CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter is concerned with the literature review on weft-knitted fabrics. Since a voluminous amount of literature is available this review will be somewhat biased towards certain topics. This survey is based upon an intensive search of the journals published in textile technology. Articles from other sources are also included, and the subject is reviewed under different captions.

The concern of the previous workers with the above aspects namely structure of weft-knitted fabrics and their properties is reflected in the following literature review.

2.2 BENDING AND SHEAR PROPERTIES

Postle and Hamilton (1975) have presented a study of the mechanical and related physical properties for a wide range of wool plain and double knitted fabrics. Results have been discussed in terms of the basic structural parameters (tightness factor and run-in-ratio) for the fabrics investigated. Postle and Hamilton (1975) have shown that the basic mechanical and physical properties of plain and double-knitted wool fabrics may be expressed as functions of the structural parameters of these fabrics, viz. the tightness factor K and, in the case of double knitted fabrics, the run-in ratio R. The authors conclude that control of these parameters during
knitting, coupled with adequate fabric relaxation during finishing, should allow complete specification and reproducibility of knitted fabric properties.

Choi and Ashdown (2000) have studied the effect of changes in knit structure and density on the mechanical and hand properties of weft-knitted fabrics for outerwear. A series of six knitted fabrics differing in structure and fabric weight was tested for tensile bending, shear, compression and surface properties using, KES (Kawabata Evaluation System) and the relationship between fabric density and the mechanical properties was studied. Properties such as tensile, bending, shear and surface properties show an increase with the increase in density. Compressional properties generally show a decrease with knit density for all fabrics. Total hand value (THV) of the fabrics shows an increase with the increase in density. Choi and Ashdown’s work is a good study in so far as it deals with the relationship between structure and properties of weft-knitted fabrics.

Using a new constant, Ramkumar et al (2000) have studied the effect of loop length and yarn linear density on the static and kinetic friction of 1 x 1 rib fabrics produced from cotton. The variation in the structure of the knitted fabric is reflected in the frictional properties as defined by the new frictional constant. Static and kinetic friction values are found to be higher with 18.4 tex cotton yarn and lower for 14.0 tex implying that the area of contact plays a very important role. Also, with the increase in loop length, both the coefficients show an increase again implying that area of contact plays a crucial role.

2.3 MECHANICAL PROPERTIES

A brief overview of research work on the mechanical properties of knitted fabrics is given in this section.
2.3.1 Bending Properties

The bending characteristics of wool knitted fabrics were investigated by Hamilton and Postle (1976) using an apparatus which is similar to that developed by Chapman (1974). The apparatus was able to measure and record the bending stress-strain curve (bending moment vs curvature) of fabrics. They used geometrical and rheological models to calculate the bending rigidity values of fabrics. They also analysed critically the hysteresis curves for relaxed and unrelaxed knitted fabrics. Gibson and Postle (1978) studied the bending and shear behaviours of double knitted fabrics like Punto-di-Roma and Swiss double pique, and warp knitted fabrics with the help of geometrical models. They studied the bending properties of fabrics knitted from wool and polyester textured yarns using a pure bending tester. It was found that the effect of finishing treatment on knitted fabrics was less compared to woven fabrics.

2.3.2 Tensile and Shear Properties

Shanahan and Postle (1974a,b) conducted a theoretical analysis of the tensile properties of wool and nylon mono-filament plain knitted fabrics. They considered both the elastic deformation of loop and the yarn compression as possible mechanisms for fabric extension. The correlation between the experimental and theoretical initial modulus was found to be good. They also investigated the effect of relaxation treatment on the initial load - extension behaviour of knitted fabrics. They found that relaxation had very little effect on the initial modulus of knitted fabrics. A two dimensional loop model was used by them to predict the load-extension behaviour of knitted fabrics theoretically. The energy analysis technique was applied to the biaxial deformation of knitted fabrics by de Jong and Postle (1977a). They studied the nature of yarn contact and the distributed forms between interlocking loops using the energy analysis. Experimental work on the
tensile properties of knitted fabrics was undertaken by Somashekhar (1975) and Hallos et al (1990).

The work on the shear of knitted fabrics is slight compared to tensile properties of knitted fabrics. Carnaby and Postle (1974) conducted a study of the shear behaviour of plain 1 x 1 rib and interlock wool weft knitted fabrics. They used a modified version of the shear tester developed by the Fibre Institute, TNO of Delft. They have mentioned about the parameters which are used to represent shear. The objective bending measurements were discussed in terms of the geometrical changes occurring within the unit cell of the knitted fabrics. They found that the low shear resistance of knitted fabrics was due to large frictional restraints and low resistance to fibre slippage. Hamilton (1975) conducted a detailed study on the shear behaviour of single and double jersey knitted fabrics.

2.3.3 Compression Properties

Postle (1971a,b) studied the lateral compression property of plain knitted fabrics made of different types of yarns. He applied a general geometrical model based on the assumption of constant unit cell configuration to derive simple relationships for effective diameter and specific volume of yarn as it exists within the fabric, the fabric thickness and the bulk density of knitted fabrics. He found that the thickness - pressure relationship was non linear. Williams and Leaf (1974) studied the thickness of plain knitted cotton fabrics. They studied the compression and decompression property of knitted fabrics using a thickness gauge. They established a pressure thickness relationship of the form $T = a + b \exp(-kP)$ where $T$ is the fabric thickness $P$ is the pressure on the fabric, and $a$, $b$ and $k$ are constants. In the recent past, many researchers have utilised the Kawabata compression tester to study the compression properties of knitted
fabrics. Pau-Lin Chen et al (1992) have used the KES-FB3 tester to study the compression properties of a set of knitted fabrics.

The availability of the Kawabata set of equipment has made it possible to measure the low stress mechanical properties of knitted fabrics. Chen et al (1992) have carried out the evaluation of handle of 50:50 cotton polyester open and yarns. Hallos et al (1990) have carried out the evaluation of handle of a set of double jersey fabrics made from spun polyester wool and textured polyester. They compared different fabrics using polar profiles derived from the subjective and objective results. Begum (1994) has carried out a study of low stress mechanical properties of plain knit fabrics produced from ring and double-rove and rotor spun polyester cotton yarns. Fabrics made from ring and double rove yarns were found to be softer than fabrics made from rotor yarns. Gong (1995) has carried out a study of the low stress mechanical properties of 1 x 1 rib knitted fabrics made of acrylic, cotton and wool. These fabrics were subjected to fifty laundering cycles, and the mechanical properties were evaluated. Principal component analysis (PCA) was used to analyse the results, and the results were represented in the form of vector maps.

It is clear from the survey of literature that research work on handle of knitted fabrics is scant compared to the vast amount of information available on the mechanical properties of woven fabrics.

Changes that occur in acrylic, cotton and wool knit wear fabrics as a result of repeated laundering have been successfully quantified by both subjective evaluation of appropriate fabric sensory attribute and objective measurement of mechanical properties. The sensory property changes are related to dissatisfaction expressed by consumers with the wash-wear performance of many knit wear fabrics, and also provide much more detailed information than typical consumer studies (Mackay et al 1999).
Changes in some of the objectively measured fabric mechanical properties are related to specific physio-chemical changes, occurring at the fibre's level in the wool, cotton and acrylic fabrics. Mackay et al (1999) believes in using PCA (Principal Component Analysis) to provide overview on the subjective and objective data. Specific changes in the three fibre types made by the laundering process have been attributed to variables such as agitation level, detergent product and drying method.

It is suggested that PCA of the combined, subjective and objective data provides a means expressing fabric sensory attributes in terms of selected objective measurements and of defining a total hand value for any fabric sample. This approach obviates the need to derive THVS from HVS (or from objective measurements) by using regression equations based on "once - and for - all" expert judgement on 1 x 1 rib reference fabrics.

Park and Hwang (1999) have developed a simple and practical hand evaluation method to calculate the new overall hand value using seven mechanical properties, and this has been compared with the total hand values (THV) obtained from KES-FB system. Double weft knitted fabrics considered are interlock, royal interlock and mock royal interlock from. By using fuzzy transformation matrix, the mechanical and physical, properties of the double weft knitted fabrics, namely tensile, bending shear compressional and surface properties have been analysed; these knitted fabrics differ in structural aspects. It has been concluded that the total hand value predicted on the basis of fuzzy transformation matrix is quite accurate. The alternative method resulting from the principal mechanical properties (EMT, RT, RC, MIU, W, B, 2HG), it has been pointed out, will provide researchers with a simple hand test method for double knit fabrics.

Park, Hwang and Kang (2000) have also applied fuzzy logic and neural networks to total hand evaluation of knitted fabrics.
Quaynor et al (1999) have reported on the dimensional changes in knitted silk and cotton fabrics following laundering process. Both plain and 1 x 1 rib fabrics were considered and they were subjected to relaxation process and an extended series of wash and tumble dry cycles changes in dimensions have been measured after every process and cycle.

Statistical analysis of the experimental data reveal the effect of yarn type as well as linear density and tightness factor on the linear and area shrinkage behaviour of silk as compared to cotton. It has been found that cotton shrinks more than silk, and silk rib units stretch excessively in width. Silk attains full relaxation after one laundering cycle, and it has been pointed out that it is possible to predict fabric dimensional changes with wet relaxation as well as with laundering especially in silk.

Quaynor et al (2000) have investigated the effects of laundering and laundering temperatures on surface properties and dimensional stability for plain flat, knit, silk, cotton and polyester fabrics with varying cover factors. The fabrics are subjected to relaxation processes and an extended series of wash and tumble dry cycles in laundering baths of various temperatures. Dimensions, surface friction and roughness of fabrics have been measured in every process. Changes in dimensional stability and surface properties with relaxation processes and laundering temperatures are classified. Relations existing between frictional motion and structural parameters have been discussed.

The results show that the dimensional stability of silk is sensitive to a particular temperature. Highest shrinkage is recorded with slackly knitted cotton at the highest temperature which is a well known phenomenon. There is a considerable effect of wet relaxation on the dimensional stability as well as surface properties. Silk’s, coefficient of friction is the highest, and the lowest surface friction occurs at the highest
temperature. Slackly knitted fabrics also display higher friction than those of tightly knitted fabrics. The coefficient of friction has a tendency to decrease with increasing tightness, while the surface roughness shows an opposite tendency. There is a good correlation between stick slip motion and ribs on the fabrics.

Jeddi and Otaghsara (1999) have investigated the effects of yarn twist and fibre percentage in blends on the dimensional properties of the interlock structure. A series of interlock weft knitted fabrics was produced from open end cotton polyester blended yarns with different yarn twist, loop length, fibre percentage in blend, and a variety of relaxation treatments. A comprehensive experimental analyses show that the $K_s$ value (stitch density multiplied by the square of loop length) is related to yarn density, fibre percentage in blends, and relaxation treatments. They have concluded that the correct relaxation state for cotton fabrics to reach the maximum shrinkage is full mechanical relaxation, and for cotton polyester blended and 100% polyester fabrics is chemical relaxation. The empirical results show that the effect of mechanical relaxation decreases as the percentage of polyester in blends increases.

Tavanai, Denton and Hepworth (1997) have investigated the effects that retraction and torsion in fine textured yarns have on knitted structure and extensibility. Yarn torque, apart from causing spirality in plain-knitted fabrics, also leads to other effects. Loop distortion, as a result of yarn torque and the contribution of retractile power and twist liveliness of fine false-twist textured nylon yarns to geometrical parameters and extensional properties of single and two feeder plain knitted fabrics have been investigated. A model to represent the structure of plain knitted fabrics from such high-torque hosiery yarns has been put forth. Twist liveliness affects both geometrical parameters and the extensional properties of plain knitted fabrics.
Morooka et al (2000) have reported a very interesting study on the compressive properties of panty hose fabrics knitted from nylon, silk and polyurethane fibers. Different kinds of panty hose fabrics were studied for cylinder - elongation experiments and wear experiments. Compressive properties, which include compressive energy, compressive resilience and fabric thickness, were found to differ remarkably according to the types and the sites of hose and posture while being worn. The pantyhoses were extended to different levels, and the compression properties have been examined. There is some semblance of this work already done by Thirlwell and Treloar (1965) on the non-woven fabric.

2.4 THE HANDLE OF FABRICS

2.4.1 Introduction

Textile scientists have made a considerable progress in objectively measuring handle of fabrics. A major upsurge in research on handle measurements took place due to the pioneering work of Professor Kawabata of Kyoto University. A brief over view of the handle of fabrics is given.

2.4.2 Fabric Handle

The term fabric handle has been defined in various ways such as

a) the quality of a fabric or yarn assessed by the reaction obtained from the sense of touch
b) the sum of sensations expressed when a fabric is handled by touching, flexing of fingers and so on.

Lundgren (1969) has defined as the summation of weighted average contributions stimuli evoked by fabric on major sensory centres.
There are two methods which are very popular in handle measurements. They are the subjective and objective test methods.

2.4.3 Subjective Measurements

The evaluation of fabrics by judges for quality attributes such as stiffness, softness, resilience etc in some order is the principle behind the subjective evaluation of fabrics. These are basically two main categories in subjective evaluation. They are:

2.4.4 Magnitude estimation

It is based on awarding a score, to each quality attribute of the fabric on an arbitrary scale.

2.4.5 Ranking method

This method involves comparing two different fabrics for handle as a whole or each individual attribute of the fabric and giving the preference.

2.4.6 Previous Work on the Subjective Evaluation of Handle

Binns (1926a) conducted a systematic study on the subjective evaluation. He employed both experts and non experts within the wool trade to evaluate fifteen different fabrics made from three different lots of wool. He found that both the trained and untrained judges had a tendency to use both vision and touch to evaluate the fabrics. He published a psychologically based analysis of handle. In this study, the subjects were asked to grade the cloths by sight alone for "smartness of appearance" by touch alone for
"softness of handle" and by full judgement on a commercial basis and in the case the judges buy the fabrics. An important conclusion which he arrived in this study observing the way in which the judges judge the fabrics was that the final discrimination and evaluation was determined by the sense of touch. He also carried out a comparative study between the judgements of individuals skilled in the textile trade and the natural judgements of untrained adults and children. The results of the study suggested that the experts', judgement were based upon an appreciation of the material due to the special and intensive training on the intricate technical features about the cloth. The judgement of children and untrained judges is based upon the sensory factors which are in immediate and direct liaison with the senses of touch and sight. Binn's (1926b) comprehensive study of subjective evaluation dealt with all aspects of the subjective evaluation of wool textiles. Vaughn and Kim (1975) and Ellis and Garnsworthy (1980) have reviewed various handle evaluation methods. More recently, Slater (1997) has reviewed the subjective testing methods in textiles. Stearn et al (1983) used an international panel of judges consisting of experts and consumers to analyse the handle of fabrics. Mahar (1988) conducted subjective evaluation of handle of a set of 87 winter style suiting fabrics assembled in Australia. Gong (1995) used the expertise of experts in a finishing factory to rank the knitted fabrics for their handle properties. Recently, Mackay (1992) has used the sensory evaluation panel co-ordinated by the sensory science unit of the Unilever Research Laboratory to evaluate the handle of characteristics of a set of 1 x 1 rib knitted fabrics. The panelists used a set of ten tactile descriptors which are given on Table 2.1. The average scores from a panel of 20 judges were used for ranking the fabrics.
More recently, Talebpoor (1996) has carried out the subjective evaluation of a set of cotton fabrics with different finishing treatments. The judges were asked to evaluate the smoothness of the fabrics. The judges ranked the fabrics and the ranking were compared with the measured frictional values. The static and kinetic coefficients of fabric friction were increased by easy care finishing with DHDMI but were decreased by the application of a silicone softener. The latter was found to be highly effective in maintaining a low surface friction even when higher DHDMI add-on was used.

It is clear from the foregoing discussions that the subjective evaluation of handle depends on subject’s mental state, education, experience in a particular trade. Therefore extreme care has to be taken in selecting the judges to evaluate the quality fabrics. Furthermore, caution
should be exercised in choosing the subjective test methods. In general, paired comparisons technique can be considered as a reliable test method.

2.4.7 Objective Evaluation of Fabrics

Peirce (1930) pioneered research on the objective evaluation of fabrics. In his classical paper, "The Handle of cloth as a measurable quality", he attempted to measure the mechanical properties of fabrics such as stiffness and compression. However, he did not attempt to measure the frictional properties of fabrics. He characterised the handle sensation with the help of eight measurable mechanical properties such as:

1) bending length
2) flexural rigidity
3) thickness
4) hardness
5) bending modulus
6) compression modulus
7) density and
8) extensibility

Following the earlier attempts of Peirce (1930), many researchers have tried to devise physical test methods that can correlate well with the sensation of the feel of fabrics. Dreby (1942) considered pliability, smoothness and fullness to be important to the handle of fabrics. His result showed that the more the flexibility compressibility, the smoother the fabric, and vice versa. It is evident from the experiments of Peirce (1930) and Dreby (1942) that there has been a great interest to correlate the sensation of feel with the mechanical properties of fabrics.
Vaughn and Kim (1975) outlined different objective test methods for the parameters associated with the handle of fabrics. They measured twenty different mechanical properties of fabrics and expressed handle in terms of their mechanical properties. The mechanical properties considered by Vaughn and Kim (1975) to be important for the evaluation of handle of fabrics are shown in Table 2.2.

**Table 2.2**

**Mechanical Properties considered by Vaughn and Kim (1975)**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Mechanical Property</th>
<th>Measurable Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Elastic Flexural Rigidity</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Bending Hysteresis</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Bending</td>
<td>Bending Length</td>
</tr>
<tr>
<td>4.</td>
<td>Loop Softness</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Bending Recovery</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Drape</td>
<td>Drape coefficient</td>
</tr>
<tr>
<td>7.</td>
<td>Shearing stress</td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Shearing width</td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Shear</td>
<td>Shearing Recovery</td>
</tr>
<tr>
<td>10.</td>
<td>Initial Shear Modulus</td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Shearing Recovery</td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>Tensile Extensibility</td>
<td></td>
</tr>
<tr>
<td>13.</td>
<td>Initial Young's Modulus</td>
<td></td>
</tr>
<tr>
<td>14.</td>
<td>Tensile Recovery</td>
<td></td>
</tr>
<tr>
<td>15.</td>
<td>Thickness</td>
<td>Thickness</td>
</tr>
<tr>
<td>16.</td>
<td>Compressibility</td>
<td></td>
</tr>
<tr>
<td>17.</td>
<td>Compression</td>
<td>Hardness</td>
</tr>
<tr>
<td>18.</td>
<td>Compressional Resilience</td>
<td></td>
</tr>
<tr>
<td>19.</td>
<td>Areal Density</td>
<td>Weight per Unit Area</td>
</tr>
<tr>
<td>20.</td>
<td>Friction</td>
<td>Coefficient of Static Friction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Coefficient of Dynamic Friction</td>
</tr>
</tbody>
</table>
More recently, Bishop (1996), in his Textile Progress, has summarised different test methods which are closely associated with fabric hand. It is clearly evident from the studies of previous research workers that there is a correlation between the mechanical properties of fabrics and handle. The following section gives a brief overview of the instruments which are used for measuring low stress mechanical properties.

2.4.8 Instrumental Evaluation of the Mechanical Properties of Fabrics

In this section, a brief overview is given about different instruments for measuring the mechanical properties of textiles. A detailed description about different instruments and their developmental history has been dealt with by Chen (1995).

2.4.8.1 Tensile Testing

Extensibility of fabrics is considered to be an important contributor to the handle of fabrics. Measurement of the extensibility of fabrics and their tensile properties started during the early part of this century. Stanton and Booth (1910) conducted uniaxial tensile tests of fabrics. Wallen and Lewis (1916) devised the grab tensile tester for uniaxial tensile measurements. In addition to uniaxial tensile testing, fabrics have been tested basically for their tensile properties. It has been reported by Chen (1995) that Hass and Dietzius (1917) were the first to conduct a biaxial tensile test on fabrics. Uniaxial tensile testing is a popular method of measuring the tensile properties of fabrics, and a wide range of instruments are available for measuring them. Kawabata (1996) has developed a sophisticated tensile tester to measure the four stress tensile properties of fabrics.
2.4.8.2 Shear Testing

Dreby (1942) used an instrument called the "Planofex" to measure the distortion of fabrics on its own plane without causing any wrinkles. A large amount of work on the shear properties of fabrics was carried by the Swedish Institute for Textile Research. Morner and Eeg-Olofsson (1957) developed an instrument to study the shear properties of fabrics.

Treloar (1965) developed a simple instrument to measure the shear properties of fabrics. The shear force $F$ is related to the shear resistance $R$ in the sample and a horizontal recovering force caused by shear strain under the normal load $W$ which is given by

$$F = R + W \tan \theta$$

where $\theta$ is the angle of inclination, Spivak (1966) later modified Treloar's equipment to make it more suitable for routine shear measurements. Hamilton (1975) used shear deformation model characteristic of "equal length of side" as a basis for his shear tester.

Owing to the complexities involved in fabricating suitable instruments for measuring the shear properties, efforts were made by many textile scientists to establish a relationship between the bias direction strains and the shear angle of fabrics. Lindberg et al (1961) established the relationship between bias compressional strain and the shear angle of worsted fabrics. Cooper (1963) used a simple bias extension as an alternative for shear measurements. Kilby (1963) worked on a theoretical relationship between bias extension and the shear of fabrics. In the theory, he regarded a fabric as trellis which is equivalent to an anisotropic lamina which shows the Poisson's effect and two symmetrical planes at right angles...
to each other. The Young's modulus in a direction $\theta$ to fabric warp axis can be expressed as

$$\frac{1}{E_\theta} = \frac{\cos^4\theta}{E_1} + \left( \frac{1}{G} - \frac{2V}{E_1} \right) \sin^2\theta \cos^2\theta + \frac{\sin^6\theta}{E_2}$$  \hspace{1cm} (2.2)

In general the shear modulus is less than the two tensile moduli $E_1$ and $E_2$. In the case of $\theta = 45^\circ$, the above formula can be written as

$$E_{45} = 4G$$  \hspace{1cm} (2.3)

where $G$ is the shear rigidity of fabrics.

### 2.4.8.3 Bending Measurements

There is a repertoire of literature available on the theory of bending of fabrics and instrumental methods to measure the bending properties of fabrics. Grimshaw (1922) pioneered the measurement of the bending properties of fabrics. His method is based on the ability of fabrics to bend its own weight. Peirce (1930), as a part of his research on the measurement of handle of fabrics, developed a flexometer for measuring the bending properties of fabrics. The bending tester developed by Peirce (1930) is used as a routine test for the measurement of handle of fabrics.

Peirce's bending tester was modified by the Shirley Institute, and the modified equipment came to be known as the Shirley Stiffness Tester.

In 1957, Eeg-Olofsson designed the first pure bending tester as the measurement of pure bending is important to the assessment of handle. During the same period, a pure bending tester was developed by Isshi (1957) in Japan. The apparatus was designed to bend fabric samples to form a
segment of a circle whose radius changed according to bending deformation. Cantilever bending tester was developed by Livesey and Owen (1964) which had the ability to measure the bending hysteresis of fabrics. Abbott and Grosberg (1966) modified the cantilever tester of Livesey and Owen. They adopted the Instron tensile tester to measure the bending tester based on the principle of Livesey and Owen's bending tester (1964). Popper and Backer (1968) modified the bending tester developed by Isshi. The instrument had electronic instrumentation. Capacitors were used which transduced the mechanical displacements into voltage inputs. These voltage outputs were proportional to the bending moment, and the bending moments were recorded automatically. Following these earlier researchers, many have adopted the Instron tensile tester to measure the mechanical properties of fabrics. Ly (1986) developed a bending device which could be used on the Instron tensile tester. Kawabata (1996), as a part of the set of Kawabata equipment, developed a sophisticated bending tester which bends the fabric over an arc of a circle.

2.4.8.4 Compression and Softness Measurement

Softness has been considered as one of the most important handle attributes. Percentage compression is used as a measure of softness of fabrics.

Peirce (1930) and Schiefer (1933) have developed methods to measure compression. Dreby (1942) also developed a compression meter, and used hydraulics to measure the thickness and hence compression of fabrics. Rowlands (1963) and Mackay (1992) have used Instron tensile tester for measuring the compressional properties of fabrics.
2.4.9 Kawabata Evaluation System for Fabrics

The fundamental research on the mechanical properties of textiles showed that the mechanical properties of fabrics have a profound influence on the handle characteristics of fabrics. In the early seventies, a major upsurge in the research on handle took place due to the pioneering efforts of Professor Kawabata (1982). With the help of the handle evaluation and standardisation committee, Kawabata identified primary hand values which the Japanese experts considered important for the feel of fabrics. In collaboration of with Kato Tech Co., Kawabata developed the first series of Kawabata set of instruments. KESF consists of four instruments:

- KES - FB1 Tensile and Shear Tester
- KES - FB2 Bending Tester
- KES - FB3 Compression Tester and
- KES - FB4 Surface Friction and Roughness Tester.

The concept behind the Kawabata hand evaluation system is given in Figure 2.1. There are in total sixteen different parameters obtained from the Kawabata set of equipment. Table 2.3 gives the mechanical and surface properties by the Kawabata set of equipment. Initially, the system was used for studying the handle of wool fabrics.

![Figure 2.1 Kawabata Handle Evaluation System](image)
Table 2.3

Mechanical and Surface Properties Measured by the Kawabata set of Instruments

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>LT</td>
<td>Linearity of Load/ extension curve</td>
<td>None</td>
</tr>
<tr>
<td>WT</td>
<td>Tensile energy</td>
<td>N/m</td>
</tr>
<tr>
<td>RT</td>
<td>Tensile Resilience</td>
<td>%</td>
</tr>
<tr>
<td>B</td>
<td>Bending Rigidity</td>
<td>$10^4$ Nm</td>
</tr>
<tr>
<td>2HB</td>
<td>Bending Hysteresis</td>
<td>$10^3$ N</td>
</tr>
<tr>
<td>G</td>
<td>Shear Stiffness</td>
<td>N/m deg.</td>
</tr>
<tr>
<td>2HG</td>
<td>Shear hysteresis at 0.5 deg. shear angle</td>
<td>N/m</td>
</tr>
<tr>
<td>2HG5</td>
<td>Shear hysteresis at 5 deg. shear angle</td>
<td>N/m</td>
</tr>
<tr>
<td>LC</td>
<td>Linearity of compression curve</td>
<td>None</td>
</tr>
<tr>
<td>WC</td>
<td>Compressional energy</td>
<td>N/m</td>
</tr>
<tr>
<td>RC</td>
<td>Compressional Resilience</td>
<td>%</td>
</tr>
<tr>
<td>MIU</td>
<td>Coefficient of friction</td>
<td>None</td>
</tr>
<tr>
<td>MMD</td>
<td>Mean deviation of MIU</td>
<td>None</td>
</tr>
<tr>
<td>SMD</td>
<td>Geometrical roughness</td>
<td>$\mu$m</td>
</tr>
<tr>
<td>T</td>
<td>Fabric thickness</td>
<td>mm or cm</td>
</tr>
<tr>
<td>W</td>
<td>Fabric weight/Unit area</td>
<td>$g/m^2$</td>
</tr>
</tbody>
</table>

2.4.9.1 Tensile Property Measurements (KES-FBT)

A fabric sample of 20 cm x 5 cm is clamped to the two jaws of the tensile tester, and is extended upto a pre-set load of 50 N/m; The instrument is based on strip biaxial extension of fabrics. The non linear tensile behaviour of the fabric is characterised using three parameters such as the tensile energy (WT), the linearity of the load-extension curve (LT) and the tensile resiliency (RT).
2.4.9.2 Shear Property Measurements (KES - FB1)

In this tester, a shear strain of $8.3 \times 10^3$/s is applied to the fabric upto a maximum shear angle of 8 degrees. The slope of the shear curve is a measure of the shear rigidity. The shear hysteresis and the rigidity values are measured using the KES - FB1 shear tester.

2.4.9.3 Bending Property Measurements (KES - FB2)

The instrument is based on the pure bending of fabric over an arc of a circle. The fabric of 1 cm in length is subjected to a pure bending at constant curvature of $5 \times 10^{-3}$ m$^{-1}$/s. The bending hysteresis and the rigidity values are obtained from the bending tester. The slope of the curve is a measure of the bending rigidity of fabrics.

2.4.9.4 Compression Property Measurements (KES - FB3)

The KES - FB3 is used for obtaining the compression parameters. The fabric specimen is compressed at a maximum pressure of 50 gf/cm$^2$ in a constant velocity of 20 $\mu$m/s. Three different compression parameters such as the compressional energy (WC) the compressive resilience (RC) and the linearity of the compression curve (LC), are used to characterise the compressional properties.

2.4.9.5 Surface Property Measurements (KES - FB4)

A friction sensor which consists of 10 parallel piano wires of 0.5 nm in diameter is used to measure the friction of fabrics at a normal load of 50 gf. The surface tester also measures the geometrical roughness of fabrics. The surface roughness sensor is a bent piano wire of 0.5 mm
diameter. The surface properties are characterised using three parameters. They are:

- MIU : Mean frictional coefficient
- MMD : Mean deviation of the frictional coefficient
- SMD : Mean deviation of surface contour.

The sixteen different mechanical properties measured by the KES-FB system are used to calculate the primary handle values and the total hand value of fabrics.

2.4.10 FAST System

Fabric assurance by simple testing is a simplified system of objective measurement of fabric properties. This system was developed by the Division of Wool Technology, CSIRO, Australia (1989). It is used for assessing appearance, handle and performance of fabrics. FAST consists of three instruments and a test method. Initially, their system was used for determining the handle of woollen and worsted fabrics.

- FAST-1 Compression meter
- FAST-2 Bending meter
- FAST-3 Extension meter
- FAST-4 Dimensional stability test

2.4.10.1 FAST-1: Compression Meter

The instrument measures the thickness of fabrics under two predetermined loads. The instrument has a compression cup of 10 cm² in area which provides the initial load of 2 g/cm² on the sample. A maximum pressure of 50 gf/cm² is applied on the sample by an additional weight. The
difference in thickness at two different loads is measured as the surface layer thickness.

2.4.10.2 FAST-2: Bending Meter

This instrument works on a cantilever bending principle. The photo cell in the instrument measures the edge of the bending fabric. The bending length values are read directly and from these values, the bending rigidity values are calculated. Bending rigidity is a measure of the stiffness and the handle of fabrics.

2.4.10.3 FAST-3: Extensibility Meter

The extensibility of a fabric is a measure of stretch of a fabric which influences the performance and appearance of garments. The extensibility meter measures the extension of fabrics at three different stress levels, 5, 20, and 100 gf/cm simulating the kind of deformations the fabric undergoes during garment manufacture.

2.4.10.4 FAST-4: Dimensional Stability Test

This is a test method for measuring fabric dimensional stability in terms of its hygral expansion, relaxation and shrinkage. The fabric is dried in an oven at 105°C and the dry dimensions of the fabric are measured. The fabric is then wetted and its wet dimensions are measured. The fabric is then dried and its final dry dimensions are measured. The wet and dry dimensions are used to calculate the shrinkage and hygral expansions. All the instruments are connected to a PC, and the data are collected and printed out using an in-built software.
Table 2.4 gives the mechanical parameters measured by the FAST system. The results are displayed in the form of "fabric finger prints". These may be used for fabric specifications, developing new fabrics, comparing fabric finishing, assessing stability of finished fabrics and predicting tailoring performance and appearance of garments.

Table 2.4
Mechanical Properties measured by the FAST System

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Expression</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface thickness</td>
<td>ST = T₂ - T₁₀₀</td>
<td>T₂ = Average thickness at 2 g/cm²</td>
<td>mm</td>
</tr>
<tr>
<td>Relaxed surface thickness</td>
<td>STR - T₂R - T₁₀₀R</td>
<td>T₂R = Average relaxed thickness at 2 g/cm²; T₁₀₀R = Average relaxed thickness at 100 g/cm²</td>
<td></td>
</tr>
<tr>
<td>Bending rigidity</td>
<td>9.81 x 10⁶ x WC³</td>
<td>W = Fabric weight (g/m²); C = Bending μN.m length (mm)</td>
<td></td>
</tr>
<tr>
<td>Extension</td>
<td>E5</td>
<td>E5 = Average extension at 5 g/cm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>E20</td>
<td>E20 = Average extension at 20 g/cm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>E₁₀₀</td>
<td>E₁₀₀ = Average extension at 100 g/cm</td>
<td></td>
</tr>
<tr>
<td>Shear rigidity</td>
<td>G = 123/EB⁵</td>
<td>EB⁵ = Average bias extension at 5 g/cm</td>
<td></td>
</tr>
<tr>
<td>Relaxation shrinkage</td>
<td>RS = (L₁ - L₃)/L₁</td>
<td>L₁ = Initial dry length of fabric sample; L₃ = Relaxed dry length of fabric sample</td>
<td></td>
</tr>
<tr>
<td>Hygral expansion</td>
<td>HE = (L₃ - L₄)/L₄</td>
<td>L₃ = Relaxed wet length of fabric sample</td>
<td></td>
</tr>
<tr>
<td>Formability</td>
<td>F = (E₂₀ - E₅)/14.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Other than these two well established fabric evaluation methods, many research workers have used the Instron tensile tester to measure the handle of fabrics. Force-displacement curves from Instron have been used to characterise fabrics when a circular specimen of fabric was extracted through a nozzle. Sheta (1979) studied the handle of fabrics using the nozzle extraction method. She also carried out a theoretical analysis of the deformation of fabrics at several stages as it is being extracted through the nozzle. Pan and Yen (1992) have also carried out experiments using nozzle...
extraction method to study the handle of fabrics. They have also analysed the shape of extraction curves. Figure 2.15 shows the typical traces of force-displacement curves as the fabric is being pulled through the nozzle.

Behery (1986) has used the extraction method to calculate the hand moduli for a set of commercial fabrics. He also carried out a correlation study between the total hand value calculated by the Kawabata Evaluation system and hand moduli calculated by the nozzle extraction method. Sultan et al (1992) used the nozzle extraction method to study the handle of commercial fabrics. They found that the correlation between the nozzle extraction force and the Kawabata measurements was good.

2.5 RAISING TREATMENT

Raising is one of the oldest textile finishing processes, and is the key process in the production of a wide variety of fabrics, including blankets, flannelettes and industrial fabrics. The object of raising is to produce a file or rap on the fabric surface. Originally, this was carried out by hand which was later replaced by machine raising using a teasel gig in which teasels are mounted on the surface of a cylinder.

Raising is a technique used in mechanical finishing providing fabrics with a fuller and softer handle and improving their warmth retention properties by increased volume. The process of raising consists of lifting from the body of the fabric a layer of fibres which stand out from the surface; in many cases a specially prepared surface results from milling or even from particular woven structures. The formation of pile or cover on a fabric results in a "lofty" handle, and may also subdue the weave or pattern of the cloth in addition to blending the various colours. In some sequence of processes, the raising operation may be a preliminary to milling so as to produce a heavier surface matting of the fibres.
2.5.1 Types of Raising Machines (Based on the type of wire point)

Raising machines are of two types based on the type of wire point - teasel and card wire machines. As the output of the card wire machine is higher than that of the teasel type, it is customary to start raising on the wire machine and complete it with teasels; there are certain finishes which can only be produced with teasels. Both types of raising may be done with the fabric in the wet or dry state, but moist raising is probably more widely adapted for wool if not for cotton.

In teasel raising machine, teasels are obtained from a species of the thistle plant specially cultivated for the purpose; some teasels are 2 inches long, but the average type is 1.5 to 1.75 inches in length for commercial use. King teasels are 4 inches long. The teasels are prepared with steam or hot water and them set into frames or iron slats as tightly as possible to form one or two rows. The slats or frames are placed on a drum which rotates, and the fabric is brought into careful contact with the teasel-filled slats; raising must take place very gradually and the fibres are really untangled and lifted instead of being torn from the surface of the fabric, the process usually starts with old teasels whose points have been worn and softened. New and sharper teasels may be used when some surface or pile has been developed. In the course of the process, the teasels become filled with wool fibres and also become damp when they are removed drying and brushing. An extension of the moist tasseling process is the wet raising where the cloth is actually saturated with water during the raising treatment; this effect is not strictly raising, but lays the raised pile in one direction on the surface of the cloth. In the moist and wet processes, the swollen fibres are less rigid, and this assists raising; dry raising is very suitable for fabrics which have not been milled and a more spongy effect is produced.
Card wire raising machines are usually constructed on the basis of a cylinder around which there is a mounted small roller covered with the wire filleting. Two main types of machine are available, single and double acting. In the single-acting machine, the pile or cover is raised in only one direction as the wire-covered rollers rotate in the opposite direction to that of the cylinder. The double acting machine has two sets of rollers termed pile and counter pile rollers which rotate at the same speed and also in the same direction; the points of the card wire are set in opposite direction to each other, and by adjusting the speed of the two types of roller, more or less raising effect can be produced. Very different effects are created by the single and double acting machines in the former, the pile is laid like a fleece, whereas in the latter the pile is raised to stand erect. The teasel - raising gig imparts a brushing and polishing action, which is not realised with the Moser or card-wire machines. The severity of the action also differs in the two machines.

A very mild form of raising may be produced on cotton or wool goods by the sueding machines. A series of rollers is covered with an abrasive surface such as sand paper or emery cloth, and the fabric to be sueded is brought into varying degrees of contact with the abrasive surface by the use of guide rollers.

2.5.2 Types of Raising Machines (Based on number of drums)

Two types of raising machines namely, single drum raising and double drum raising machines are employed.
2.6 TYPES OF PEACH FINISH PRODUCED BY DIFFERENT MANUFACTURERS

Nair (2000) describes the different types of peach finishing machine produced by various manufacturing units as follows.

Table 2.5

Details of Raising Machines

<table>
<thead>
<tr>
<th>Exhibitor</th>
<th>Machine</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sperroto</td>
<td>SM.4/SM.6/SM.8</td>
<td>Models with 4, 6 or 8 emerizing rollers; all of roller widths 190 &amp; 240 cms; SM.6 has also 360 cms width; variety of effects of effects; on all fabric-woven and knits; each roller with self-breaking motor; device to quickly block and release the emery; devices for automatic fabric tension control and change fabric angle to the roller; suction cleaning of roller and brushing of fabric; options for automatic stop at seam and restarting; variable speeds for each roller; rotation of roller in both directions; sueding of reverse side of fabric; computerized control programme and memory for all working parameters.</td>
</tr>
<tr>
<td>Rimer, Italy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sucker-Muller-Hacoba</td>
<td>SF-4C</td>
<td></td>
</tr>
<tr>
<td>---------------------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>Suitable for all types of finishes and fabrics; special mode of fabric guidance for elastic articles to reduce fabric creasing; powerful roll drives to speeds of 950, 1200 or 1600 rpm, settable with step pulleys; beater roll device to clean emerized fabric surface; automatic seam passing; digital display of emerizing rolls; variety or rolls-cylindrical, slat-type with 2 or 5 beater edges, brush slat or solid brush rolls for different sueding effects; enclosure for protection and noise reduction from low frequency slat rolls; special air inlet sound absorbers for extractor; extra unit for emerizing reverse side in a single cycle.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Germater, Germany</th>
<th>Multisystem DE (Optisystem 6725/6726, Multisystem 6728 and machines; Twin system 6730 is Convertible Raising Machines for Emerizing (6))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Special emerizing control module; advantages of both flat and drum flexibility to process a wide variety of fabrics including very sensitive ones; electronic controls for smooth start up and breaking; patented 3 star emerizing roller settings - 24 rollers out of 36 in use at a time and fully automatic change over in 3 minutes; total machine alteration for a new function in less than 1 hr, high rpm of emerizing rollers.</td>
<td></td>
</tr>
<tr>
<td>Company</td>
<td>Model</td>
</tr>
<tr>
<td>------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>Sperroto Rimer, Italy</td>
<td>Plurima (wet sueding)</td>
</tr>
<tr>
<td>Lafer, Italy</td>
<td>Aquasand Multi-action Sueding Machine</td>
</tr>
<tr>
<td>Lafer, Italy</td>
<td>GRI 200 Raising/Sueding Convertible Machine</td>
</tr>
<tr>
<td>Company</td>
<td>Machine Type</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Torres</td>
<td>Micropunt 153</td>
</tr>
<tr>
<td>Lamperti SPA, Italy</td>
<td>Type SMB</td>
</tr>
<tr>
<td>Chien Lun, Taiwan</td>
<td>Flat Sueding Machine</td>
</tr>
</tbody>
</table>
Menzel Type MSM Hand wheels to adjust contact Germany rollers between sueding rolls and dial indicators; strong and durable idler, spreader and draw roller at inlet for proper fabric feed; variable speed drive and differential in draw rolls and tension bars for tension control; five sueding rolls with choice of sanding grits; transparent unbreakable covers for viewing of sueding rolls; lint collection ducts and devices; factory-tested electrical control panel; high exit frame with powered drive rolls and rider roll.

<table>
<thead>
<tr>
<th>Company</th>
<th>Model</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paulus Henri</td>
<td>Ecotronic BRTK CBTK</td>
<td>Raising-cum-emerizing Belgium machines</td>
</tr>
<tr>
<td>Comet, Italy</td>
<td>PM 88/S</td>
<td>Sueding machines having all the regular features.</td>
</tr>
<tr>
<td>Dhall, India</td>
<td>Emerizing machine</td>
<td>All features of a modern emerizing machine.</td>
</tr>
<tr>
<td>Redman, USA</td>
<td>DuraSuede (Emerizing Roll Surface)</td>
<td>New flexible sueding wire to replace sandpaper of sueding rolls; an exciting replacement; wire with speciality treated surface for high abrasive action; gives uniform emerizing; long life to eliminate frequent paper changes; better fabric strength retention; no dye smear of dyed/printed; no abrasion marks; wire can be tailor-made for new effects.</td>
</tr>
</tbody>
</table>
2.6.1 Brushing machines

The brushing machine is intended to make the cloth level and clean; it removes loose fibres and foreign matter which may have become entangled with the pile and also can be used to raise the tips of the fibres before shearing. Brushing may also follow shearing to remove any loose-cut fibres.

The brushing treatment is often combined with steaming to remove press glaze; alternatively, brushing may be employed to lay the pile in one direction where it is fixed by the action of steam. The usual type of machine comprises two brush cylinders, the bristles being of different quality to suit various types of work, arrangements can be made whereby the fabric strikes each brush twice. The amount of contact may be varied by a simple can device, or by lifting the fabric on rollers.

The machines include drum and table raising machines. The raising elements used are predominantly flexible wire hooks whose, design versatility and geometric arrangement have reached a sophisticated level of development. Generally very few efforts are known to be undertaken in order to do research into the use of novel elements for finishing of textile surfaces.

The various factors that affect the raising process are:

a) The raw material
b) The cloth structure
c) The raising conditions such as moisture, presence of acids or alkalis, neutral salts, lubricants etc.
For example, coarser fibres of long staple are particularly suited for the production of rugs and blankets, while finer materials are best suited for the production of fabrics in which a sharp, dense pile is required. Plain weave fabrics are the most difficult to raise and fabrics with long weft floats yield the most pile. Greater the number of wefts (the number of warp remaining constant), the more difficult the fabric to raise. As the twist in the yarn increases, the fabric becomes more difficult to raise. Wet cloths are easier to raise than dry cloths, unless raising is done for long periods. As a result, the moisture content of the fabric should be maintained constant, otherwise uneven results would be obtained. With viscose rayon, excessive moisture should be avoided. Acids and alkalis favour raising. Hence woolen fabrics containing acids or alkalis are easier to raise than those which are neutral. Swelling agents and lubricants facilitate raising. Agents, which depress swelling, hinder raising.

The raising process subdues the colour in the fabric, softens the outlines of the design and improves the handle. It is used to develop some structural features and to prepare the fabric for other processes like napping. Fabrics may be raised either in the wet condition or in the dry condition, the former being used to produce a laid pile.

Fabrics, which are difficult to raise, take long time to raise. However, it is not advisable to raise quickly as it produces rough and uneven pile, but there are limitations to the time which might be spent on this process. The speed of raising of wool depends on the setting of the machine and on the fabric properties. For example, the more heavily felted the cloth, the longer will it take to raise a given amount of pile. Denser the cloth, closer and finer the pile produced. Dyed fabrics raise differently from undyed fabrics. Acid dyes are harmless in this respect except some brown acid dyes that cause a substantial reduction in the amount of pile produced.
by a given treatment on the raising machine. In the case of wool, dyeing with acid milling dyes, neutral dyeing acid, dyes, direct dyes and chromic dyes causes the fabric more difficult to raise but fabric dyed with 1:1 metal complex dyes 1:1 metal complex dyes are easier to raise than undyed fabrics. Uneven raising may also be due to improper setting of teasels or by wrong adjustment of the card wire machines. Excessive counterpile action yields fabrics with horizontal streaks and the uneven results may arise from the fabric with tight or slack selvedges. Uneven setting of teasels and wrongly designed selvedges lead to torn selvedges. Fabric with unusually long selvedges should be avoided though they ensure that the fabric does not curl during scouring and milling; they are very easily raised. The most serious defect of raising is the strength loss the fabric undergoes during raising. The raising action is mainly confined to weft threads. Hence, there is a considerable strength loss of weft yarns. Fabrics which require a high degree of raising should have a strong weft yarn.

In the gig or teasel machine, the fabric is passed over a revolving cylinder which is covered with teasels. The teasels wear out rapidly. In another type of raising machines, the rollers are covered with card clothing. The double action machine has two sets of rollers called "pile" and "counterpile" in one of which the point of card wires faces the direction of rotation, while in the other the clothing is in the opposite direction. The cylinder and the fabric rotate in the same direction and for maximum degree of raising, the pile rollers are run as slowly as possible and the counter pile rollers more as quickly as possible.

2.6.2 Peach Finish

The mechanical finishing is one area in which finishers are able to bring a high degree of flair to fabric characteristics. The innovation in
Surface effect finishing has added value and product differentiation potential. A large number of new generation surface effect finishing machines have come to the market through machinery manufacturers like Lafer, Sperotto Rimar, Biancalani, Dantipaelo and Caru. Fisher (1993) has described peaching as sanding because tightly woven or knitted structure of fabrics is passed over a rotating high speed rollers covered with emery cloth or sand papers. It literally cuts or abrades the surface filaments and consequently changes the fabric surface and its mechanical properties. This surface finish creates a visual effect and different hand on the material without weakening the fabrics. Emerizing, sanding, sueding, raising, peaching are some of the descriptions of the same finish. The final effect resembles that of a suede or a peach skin as is produced by broken filaments while creating a soft nap or pile on the surface of the fabric.

Kakiuchi Mamuru (1996) states that napping the woven fabrics comprising of cellulosic fibres or their blends with synthetic fibres results in a smooth surface. Partial breakage of cellulose fibres in warp yarns and treating the fabrics with cellulose degrading enzymes would create peach skin like surface on the fabrics. Rudie (1997) states that peaching processes to impart a light peach skin finish to the khaki pants by which the Friday wears and the popularity of golf apparel sales had increased. They provide a more formal look while maintaining comfort and a casual feel. It is often desirable to have a face finish which possesses a suede like hand. The face finishing is accomplished by the mechanical raising of some of the fibres from the surface of the fabric to create a suede effect. Bueno et al (1997, 2001) have demonstrated that the surface hairs on the fabrics due to sueding and raising process can be measured by an optical multi directional roughness meter. The multidirectional roughness meter provides information about the fabric surface state and the fundamental directions of fabric relief. Bueno’s contribution to the sanding of fabrics is a significant
one, as it characterises the fabric surface. His work has demonstrated that the multidirectional - tribometer method is superior to the KES-F surface tester for the characterisation of various finishing processes.

2.6.3 Brief history on Peach finish

The first peaching machine was built in the early 1900 for the leather industry. Lafer's and Torres Maquinaria Teatil have introduced sueding machine to textile fabrics. This was developed with a joint effort between Lee dyeing company, Richard Evans and Curtin Herbert Company. George Curtin Sr. Italian Machine Company has opted to use light weight composite fibre rather than a traditional steel construction for the rollers on its latest raising machine. Hall and Boyden, U.K., have recently introduced an emerizing into its product range. Infinite variations of fabric tension, emerising roller speed and fabric impeachment are possible on its emerizing rollers and the machines designed to allow their easy removal for emery cloth changes. The machine was installed at Halley Stevenson Ltd., Dundee, Scotland.

Danti Paolo's new raising machine has special features like automatic loading of the fabric on to the main drum automatic raising, processing speed, and allowing high production with the same effect.

Parex Riley and Parex Mather have introduced new raising machines incorporating several improvements, offering increased production, a high speed cylinder with fabric speed between 10 to 40 meters per minute. The machines feature simple to use quick and accurate adjustment easy card wire change over without removing the rollers.
Sperotto Rimar, an Italian based company has focused attention on accurate control of fabric tension in its vetena and with its plunima machine has opted for a wet sueding technique. According to speratto, dry sanding produces a dense and accelerated surface pile due to the partial removal of fibrous material, whereas wet sueding achieves surface softening without pile formation that is discernible to the truck, as well as a discoloured or aged appearance. The water performs a kind of lubricating action on the fabric producing a more superficial abrasion and removing a less fibrous material.

2.6.4 Methods of producing peach finish fabrics

According to M.Tech. (1997) sueding is the process by which the fabric runs through the machine horizontally, transported through frequency controlled drawing and draw off rollers driven by a variable speed gear. These ensure stepless and constant tension and crease free feed of the fabric into the sending zone by a speader. The sending zone itself comprises five cylindrical aluminium rollers covered with emery papers driven by individual brake motors. Adjusting the angle of contact with the rollers and the grain size of emery used varies the intensity of the sending effect. The most common grain sizes are between 180-800 grains per cm². The best effects can be obtained using more than one-grain size in a single pars with the first rollers using coarser emery than later ones.

Biancalani has developed a technique that achieves the handle and loops of an enzyme treatment with less of no enzyme product. The technique uses a combination of 2 machines (Retra and Airo). A Retra machine achieves a superficial abrasion of the fabric causing mirror fibrillation. Airo machine softens and dries the fabric, enhancing the micro fibrillation effect.
The abrasive action is very delicate avoiding breakages fraying and ragging. The fibres retain original properties practically unaltered. This is modular in construction; each module has a wetting and moisturizing section and a set of bars. After each set of bars, a couple of squeezing rollers provides the fabric and also eliminates excess water from wet fabrics.

Sperotto Rimar has introduced wet sanding machine which operates with constraint and control tension to avoid both side - centre side controlled by a roller, operating parameters key board, monitor and controlled via a PLC. The sending rollers are covered with special synthetic abrasive material. The machine can process all kinds of light and heavy woven fabrics of natural and synthetic fibres at speeds between 10-30 m/min, one model allows fabric treatment on both sides during a single step.

2.6.5 Characteristics of peach finish fabrics

Peaching / emerizing changes and softens fabric handle and gives the fabric a greater degree of warmth. Application of emerizing to synthetic fibres can reproduce the properties of national fibres and the resulting fabrics would provide easy care substitutes for the natural fabrics. Recent environmental awareness has resulted in a general public animosity towards chemical processing.

It has been Asio found that sueding, emerising, finish improves moisture retention properties with good wash fastness for synthetic fibres natural fibres or composites. Marie Ange Bueno (1997) has reported that sanding and raising changes the fabric surface with the formation of dense hairiness and hide the fabric structure and makes the surface smoother.
2.6.6 Effect of peach finish on yarn and fabric structure

The contribution of yarn structure to the visual aesthetic qualities of a fabric is transmitted mainly through the surface geometry of the constituent yarn in texture. Softness and bulkiness of a fabric are aided by yarn structural features. Many of the fabric aesthetics attributed to yarn structural features are modified to some degree in fabric finishing. In fully brushed or semi brushed fabrics, the textural features of the constituent yarns tend to be masked.

Peach finished fabrics have special features like yarn hairiness, yarn flatness, fibre packing density etc. and play an important role on the fabric surface and yarn structure. The spun yarn provides a unique combination of structural features that contribute a constantly varying or a kind of natural textural appearance to fabrics. All the features that contribute by spun yarn texture are to provide visually subtle surface roughness, a fair amount of softness, good bulk or cover power and low lustre in apparel fabrics. The appeal of apparel fabrics depends on the interaction of the visual effect of fabric texture and its feel in the hand of the consumed.

Table 2.6 summarises the summary of research work done on the fabrics.
Table 2.6
Summary of Work Done on Peach Finish

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Authors</th>
<th>Year</th>
<th>Types of fabrics used</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Mitsuishi Hisayasu Nishina</td>
<td>1982</td>
<td>Cotton, polyester spun, polyester filament, polyester cotton, 65/35 blends</td>
<td>Paper raising and washing were found to improve fabric hand</td>
</tr>
<tr>
<td>2.</td>
<td>Mitsuishi</td>
<td>1984</td>
<td></td>
<td>The effect of raising on the structure and properties of finished fabrics has been studied.</td>
</tr>
<tr>
<td>3.</td>
<td>Deboos</td>
<td>1988</td>
<td></td>
<td>Effect of surface finishing on the physical properties of wool fabrics has been studied.</td>
</tr>
<tr>
<td>4.</td>
<td>Postle, Dhingra and Liu</td>
<td>1989</td>
<td></td>
<td>Peach finished fabrics were studied for surface roughness.</td>
</tr>
<tr>
<td>5.</td>
<td>Holme</td>
<td>2002</td>
<td></td>
<td>Emerizing, sanding and sueding machines have been used to finish polyester micro fabrics. These impart a peach like surface.</td>
</tr>
<tr>
<td>6.</td>
<td>Matsudaira and Matsui</td>
<td>1992</td>
<td></td>
<td>Peach finished fabrics were evaluated which showed changes in mechanical properties and fabric hand. By using discriminant analysis with the primary hand values as variables, a distinctive zone of silk-like and peach - skin like fabric hand was demonstrated.</td>
</tr>
<tr>
<td>8.</td>
<td>Chatterjee, Mukhopadhyay, Mitra and Samantha</td>
<td>1997</td>
<td></td>
<td>Effects of raising on the mechanical properties of jute/ polypropylene fabrics was studied. It was found that raising increased fabric tenacity, abrasion and compressional recovery.</td>
</tr>
<tr>
<td>9.</td>
<td>Paul and Naik</td>
<td>1997</td>
<td></td>
<td>Possibility of peach finish to denim is discussed.</td>
</tr>
</tbody>
</table>
Candan and Onal (2002) have conducted studies on the shrinkage of weft knitted fabrics by subjecting them to several laundering cycles followed by tumble drying. It has been found that double pique fabrics shrink less widthwise but more lengthwise than the other types. Yarn type and fibre blend have a relatively more significant contribution to fabric shrinkage lengthwise than widthwise. However, the contribution of yarn fibre blend in width shrinkage. A reverse proportion between fabric tightness and the direction of fabric shrinkage has been noticed. Width shrinkage increases with the increased tightness factor as the laundering process progresses. Hence, the tighter the fabric, the higher the width shrinkage during laundering. The relation is reversed for length shrinkage.

Chen et al (2002) have reported on relaxation shrinkage characteristics of steam-ironed plain knitted wool fabrics. It has been found that the dimensional changes of steam ironed fabrics are identified as depending on yarn linear density, fabric, tightness, antifelting treatment of wool yarn, and the degree of extension imparted to the fabrics during steam ironing. Further analysis also shows that whether or not the fabrics are treated with steam ironing and regardless of the extensions imparted during steam ironing, all fabrics with the same yarn and knitting parameters approach similar dimensions and shapes after IWS 7A washing.

Wakida et al (2000) have carried out an investigation on the effect of liquid ammonia, sodium hydroxide/liquid ammonia and subsequent cellulase treatments on mechanical properties of cotton fabric. Shearing and bending hysteresis curves show that the parameters G, 2HG, B and 2HB decrease with the ammonia treatment. Although independent cellulase treatment decreases the parameters and produces a soft handle, the combination with ammonia, sodium hydroxide and ammonia and with subsequent cellulase is much more effective at improving hand.
Harlock and Ramkumar (1997) have investigated the effect of knitted structural variables on the low stress mechanical properties of cotton rib knitted fabrics. Their conclusions are that the mechanical properties of fabrics influence the handle and quality of fabrics; and the structural parameters have a unique role in determining the handle. The lighter the fabric, the better the consumer ranking.

Ramkumar (2000) has dealt with the handle of 1 x 1 cotton rib fabrics. He has also made refinements in characterising the friction of fabrics. Initially, he suggested a new friction constant

\[
K = \frac{1}{C^{1-n}} \quad \text{(2.2)}
\]

where 'C' and 'n' are constants. Later, this was changed to R, which is equal to C/n. This, he feels can be used for comparing different fabrics. He has demonstrated the validity of this parameter, in respect of enzyme treated fabrics. Ramkumar et al (2002) have studied the effect of sliding velocity on the frictional properties of non woven fabric substrates utilizing the new friction factor 'R'. It was found that R which is equal to C/n could reflect changes in weight of the non woven fabric substrates.

Ramkumar et al (2003) have reported on an ingenious method of determining frictional properties of fabrics. A polymeric artificial human finger sensor fabricated from polyvinyl siloxane material was found to emulate the feeling mechanism of the fingers. This polymeric sensor was converted to a friction sledge which could be used to measure the frictional properties of fabrics. Using this sledge, Ramkumar et al (2001) report on the frictional properties of knitted fabrics. Another ingenious method that was used was the reciprocating sliding friction apparatus to simulate the actual to- and fro- reciprocating motion of a human finger on a fabric. It was found
that both loop length and yarn linear density influenced the frictional interaction of the artificial finger sledge on knitted fabrics. This apparatus has the potential of characterising the frictional feel and handle of fabrics. Thus the work of Ramkumar is a significant contribution to friction.

De Arjauo et al (2002) have dealt with the modeling of the mechanical behaviour of weft-knitted plain structure. They have considered knitted structures made from glass fibres on a flat knitting machine and have predicted the stress strain properties. Further, they have also predicted the mechanical properties of a composite material which is nothing but a knitted fabric impregnated in resin. Kurbak and Bayazit (2000) have carried out work on the dimensional changes in rib fabrics knitted with presser foot and conventional take down systems. It has been found that course spacing of rib fabrics knitted conventionally is always greater than the presser foot knitted ones for all relaxed conditions. The wale spacings do not change much with relaxations.

Cheikhrouhou, Msahli, Zitouni and Sakli (2001) have recently reported on the influence of stitch length on knitting control parameters. The factors affected are mass and thermal insulation power. That a decrease in the mass per unit area results from an increase in the stitch length and that the quantity of yarn consumed decreases as a consequence of this has been demonstrated by them.

Xin, Hu and Yan (2002) have used a fractal vector derived from different scales to describe the roughness of a fabric surface and applied the Baye's classification method to classify the appearance grade of Polar fleece objectively. For this study, a set of 15 commercially available polar fleece fabrics with different colours was used. Their results showed that good correlation could be achieved between calculated and grades and subjective grades.
Kurbak (1998) has dealt with the dimensions of plain knit fabrics. He has derived some complicated equations, and has validated them. His main focus is the use of presser foot instead of the regular take down motion in the knitting machine and its effect on dimensional properties.

Higgins, Anand, Hall and Holmes (2003) have reported on factors during tumble drying which influence dimensional stability and distortion of cotton knitted fabrics. The length and width shrinkages, skewness, spirality and moisture content of three weft knitted cotton structures, plain single jersey interlock and lacoste were determined at regular intervals during tumble drying. Significant length and width shrinkages occurred in all three structures with the amount of shrinkage increasing rapidly in plain single jersey and lacoste as the moisture contents fell below 30 percent. Distortion was less affected by tumble drying. An attempt was made to isolate the effect of heat and agitation during tumble drying. It has been demonstrated that similar patterns of shrinkage and distortion occur whether heat is applied during tumble drying or not. The tumbling action in a tumble drier has the greatest influence on the dimensional stability and distortion of weft knitted fabrics.

Chen, Au, Yuen and Yeung (2000) have conducted studies on the effects of yarn and knitting parameters on the spirality of plain knitted wool fabrics. That the twist factor of two-ply wool yarn, loop length and fibre diameter affect spirality have been pointed out by them. In general, increasing the twist factor of two ply yarn loop length and fibre diameter increases the angle of spirality. They have used the experimental data to derive empirical equations linking the angle of spirality to the twist factor of two ply yarn, loop length and fibre diameter in both the dry relaxed and simulated industrial relaxed fabrics. The most important result is that relaxation treatment of fabrics in water decreases the angle of spirality.
A paper by Dias and Lanarolle (2001) describes the stitch length variation in circular knitting machines due to yarn winding tension variation in the storage yarn feed wheel. Several fabric samples were knitted with different winding tensions to the storage yarn feed wheel, and the stitch lengths of the samples were measured. Their results show that the stitch length is largely affected by the winding tension to the storage yarn feed wheel.

N. Ucar, Realff, Radhakrishnaiah and M.Ucar (2002) have carried out a study on the bagginess of knitted fabrics. They have found that it is possible to predict bagginess of knitted fabrics from the mechanical properties obtained from Kawabata system. By measuring shear and bending parameters of fabrics it is possible to evaluate the bagging properties of knitted fabrics.

2.7 THE HANDLE OF FABRICS

A considerable amount of work has been done on the handle of fabrics, and this section gives a brief overview of the handle of fabrics.

2.7.1 Objective Evaluation

Peirce (1930) was the forerunner in the area of handle, followed by Dreby (1942) who considered pliability smoothness and fullness to be important to the handle of fabrics. Vaughn and Kim (1975) have measured mechanical properties and expressed handle. Bishop (1996) has summarised different test methods which are closely associated with fabric hand. It is evident that there is a correlation between the mechanical properties of fabrics and handle. The following section gives a brief overview of the instruments which are used for measuring low stress mechanical properties.
Total fabric character is divided into four categories: aesthetics, comfort, performance, and tailorability. The study of every particular category is of course essential, but in reality, the hand determines the value of fabric.

Binns (1926) employed people with a wide range of background—from teen ages to adults, and from dress-goods experts to teachers with no textile appearance—in order to investigate the hand characteristics among different groups and individuals. Howorth and Oliver (1958) employed a multi-factorial analysis and found that the most significant subjective terms are smoothness, stiffness, and thickness or weight.

2.8 GEOMETRICAL MODELS OF THE PLAIN KNITTED STRUCTURE

Chamberlain (1926), Peirce (1947), Leaf and Glaskin (1955), and Leaf (1960) have made attempts to define geometrically the configuration of the unit cell, the loop of a plain knitted fabric.

The earliest models were based on the assumption that the basic structure was such, in which the shape of the loops was a simple arrangement of parts of circles and arcs joined by straight lines. Peirce (1947) also assumed that these loops, in which maximum packing of the yarns had taken place, lay on a cylinder to allow for the three-dimensional properties of the knitted loop. The basic fabric parameters such as the wale-spacing, the course-spacing, and the stitch length depended on the yarn diameter (the wale-spacing and the course-spacing were 4 times and 3.4643 times the yarn diameter, respectively, and, the stitch length was 16.66 times the yarn diameter). However, in reality, many knitted structures do not obey these constant dimensions. In the situation involving any increase or decrease in the stitch length without changing the yarn diameter, since the
wale- and course- spacings are constant it is not possible to generate different plain-knitted structures. For any given value of yarn diameter, the stitch length must be determined by other fabric parameters. Hence Peirce's theoretical results did not agree with the practical results.

Peirce (1947) tried to overcome those limitations by introducing extra spaces along the wale line and course line in the centre of each stitch for obtaining the desired relationship between the stitch length, the wale-spacing, the course-spacing and the yarn diameter for his model. The stitch length was then deduced as a function of the wale-spacing, the course-spacing and the yarn diameter. However, Peirce did not apply these variations in the shape of the stitch model to fitting the extra yarn length. This relationship is therefore quite arbitrary and reduces the generality of the stitch model. Peirce's geometrical model, although can be used to estimate the relationships between fabric dimensions, is not suitable for the graphical representation of plain-knitted structures in terms of the desired fabric parameters.

Shinn (1955), based on an indepth study Chamberlain's 2-D model deduced that the stitch length was a function of the yarn diameter and that it was sixteen times the yarn diameter. In this way, the variations in the length of a stitch were limited by the yarn diameter. However, for a given yarn diameter, it is possible to produce a plain-knitted structure that has different lengths.

Leaf and Glaskin (1955) analysed the path of the central axis of Peirce's model as a 3-D curve by obtaining the torsion or twist and curvature produced by bending the yarn into the stitch shape. Their expression for torsion showed discontinuities along the stitch. It was therefore concluded that a stable fabric could not be built up from stitches of the type proposed by Peirce (1947). Leaf and Glaskin (1955) proposed a
new 3-D geometrical model for a plain-knitted structure in which the torsion was continuous at all the points of the stitch. The projections of the central axis of the yarn laid on the surface of a series of circular cylinders, whose generators were perpendicular to the plane of the fabric. The authors concluded that fabric dimensions depended on the cover factor, not the stitch length.

Demiroz and Dias (2000) created realistic images of knitted structures on a computer screen based on a geometrical model. The concept was to fit the unit cell, i.e. a stitch within a raster representing the yarn diameter the course - spacing the wale-spacing and the stitch length.

Leaf (1960) in his model assumed, that the loops consisted of two elasticas joined as mirror images and that these loops lay on a surface whose cross section was a sine function. "Unfortunately, this model of the loop cannot be regarded as indicating the mechanism by which the loops are actually produced. The form of the elastica assumed requires that the cloth has a tension on it and also requires the pressures that must exist at the cross-over points (Postle, Carnaby and de Jong 1988).

Chen, Au, Yuen and Yeung (2003) have investigated the effects of yarn and knitted parameters on the spirality of plain - weft-knitted wool fabrics. Their results show that the twist factor of two ply wool yarn is the most important factor influencing fabric spirality. Loop length and fibre diameter also show significant effects. In general, increasing the twist factor of two-ply yarn, loop length and fibre diameter increases the angle of spirality. The experimental results demonstrate that relaxation treatment of fabrics in water decreases the angle of spirality. The experimental data also lead to the derivation of empirical equations linking the angle of spirality to the twist factor of two-ply yarn, loop length, and fibre diameter in both the dry relaxed and simulated relaxed states.
Choi and Lo's (2003) paper in which they have proposed a new mathematical model describing a plain knitted fabric is an interesting study. One major feature of this model is that the yarn in the fabric can be naturally covered with non-linear mechanical properties. The new model is able to describe the dimensions and also the low stress mechanical properties of a plain knit. Based on an energy analysis, the inadequacy of the classic K-values is explained. A more precise prediction of fabric dimensions is possible by including the degree of set as one of the parameters.

Yamada, Ito and Matsuo (2003) have analysed the application limits of the linearizing method by Kawabata et al (1998) in terms of Hook's law by using a rectangular coordinate system rotated by an arbitrary angle $\theta$ from the coordinate system along the principal structural axis direction. The method is essentially a modification of the infinitesimal elastic theory. Estimations are made by strip-biaxial and uniaxial extensions. The predicted results are in good agreement with the results for specimens with symmetrical deformation. The parameters obtained by strip biaxial extension can be used to predict the load-strain relation under uniaxial stretching with a dimension free in the transverse direction, and again agreement is good. In contrast, application is very difficult for fabrics with considerable asymmetrical mechanical anisotropy and strong non-linearity. Even so, it is obvious that the linearizing method is a useful technique for predicting the mechanical properties of many kinds of fabrics with symmetrical structures $< 20\%$ with wear of because of practical strain.

Candan and Onal (2002) report on the dimensional, pilling and abrasion properties of weft-knits made from open end and ring spun yarns. It has been found that the knitted fabrics made from blended yarns, namely, polyester/cotton 50/50 have a lower dimensional stability when compared to fabrics made from 100% cotton ring and open end spun yarns. Lacoste
fabrics perform well due to their low pilling tendency compared to single jersey fabrics.

In the case of the two thread fleece structure, fabrics from 100% cotton (i.e., both face and fleece yarn) open end yarns have higher pilling rates compared to FBOE (face yarn is cotton, fleece yarn is 50/50 PET/cotton) and FBB (both face and fleece yarn are 50/50 PET/cotton) fabrics. One interesting point is that any damage occurring as a result of repeated launderings and pilling tests is not as severe as that reported in the literature. They have found that the lacoste fabrics have the least resistance to abrasion.

Candan, Nergis and Iridag (2000) have studied the dimensional and some physical properties of a series of plain jersey and lacoste fabrics made from both cotton ring and open-end spun yams. Their results show that structural differences in the yarn play a large part in determining the dimensions and behaviour of these two fabric types. The amount of relaxation shrinkage occurring with open-end spun yarn is greater than that with ring spun yarns. Ring spun yarn knits have performed slightly better than open-end spun knitted fabric.

Yan, Hocker and Schafer (2000) have investigated the handle of bleached knitted fabric made from fine yak hair. They used FAST system to assess the quality of knitted fabrics. Results of amino acid analysis and SEM investigations are used as a basis for discussing the reasons for handle impairment. They have suggested an improved process for better handle and less fibre damage for fine yak hair. Abou-Hann, Youssef, Pastone and Gowayed (2003) have developed an automatic fabric evaluation system for analysing knit structures and evaluating fabric properties objectively. Fabric images are captured with a CCD camera, and digital images are processed by histogram equalisation, binary morphological operators, and pattern
recognition. This technique can evaluate courses and wales per unit length, fabric cover and weight per unit area. The knitted fabrics have been tested after various processes and at different relaxation conditions and the structural changes that occur have been documented with the new approach. The fabric structural parameters evaluated by the automatic fabric evaluation system compare favourably with those measured by manual techniques.

Savci, Curiskis and Pailthorpe (2001) have reported studies on the knit ability of glass fibre weft-knitted preforms for composites. The results of the electron microscope study imply that needle breaks are due to tension peaks as a result of variations in the coefficient of friction, input tension and needle imperfections. The number of needle breaks indicates the difficulty of knitting with glass fibres, but the knittability of glass fibres is also established for the full milano structure with respect to fabric tightness and specific stitch cam settings. The study also covers an assessment of fabric geometry with glass fibres. The results of Savei's research demonstrate the presence of loop distortion in the preforms due to the yarn twist and the coefficient of friction between the knitting elements.

Bayazit (1999) has made a comparison of the dimensional and physical properties of four pique fabrics with single jersey fabrics. For this purpose, he used two counts, 18\(^s\) (32.81) and 20\(^s\) (29.52) rotor cotton yarns for producing five types of weft-knitted fabrics each with three loop lengths. The fabrics were subjected to dry and full relaxation treatments and studied for dimensional and physical properties. The major findings of the study are that tucks cause an increase in physical properties like air permeability, abrasion resistance and dimensional properties. The paper by Bayazit is a useful one as it is targeted at the study of the structure property relationship of weft-knitted fabrics. Using the same type of cotton yarns, the structures were varied which included single jersey, and pique fabrics.
De Araujo and Neves (1986) have reported on the influence of run-in ratio on the dimensional properties of single jersey pique fabrics. Using different types of combed cotton yarns, the authors had produced 84 samples with the run-in ratio ranging between 0.7 to 1.3. They have studied the fabric geometry, fabric width, fabric areal density and fabric thickness and have found that run-in ratio affects most of these properties. The interesting aspect of their work is the effect of run-ratio on fabric aesthetics. A decrease in this parameter increases the pique effect while the reverse makes the fabric appearance become twist like. This has been attributed to the bowing-out of the plain loops in the course containing tuck stitches, and it becomes more pronounced for the thicker fabrics. The authors conclude that the run-in ratio is found to be a very useful parameter for fabric engineering.

Bayazit (2003) has investigated the dimensional and physical properties of cotton/spandex single jersey fabrics, and compared these with the fabrics knitted from cotton. The results show that at the amount of spandex increases, loop length values remain nearly the same and the course and wale spacing values decrease. Fabrics knitted from spandex were found to be tighter and heavier, but air permeability, pilling grade and spirality were lower.

Ramasamy and Annadurai (1998) have reported on a comprehensive work on the study on the dimensional properties of single jersey derivatives. Using 34s (17.36 tex) combed cotton yarns three structures namely single jersey double lacoste and fredperry structures were produced with different loop lengths.

Grey cotton fabrics are produced under high stress and extension, and thus exhibit large and varied amounts of shrinkage. Measurements of shrinkage in grey fabrics are therefore of little value to fabric finishers.
What is most important is the reference state of the fabric and this acts as a target of the norm for assessing fabric dimension behaviour.

The dimensional behaviour of knitted fabrics is dictated by the knitted loop. Peirce (1947), Shinn (1955), Leaf (1955, 1964, 1961), Doyle (1952, 1953), Munden (1959), Postle (1968, 1967), and recently Demiroz and Dias (2000) have significantly contributed to the geometric analysis of plain knitted fabrics. Leaf and Glaskin (1955) have developed geometric model which has been validated for composites by Ramakrishna et al. (2000). Their work is thus very useful to the research workers.

Demiroz and Dias (2000) have created plain knitted fabrics by employing spline curves which is useful in the visual display of knitted fabrics on a CAD system.

Yarn jamming in a knitted fabric has long been identified as a major factor determining its dimensional and mechanical properties. Knapton, Richards and Fong (1970) have concluded that the stability of a cotton loop is reached when yarn bulking is restricted by yarn jamming.

Alternatively, the dimensional properties of knitted fabrics were studied by Hepworth and Leaf (1968), Postle and Munden (1967) and Shanahan and Postle (1970). Postle and Munden (1967), Hepworth and Leaf (1968, 1976, 1978) and Shanahan and Postle (1970) have considered yarn as an elastica a concept put forward by Love (1944) which is naturally straight. Konopasek (1970) also treated yarn as an elastica, and has given a computation scheme for the calculation of knitted fabric dimensions. Mac Rory et al (1975) and Hepworth (1978) attempted to tackle the biaxial load case with the loop elements being straightened while Hepworth's model concentrated on the effect of yarn jamming.
Heap, Greenwood, Leah and Eaton (1983) have reported extensive experimental work in their STARFISH project. One of their objectives was to predict the dimensional changes of finished knitted cotton fabrics of some selected structures based on the knitting parameters and finishing route. In their prediction, the dimensional changes were measured against the so-called reference state of a fabric. This very important reference state was assumed to be reached by a vigorous relaxation process of five wash and tumble drying cycles. Heap et al (1983) noted that further relaxation after five cycles might still result in further dimensional changes, even though these changes might be small. A theoretical model will be a solution to the situation such that a theoretical reference state can act as a guide to the effectiveness of relaxation processes. Such a model must be relatively simple and able to interface with the fabric actually knitted by a machine and recently Choi and Lo (2003) have developed a new energy model of plain knitted fabrics.

Soe, Kyaw Matsuo, Nakajima and Takahashi (2001) have recently reported on compression property of wool weft-knitted fabrics based on the yarn property. Toussi, Khorram and Jeddi (2001) have studied the influence of yarn variations on the spirality of double jersey knitted fabrics. Wang Libing, Hu and Chan (2001) have investigated the influence of stitch density to stitches properties of knitted fabrics. Maroufi, Harlock and Brook (2001) have reported on the effect of cotton interlock knitted fabric parameters on wicking behaviour. Chen, Qihong, Au, Yuen and Yeung (2001) have studies the dimensional properties of plain knitted wool fabrics in the industrial relaxed state. Woollen yarns were knitted on a coarse gauge fladbed knitting machine, and the fabrics studied for their dimensional stability. They have found that Munden's constants do not hold good for the fabrics subjected to full relaxation treatments. Dias and Lanarolle (2002) report on the stitch length variation in the storage yarn feed wheel in circular weft-knitting machines due to yarn winding tension variation.
Zhuang, Harlock and Brook (2002) have studied the longitudinal wicking of weft knitted fabrics by image analysis. This was found to be more reliable compared to the manual method. Using this set up, the validity of Washburn equation was investigated in vertical and horizontal wicking methods.

2.9 SUMMARY

From the above, it is clear that a considerable amount of work has been done on weft-knitted fabrics on their dimensions and low stress mechanical properties. However, there are certain key issues to be addressed and this has been dealt with in this thesis. A critical analysis of Kawabata's various parameters has been made and new ways of extracting the parameters have been suggested.