knitting yarn requires reasonable tenacity. A certain minimal tenacity is required otherwise the yarn willn’t have enough strength to withstand the knitting stresses.

**Yarn metal friction** -- Very low coefficient of yarn metal friction may have slippage of yarn around needles whereas a higher value is likely to cause
cutting action on needles. Hence it is necessary to check yarn metal friction before knitting.

Loop and Knot strength -- Loop strength and knot strength of yarns indicates the brittleness of the yarn [120]. If a textile yarn is looped or knotted, it's tensile strength may reduce. Tensile stress acts parallel to yarn axis. However this is not true in case of knitting. The yarn is bent over an angle while passing round tension rods, needles or through needle holes, the stress is no longer of purely tensile character. Rupture of loops can occur at lower value than normal tenacity of yarns. Hence it is necessary to check loop strength of yarns. In addition to loop stress, the yarn must also be able to withstand stresses produced upon tying of knots. Material which possesses low strength knots is bound to be troublesome in knitting. Generally yarns having loop and knot strength ratio greater than 70 % are expected to perform well during knitting.

Snarling tendency -- The tendency of yarn to snarl due to unrelieved torque is important factor affecting the spirality of the knitted fabric. Yarns with lesser snarling tendency are favorable for knitting.

Flexural rigidity -- This is index of yarn resistance to bending and flexing. The lower is the bending resistance, the easier it is to bend and kink the yarn into loops.

Regularity -- A yarn having less unevenness and imperfections values is likely to give better appearance to the knitted fabric.

The coefficient of friction of yarn against stainless steel was measured on the Shirley Yarn Friction Recorder Winder at a speed of 54 m/min [121].

Loop breaking load and loop breaking extension was measured on Instron Tensile Tester 4465 at a guage length 7 inches and a rate of traverse of 12 inches/min according to British Standards [122]. Loop strength ratio is a ratio of mean loop breaking load and twice mean yarn breaking load (measured under same conditions)

For measuring knot breaking load and knot breaking extension of yarns, 60-70 cm of yarn was withdrawn from sample. A single overhand knot was tied
as per British Standards [122], at approximately middle of the specimen taking care not to lose any twist and the specimen was mounted on Instron Tensile Tester 4465. The grips were set to give a specimen length of 500 mm and time to break 20±3 sec. Then knot breaking load and breaking extension was recorded. Knot strength ratio is a ratio of mean knot breaking load and mean yarn breaking load (measured under identical conditions).

There is no standard method prescribed for testing the liveliness of a yarn. The method suggested by De Araujo [123] and Lord P. R. [124] was used to determine twist liveliness. The assessment is usually made by allowing the ends of a length of yarn to be brought together and measuring the self-twisting of the loop. The technique is illustrated in Fig.3.4. Yarn of length AB, substantially greater than 50 cm, was cut from the main sample, taking care not to lose any twist. A dead weight (W) was attached to one end and the other end was fixed. A small weight of 0.195 g was placed at a distance of 25 cm from one end, which was held fixed between the fingertips at C. End C was moved towards A until the yarn just started snarling from the center. The distance between points A and C was measured. This procedure was repeated 20 times, and the average was taken. The distance AC for different yarns is shown as value of snarling tendency.

Fig.3.4 Method of measuring snarling tendency of yarn.
3.3.3 Evaluation of fabric properties

The dry relaxed fabric samples were conditioned in the standard atmospheric test conditions of 65% ± 2% RH and 27°C ± 2°C and then tested for the following properties according to the standard test methods.

Bursting strength of the fabric was measured on Prolific bursting strength tester [125]. Fabric samples were held between upper and lower clamps having 30.5 and 38.1 mm diameter respectively. A constant tension was applied on all the samples. Pressure was applied to the underside of diaphragm until the specimen bursts. Rate of fluid displacement in the diaphragm was kept at 95 cc/min.

Flat abrasion resistance of the fabric was measured on Prolific abrasion tester [126]. Abrasion resistance is expressed as average number of cycles required to produce a hole in a knitted fabric. Zero number emery paper was used as a abradant.

Air permeability of the fabric was measured on Prolific air permeability tester [127]. It is given as volume of air passing through a defined area of 10 cm² under a specified pressure difference of 10 mm between two fabric surfaces. From the rate of air flow the air permeability of the fabric was measured. Moisture regain of the fabric was determined according to ASTM standards [128].

Thermal resistance of the fabric was measured on Sasmira thermal conductivity apparatus [129]. In this case time taken by the hot plate to cool down from 50°C to 49°C was noted down for each sample and clo value was found. The guard box temperature was maintained a 50°C.

The pilling tendency was tested using Heal’s pilling boxes [130]. The samples treated in this apparatus were evaluated as follows

5- No pilling
4- Slight pilling
3- Moderate pilling
2- Severe pilling
1- Very severe pilling
3.3.4 Relaxation properties

Dry relaxation: Fabrics knitted in tubular form were laid free from constraints for 24 hours on a flat surface to facilitate recovery from the stresses imposed during knitting in standard atmospheric conditions (65% ± 2% RH and 27°C ± 2°C) [131].

Wet relaxation: Fabric samples were put into a large stainless steel tub containing water and 0.1% wetting agent maintained at a constant temperature of 40°C. The samples remained in this container for 24 hours before being lifted out, then allowed to dry naturally for at least 3 days. After drying, the fabric samples were brought back to the standard conditions (65% ± 2% RH and 27°C ± 2°C).

Full relaxation: Knitted samples were put into a large stainless steel tub containing water and 0.1% wetting agent maintained at a constant temperature of 40°C. The samples were wetted thoroughly for 24 hours, washed thoroughly, then briefly hydroextracted and tumble-dried for 1 1/2 hours at 70°C. The samples were laid on a flat surface for 24 hours in standard atmospheric conditions of 65% ± 2% RH and 27°C ± 2°C.

Course and wale density of the fabrics was measured with thread counting glass. Stitch length of the knitted fabric was measured according to British Standards [132]. The stitch density was obtained by multiplying wales/cm and course/cm. The knitting constant were calculated from the following equations

\[ K_c = \text{Course/cm} \times \text{Stitch length} \]
\[ K_w = \text{Wales/cm} \times \text{Stitch length} \]
\[ K_s = K_c \times K_w \]

Loop shape factor, tightness factor and fabric bulk were calculated by following formulas

Loop shape factor = \( K_c / K_w \)

Tightness factor = \((T)^{1/2}/l\) where T is tex of yarn and l is loop length.

Fabric bulk \((\text{cc/g}) = \text{Thickness (cm)} / \text{Weight of fabric (g/cm}^2)\)
Thickness of the fabric was measured on Prolific thickness tester at a foot pressure of 20 gf/cm² [133]. Skewness of the fabric was measured according to ASTM standards [134].

3.3.5 Evaluation of Comfort Properties

Comfort is one of the most important aspects of clothing. Clothing comfort can be classified into three groups: Psychological, Tactile and Thermal comfort [135]. Psychological comfort bears little relation to the fabric's properties and is mainly related to the fashion trend prevailing in the society. Tactile comfort is essentially a result of how much stress is generated in the fabric and how it is distributed over the skin and therefore has a strong relationship with both the mechanical and surface properties of the fabrics. Tactile comfort is also directly related to fabric handle. There is quite a difference in a fabric handle preference from individual to individual due to differences in their cultural background, climatic differences and sometimes references may even be opposite. Thermal comfort is related to the fabric's ability to maintain skin temperature and allow transfer of perspiration produced from the body.

Moisture transport through clothing also plays a key role in comfort. The clothing acts as a barrier or buffer to the free exchange of heat and moisture so that an energy balance is maintained between wearer and environment. During physical exertion, the body produces excess heat, which has to be transmitted out via skin and thus the clothing. How much heat has to be transmitted out depends on the situation and the surrounding temperature. If the release of heat occurs in the form of water vapours, the clothing should be able to absorb it. However if the water vapour is not transferred away from the skin as quickly as possible, the formation of liquid sweat takes place and subsequently the body looses too much heat of vaporisation. These phenomenon lead to disturbance on energy balance between the body and the environment and creates discomfort to a large extent. Hence moisture transport properties are an important part of comfort properties.
3.3.5.1 Fabric moisture transfer properties

Three types of tests were performed to evaluate moisture transfer properties – Wicking behaviour, water vapour transfer and total absorbency.

3.3.5.1.1 Wicking behavior

When a porous material such as fabric is placed in contact with a liquid, spontaneous uptake of liquid may occur. Spontaneous uptake in the plane of a fabric is called wicking. The ability of a fabric to absorb water especially by a wicking or capillary action may be observed by timing, the rate at which the water climbs up a narrow strip of fabric suspended vertically with its lower end dipping into water.

Two methods were used for assessment of wicking behavior i.e. strip test and spot test [136]. Prior to testing all the fabric samples were conditioned to moisture equilibrium and the fabrics were tested in standard atmospheric condition of 65% ± 2% RH and 27°C ± 2°C temperature.

3.3.5.1.1.1 Strip test

A strip of the test fabric 6 inches * 1 inch, preconditioned at 65% ± 2% RH and 27°C ± 2°C was suspended vertically with its lower end immersed in a reservoir of distilled water [136]. The wicking behavior was studied by using a 0.2% soap solution. The soap solution was used because wicking with pure water was too slow and immeasurable. The height reached (at constant time of 15 sec, 1 minute and 15 minutes) by water in the fabric above the water level in the reservoir was measured. Wickeability of the test fabrics was also measured from the wicking height by using the formula:

\[
\text{Wickeability} = \frac{\text{Average rise in height} \times \text{Percentage of mass}}{100} \]

\[
\text{Percentage of mass} = \frac{\text{Wet weight} - \text{Dry weight}}{\text{Dry weight}} \times 100
\]

3.3.5.1.1.2 Spot test

A drop of liquid (distilled water, drop volume 30 mm³) was delivered from a height of approximately 6 mm onto horizontal specimen of test fabric (preconditioned at 65% ± 2% RH and 27°C ± 2°C) [136]. The region of the test fabric on which the drop falls was illuminated by a beam of light to create a bright reflection from the liquid surface and the elapsed time between the drop reaching the fabric surface and the disappearance of the reflection from the
liquid surface was measured. The time taken for complete absorption of the drop was noted.

3.3.5.1.2 Water Vapour Transfer

The modified evaporation cup method was used to measure the water vapour transferred through the fabric. The fabric assembly was sealed over a cylindrical cup containing the water 1 cm below the brim. Evaporation takes place under standard atmospheric conditions of 65% RH and 27°C temperature. Loss in the weight of cups was measured after 24 hours of starting the experiment for all the samples.

3.3.5.1.3 Total Absorbency

The water holding capacity of the fabrics was determined by using a 0.2% soap solution [135]. A sample of size 20 cm * 20 cm was dipped in the solution for five minutes and then hung vertically to allow any extra water to drip down for a five minute period, it was then weighted. The percentage gain in the weight of the fabric sample was taken as the total absorbency of the fabric. Fabrics were conditioned in a standard atmosphere for 24 hours before all the tests were carried out.

3.3.5.2 Low Stress mechanical Properties

The fabric mechanical properties, measured at low stress levels, are more important from the comfort standpoint. Studies have established that handle, comfort, tailorability, garment formability and appearance depend on low stress mechanical properties such as bending, tensile and shear at low stress levels [137,138,139]. Kawabata evaluation system for fabrics [KES-FB] measures the surface properties in addition to above properties [140,141,142]. Fabric selection for tailoring and selection of tailoring instructions are carried out on the basis of low stress mechanical properties [143,144]. Fibre composition, spinning and twisting, weave structure and weaving, and finishing processes are altered to achieve fabric properties close to specifications in terms of low stress mechanical properties [145,146,147]. Kawabata instruments (KES-FB) were used because of their unique ability to measure fabric mechanical properties at small stresses with a high degree of sensitivity.
The tensile and shear behaviour of all fabrics were studied on a KES-FB 1 (tensile shear tester) and the bending properties were measured by using a KES-FB 2 (pure bending tester). Compression properties and fabric thickness were measured with a KES-FB 3 (compression tester) and surface roughness and friction were measured using the KES-FB 4 (surface tester). These four instruments are used to test fabrics at low stress levels simulating the day to day handling of the fabrics and garments. All the seventeen properties measured by the set of four instruments are listed in Table 3.2.

Table 3.2 Fabric mechanical and surface parameters.

<table>
<thead>
<tr>
<th>Property</th>
<th>Symbol</th>
<th>Characteristic value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Tensile</td>
<td>EM2</td>
<td>Extensibility at 500 gf/cm</td>
<td>%</td>
</tr>
<tr>
<td>2.</td>
<td>LT</td>
<td>Linearity of load-extension curve</td>
<td>-</td>
</tr>
<tr>
<td>3.</td>
<td>WE</td>
<td>Tensile energy</td>
<td>gf.cm/cm²</td>
</tr>
<tr>
<td>4.</td>
<td>RT</td>
<td>Tensile resilience</td>
<td>%</td>
</tr>
<tr>
<td>5. Bending</td>
<td>B</td>
<td>Bending rigidity</td>
<td>gf.cm²/cm</td>
</tr>
<tr>
<td>6.</td>
<td>2HB</td>
<td>Hysteresis of bending moment</td>
<td>gf.cm/cm</td>
</tr>
<tr>
<td>7. Shear</td>
<td>G</td>
<td>Shear rigidity</td>
<td>gf/cm. degree</td>
</tr>
<tr>
<td>8.</td>
<td>2HG</td>
<td>Hysteresis of shear force at 0.5° shear angle</td>
<td>gf/cm</td>
</tr>
<tr>
<td>9.</td>
<td>2HG5</td>
<td>Hysteresis of shear force at 5° shear angle</td>
<td>gf/cm</td>
</tr>
<tr>
<td>10. Compression</td>
<td>LC</td>
<td>Linearity of compression-thickness curve</td>
<td>-</td>
</tr>
<tr>
<td>11.</td>
<td>WC</td>
<td>Compressional energy</td>
<td>gf.cm/cm²</td>
</tr>
<tr>
<td>12.</td>
<td>RC</td>
<td>Compressional resilience</td>
<td>%</td>
</tr>
<tr>
<td>13. Surface</td>
<td>MIU</td>
<td>Coefficient of friction</td>
<td>-</td>
</tr>
<tr>
<td>14.</td>
<td>MMD</td>
<td>Mean deviation of MIU</td>
<td>-</td>
</tr>
<tr>
<td>15.</td>
<td>SMD</td>
<td>Geometrical roughness</td>
<td>Micron</td>
</tr>
<tr>
<td>16. Fabric construction</td>
<td>W</td>
<td>Fabric weight per unit area</td>
<td>mg/cm²</td>
</tr>
<tr>
<td>17.</td>
<td>T</td>
<td>Fabric thickness</td>
<td>mm</td>
</tr>
</tbody>
</table>
3.4 RESULT AND DISCUSSION

3.4.1 Yarn properties

Table 3.4 and 3.5 in the appendix shows properties of the silk-polyester and silk-viscose blended yarns at various blend levels respectively. Stress-strain curves of all silk-polyester blended yarns are shown in Fig.3.5. It is evident from this figure that tenacity of 100% polyester yarn is minimum and it increases gradually with the addition of silk fibre. The elongation at break of polyester yarn is much greater than silk yarn. These trends may be attributed to the lower tenacity and higher elongation at break of the polyester fibre in comparison to silk fibre as can be observed from Table 3.1 in section 3.2.1.

![Stress-strain curves of silk-polyester blended yarns.](image)

The stress-strain curves of silk-viscose blended yarns are shown in Fig.3.6. The tenacity of the viscose yarn also improves with the addition of silk fibre in the blend. It implies that addition of stronger fibre in the blend improves the tenacity of yarn gradually.
Fig. 3.6 Stress-strain curves of silk-viscose blended yarns.

For the sake of clarity, stress-strain curves of 100% silk, polyester, viscose and cotton yarns are also shown separately in Fig. 3.7.

Fig. 3.7 Stress-strain curves of 100% silk, polyester, viscose and cotton yarns.
From Fig.3.7 the tenacity of 100% silk yarn is found to be maximum. This trend accords with the values of tenacity of silk. The fine denier of silk fibre has also resulted in more number of fibres in cross-section and hence more fibre to fibre friction in comparison to all other yarns. It can be clearly observed that tenacity of 100% polyester yarn is less than 100% viscose yarn. Although tenacity of polyester fibre is slightly greater than viscose fibre but tenacity of polyester yarn is lesser than viscose yarn. This trend can be explained on the basis of elongation % at break of fibre and yarn.

100% polyester yarn is breaking at 23 % only whereas the elongation % at break of polyester fibre is 50.1%. As the polyester fibre used was of antipill type, hence it is having low modulus and tenacity, in comparison to silk and viscose fibre. During manufacturing of the yarn, therefore many of the fibres got permanently deformed especially during twisting. Hence the yarn broke at much lower extension value and at this extension value, corresponding value of fibre tenacity is lower, resulting in lesser tenacity of the polyester yarn. The full potential of polyester fibre tenacity is not being utilised. The elongation % at break of viscose fibre is 16.8% and that of corresponding yarn is 16.0%. This is due to higher modulus of viscose fibre. Hence at the time of breaking, the fibre has elongated to maximum extent resulting in full utilisation of it's tenacity.

The values of elongation % at break for all silk/polyester and silk/viscose blended yarns have been plotted in Fig.3.8. For the sake of comparison the
values of cotton yarn have also been shown simultaneously. It is clear that strain % at break value is maximum for 100% polyester yarn and it decreases significantly with the addition of 20 % silk. In the case of silk-viscose blends the change is not so much. The breaking extension lies between 13-16% for all blended yarns. The breaking extension of 100 % silk yarn is 13%. It is close to breaking extension values of the yarn made from viscose rayon fibre. Hence addition of viscose does not make much of a difference in breaking extension of blended yarns.

The values of yarn tenacity for silk-polyester and silk-viscose blended yarns have been plotted in Fig.3.9. It is clear that yarn tenacity increases with increase in silk fibre content for both kinds of blends. This trend may be attributed to the greater fibre strength and fine denier of silk fibre. Hence addition of stronger fibre has resulted in stronger yarn. Fine denier of silk fibre have also resulted in more number of fibres in cross-section, more area of contact and increased cohesiveness due to more fibre to fibre friction. Silk-polyester blends exhibit comparatively lower values of tenacity in comparison to silk-viscose blends. All silk-polyester blended yarns are breaking within a range of 13-15 % elongation at break. Due to lower modulus and high extension of the polyester fibre, contribution of the polyester fibre tenacity towards yarn tenacity is lower at all levels of silk % in the blend, hence tenacity of all silk-polyester blended yarns is lesser than silk-viscose yarns. Due to higher modulus of the viscose fibre and reasonable matching of stress-strain curves of silk and viscose fibre, the contribution of the viscose fibre towards yarn tenacity is more, hence all silk-viscose blended yarns are having greater tenacity than silk-polyester blended yarns.

The values of fibre strength realization for both kinds of blends are shown in Fig.3.10. The expected tenacity of the blended yarns were calculated from the stress strain curves of respective fibres as shown in Fig.3.11 and Fig.3.12 for silk-polyester and silk-viscose blends respectively following the procedure suggested by Hamburger [116]. Fig.3.10 indicates that fibre strength realization is minimum in case of pure polyester yarn and increases with the
increase in the silk content in the blend. Due to good compatibility of stress-strain curves of silk and viscose fibres, fibre strength realization values lies within range of 70-80%. Silk rich blends are exhibiting comparatively greater values of fibre strength realization in both the cases.

Fig. 3.10 Fibre strength realisation of yarns.

Fig. 3.11. Fibre strength realization of silk-polyester blended yarns.
Fig. 3.12 Fibre strength realization of silk-viscose blended yarns.

All the silk-polyester and silk-viscose blended yarns are of good quality. These yarns have good evenness value, less imperfections and hairiness (Fig. 3.13, 3.14 and 3.15). The lower value of U% for silk yarn is due to fine denier of silk fibre and hence more number of fibres in yarn cross-section.

Fig. 3.13 U% of silk blended yarns. Fig. 3.14 Total imperfections/250m of yarns.

The flexural rigidity of the yarns is shown in Fig. 3.16. It is observed to increase with the increase in proportion of silk in the yarn, in both kinds of...
blends. Silk fibre has a higher initial modulus, therefore as the silk content in the blend increases, stiffness also increases.

Values of the flex abrasion resistance of the yarns are plotted in the Fig.3.17. The abrasion resistance of silk yarn is found to be maximum. The abrasion resistance of the yarn depends upon toughness index of the yarn which in turn is governed by tenacity and elongation of the yarn. A combination of high tenacity and elongation can be ascribed to higher abrasion resistance of the silk yarn.

Values of yarn diameter are shown in Fig.3.18. As the count of all the yarns is same, hence with the change in blend proportion, yarn diameter does not show any trend. Grading was given to the appearance boards of all yarns.
as shown in Table 3.4 and 3.5 in the appendix. Appearance of 100% silk and all silk-blended yarns is good.

3.4.2 Yarn Properties for Knitting

Table 3.6 and 3.7 shows important yarn properties for knitting. The nearly equal values of yarn metal friction for silk and cotton yarn suggests that both yarns can be knitted simultaneously on the knitting machine with same parameters. This has been found true practically also. Value of yarn metal friction for 100% polyester yarn is lowest among the yarns studied and increases with increasing percentage of silk in the blend, whereas decreasing trend is observed in case of silk-viscose blends (Fig.3.19). The polyester fibre has circular cross-section, hence yarn and fabric formed from 100% polyester are comparatively smoother in nature. The yarn metal friction is measured by passing the yarn around two steel pulleys and difference in tension is a measure of yarn metal friction. The smooth surface of polyester yarn might have caused lower yarn metal friction in case of 100% polyester yarn. The serrated and triangular cross-section of viscose and silk may be responsible for slightly higher values yarn metal friction for the viscose and silk yarn in comparison to polyester yarn.

Fig.3.19 Yarn metal friction of yarns. Fig.3.20 Loop breaking load of yarns.

Loop breaking load goes on increasing with the increase in proportion of silk in the yarn in both the cases (Fig.3.20) and they are practically same for
both the blended yarns. 100% silk yarn shows maximum value of loop breaking load. A similar behaviour was observed for the values of yarn tenacity also.

The values of loop breaking extension are displayed in Fig.3.21. Loop breaking extension of 100% polyester yarn is maximum and it goes on decreasing with increase in silk content whereas reverse trend is followed in case of silk-viscose blends. This may be ascribed to greater value of elongation at break of polyester fibre. Loop strength ratio (ratio of loop strength to twice single yarn strength measured under same conditions) of all the silk-polyester blended yarns is greater than 90% as depicted in Fig.3.22. In case of viscose yarn, loop-strength ratio is marginally lower than polyester yarn but improves with addition of silk fibre.

The values of knot-breaking load are displayed in Fig.3.23. This value increases with silk content for both types of blends and 100% silk yarn exhibits maximum value of knot breaking load among the yarns studied. Silk being a stronger component, hence addition of silk increases knot-breaking load. Knot breaking extension of polyester yarn is maximum as shown in Fig.3.24 as polyester fibre had the maximum breaking extension also. All silk-viscose blends have knot-breaking extension greater than 10% but it hardly changed with change in blend percentage.
Knot strength ratio (ratio of knot breaking load and mean yarn breaking load measured under identical conditions) of all the yarns is greater than 80% as shown in Fig.3.25. Hence these yarns are likely to perform well during knitting.

Snarling tendency in the yarns is the primary cause of spirality in the knitted fabrics. The results show that snarling tendency of 100% silk and polyester yarn is lesser than viscose and cotton yarn (Fig.3.26). This is due to good steam setting properties of the silk and polyester fibres. Viscose and cotton can't be steam set, hence a higher value of snarling tendency is observed in 100% viscose and cotton yarn even after steaming.
3.4.3 Fabric properties

Properties of the single jersey weft knitted silk-polyester and silk-viscose blended fabrics in comparison to cotton fabric have been shown in Table 3.8 and 3.9 in the appendix. Fig.3.27 reveals that all silk fabrics exhibit maximum value of bursting strength followed by polyester, viscose, whereas cotton exhibits minimum value. The bursting strength of the fabric depends upon the extensibility, tenacity of yarn and the structure of the fabric. As all the fabrics are having similar construction (single jersey fabrics), hence higher values of elongation and tenacity for silk, polyester and viscose yarns can be ascribed to their higher bursting strength in comparison to cotton fabric.

Fig.3.27 Bursting strength of fabrics. Fig.3.28 Abrasion resistance of fabrics.

The flat abrasion resistance of fabrics in the descending order is silk, polyester, cotton and viscose (Fig.3.28). The abrasion resistance of a fabric depends upon toughness index or product of tenacity and elongation of yarn. This maximum abrasion resistance of the silk fabric may be attributed to the highest yarn tenacity of 100 % silk yarn. Hence it is difficult to abrade fibres from the surface of the yarn. It is clear from Fig.3.29 that air permeability of cotton fabric is least among all the fabrics. This may be due to higher values of yarn hairiness and yarn diameter of cotton yarn as observed already in Table 3.5 in the appendix. Moisture regain values of the fabrics are shown in Fig.3.30. Moisture regain of all silk and silk-viscose blended fabric is greater than cotton.
Pilling tendency of the fabrics has been shown in Table 3.8 and 3.9 in the appendix. It is clear that silk and viscose rich blends have more tendencies to form pills as compared to polyester and cotton fabric. As we have chosen combed cotton and low tenacity polyester, which is manufactured specially for apparel purpose where low pilling tendency is desired, hence this trend is observed.

Pilling tendency of the fabrics has been shown in Table 3.8 and 3.9 in the appendix. It is clear that silk and viscose rich blends have more tendencies to form pills as compared to polyester and cotton fabric. As we have chosen combed cotton and low tenacity polyester, which is manufactured specially for apparel purpose where low pilling tendency is desired, hence this trend is observed.

Thermal resistance of the fabrics has been shown in Fig.3.31. Cotton fabric exhibits maximum thermal resistance. This may be due to more yarn
hairiness, yarn diameter and hence more fabric thickness, fabric bulk and lesser air-permeability of cotton fabric.

3.4.4 Relaxation treatment

3.4.4.1 Dry relaxed fabric

The relaxed state of the fabric has been described as the state in which stresses and strains in longitudinal and transverse direction, induced on the yarn during the several processes in manufacturing of the fabric are relieved and the fabric take up a unique geometrical configuration corresponding to minimum energy level.

![Fig.3.32 Courses/cm of silk-polyester fabrics.](image1)

![Fig.3.33 Courses/cm of silk-viscose fabrics.](image2)

![Fig.3.34 Wales/cm of silk-polyester fabrics.](image3)

![Fig.3.35 Wales/cm of silk-viscose fabrics.](image4)
Table 3.10 and 3.11 in the appendix shows the properties of dry relaxed silk-polyester and silk-viscose blended fabrics respectively. The values of courses/cm for silk-polyester and silk-viscose blends are plotted in Fig.3.32 and Fig.3.33 whereas wales/cm are plotted in Fig.3.34 and 3.35 respectively. The values of dry, wet and fully relaxed fabrics are also plotted simultaneously. In case of dry relaxed fabric of silk-polyester blends, not much change is observed in the values of wales/cm and courses/cm. It implies that silk, polyester and cotton yarns can be knitted simultaneously to get single jersey fabrics of similar construction.

From Fig.3.33 not much change is observed in courses/cm of viscose knitted fabric whereas wales/cm of viscose fabric are slightly lower than silk fabric (Fig.3.35). This trend may be due to comparatively lesser contraction of viscose fabric after knitting. Single jersey fabrics tend to shrink in widthwise as well as in lengthwise direction immediately after knitting. In this study yarn count, twist and knitting machine parameters are constant for all kinds of fabrics, hence the slight difference in wales/cm of silk and viscose fabric can be attributed to lesser widthwise contraction of the viscose fabric, resulting in slightly greater width of the dry relaxed fabric and hence lower value of the wales/cm in the fabric.

Fig.3.36 Stitch density of silk-poly. fabrics. Fig.3.37 Stitch density of silk-viscose fabrics.
For dry relaxed fabric, a slight increase in value of stitch length with increasing proportion of silk is observed as shown in both Fig.3.38 and 3.39. The same trend was also observed in the values of yarn flexural rigidity in Fig 3.16. The loop length of a knitted fabric depends upon yarn type, yarn flexural rigidity, yarn count and cam setting. In this study all parameters are same except yarn rigidity. Hence change in values of the stitch length may be due to change in flexural rigidity of the yarn. For viscose yarn having lower flexural rigidity, it is easier to bend the yarn to form a loop, resulting in lesser loop length than all silk yarn.

The values of knitting constant (Kc, Kw and Ks) have also been shown in Table 3.10 and 3.11 in the appendix. These values show an increasing trend with increasing proportion of the silk in the blend in both the blends. This is due to increase in stitch length of the fabric with blend proportion.

Values of loop shape factor have been plotted in Fig.3.40 and 3.41. Loop shape factor is a measure of ratio of course/cm and wales/cm. Not much change was observed in the values of courses and wales/cm of the silk-polyester fabrics with change in silk % in the blend. The same trend is also
observed in loop shape factor in Fig.3.40. A comparatively higher value of loop shape factor is observed for 100 % viscose fabric in Fig.3.41. This is due to lower value of wales/cm for viscose fabric observed earlier.

Fig.3.40 Loop shape factor of SP fabrics. Fig.3.41 Loop shape factor of SV fabrics.

Fig.3.42 Tightness factor of SP fabrics. Fig.3.43 Tightness factor of SV fabrics.

The values of tightness factor for dry relaxed fabric show a decreasing trend as depicted in the Fig.3.42 and 3.43. The tightness factor is inversely proportional to the stitch length as yarn linear density of all the yarns is same. Hence owing to increase in value of stitch length with the increase in silk
percentage as observed earlier, the tightness factor show a decreasing trend for both blends.

Fig. 3.44 Thickness of silk-polyester fabrics. Fig. 3.45 Thickness of silk-viscose fabrics.

Thickness of the fabrics is plotted in Fig. 3.44 and 3.45. Thickness of cotton knitted fabric is maximum among the fabrics studied. This may be attributed to the higher value of yarn diameter as observed earlier in Fig. 3.18.

Fig. 3.46 Skewness of silk-polyester fabrics. Fig. 3.47 Skewness of silk-viscose fabrics.

Spirality or skewness of the fabric indicate degree of loop distortion arising from unrelieved residual torque in the yarn. Skewness in the silk, polyester and viscose fabric is much lower than cotton fabric (Fig 3.46). Viscose
fabric exhibits slightly higher skewness than silk fabric (Fig. 3.47). Skewness values in the fabric accords with the values of snarling tendency in the yarn as already shown in Fig.3.26. All the yarns were given steam treatment before knitting. As viscose and cotton yarn can't be steam set, hence even after steaming treatment given to the yarns, the viscose and cotton knitted fabrics are showing higher values of skewness.

Fig.3.48 Weight/m² of silk-polyester fabrics. Fig.3.49 Weight/m² of silk-viscose fabrics.

Weight/m² of the fabric is depicted in Fig.3.48 and 3.49. It is combined effect of stitch density, stitch length and yarn linear density.

Fig.3.50 Fabric bulk of silk-polyester fabrics. Fig.3.51 Fabric bulk of silk-viscose fabrics.
Fabric bulk, which is ratio of thickness and weight/sq. metre of the fabric, is shown in Fig.3.50 and 3.51. Fabric bulk of all silk-polyester and silk-viscose fabrics lies within a range of 3 and 3.5.

### 3.4.4.2 Wet relaxed fabric

The properties of single jersey wet relaxed silk-polyester and silk-viscose wefts knitted fabrics are shown in Table 3.12 and Table 3.13 in the appendix. These tables reveal that shrinkage has taken place in all the fabrics. Shrinkage has taken place in length wise as well as in width wise direction. This is happening because tension has relieved along and across the fabric. During manufacturing, all knitted fabrics are in distorted stage. At the knitting stage, loop shape distortion takes place and machine factors like take-down tension and widhwise stretching play an important part in determining fabric deformation. Hence dimensional changes due to relaxation occur when the high internal fabric stresses are relieved.

The tension may be at the interlocking points in the fabric. Inter yarn friction obstruct the relaxation of the fabric in dry state. Wetting induces fibre swelling and relaxes strains permitting the units of the fabric to take up a strain free relaxed position, if it is free to do so. The process of relaxation has been found to cause reduction in inter fibre friction and thus allowing the longitudinal stresses and strains to die away as the yarn is more free to move because of reduced inter yarn friction. The initial attack of the water molecules is on cross over points of the loops which provides a lubricating action and thus reducing inter-yarn friction considerably. The polar water molecules enter the inter stitches and causing the yarns to swell and to contract in the other direction. When the yarn in a fabric is swollen, the increased diameter of the yarn makes it impossible to keep same loop shape. The shape of the loop changes so that large swollen diameters can be accommodated.

It is further observed from Table.3.12 that shrinkage in cotton knits is greater than silk and polyester fabrics. Polyester fabric exhibits minimum shrinkage after wet relaxation. The slight shrinkage in 100% polyester fabric
may be due to relieving of take-down tension applied during knitting. The shrinkage goes on increasing with increasing proportion of silk in the blend.

It is clear from Table 3.13 that all viscose knitted fabric has undergone more relaxation shrinkage that all silk and cotton knitted fabrics. Shrinkage of knitted fabric is determined by a number of factors, such as fibre characteristics, machine gauge, yarn twist, knitting tension and washing method. As all the factors are same for all the fabrics, except fibre characteristics, hence this trend may be due to hydrophilic nature of silk, viscose and cotton fibres.

Further lengthwise shrinkage is greater than widthwise shrinkage for all the fabrics studied. The forces exerted by take down mechanism have a significant effect on shrinkage of fabric. The shrinkage of wet relaxed fabric depends on processing and knitting variables and in particular on take down tension. Higher take down tension during knitting leads to more length shrinkage after relaxation. Hence this trend may also be due to higher take-up tension kept during knitting for all the samples. Further relaxation appears to have occurred more readily at apex of the loop than at the sides. On relaxation the knitted loops become narrower as the fabric shrinks in area. The loop apex should relax more easily than the sides of the loop, seems reasonable since less fibre-fibre friction is involved upon distortion of the apex.

Due to shrinkage in the knitted fabric after wet relaxation, the values of course/cm and wales/cm have increased for both types of blends as shown in Fig.3.32, 3.33, 3.34 and 3.35. The increase is more prominent in case of viscose majority blends. Increase in values is proportional to the amount of shrinkage in the fabric.

In general values of stitch density have also increased after wet relaxation in comparison to dry relaxed fabric. Stitch length of all the fabrics has reduced after wet relaxation. Natural shape of the knitted loop is determined by minimum energy conditions that the loop tends to this state on relaxation. To accommodate the large swollen diameter of the yarn, loop length diminishes after wet relaxation. Due to increase in value of course/cm and wales/cm,
values of $K_c$, $K_w$ and $K_s$ have increased after wet relaxation as shown in Table 3.12 and 3.13 in the appendix.

Shrinkage in the fabric is accompanied by change in shape of the loops, hence values of loop shape factor have increased in comparison to dry relaxed fabric (Fig.3.40 and 3.41). Loop shape factor is the measure of the ratio of width to length of the loop. This ratio is critically affected by fabric distortion, since such distortion causes an increase of a parameter with corresponding decrement in the other.

In general values of tightness factor have increased due to reduction in value of loop length as shown in Fig.3.42 and 3.43. Thickness of all the fabrics has increased after wet relaxation (Fig.3.44 and 3.45). This is because of the fact that shrinkage induces swelling in the yarn which causes the cross over points to contract resulting in bringing the loops closer. It leads loop-intermeshing angle to reduce in vertical direction and to increase in horizontal direction thus resulting in more thickness values. Slight increase in thickness is also observed in case of polyester fabric. Due to stresses imposed during knitting, slight shrinkage is observed in polyester fabric, this may have caused increase in thickness of polyester fabric.

It is clear from Fig.3.46 and 3.47 that angle of spirality has increased after wet relaxation in case of silk-polyester blends as well as in silk-viscose blends. Dry relaxed fabric is not able to attain minimum energy state as the freedom of loop movement is restricted due to yarn to yarn friction. During wet relaxation, yarn to yarn movement is eased due to reduction in yarn to yarn friction and hence an increase in skewness value is observed in all the fabrics.

Weight/m$^2$ of the fabrics has increased after wet relaxation according to the areawise shrinkage in the fabrics. It is further noticed from Fig.3.50 and 3.51 that fabric bulk has increased after wet relaxation. This is due to yarn swelling and increased thickness of fabric after wet relaxation.

3.4.4.3 Fully relaxed fabric

Properties of single jersey weft knitted fully relaxed fabrics are shown in Table 3.14 and 3.15 in the appendix. It has been noted from both the Tables
that full relaxation has caused slightly more shrinkage than after wet relaxation, in both lengthwise and widthwise direction. The logical explanation for this is the lack of vigorous agitation action in wet relaxation treatment.

In case of full relaxation, during tumble drying, the water molecules which are randomly distributed, get an opportunity to attack the inter yarn spacing at various places in the fabric and the extent of inter yarn lubrication increases quantitatively. The vigorous shaking action results in very chaotic situation accompanied by more inter yarn lubrication and hence more shrinkage in the fabric.

On the other hand during wet relaxation, vigorous shaking effect is absent and the results in more or less comparatively gentle treatment leading to lower values of shrinkage. In comparison to dry relaxed fabric, values of course/cm, wales/cm and stitch density have increased after full relaxation. Stitch length has also reduced further due to yarn swelling in case of silk-polyester and silk-viscose blended fabrics. It is observed from Table 3.15 that shrinkage of 100% viscose fabric is considerably greater than silk and cotton fabric. The shrinkage of all silk-viscose blended fabric is also greater than equivalent cotton and silk fabric. Due to higher shrinkage, the increase in values of course/cm, wales/cm and stitch density is greater in case of viscose rich blends.

Due to change in shape of the loops, loop shape factor has increased after full relaxation (Fig. 3.40 and 3.41). Dimensional changes of the fully relaxed state are largely due to changes in loop shape.

Tightness factor has also increased due to reduction in values of stitch length (Fig.3.42 and 3.43). Yarn swelling and decreased stitch length has caused increase in thickness of silk-polyester blended fabric. In comparison to dry relaxed fabric, thickness of all the fabrics have increased but this increase is less as compared to after wet relaxation. This may be due to tumble drying of the samples at 70°C whereas the samples are dried in standard atmospheric conditions after wet relaxation.
After full relaxation, the increase in skewness is greater than after wet relaxation (Fig. 3.46 and 3.47). Due to tumble drying, the reduction in yarn to yarn friction is greater than during wet relaxation, hence increase in skewness is comparatively more than after wet relaxation.

Weight/m² of all the fabrics has increased after full relaxation. The increase in weight is proportional to areawise shrinkage of the fabric. Fabric bulk has also increased after full relaxation. The increase in values of fabric bulk is proportional to increase in the thickness of the fabric.

3.4.5 Comfort Properties

3.4.5.1 Moisture transfer properties

Moisture transfer properties of silk-polyester blended fabrics are compared with cotton fabric of equivalent construction in Table 3.16.

<table>
<thead>
<tr>
<th>Table 3.16 Moisture transport properties of silk-polyester blended fabrics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td><strong>1. Wicking test</strong></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><strong>2. Water vapour transfer</strong></td>
</tr>
<tr>
<td>(gm)</td>
</tr>
<tr>
<td><strong>3. Total absorbency %</strong></td>
</tr>
</tbody>
</table>

(Figures in parenthesis represent CV %)

Wicking rate depends upon fibre characteristic, yarn structure (the separation between the fibres in the yarn) and fabric structure. In this study, all the yarns are ring-spun with same twist and all are single jersey fabrics, hence wicking behavior will depend upon fibre characteristic and fibre porosity. The better is wicking ability of the fabric, faster is the liquid water transferred through fabric resulting in uniform moisture distribution of the fabric. Table 3.16 reveals
that rate of increase of wicking height is slow in the start in case of cotton fabric whereas all polyester fabric displays very fast wicking properties. Wickability of the fabrics is in the order of cotton, polyester and silk. Higher wickability in the fabric is supposed to facilitate the transfer of perspiration through the fabric quickly. Rate of wicking is slow in the start for fabrics made from hygroscopic fibres as it takes more time to absorb the water. Hence the slow rise of water in the start for the cotton fabric may be attributed to absorption of the moisture by cotton fabric and swelling of fibres. Fabric made of manmade fibres wicks more quickly due to their hydrophobic nature. Further, all the fabric testing was done in unfinished stage (no scouring, bleaching etc.), hence the presence of layer of wax on the surface of cotton fibre, prevents fast rise of water on the surface of fabric hence lower rate of wicking was observed in case of cotton fabric.

Drop absorption time or spot test is a simulation of the condition of the absorption of a drop of liquid sweat by the fabric. This property also depends upon wickability of fabric. It is observed from Table 3.16 that polyester fabric display instant disappearance of spot whereas cotton fabric takes maximum time for this. Polyester fabric transports the drop instantly whereas silk and cotton fabric take more time due to time consumed in absorption, swelling of fibre and unfinished nature of the fabrics.

Water vapour transfer mainly depends upon air permeability of the fabric and represents the ability to transfer perspiration coming out of the skin. In this study the polyester fabric has maximum ability to transfer the moisture whereas cotton has the least. These results are showing the same trend as shown previously by air permeability of the fabrics in Table 3.8 in the appendix.

Total absorbency depends on the air proportion available within the fabric and is a measure of sweat holding capacity of the fabric. This property is especially useful for sportswear. Cotton fabric exhibits maximum sweat holding capacity followed by silk and polyester knitted fabric. It implies that although wicking rate of cotton is slow in the start, but total absorbency is maximum. Silk fabric has good wickability, water vapour transfer ability and total absorbency.
Moisture transport properties of silk-viscose blended fabrics are shown in Table 3.17. The results given in Table 3.17 show that wickability of all viscose fabric is greater than cotton and silk fabric. It is also apparent that wicking rate is faster in case of viscose fabric. In general, faster wicking rate promote quick drying and faster cooling in the hot environment.

Table 3.17 clearly indicates that drop absorption time of 100% viscose fabric is much less than 100% silk and cotton fabric. It indicates quick absorption of drops of liquid sweat by viscose fabric. Drop absorption time increase with increase in silk content in the blend.

<table>
<thead>
<tr>
<th>1. Wicking test</th>
<th>Viscose</th>
<th>V8S2</th>
<th>V6S4</th>
<th>V4S6</th>
<th>V2S8</th>
<th>Silk</th>
<th>Cotton</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Wicking height (cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 sec.</td>
<td>1.5</td>
<td>1.25</td>
<td>1.1</td>
<td>0.8</td>
<td>0.6</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>5 min</td>
<td>6.0</td>
<td>5.5</td>
<td>5.1</td>
<td>4.8</td>
<td>4.4</td>
<td>3.0</td>
<td>3.2</td>
</tr>
<tr>
<td>15 min</td>
<td>7.6</td>
<td>7.5</td>
<td>7.1</td>
<td>6.9</td>
<td>6.5</td>
<td>6.1</td>
<td>6.8</td>
</tr>
<tr>
<td>Wickability</td>
<td>13.42</td>
<td>11.45</td>
<td>10.34</td>
<td>8.25</td>
<td>6.86</td>
<td>5.56</td>
<td>8.86</td>
</tr>
<tr>
<td>(b) Spot Test (sec)</td>
<td>1.1</td>
<td>1.21</td>
<td>4.2</td>
<td>15.4</td>
<td>21.5</td>
<td>44.5</td>
<td>160</td>
</tr>
<tr>
<td>2. Water vapour transfer (gm)</td>
<td>9.51</td>
<td>9.05</td>
<td>8.83</td>
<td>8.43</td>
<td>8.14</td>
<td>8.34</td>
<td>7.72</td>
</tr>
<tr>
<td>3. Total absorbency %</td>
<td>3.33</td>
<td>3.25</td>
<td>3.24</td>
<td>3.28</td>
<td>3.11</td>
<td>3.13</td>
<td>4.21</td>
</tr>
</tbody>
</table>

(Figures in parenthesis represent CV %)

Water vapour transfer is an important parameter in determining comfort of the fabric, as it represents ability to transfer perspiration coming out of the skin. Table 3.17 shows viscose rich blends are able to transfer more water vapours through the fabric. This trend may be ascribed to the better air permeability of the viscose fabric as already observed in Table 3.9 in the appendix.

It is noted from Table 3.17 that total absorbency of viscose fabric is slightly greater than silk fabric but lesser than cotton fabric. Total absorbency indicates liquid sweat holding capacity of the fabric.
Viscose fabric represents faster wicking action, good ability to transfer water vapours and slightly more total absorbency than silk fabric.

3.4.5.2 Low stress mechanical properties

Low stress mechanical properties of 100% silk, polyester, viscose and cotton knitted fabrics were evaluated. Due to financial constraints, Kawabata evaluation of blends was not performed and it was limited to only 100% silk, polyester, viscose and cotton knitted fabric for outerwear purpose.

3.4.5.2.1 Tensile properties

From Table 3.18 it is evident that cotton fabric is exhibiting maximum value of mean tensile elongation (EM) followed by silk, viscose and polyester fabrics. Elongation in coursewise (widthwise) direction is also greater than walewise (lengthwise) direction in all four fabrics studied.

EM indicates low stress extensibility. This extensibility is related to ease of crimp removal which depends upon mobility of threads within the fabric. It may be mentioned here that a larger value of EM in walewise direction causes problems in tailoring due to distortion of fabric during sewing whereas higher EM in coursewise direction is favorable as it provides wearing comfort.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Strain at 500 gf/cm² of tensile load (EM)</th>
<th>Linearity of load-extension curve (LT)</th>
<th>Tensile energy (gf/cm²) (WT)</th>
<th>Tensile resilience (RT) %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wale Mean</td>
<td>Course Mean</td>
<td>Wale Mean</td>
<td>Course Mean</td>
</tr>
<tr>
<td>Polyester</td>
<td>14.8</td>
<td>30.6</td>
<td>22.7</td>
<td>0.77</td>
</tr>
<tr>
<td>Viscose</td>
<td>16.2</td>
<td>33.1</td>
<td>24.7</td>
<td>0.79</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 3.18 a higher value of linearity (LT) is observed in case of viscose and polyester fabric as compared to silk and cotton fabric. The higher value of LT in case of viscose and polyester knitted fabric indicates relatively inextensible nature of viscose and polyester fabric in comparison to cotton and silk fabrics. The linearity of tensile property (LT) affects the fabric extensibility in...
the initial strain region. Generally, relatively inextensible fabrics have highest value of tensile linearity in the region 0.8-0.9, whereas most extensible fabrics have the lowest value in the region 0.5-0.6.

Table 3.18 reveals that tensile energy per unit area (WT) for polyester, viscose and silk fabric is lower than cotton fabric. WT represents area under load elongation curve. Tensile resilience (RT) of polyester, viscose and silk fabrics is better than cotton fabric. It indicates good recovery properties of polyester, silk and viscose fabrics at low stress levels.

3.4.5.2.2 Bending properties

Table 3.19 reveals that polyester and silk fabric exhibit higher values of mean bending stiffness (B) than viscose and cotton fabric. It implies that resistance offered when bent by external force is higher in case of polyester and silk fabrics due to lower mobility of the threads within the fabric.

The hysteresis of bending moment (2HB) also shows the same trend as shown by bending rigidity and it is a measure of recovery from bending deformation.

<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>gfcm$^2$/cm</td>
<td>gfc/cm</td>
</tr>
<tr>
<td>Wale</td>
<td>Course</td>
<td>Mean</td>
</tr>
<tr>
<td>Polyester</td>
<td>0.1305</td>
<td>0.0392</td>
</tr>
<tr>
<td>Viscose</td>
<td>0.0491</td>
<td>0.0764</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>

3.4.5.2.3 Shear properties

It is evident from Table 3.20 that shear stiffness (G) of silk fabric is lesser than polyester and viscose fabrics. A highest value of shear deformation is observed in case of polyester fabric followed by viscose, silk and cotton fabric. The same trend is observed for hysteresis of shear force. Hysteresis of shear force (2HG at 0.5° and 2HG5 at 5°) represents elasticity of shear deformation. A lower value of shear hysteresis implies good recovery from shear deformation.
Table 3.20 – Shear properties

<table>
<thead>
<tr>
<th>Sample</th>
<th>Shear stiffness (G)</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>Polyester</td>
<td>0.8134</td>
<td>0.7987</td>
<td>0.8060</td>
</tr>
<tr>
<td>Viscose</td>
<td>0.5856</td>
<td>0.7521</td>
<td>0.6688</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>

3.4.5.2.4 Surface properties

Surface properties of the knitted fabrics are mentioned in Table 3.21. It is observed that coefficient of friction (MIU) is minimum for silk fabric. This is due to smooth surface of the silk fabric in comparison to other fabrics. Coefficient of friction depends upon contact area of the contactor with the fabric. Mean deviation of MIU (MMD) and geometrical roughness is also least for silk fabric.

Table 3.21 – 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>Polyester</td>
<td>0.2597</td>
<td>0.2347</td>
<td>0.2472</td>
</tr>
<tr>
<td>Viscose</td>
<td>0.2523</td>
<td>0.2675</td>
<td>0.2599</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>

3.4.5.2.5 Compression properties

The results of the compression properties are shown in Table 3.22. The values of linearity of compression (LC) are lower for silk fabrics in comparison to other fabrics. Linearity of compression depends upon shape of pressure thickness curve. The values of compressional energy (WC) is also lower for silk and viscose fabrics.
Compressional resilience (RC) of silk fabric is better than all other fabrics studied. Compressional resilience indicates elasticity of compressional deformation. A higher value of RC reflects good recovery properties. Silk possesses highest value of RC followed by polyester, viscose and silk fabric.

Table 3.22 - Compressional properties

<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>Polyester</td>
<td>0.320</td>
<td>0.470</td>
<td>57.68</td>
<td>1.20</td>
<td>13.85</td>
</tr>
<tr>
<td>Viscose</td>
<td>0.262</td>
<td>0.365</td>
<td>56.23</td>
<td>1.15</td>
<td>14.72</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>

3.4.5.2.6 Thickness and Weight

Thickness of cotton fabric is found to be greater than all other fabrics as shown in Table 3.22. This may be due to greater yarn diameter in case of cotton yarn. The variation in weight of fabrics may be due to count variation.

3.4.5.2.7 Fabric hand

Fabric hand is based on the end use of the fabric and accordingly primary hand expressions are selected. The knitted fabrics were evaluated on the Kawabata evaluation system for outerwear. Koshi, Numeri and Fukurami are three primary hand expressions for outerwear fabrics. The results of the primary hand values of the knitted fabrics are given in Table 3.23.

Fig.3.52 illustrates the profile of the hand values for the knitted fabrics. Since four different properties are to be compared, for ease of comparison, four radially projecting lines have been drawn from a common origin. An outer circle with an arbitrary radius is drawn from the origin, each representing a parameter as shown in Fig.3.52. Since the units of different properties are different, to normalize them, the scale for the values was chosen in such a way that whole range of parameters is covered for all types of knitted fabrics studied. Such a plot results in a property profile which can be easily visualised for comparison purposes.
Table 3.23 Hand Values for single jersey knitted outerwear fabrics.

<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>Polyester</td>
<td>2.20</td>
<td>6.38</td>
<td>6.29</td>
<td>3.16</td>
</tr>
<tr>
<td>Viscose</td>
<td>1.03</td>
<td>5.87</td>
<td>5.23</td>
<td>2.33</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>

It may be observed from the Table 3.23 that Koshi value for polyester fabric is highest, followed by silk, viscose and cotton fabric. Koshi is a feeling related with bending stiffness. Springy property promotes this feeling. Further high value of Numeri (smoothness) is observed for silk fabric. Numeri is a mixed feeling which comes from smooth, limber and soft feeling. The Numeri value indicates maximum smoothness in case of silk fabric followed by cotton, polyester and viscose.

Fukurami (fullness and softness) of silk and polyester fabric is greater than cotton and viscose fabric. Fukurami is a feeling which comes from bulky, rich and well formed feeling. It is related to the springy property in compression and thickness accompanied with warm feeling. Fukurami values are least in case of viscose knitted fabrics.
It is evident from the Table 3.23 that total hand value of silk knitted fabric is maximum and viscose is minimum. The degree of "good" hand is expressed by the Total Hand Value (THV). THV of polyester knitted fabric is also greater than cotton fabric. It implies that silk fabrics are more suitable for outerwear purpose than polyester, viscose and cotton fabric.
3.5 CONCLUSION

It is possible to produce 100% silk, silk-polyester and silk-viscose blended yarns on cotton spinning system. 100% silk yarn has maximum tenacity and it reduces with the addition of polyester and viscose fibre. All the yarns produced have sufficient strength, elongation at break, good evenness value and fulfills all other properties required for knitting operation. Another significant finding is that silk knitted fabric can be produced on the same knitting machine on which cotton knitted fabric are produced keeping the same settings.

The silk knitted fabric has excellent abrasion resistance and bursting strength. Test results have shown that total hand value of silk knitted fabric is greater than equivalent polyester, viscose and cotton knitted fabric. All these results suggest that silk and silk-polyester blended knits are ideally suited for apparel as well as for upholstery purpose.

Silk-viscose blended fabrics having silk content more than 40% are having good abrasion resistance, bursting strength, moisture regain values. Moisture transport properties of these fabrics are also better than silk fabric. In short comfortable, luxurious and durable knits in all spheres of garment making can be produced by addition of silk to viscose fibre.