CHAPTER 1

GENERAL INTRODUCTION

1.1 INTRODUCTION

Apparel manufacturing in a Quick Response (QR) environment must have the ability to quickly optimise its processes when faced with rapidly changing fabrics with variable material properties. The variability is inherent within a given fabric and between different types of fabric. In order to deal successfully with this challenge, it is necessary to understand how important material properties permeate the manufacturing chain. The important properties are to be measured quickly and reliably (not dependent on traditional laboratory techniques and constraints). It is important to lay the ground work for dealing with property variability in the design of apparel fabrics as well as in the manufacturing and finishing of these products.

New technologies and methods to characterise fabric properties and control textile and apparel manufacturing processes to optimise quality and productivity in a garment manufacturing environment are to be developed. Such of the properties as are essential for the knitted fabrics will have to be determined. The aim of this thesis is to explore the possibility of testing the knitted fabrics using Kawabata Evaluation System (KES). It appears that the whole system needs a complete change as the parameters that are provided do not adequately characterise the fabrics. These issues are addressed in this thesis while studying the structure property relationship of weft-knitted fabrics.
Globally, there is a spurt in the demand for knitwear. This growth in demand can be attributed to the basic properties of the knit fabric like the ability to stretch and adapt the shape of the wearer comfort and softness. Also, there is a growing preference for environment-friendly products. According to industry sources, the share of knits in the apparel retail business in the European Union, USA and Japan is 60%. Currently, some of the knitted fabrics preferred are 100% cotton jersey, pointelles (novelty fabric) of both 100% cotton and 65/35 cotton polyester blends nylon/lycra spandex, stretch lace and cotton/lycra knits.

There are 6600 organised knitwear manufacturing knits in this sector in India, excluding job workers with an annual production of about 1500 million pieces. Knitwear exports from India constituted 48% of garment exports in volume in 1994. The average unit value of cotton knitwear from India is rather poor compared to that of Hong Kong and China.

The major export centre is Tiruppur exporting almost 60% of the knitwear export volume in 1994. The second major centre is Ludhiana. The evolution of knitwear products growth can be seen in four stages (development of greater specialised infrastructure in both these centres is a must for more balanced and quality driven knitwear exports.

Stage I - Vests and briefs.
Stage II - T-shirts, cardigans jersey, pullovers, polo shirts.
Stage III - Outerwear, ladies blouses, trousers, shorts, pullovers, track suits, pyjama, night dresses, shirts, sportswear industrial garments etc.
Stage IV - Garments using technical fabrics, etc.
Of the total knitwear export from India the composition of items is given in Table 1.1.

Value addition in knitwear can be achieved by embroidery, sequin bead, ari/dori work ethnic points, tie and dye.

Table 1.1

Knitwear Exported from India (1993)

<table>
<thead>
<tr>
<th>Items</th>
<th>Share %</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-shirts and blouses</td>
<td>34.9</td>
</tr>
<tr>
<td>Sweat shirt</td>
<td>5.9</td>
</tr>
<tr>
<td>Sweaters</td>
<td>5.8</td>
</tr>
<tr>
<td>Skirts and Dresses</td>
<td>4.7</td>
</tr>
<tr>
<td>Socks</td>
<td>7.8</td>
</tr>
<tr>
<td>Others</td>
<td>27.5</td>
</tr>
</tbody>
</table>


Growth in the knitwear sector between the years 1991 and 1994 has been higher as compared to the woven sector. Average growth rate of knitwear exports is around 35%. In terms of volume, the total share of exports of knitted garments has increased from 26% of the total exports of garments from India in 1983 to 48 percent in 1994, and 17% to 30% in terms of value. About 90% of the knitted garment export is made up of cotton. The share of synthetic and woollen knitted garments, whose value realisation is subsequently higher at US $ 5.78 and US $ 6.34 is hardly around 5% each. The knitting industry is yet to make a break through in sophisticated knit garments like track suits, athletic wear, sweat shirts, shorts, trunks, swimwear, tights body, supporting garments, womens lingerie athe - leisure wear active sportswear etc.
Indian garment exporters have to devise effective transition strategies in the count down period up to MFA (Multifibre arrangement) phase out in the year 2005 AD. These transition strategies are meant to result in increase UVR (Unit value realisation) diversification of product mix, entry into new markets, upgradation in market levels and synergistic marketing. Manufacturing of knitted garments which require higher technology may result in higher UVR. This also calls for a high quality research into the properties of knitted fabrics.

All over the world, while the garments used in the working environments are generally woven, knitwears have succeeded in monopolising the leisure hours. Comfort has taken precedence in the buying criteria and this has brought knitwear into the centre stage. Cotton, silk, synthetic, wool and wool blends are chosen in view of the changing climatic conditions. The Indian knitwear is dominated by cottons, and the woollen knitwear, though substantial at one point of time, declined with the collapse of the Soviet markets.

The cotton knitwear exports registered an increase in quantity from 165.60 million in 1989, to 407 million pieces in 1994. The woollen knitwear declined from 9.9 million pieces in 1987, to 9.1 million pieces in 1994. The combined UVR (Unit value realisation) has shown a marginal change from US $ 2.33 in 1989, to US $ 2.64 in 1994 (Table 1.2).

The knitwear exports in value terms have risen from US $ 420.74 million in 1989, to US $ 1122.6 million in 1994 recording a CAGR (Compounded Annual Growth Rate) of 21.69 percent over this period. The knitwear has gained considerable importance in the garment export industry, and the trend is expected to grow and continue in the next few years with production infrastructure for knitted fabrics and knitwear improving considerably in the recent years.
### Table 1.2

Knitwear Exports from India (1989-94) (Volume in million pieces; Value in million US $, VVR in US $/piece)

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Cotton Knitwear</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>165.6</td>
<td>222.0</td>
<td>243.3</td>
<td>303.0</td>
<td>413.1</td>
<td>407</td>
<td>19.7</td>
</tr>
<tr>
<td>Value</td>
<td>336.12</td>
<td>485.12</td>
<td>511.5</td>
<td>699.2</td>
<td>941.4</td>
<td>1007.9</td>
<td>24.56</td>
</tr>
<tr>
<td>UVR</td>
<td>2.03</td>
<td>2.19</td>
<td>2.1</td>
<td>2.31</td>
<td>2.28</td>
<td>2.48</td>
<td>4.08</td>
</tr>
<tr>
<td><strong>Synthetic Knitwear</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>5.00</td>
<td>7.3</td>
<td>5.3</td>
<td>7.2</td>
<td>9.6</td>
<td>9.9</td>
<td>14.64</td>
</tr>
<tr>
<td>Value</td>
<td>17.29</td>
<td>34.89</td>
<td>22.4</td>
<td>29.2</td>
<td>39.5</td>
<td>57.2</td>
<td>27.03</td>
</tr>
<tr>
<td>UVR</td>
<td>3.46</td>
<td>4.78</td>
<td>4.23</td>
<td>4.06</td>
<td>4.11</td>
<td>5.78</td>
<td>10.8</td>
</tr>
<tr>
<td><strong>Woollen Knitwear</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>9.9</td>
<td>6.60</td>
<td>1.5</td>
<td>2.8</td>
<td>10.5</td>
<td>9.1</td>
<td>1.67</td>
</tr>
<tr>
<td>Value</td>
<td>67.33</td>
<td>41.78</td>
<td>8.5</td>
<td>22.5</td>
<td>71.8</td>
<td>57.5</td>
<td>3.1</td>
</tr>
<tr>
<td>UVR</td>
<td>6.80</td>
<td>6.33</td>
<td>5.67</td>
<td>8.04</td>
<td>6.84</td>
<td>6.32</td>
<td>1.45</td>
</tr>
<tr>
<td><strong>Total Knitwear</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>180.5</td>
<td>235.9</td>
<td>250.1</td>
<td>313.0</td>
<td>433.2</td>
<td>426.6</td>
<td>18.74</td>
</tr>
<tr>
<td>Value</td>
<td>420.74</td>
<td>561.79</td>
<td>542.4</td>
<td>750.9</td>
<td>1052.7</td>
<td>1122.6</td>
<td>21.69</td>
</tr>
<tr>
<td>UVR</td>
<td>2.33</td>
<td>2.38</td>
<td>2.17</td>
<td>2.4</td>
<td>2.43</td>
<td>2.64</td>
<td>2.52</td>
</tr>
</tbody>
</table>


'CAGR' - Compounded Annual Growth Rate

'UVR' - Unit value realisation.
The main items exported are T-shirts followed by cardigans, jerseys and pullovers ladies knitted blouses, dresses and skirts.

Although the knitwear exports have increased over six folds in 10 years, the unit value realisation has been very poor, and it is clear that Indian knitwear are going as very low value added high volume commodity for the discount and mass markets.

A series of articles on structural mechanics of fabrics was published in an issue of the Journal of the Textile Institute to Commemorate, the anniversary of Professor Kawabata’s death.

In the issue of the journal of the textile institute which was published in commemoration of Professor Kawabata of Kyoto University, leading scientists such as Hearle and Postle have contributed papers which deal with the structure property relationship in woven and knitted fabrics. Postle’s paper on structural mechanics of weft-knitted fabrics for apparel and composite materials is noteworthy as it deals with the biaxial extension curves of weft-knitted fabrics. The research group led by Postle at the University of New South Wales, Australia for the past thirty years or so has carried out research on bending, shear, compression and tensile properties of weft-knitted fabrics. Hamilton and Postle (1977) published a number of papers on the bending and shear of weft-knitted fabrics produced from woollen yarns which have contributed to the product design and quality control.

Shanahan and Postle’s work on the prediction of tensile properties of weft-knitted fabrics is a significant contribution and represents a good and well-timed attempt to expose the fundamentals of the tensile properties of knitted fabrics. Their inclusion of setting on yarn bending rigidity and of yarn compressibility are indeed original contributions.
Hu (1994) has predicted the tensile properties of woven fabrics by non-linear regression analysis; thus her contribution to the area of fabric mechanics is a significant one.

1.2 ROLE OF LOW-STRESS MECHANICS OF FABRICS

The science and engineering of textiles and clothing have played an important role in one of the major technological transformations known to mankind, the computer revolution. Textile and clothing plants of the future will be significantly different from the ones of today. The principal functions carried out in the production of textile materials and end products (fibres/yarns/fabrics/garments) namely, product design, production planning and scheduling, manufacturing material handling and distribution will be integrated into a single entity giving rise to a computer-integrated textile enterprise. The implementation of management philosophies, such as quick response and just-in-time, in the textile and apparel industries is requiring increased flexibility, higher quality, and faster response time in new manufacturing systems. Automation and the linking of the processes are two ways to reduce labour, improve quality, and increase productivity. Knowledge based system are required to control highly flexible automated devices for handling limp materials. These computer systems must be able to take fabric property information and predict the fabric bending behaviour or other mode deformation properties during the handling process. The computer algorithm must be based on numerical models for predicting the deformations of typical fabrics. All these need more knowledge, thorough understanding and mathematical models of fabric mechanics especially in low-stress mechanical responses and the relationships with fabric structure than ever before.

The study of fabric mechanics under low-stress conditions which exist in ordinary manufacturing and wear processes, should serve two
sectors, namely, apparel manufacturing and wear performance and fabric formation.

The understanding of the formation mechanisms of fabrics is useful for fabric design and process, control, and includes the investigation of the relationships between fibre properties, yarn structure, fabric, construction and fabric properties on the one hand. Low stress mechanical responses are related to fabric hand, quality and performance. Therefore low-stress structural mechanics can be applied to quality control, process control, product development, process optimization and product specification clothing construction automation of clothing manufacturing and computer-aided clothing design.

1.3 PREVIOUS STUDY ON THE MECHANICS OF FABRICS

The study of woven fabric mechanics dates back to very early work reported by Haas (1912) in the German aerodynamic literature at the time of worldwide interest in the development of airships. The work of Peirce (1937) presented a geometrical and a mechanical force model of the plain weave structure, both of which have been used extensively and modified by subsequent workers in the field considerable progress has been made over the last 70 years in the development of the theory of geometrical structure and mechanical properties of fabrics. Responding to the demands from industry, the investigation of the geometry and mechanical behaviour of fabrics moves successively through observation, explanation and prediction. The main advances were included in the two books edited by the leading figures; Hearle, Grosberg Backer, Thwaites, Amirbayat, Postle and Lloyd. Some progress, in this process resulted in the birth of the Kawabata Evaluation system for fabric testing which proved to be beneficial for the objective measurement of fabric and clothing manufacturing control as well as the development of new materials for apparel fabrics.
The KES-F system can provide five modes of tests under low-stress conditions, 17 parameters with 29 values in warp and weft (woven fabrics) or wale and course (knitted fabrics) and five charts consisting of 9 curves for one fabric. This large amount of data was intended to provide a full description of the fabric.

The structure of the weft-knitted fabrics can be varied by altering the loop length and also by twist in the yarn. In a four-track circular knitting machine, a number of structures such as single lacoste, double lacoste and fredperry besides single jersey can be produced. Wet treatments such as scouring and bleaching can also vary the geometry of weft-knitted fabrics as following these treatments, consolidation occurs in the fabrics. The structure of single jersey pique fabrics is altered by run-in ratio. Changes in the low stress properties of weft-knitted fabrics which differ in their structure have been investigated by many research workers. Many have used bending or shear testers which are based on the design of the previous research workers or KES (Kawabata Evaluation System). In the Kawabata system, the results provided by the various instruments have been taken without going into the curves or the charts. There is a tendency to consider only the handle of fabrics which is based on the low stress mechanical properties. The curves and the charts provided by the instruments are to be analysed critically to interpret the data. Dhingra et al (1989) provide normalised compressibility as an additional parameter in the parameters describing fabric low-stress mechanical properties. A comprehensive survey of experts views on the objective measurements together with discussions are given by Stylios (1991). The results obtained with the surface tester have been found to give erroneous values which cannot be used for purposes of comparison by Bueno and Renner (2001). These authors have developed a surface roughness tester which has been found to give better results on friction of fabrics.
Recently, Kyoto University under Matsuo has carried out very useful work on bending and compressional properties of weft-knitted fabrics. Alimaa and Soe have studied the knitted fabric properties from the yarn and geometrical properties of weft-knitted fabrics and have been able to predict the fabric properties. Amirbayat and Alagha (1995), based on two behaviours of orthotopic sheets the interrelations of inplane properties and buckling of flexible sheets under tension have discussed and showed that testing three bias fabric samples under concentrated forces (which causes the fabric to buckle) is a method to evaluate the in-plane (tensile and shear) and out-of plane (bending) deformation of the fabric. Alamdar-Yazdi (2000) and Amirbayat (2000) have followed this methodology and tested 39 fabrics on a tensile tester and obtained bending shearing and tensile properties from the charts. This work shows that it is possible to get bending, shearing and tensile properties of fabrics from the tensile test of bias cut samples (22.5°, 67.5° and 45° to the warp). However, only woven fabrics have been tested, and much work remains to be done with knitted fabrics.

There are different directions of the research in this field in terms of methods and emphasis.

They are:

1. **Component oriented direction**: Prediction of mechanical responses of fabrics from yarn properties, inter yarn interactions fabric structures with some assumptions. Hearle, Grosberg and Postle were the pioneers in this field. This involves numerous pages of mathematics and personalised programmes. The theoretical basis is the minimum energy principles and mathematical deduction of construction. It starts from physical concepts and assumptions which facilitate further deductions.
2. **Phenomena-oriented direction:** Olofsson (1967) and Skelton (1974) have dealt with this type of approach. Here the responses of fabrics to applied loads in the form of elastic, visco elastic, frictional and plastic parts is considered. Therefore, rheological models consisting of different combination of components like the spring which represents the elastic part, dashpot which represents the frictional part simulate combined responses of fabrics to applied forces. Then the general relationships of stress-strain could be deduced.

3. **Result-oriented direction:** This is in contrast to component oriented direction which starts not from assumptions and concepts but from hypothesis - a function or a statement to describe the experimental results and then goes back to find the relationship of this function with fabric component and then test it and finally, to apply it to further analysis. The theoretical background of this approach is more related with pure mathematics, especially numerical methods and statistics. It allows estimates to be made of purely mathematical observations so that it avoids many subjective assumptions which may be misleading.

Although the KES system has received wide attention for fabric objective measurement in which the investigation and application of the system are only confined to the parameters extracted from the test equipment, the understanding of the charts recorded from each tester is ignored. This apparent neglect of the area of important technological interest stems from the difficulties inherent in the complexity of curves themselves which are intrinsically nonlinear.

In addition, in practice the information from the KES system is so comprehensive and extensive that it is too complicated to handle or to
interpret. A technique of extracting information from massive amounts of
datas of this type is needed to explain the main features of the relationship
hidden or implied in the data and charts.

1.4 SCOPE OF THE STUDY

This study is based on the mechanical and surface properties
measured on the KES system.

Three aspects of discussion are involved in this project:

1) To characterise the tensile, shear, bending and compression
   behaviour of a series of weft-knitted fabrics in a different way.

2) To relate the physical properties of the fabrics to the structure
   of those fabrics as well as the relationships between physical
   properties.

There are two possible ways to explore problems of improving the
procedures for obtaining the stress strain relationships as well as the
relationships of mechanical properties with fabric structures.

1) To analyse and improve some of the existing structural and/or
   mechanical models and calculating procedures for general
   relationships.

2) To improve the methodology of the mathematical description
   of the mechanical properties and behaviour of fabrics.

As was pointed out by Peirce (1937), physical and statistical
theories may be combined with the geometrical theory to give a fuller
account of various phenomena. Therefore, the following particular approaches are employed.

1) Statistical analysis has been used extensively to compare differences between the wale way and course way properties of weft-knitted fabrics and relationships of physical properties tested on KES system.

2) The methodology of expressing the mechanical properties such as the bending and shear hystereses values has been changed.

From the work viewed in an overall perspective, it is expected to provide a good understanding of the mechanical behaviour and properties of knitted fabrics and may be able to provide directions to future research into fabrics and the application of KES system in practice.

1.5 FEATURES OF THE PRESENT WORK

There are several ways in which the present work differs from conventional methods.

First, in conventional approaches an investigation process for the fabric structural mechanics of a fabric starts from designing a fabric. Then based on the yarn properties and processing conditions, fabric behaviour was predicted. In most conventional methods of analysis for knitted fabrics, it is necessary to include a number of initial assumptions relating to the nature of yarn contacts and yarn cross-sectional shapes, yarn properties and deformation restrictions within the unit cell of the fabric. Such assumptions usually represent great simplifications and are liable to introduce large errors in any analysis of fabric mechanical or rheological properties. In contrast to these, the present study is concerned with a series of weft-
knitted fabrics which has been tested for mechanical properties. Based on the results obtained, analysis of data and inferences can be made for various phenomena observed. Therefore there are fewer assumptions and controlled conditions in the present work, and it deals with real fabrics and real data.

The processing conditions of the samples were known, a comparison of the wale way and course way properties has been made.

The compressional properties have been reassessed from the pressure-thickness curves provided by the charts obtained on the KES system. A number of methods suggested have been attempted to characterise compression.

The effect of run-in ratio on the low stress mechanical properties of single-jersey pique fabrics is another area which has been investigated.

The effect of sanding finish on the characteristics of a series of weft-knitted fabrics has been examined. Tensile and bending behaviour have been predicted.

1.6 ARRANGEMENT OF THE THESIS

The thesis consists of 15 Chapters. Chapter 2 is concerned with the literature survey. Chapter 3 deals with the yarns which were produced for the knitting of fabrics. Chapter 4 is concerned with the materials and methods used in the study.

Chapter 5 discusses the general analysis of results of the mechanical properties. Included in Chapter 6 are the effects of twist tightness factor and chemical treatments on the low stress mechanical properties of single jersey and single jersey derivatives.
Chapter 7 deals with the effect of sanding on the low stress mechanical properties. In Chapter 8, the influence of run-in ratio on the mechanical properties of pique fabrics is discussed. Chapter 9 is concerned with the modelling of tensile properties. Chapter 10 deals with bending of fabrics and its prediction from yarn bending and geometrical properties of fabrics.

In Chapter 11, the compression properties are discussed, Chapter 12 deals with the energy methods. Application of discriminant analysis to the classification of fabrics is discussed in Chapter 13, Chapter 14 discusses the parameters of Kawabata Evaluation System (KES) critically. The consolidated summary of results is discussed in Chapter 15.