CHAPTER 2

LITERATURE REVIEW.
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Lot of research has been done in the various fields of silk, but most of the research is concentrated on mechanism of fibre formation by silk worms [1,2], drying of silk cocoons [3], silk reeling and disposal of reeling waste [4,5], characterisation of silk fibre in terms of cross sectional shapes [6,7] and properties [8], dyeing of silk yarn [9] and fabrics [10], by-products and wastes of silk industry [11], degumming of silk waste [12] and fabric [13], effect of various parameters on degumming [14,15,16] and comparative study of various methods of degumming [17].

Some information is available on silk blending, properties of silk blended yarns and fabrics. The information reported has been divided into three parts-different production techniques used, properties of silk and silk blended yarns and properties of silk and silk blended fabrics.

2.1 Silk and Silk Blended Yarns and Fabrics

2.1.1 Different Production Techniques Used for Producing Silk and Silk Blended Yarns

Various technologies used to produce silk blended yarns are worsted spinning system [18], waste silk processing [22,23], charkha spinning [19], ring-spinning system [20] and chemical bonding [24].

Normal tenacity 2 denier polyester fibre having variable cut length 70-120 mm was blended with waste silk of 1 denier and 47 mm mean fibre length in various proportions, 85:15, 70:30 and 50:50 polyester/silk [18]. Blending was done by giving five passages of gilling. Yarns of 53 Nm were spun on regular worsted spinning machines.

Tasar silk waste was first degummed following soap soda method [19]. After thorough drying, the silk waste was hand opened to facilitate processing. The degummed tasar silk waste was blended with 1.5 denier normal tenacity polyester fibre having variable cut length of 38mm. Polyester was first processed on the fine fillet opener. Degummed Tasar silk waste was also processed on coarse fillet opener. Blending was done on the coarse fillet where the lap of polyester fibre was kept in between two layers of tasar silk waste lap. The lap weight was varied according to the blend proportion required. This lap was processed once on coarse fillet and
twice on the fine fillets for more uniformity. The lap processed from the fine fillet was processed thrice on the drawing machine. The drawn slivers were fed to Amber charkha with 6 spindles.

Polyester fibre (51mm, 1.5 denier) was blended with silk fibre (51mm, 4 denier) in various blend proportions 65:35, 70:30, 75:25 and 80:20 to produce four sets of yarns of 14.76 tex at various twist levels [20]. Both components were hand opened and sandwiched well for homogenous blend. The multi-layered fibre material was carded twice and carded slivers were drawn twice on drawframe. After preparing roving on simplex, yarns were spun on ringframe.

The tasar silk waste was degummed using soap and soda method [21]. The degummed silk waste was opened manually and then blended with polyester staple of 51 mm and 1.4 denier, viscose staple fibre having variable cut length of 51 mm and 1.5 denier and acrylic staple fibre of 61 mm and 2 denier. The degummed hand-opened tasar silk waste was first processed on coarse fillet opener for making the fibres parallel in the lap. Blending with second fibre was done on the fine fillet opener. The lap from fine fillet was processed thrice on drawing machine. The slivers were then set for spinning in the 6 spindles charkha.

Muga and eri wastes of 5.3 denier and 6.0 denier respectively were blended with normal tenacity polyester of 3.0 denier having variable cut length (90-120mm) [22]. Blending was done at the carding stage in the proportion of 60/40 and 50/50 polyester/ silk respectively and yarns were spun on spun-silk spinning machines.

Mulberry silk waste was blended in 50:50 proportion with polyester staple fibre having a cut length of 51mm and 1.4 denier, viscose rayon staple fibre having a cut length of 51mm and 1.5 denier and acrylic staple fibre of 61mm and 2.0 denier [23]. Processing, blending and spinning operations were carried out at the Waste silk project KVIC, Bangalore. Yarns of 30⁹ count were spun on six-spindle charkha.

The technique of chemically bonding silk protein to polyester was developed to produce water-absorbing polyester "Wellkey MA" [24]. "Wellkey" is a hollow fibre, which has micro voids on the fibre sides. Some of the micro-voids are connected to the hollow portion. For this reason, it
absorbs perspiration through the micro-voids to the hollow portion and releases it to the outside by capillary action. The silk protein used for “Wellkey MA” is sericin extracted from the scouring process of silk fabrics.

2.1.2 Properties of Silk and Silk Blended Yarns

It has been seen in previous section that in most of the cases silk blended yarns have been manufactured from waste silk or coarse denier silk fibre, hence the yarn formed had higher value of unevenness and neps.

Polyester silk blended yarns produced on worsted spinning machines had very good U % values [18]. Neps per 100m of the yarn increased with the increase of silk in blend. This high number of neps was due to silk waste used in the study. The same trend was observed for imperfections also. It was found that high number of neps could be brought down by careful selection of silk and choosing right process parameters like pin density in gill intersecting.

Silk blended yarns spun from higher proportion of polyester fibres were found to be stronger, more extensible and have fewer imperfections [20]. U% values showed an increase in yarn evenness with increase in proportion of polyester fibre. The higher U % value of silk rich yarns was attributed to inappropriate length/denier ratio of silk fibres. Yarns spun from higher silk content registered lower abrasion resistance, the later however increases with increase in twist.

For tasar silk waste yarns blended with polyester viscose and acrylic fibre in 50/50 proportion, it was observed that tasar silk waste/polyester had the highest tenacity followed by silk/viscose blend [21]. 100 % tasar silk waste recorded least tenacity. Tasar silk waste/viscose blend had highest yarn elongation.

Blends of muga and eri silk waste with polyester were prepared [22]. The 60/40 polyester/eri-silk blends were having maximum tenacity 4.0 g/d and maximum value of elongation at break 10.5 %. Unevenness value was 17 %.

Mulberry silk waste was blended with polyester, viscose and acrylic in 50/50 proportion and compared with 100 % silk waste yarn [23]. The maximum tenacity was observed in case of 100% silk waste yarn 1.59 g/d,
followed by silk/polyester 1.38 g/den, silk/viscose 1.36 g/den and silk/acrylic 1.21 g/den. The silk/viscose yarn exhibited maximum elongation at break 8.6% followed by silk/polyester 8.18 %, 100 % silk 7.5 % and silk/acrylic 7.4 %.

2.1.3 Silk and Silk Blended Fabrics

Pure silk and silk blended fabrics can be classified in two groups: woven and knitted fabrics.

2.1.3.1 Silk and Silk Blended Woven Fabrics

Plain fabrics were woven from 2/53\textsuperscript{s} N\textsubscript{m} polyester/waste silk blended yarn with 50\textsuperscript{s} reed and 48 picks [18]. Then tensile strength, abrasion resistance and elongation of the fabric reduced gradually as the percentage of silk increased in the blend. Appearance of all the fabrics was also neppy due to presence of waste silk in the blends. It has been further concluded that in overall performance the 70:30 polyester/silk blended fabric exhibited all desirable properties [25].

Tasar silk waste/polyester blended yarns were woven on an ordinary treadle loom to produce plain weave fabrics using the same yarn in warp and weft [26]. The addition of polyester resulted in marked increase in the tensile strength of the fabrics. The appearance of the blended fabrics was mainly hampered by the coarse count and unevenness of the yarn. Among the five blends levels studied the 50:50 tasar silk waste/polyester blended fabrics was found to be optimum.

Fabric sample were woven from tasar silk waste yarn and its blends with polyester, viscose and acrylic yarn on ordinary loom [21]. 50/50 Tasar silk waste/polyester fabric recorded highest tensile strength while 100% tasar silk waste recorded lowest tensile strength. Based on the weightage of the ranks received in laboratory testing, 50/50 tasar silk waste/polyester blended fabric was found to possess a harmonious balance in appearance, general characteristics and serviceability among the four test fabrics.

Plain fabrics were woven on fly shuttle loom from blends of muga and eri silk waste with polyester [22]. As the percentage of polyester increased in blends the breaking strength, abrasion resistance and breaking elongation of the fabrics increased. Since the silk used for the study was waste silk, the surface of the fabric was not even.
Plain weave fabrics were prepared from 100% mulberry silk waste yarn and its 50/50 blends with polyester, viscose and acrylic fibre [23]. The tensile strength and tear strength were found to be highest for 100% mulberry silk waste fabric. Abrasion resistance was minimum for 100% silk waste fabric due to presence of more number of nepes in the fabric. Considering all the characteristics evaluated, 50/50 mulberry silk waste/polyester fabric was found to be best on the basis of its durability, appearance and general properties.

Silk fabrics woven from twistless continuous filaments yarns in both warp and weft are compared with fabrics of same structure made from polyester; rayon, acetate and nylon yarns [27]. The tensile, bending, shear, compressional and surface properties of continuous filament woven silk fabrics were measured by KESF system. In the small strain region of compression and tensile deformation, silk fabrics were readily deformed as compared to other fabrics. Shear stiffness and hysteresis of shear force of silk fabrics were extremely small.

Low values of shear stiffness and hysteresis of shear force in woven silk fabrics are due to presence of gap between the warp and weft thread at their crossover points [28]. The existence of a gap between the warp and weft threads has been proved by shear-biaxial extension theory and experimentation on silk fabrics.

Woven fabrics made from twistless continuous filament silk fabrics show a low tensile modulus in the small-load region compared with fabrics made from polyester and silk-like polyester filaments yarns [29]. It has been found that tensile behaviour of a silk fabric consists of two stages. In the first stage only the bent thread is stretched and the extensibility of a silk fabric in this stage depends on yarn bending rigidity and weave crimp. In the second stage, the tensile property of the fabric depends on yarn tensile, bending and lateral compression properties.

The soiling and soil release behavior of silk fabric was studied [30]. Silk fabric was of mulberry origin. It was degummed before use. The results obtained have been compared with those for cotton and polyester fabrics of nearly the same construction. It is observed that maximum soiling takes...
place in polyester followed by cotton and silk fabric whereas soil release behaviour of silk fabric is maximum followed by cotton and polyester.

The technology of objective fabric measurement has been applied to pure silk fabrics of different qualities, such as paz, habotai, georgette, crepe de chine, crepe satin and silk twill [31]. The instrumentally measured properties of the finished silk fabrics are discussed in terms of fabric weight, thickness, tensile properties, shear, bending, compression, surface friction and surface geometry. The mean values and the range of these low-stress mechanical and surface properties for finished pure silk fabrics are reported. Using this data, the quality characteristics of finished silk fabrics have been evaluated objectively and compared with those of other textile materials. The measurements initiate what could be an important database for the objective evaluation of finished pure silk fabrics.

The value addition at various stages, during manufacturing of silk fabric was studied [32]. In the process of production of silk cocoons and converting these cocoons to fabrics by different intermediaries, a certain amount of value addition is involved at each stage. A study was conducted for evaluating the value addition, in the process of production of soft silk fabrics. The value addition included in the production of 10 m soft silk fabric weighing 60 g/m was worked out. It has been observed that labour was the major factor, which contributed 52.6% towards value addition followed by chemicals 14.5%, electricity and fuel 12.6%. Investment contributed to the extent of 10.7%. Transport is also an important factor in silk industry, which contributes 5.6% of the total value addition in silk industry.

Wicking behavior of six different types of fabrics—silk/polyester, viscose, polyester, acrylic, cotton/polyester and viscose/polyester blended fabrics have been studied [33]. Acrylic fabrics showed maximum wicking behavior and polyester fabric minimum wicking behavior among all the test fabrics. From the study, it can also be pointed out that better the wicking behavior, better will be the skin comfort to the wearer, dyeability, dimensional stability and less static build-up possibility in the fabric.

The effect of the amount of twist in yarn on the characteristics of silk fabrics has been studied [34]. The optimum level of twist, to get the desirable properties in the fabrics was also found out. The fabric at this
optimum twist level produces excellent crepe effect while retaining its luster, feel and smoothness. The fabric has better cover. The width shrinkage is also within tolerable limits of 10-12%. The weft way finished fabric strip strength is maximum at this level of twist.

The characteristics and uses of various Indian crepe silk fabrics have been described [35]. Crepe fabrics are characterized by a pebbly or crinkled surface. The construction particulars of commercial crepe silk fabrics were described.

A comparative study of the physical properties of mulberry and tussar silk fabric has been made [36]. Tassar silk fabric shows higher bending length, flexural rigidity and elongation but lower tearing strength as compared to mulberry silk fabrics. It was observed that mulberry silk fabrics have greater tenacity, better draping behaviour, lower bending length and greater crease recovery.

The comfort properties of mulberry and tussar silk fabrics have been reported [37]. The tensile, bending, shearing, compressional and surface properties of mulberry and tussar silk fabrics have been studied to investigate their hand values. Using the data obtained, the quality characteristics of mulberry and tussar silk fabrics have been objectively evaluated and then compared. It is observed that mulberry silk fabric is better in terms of shear stiffness, bending rigidity, geometrical roughness, hand values and draping behavior but possesses lower compressional resilience as compared to tussar silk fabric.

2.1.3.2 Silk and Silk Blended Knitted Fabrics

Many trials have been taken to produce silk knitted fabric but most of the researchers tried to produce silk knitted fabrics either from undegummed filament silk or degummed filament silk.

The gummed filament silk has too little elasticity for knitting; its tenacity is also insufficient [38]. Knitting with classical latch needle knitting machine requires a higher elasticity and higher tenacity for loop forming process on bearded needles. Hence the trials on these machines were unsuccessful. Many trials were taken on circular latch needle knitting machines and loop wheel knitting machine. The significant result is that
Waga GLS loop wheel machine, a special model for filament silk has given the best results in manufacture of silk single jersey.

Silk and silk blended weft knits were developed from samples of silk yarns of different denier and twist levels in the raw and degummed states [39]. The performance of these yarns was studied and the yarns were subjectively evaluated by knitting experts to record their preference. A number of knitted structures like single jersey, double jersey, interlock, pique and jacquard fabrics were made. These knitted fabrics were tested for structural and functional parameters. Both degummed and raw yarns performed well during knitting. It was observed that in spite of being light and sheer, these silk knits are comfortable, luxurious and durable. The abrasion resistance, pilling resistance and hard wearing properties combined with the much needed luxury, make these silk knits ideally suited for upholstery.

Dimensional changes in knitted silk and cotton fabrics with laundering have been studied [40]. Deformation by laundering is investigated for single jersey and rib flat knit silk and cotton fabrics with yarn of varying linear densities and fabric tightness. The fabrics are subjected to relaxation processes and an extended series of wash and tumble-dry cycles. Changes in dimensions are measured in every process and cycle. Statistical analysis of the experimental data reveal the effect of yarn type, linear density and tightness factor on the linear and area shrinkage behaviour of silk fabric as compared to cotton. Cotton shrinks more than silk and rib knits stretch excessively in width.

Knitting of single jersey silk fabrics using double-gassed spun silk yarn and filament silk were also studied [41]. The raw silk was subjected to winding process. After winding, doubling was carried by using 4 ply in Z direction. Twisting of 4 ply on imported twisting machine was carried out. After twisting the silk was twist set on steam ager at 102°C for 30 min. Then the material was subjected for rewinding followed by degumming under alkaline medium. After degumming the silk was washed, hydroextracted, dried and the silk skeins were subjected to bobbin winding followed by cone winding. These cones were used for knitting of silk fabric.
2.2 BULK SILK YARNS AND FABRICS

2.2.1 Different Production Techniques Used to Produce Bulk Silk Yarns

The phenomenon of bulking acrylic yarns by mixing shrinkable and non-shrinkable acrylic fibres and thereby creating the warmth in the fabric is known to most of the manufacturers and researchers. Lot of research has been done to study shrinkage phenomenon of acrylic fibres [42], properties of acrylic yarn after steaming [43,44], properties of acrylic plain knitted fabrics [45], dimensional stability of acrylic knit fabrics [46], possibility of using acrylic bulk yarns in weaving [47] and change in fabric properties thereafter [48].

For improving the bulk of silk fabric several production techniques have been used which are described below.

Silk noil with a mean staple length of 20mm and fineness of 9.5 µm was blended with 41.5 mm and 15 µm acrylic fibre [49]. The blend composition was 60/40 silk noil/acrylic. After hand mixing, the loose fibre stock was fed to a woolen card. The slubbings delivered were subsequently drafted on woolen ring frame.

A mechano-chemical batch process to improve the bulkiness of the tasar silk filament yarn has been reported [50]. Some important physical characteristics like stretching potential, strength, elongation, physical bulk and fineness were also studied. The tasar silk filaments were twisted in a ring frame and then treated with zinc chloride solution. After, washing they were dried with hot air drier. The samples were then treated with urea and formaldehyde, cured, washed with hot water and dried in oven. The dried, cured samples were then untwisted and converted into hank form. After keeping in boiling water, the hanks were finally squeezed and dried.

A composite yarn of silk and acrylic filament yarn was developed by mix-reeling technique [51]. Maruko Kogyo (Okaya city, Japan) together with Asahi Chemical Industry Co. Ltd. have developed a composite yarn of silk and "Pewlon" (acrylic filament yarn). For this yarn the acrylic filament is situated at the center and is covered with silk filaments. This yarn is produced by mix-reeling technique in raw silk reeling process. This
technique can produce the yarn in any blend and denier to match the application.

Bulk silk is prepared by special process [52]. For this purpose cocoons are boiled in silk bulking assistant agent SSW at low temperature. Silk fibre is then reeled and re-reeled at low tension. Silk fibre is then finally treated by assistant agent RST to preserve the fibre crimps.

Bulk stretch real silk has been obtained from raw silk by reprocessing [53]. Compared to normal silk it has excellent bulkiness, softness, remarkable elasticity and good recovery. Chinese researchers have not divulged the details of method to manufacture bulk stretch real silk.

2.2.2 Bulk Silk Yarn properties
Silk noil/acrylic 60/40 yarn of 145 tex was prepared on woollen spinning system [49]. The same acrylic fibre was also blended with 34 mm wool in same blend ratio to produce wool/acrylic yarn of same specification on the same set of machines. Owing to the difference in fibre properties between silk and wool the silk noil/acrylic yarn was found to be stronger, slimmer, less hairy and to have lower extension at break.

The properties of bulked tasar silk filaments have been studied [50]. The effect of twist level, temperature and concentration of zinc-chloride on stress-strain characteristics of bulked yarn have been studied. The drop in tenacity of the yarn was not very significant but higher reduction in tenacity was observed for treatment with higher concentration of zinc-chloride at higher temperature. The increase in denier of the yarn was due to relaxation shrinkage caused by swelling effect of zinc-chloride during chemical treatment. The conditions used for texturising tasar silk filaments do not affect the strength significantly but impart stretch characteristics to the yarn. The bulk developed in the yarn was almost three times higher than the original parent yarn.

Compared to ordinary silk, the bulk silk is different in many respects [52]. In comparison to ordinary silk the strength of bulk silk has reduced from 3.9 to 3.7 g/d whereas stretch % has increased from 22 to 23 %. Bulkiness % has increased from 4.8 to 10.2 %. The moisture percentage of
ordinary silk is 10.8 whereas bulk silk has 12.0 %. The sericin % of bulk silk is 25.8 % in comparison to 20.3 % of ordinary silk.

In comparison to soft silk yarn, the strength of bulk stretch real silk yarn has reduced from 2.9 cN/dtex to 2.3 cN/dtex, elastic elongation percentage has increased from 0.6 % to 31.2 % whereas elastic recovery percentage has reduced slightly from 78.3 to 77.3 % [53].

2.2.3 Bulk Silk Fabric Properties

Plain-knit fabric samples were produced from 60/40 silk noil/acrylic and wool/acrylic yarns corresponding to a tightness factor of 12.0 [49]. An area shrinkage of 8 % was observed in case of wool /acrylic fabric in comparison to 1.5% shrinkage in silk noil/acrylic fabric. The bursting strength of silk noil acrylic fabric is about 14 % greater than wool/acrylic fabric. Pilling does not seem a serious problem in either type of fabric. In the subjective assessment of handle, all judges agreed that silk/acrylic is inferior to wool/acrylic fabric due to inferior quality of silk/acrylic yarn.

2.3 SILK COVERED CORE-SPUN YARNS AND FABRICS

2.3.1 Different Production Techniques Used for Producing Silk Covered Core-spun Yarns

In the field of core-spun yarns and fabrics, most of the work has been done on cotton covered nylon core-spun yarn [54,55], cotton covered polyester core-spun yarn [56,57] and viscose covered nylon core-spun yarns [58,59]. Much work has been done to observe the effect of pretension [60,61], twist multiplier [62,63], sheath fibre characteristics [64] and doubling of core-spun yarns [65,66]. Few references are available regarding weaving of core-spun yarns [67,68] but there is not a single reference available regarding knitting of silk covered core-spun yarns and comfort properties of these fabrics. In the following section different production techniques used to produce silk covered core-spun yarns are described.

Silk wrapped polyester core yarns were produced on an improved pedal spinning wheel [69]. The degummed cocoon waste was opened by hand and fed manually to the spindle through the guide and the spindle was rotated by the pedal. The core-spun yarn was produced by feeding the
core polyester filament textured yarn (50 denier with 36 filaments) from a double-flanged bobbin along with the opened cocoon waste by hand.

Silk waste covered nylon core-spun yarn was prepared on ring-frame [70]. A nylon monofilament 15 denier as core and Bombyxmori silk waste (gin cut 28 mm) as sheath were used for spinning 30 tex (20° Ne) yarns. The sheath fibres were processed on traditional carded cotton system of spinning. The suitably constant tensioned filament from a disc type tensioning device through the porcelain guide was accurately positioned at the center of the drafted strand just behind the nip of front rollers of ring frame.

Throstle-spinning machine was used to produce throstle-spun-silk /raw-silk core-spun yarn [71]. The silk staple fibres used had a mean fibre length of 36.5 mm and formed the covering layer in the throstle-spun core-spun yarn. The continuous filament core yarn was a twisted raw silk yarn.

A new kind of composite core twin-spun silk yarn was made by combining two-production methods filament core and twin spinning [72]. This novel yarn was prepared by feeding two core yarns to two rovings. Hence it is called as double core twin-spun silk yarn. In this case two kinds of raw silk continuous filaments yarns were used for core yarn. Two types of roving, spun silk and cotton were kept separate by 20 mm by guides in the drafting zone of spun silk ring spinning frame. The continuous filament core yarns passed through each tension disc, inserted directly behind the front roller in the drafted strands by means of core yarn guides.

Silk covered polyester filament core yarn was developed on specially designed and fabricated machine [73]. The synthetic yarn acting as core yarn made entry from rear side of machine and is negatively driven due to pull of the take up roller. The synthetic yarn passes through two hollow spindles between the supply packages to the take up roller. Each of these spindles carries a small bobbin of silk yarn, which is positively driven and wraps around synthetic yarn passing through hollow spindle. Both the spindles were made to rotate in S and Z direction to achieve perfect covering.

Double core twin-spun yarn was made by inserting raw silk continuous filament core yarns in both spun silk and cotton strands [74].
Various types of twin-spun silk yarns were produced by changing the position of the core. When raw silk continuous filament was inserted in the spun silk strand only, this yarn was called silk-sided single core twin-spun yarn. When a core yarn was inserted in cotton strand only, this yarn was called cotton sided single core twin-spun yarn. When a core yarn was inserted periodically in both spun silk and cotton strands, this yarn was called migrated single core twin-spun yarn. When a core yarn was inserted in the middle position between both strands, this yarn was called centered single core twin-spun yarn.

In order to make a composite silk yarn using the throstle-spinning frame, the stuffing tube for raw materials was improved to form a silk skin layer in the core-spun yarn [75]. It was found that whenever the composite silk yarn was made using the throstle-spinning frame, it was essential to consider the type of core filament, the core tension and the weight position. The composite silk yarn was finer than the throstle silk yarn under the same spinning condition.

Four types of core yarn differing in proportion of silk noil and polyester were spun on a Dref-2 spinning machine [76]. The degummed silk noil was first processed once on the coarse fillet opener. The pre-opened material was next taken to the woollen carding system. The emerging web was converted into round twistless slubbing about 5.5 Ktex. The slubbings were blended with the polyester fibres on the Dref-2 spinning system. The polyester fibres used were processed on cotton carding and draw frame. The drawn slivers produced were almost of the same tex as the slubbing of the silk fibres and ready for spinning on Dref-2 machine. Polyester multifilament of 152 denier/32 filaments was used as a core. The silk noil and polyester were used as a sheath with silk fibres on the outermost layer and the polyester fibre were laid in between for spinning of 160 tex yarns in proportions of 75/25, 50/50, 25/75, 0/100 polyester/silk-noil respectively.

2.3.2 Silk Covered Core-Spun Yarn Properties

Silk wrapped polyester core yarn was produced on an improved pedal spinning wheel and compared with yarn spun from 100% silk waste [69]. The tenacity and elongation % of the core-spun yarn was 2.6 g/d and
19.5% in comparison to normal spun yarn 2.5g/d and 20.9%. Both count and twist CV% of the core-spun yarn was better as compared to normal spun yarn.

For silk covered polyester core yarn of 98.2 denier, produced from 28-32 denier silk filament and 30 denier 12 filaments polyester filament yarn, excessive breakage of degummed silk yarn was observed during the process of covering and weaving [73]. Therefore raw silk was used instead of degummed silk. It was seen that 20 denier monofilament polyester/silk covered yarn gave minimum resultant denier of 86.6 and highest elongation % at break of 19%.

The properties of the 100% silk sheath nylon core and 85/15 silk/viscose sheaths, nylon core yarn at various twist levels have been studied [77]. The effect of test specimen length and percentage contribution of core and sheath towards total yarn strength has also been studied. It has been found that percentage contribution of sheath fibres to total yarn strength increases with increase in twist density. The tenacity of yarn increases with the increase in twist density and also from lower strain rates to higher strain rates.

The hairiness of the silk covered nylon core-spun yarn was studied at different twist multipliers (TM) under the controlled pretension of the core and compared with that of equivalent silk ring spun yarns [78]. Silk/nylon core-spun yarns have less number of protruding ends and loops than silk ring spun yarns. The incidence of protruding ends and loops from the surface of the yarns is fairly and equally disposed on both sides for all the twist levels in both types of the yarns.

The importance of stuffer-tube dimensions and motion on regularity of throatle-spun-silk/raw silk core-spun yarn has been described [79]. The characteristics of yarns made by throatle-spinning system are affected by the vertical motion cycle of the stuffer-tube. A longer cycle gives a greater index of irregularity. It is possible to improve the count variation of the yarn by controlling the weight hung on the lever during the running time of the machine.

A comparison of appearance of yarns produced on ring spinning and throatle-spinning was investigated [80]. Ring spun silk yarn was prepared
using waste silk spinning process and then compared with throstle-spun-silk/raw-silk core-spun yarn. It was found that throstle-spun yarn has a high degree of hairiness, a great number of thin places in the diameter and a random variation of thickness.

Tensile properties of the composite spun silk yarns were studied [81]. Twin spun yarns, core-spun yarns and double yarns were prepared by different spinning methods. It was observed that the mechanical properties of composite yarns varied according to the kinds of fibres and also considerably affected by the yarn structure, namely the number and direction of twisting, even if the combination and the content of fibres were constant.

2.3.3 Silk Covered Core-Spun Fabric Properties

The properties of the fabrics produced from silk wrapped polyester core yarn produced on pedal spinning wheel have been compared with fabrics made from 100% silk waste [69]. Bursting strength, abrasion resistance, flexural rigidity and crease recovery are marginally better in the case of core-spun fabric.

Plain, twill and satin fabrics were produced on 21 inches wide sample power loom having reed 80⁹ and 84 picks/inch from silk covered polyester core yarns [73]. It was observed that nylon multifilament covered yarn fabric with satin weave gave more or less silk like handle and appearance.

Crease recovery of the double-core twin-spun-silk fabrics were studied [74]. It was possible to produce three kinds of double core twin-spun yarns by changing the positions of the filament core yarns. Of the three yarn structures, the migrated structure has the best performance for both yarn and fabric, not only in tensile and compression properties of the yarn but also in crease recovery of the fabric.

2.4 ELASTIC SILK YARNS AND FABRICS

2.4.1 Different Production Techniques used to Produce Elastic Silk Yarns

In the past, attempts have done to generate elasticity in the silk by reprocessing [53] or by special mechanical processing and chemical
treatment of the silk filament [82], but details of the processes have not been disclosed. Lot of information is available about the use of spandex in the core-spun yarn but few references are available on elastic silk.

Differential tussah/mulberry elastic silk is a recently developed pure silk material, which is obtained from general mulberry silk and tussah silk by special mechanical processing and chemical treatment [82]. The details of the process have not been disclosed.

Spandex is always used in combination with other fibres, which may be natural, man made or synthetic. Spandex can be used in several forms like bare (naked) yarn, single covered, double covered yarns, core-spun yarn or plied yarns [83]. Bare spandex is difficult to handle, hence it is mostly used as plied or core-spun yarn.

The basic requirement in producing a core-spun yarn with elastic qualities is to stretch an elastic filament core yarn before feeding it to spinning frame [84]. This will provide elasticity in final yarn because the elastic core relaxes when stress is removed. The core-spun yarn can be stretched to a point where the inelastic fibres in the sheath prevent further extension. Such stretchable yarns can be produced on cotton, woollen or worsted spinning system. For producing elastic core-spun yarn it is necessary to modify conventional spinning machine to permit feeding of lycra under uniform stretch.

To produce elastic core-spun yarns, conventional spinning frames are modified with a positive feed roll system so as to feed lycra yarn to the front roll under controlled, uniform stretch and in proper position relative to the roving [85]. This mechanism consists of positively driven feed rolls that serve as a cradle for the tubes of lycra to deliver the yarn at a predetermined rate to front roll of spinning frame, ensuring constant draft. The surface speed of the feed rolls can be adjusted to give any desired draft. Du Pont suggests maximum total draft of 4.0 for 20-40 denier lycra.

The effect of core positioning on the structure and properties of spandex core-spun yarns produced on a modified ring spinning frame has been discussed [86]. Two positions of the core has been compared. In one case the core filament is on the left side of single roving (as the yarn to be spun has Z twist) and in another case the core is in the center of single
roving. The third case having core filament in the center of two roving has also been discussed. The tenacity and elongation of the core-spun yarn produced with the centered adjustment on the roving is greater than of core-spun yarn produced with core at the left side of the roving. The covering effect was correct and the yarn structure quite even when the yarn was produced with core-centered on the roving.

The unwinding and feeding of spandex yarn has been described [87]. The extremely high elasticity of spandex is equivalent to a very low modulus, which means that the slightest pull on the thread creates significant draft. Feeding the yarn from a source to a sink position requires a minimal, but steady pull to ensure that it stays in its assigned path, free from slackening. There are chances of stick slip motion to be developed during unwinding of spandex yarn. Local variations of pre-tension and fineness created during winding, knitting or weaving will impair the appearance of the fabric. If a certain amount of draft is ultimately required, the only solution is to set up the nip points at starting and terminal position of the draft section of the yarn path. Unwinding by most familiar method of thread balloon should not be used. Elastic yarns generally require an actively driven, tangential unwinding system.

2.4.2 Elastic Silk Yarn Properties

The concept of elastic silk is in infant stage; hence little information is available on elastic silk yarn properties.

The properties of the differential tussah/mulberry elastic silk yarn are compared with ordinary tussah and mulberry silk [87]. In comparison to ordinary mulberry silk, the strength of differential tussah/mulberry silk has reduced from 2.23 cN/dtex to 1.58 cN/dtex. The breaking extension has reduced from 21.6 to 20.0 % whereas bulkiness has increased from 8.3 cm³/gm to 21.0 cm³/gm.

2.4.3 Elastic Silk Fabric Properties

Elastic silk fabrics can be divided into two groups: woven and knitted.

2.4.3.1 Elastic Silk Woven Fabrics

Although some references are available regarding specification and application of spandex yarn for production of various woven fabrics
[88,89,90], effect of fabric structures on the properties of woven fabrics containing elastane yarns [91,92], but there is not a single reference of elastic silk woven fabrics.

2.4.3.2 Elastic silk knitted fabrics

Using spandex in the bare (naked) form is most economical but is very difficult to knit into fabrics [93]. On the other hand it is much simple and safe to use either core-spun or covered yarns on circular knitting machines. These yarns are fed to the knitting feeders in stretched conditions maintaining constant and uniform tension on all feeders.

Information is available about cotton/lycra knitted fabric [94], but no reference is available regarding elastic silk knitted fabrics.
2.5 PROPERTIES OF SPANDEX

Spandex fibres are entirely man-made. They are chemical fibres whose major ingredient is a polyurethane elastomer [95]. In the USA fibres containing at least 85% of segmented polyurethane have been given the generic name of 'Spandex' and typical examples are Lycra and Spanzelle. This term was coined by reversing syllables in the word expand so as to convey the elastic properties of elastomerics. The term spandex is based on chemical structure whereas the term elastomeric relates to the rubber like characteristics of the fibre. Spandex is always a minor component in fabrics. It's percentage ranges from about 2-5% of fabric weight in stretch slacks to 20-25% and occasionally higher in intimate apparel [96].

Fibres which have an extension at break in excess of 200% and also have the property of rapid recovery when the tension is released are known as elastomers [97]. 'Elastane' has been adopted as the British generic name for elastomeric fibres and is defined as long chain synthetic polymer composed of at least 85% of segmented polyurethane [98]. The word elastomeric was coined from elastic and monomer, to imply an elastic fibre.

Chemically, the elastomerics are polyurethane based fibres, whose polymers are characterized by urethane groups (\(-\text{NH}–\text{COO}–\)). Polyurethane is synthesized from urea (\(\text{H}_2\text{NCONH}_2\)). Elastomerics are man made, synthetic polymer based, segmented polyurethane filaments. They are seldom manufactured as staple fibres. Elastomerics are produced by coalescing numerous multifilament yarns. On a world-wide basis nearly 80% of all spandex produced is by solution dry spinning process [99].

The initial impetus which led to the investigation and application of the polyurethanes was the desire to create a fibre which would be of the nylon type. A fibre "Perlon U", was developed which in several respects was superior to nylon [100].

Perhaps elastomeric polymer is the most complex textile fibre polymer that has been synthesized. Two types of elastomeric polymers are synthesized. Each is extruded into filaments with excellent elastic properties but differing in their resistance to alkalis.
1. The Polyether type -- (e.g. Lycra) -- In 1958 Dupont invented “Fiber K”, the fibre to be trade marked as Lycra [101]. The first commercial elastane, namely, ‘Lycra’ was introduced by Dupont in USA in 1959. Lycra is composed of segments of polyurethane in the form of block co-polymers [102]. The presence of ether groups greatly contributes to making of this type of elastomeric polymer resistant to alkalis.

2. The polyester type --(e.g. Vyrene)-- It is even more complex than polyether type and it’s actual formula would require four pages to write. The most relevant parts of this type of elastomeric polymer are ester groups.

Both types of elastomeric polymers are linear and composed of alternatively hard and soft segments. The essential structural feature of snap-back fibres is in the molecular chain, which is an alternation of soft and hard segments [103].
Theories have been formulated to explain the elastic nature of spandex fibres [104]. Fig.2.1 shows isocyanate segments as a circle. Flexible segments (Polyester or Polyether) are coiled or folded on themselves in a regular or random manner. In this relaxed state very little orientation or crystallinity is indicated by X ray diffraction patterns.

Fig.2.1 Diagrammatic arrangement for spandex molecules in relaxed and extended state.

When the fibre is stretched the folded or coiled portion of flexible segment are extended as shown in Fig.2.1. During extension isocyanate segments are brought close together so that they attract each other as a crystallite lattice and inhibit further stretching. X-ray diffraction pattern show evidence for this increased orientation and crystallinity.

Fibres with 0% soft segment will have hard segment as continuous phase (as in case of polyurea fibre). Fibres with 70% soft segment concentration will have soft segments as the continuous phase. Below 60% soft segment concentration the elastic recovery of fibres decreases rapidly. Only those fibres with a high soft segment concentration show the properties characteristics of a good elastomeric fibre. Lycra has a soft
segment concentration of about 83% [105]. The essential feature of elastomeric fibres is that their glass transition temperature is below 0°C, so that the soft segments have a considerable degree of freedom of movement at room temperature and above.

Table 6.1 Typical properties of Spandex (Lycra) [105].

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tenacity</td>
<td>0.6 to 0.9 g/d</td>
</tr>
<tr>
<td>Elongation</td>
<td>450 to 700%</td>
</tr>
<tr>
<td>Elastic recovery</td>
<td>95-98%</td>
</tr>
<tr>
<td>Modulus at 300% elongation</td>
<td>0.22-0.30 g/d</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>1.21</td>
</tr>
<tr>
<td>Moisture regain</td>
<td>1.13%</td>
</tr>
<tr>
<td>Softening point</td>
<td>300°F</td>
</tr>
<tr>
<td>Sticking temperature</td>
<td>437 to 446°F</td>
</tr>
<tr>
<td>Melting point</td>
<td>511 to 518°F</td>
</tr>
<tr>
<td>Shrinkage in boiling water</td>
<td>5%</td>
</tr>
<tr>
<td>Flex resistance</td>
<td>Excellent</td>
</tr>
<tr>
<td>Colour</td>
<td>White</td>
</tr>
<tr>
<td>Cross-section</td>
<td>Oblong, peanut</td>
</tr>
<tr>
<td>Resistance to acid</td>
<td>Good</td>
</tr>
<tr>
<td>Resistance to alkali</td>
<td>Good</td>
</tr>
<tr>
<td>Resistance to bleach</td>
<td>Yellowed</td>
</tr>
<tr>
<td>Class of dyes used</td>
<td>Disperse</td>
</tr>
</tbody>
</table>