CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter summarizes a literature review that was performed for the relevant research related to compact spinning systems. First the development and the principles of jet ring spinning and compact spinning systems are described. The general approaches used in studying and analyzing the structure and properties of compact yarns and knitted fabrics are reviewed. Finally a brief review is made on the application of neural network and genetic algorithm in textiles.

This chapter is concerned with the literature on compact yarns which have been produced by using different methods. Over the last few years, the compact spinning technology has penetrated into the industry at a rapid phase and numerous developments have occurred in this field. This chapter presents a narrative review of literature concerning the compact spinning and the research work that has been done highlighting specific areas in which developments are occurring rapidly.
2.2 MURATA AIR - JET SPINNING SYSTEMS

Murata Jet Spinner MJS 801 was introduced by Murata at ATME' 82. It was only suitable for spinning pure synthetic fibres, blends of synthetic fibres or rich blends of synthetic with cotton fibres with a delivery speed of 160 m/min. However, Murata introduced MJS 802 in 1980 which has a 4 line drafting unit and a modified nozzle which provided better yarn control and a production rate of 210 m/min. This was found to be suitable for spinning 100% cotton yarns. Murata later launched two other new air-jet spinning systems, the 802 H and 804 RJS with a production speeds of upto 300 m/min and 400 m/min respectively. The 804 RJS was not a success.

2.2.1 Vortex spinning system

Murata's No. MVS 851, Vortex spinner was introduced in 1997, and the production of a 15 tex 100 % cotton yarn at 400 m/min was demonstrated at that time.

In 2003, Murata had exhibited its latest model MVS 861. It has been reported that the machine produces a yarn which is almost similar to the ring and rotor spun yarns. Moreover, the characteristics of MVS yarn and fabrics are observed to be comparable to those of ring spun yarns, i.e., the fabric made from MVS yarn is reported to be as smooth and as soft as that produced from ring spun yarn. However, it is said that fibres must be clean and strong and should have a staple length of at least 28 mm and uniformity.
2.2.2 MJS and MVS Spinning Systems

While MJS employs two jets, MVS uses a single jet which accomplishes the task of twisting the free fibres about the bridging fibres forming a yarn similar to the ring yarn structure (Figure 2.1). In air jet spinning, edge fibres ultimately produce wrapped fibres, and the number of edge fibres depends on the fibres at the outside. On the other hand, in vortex spinning the fibre separation from the bundle occurs everywhere in the entire periphery of the bundle. This results in a higher number of wrapped fibres in the yarn.

Basal and Oxenham (2003) have carried out a comparative study on the structure of vortex and air jet yarns. Two yarns of 30s and 40s were produced from three different blends of polyester and cotton fibres in blend ratios of 33/67, 50/50 and 67/33. The results showed that MVS yarns had higher evenness, fewer thick places and lower hairiness when compared to those made by the MJS. The vortex yarn also exhibited higher tenacity values for every blend ratio except for 100% polyester. With the increase in cotton component, the difference between the tenacity of the yarns from the two systems also increased. As regards to yarn elongation, MVS yarns exhibited higher values compared to air jet yarns.

A recent paper by Soe et al (2004) reports on the structure and properties of MVS yarns in comparison with the ring and open end rotor spun yarns. The machine used for producing MVS yarns was MVS 851 and a cotton yarn of 19.68 tex was produced at 380 m/min. The results showed that the tenacity of the cotton yarn produced from MVS system was lower than that of the ring spun yarn but evenness was better. There was no change in the imperfections in MVS yarn in comparison with ring spun yarns but in terms of hairiness the values were very low. Bending and compression properties of
MVS yarns were found to be higher than those of ring spun yarns. Murata vortex spun yarns were found to be bulkiest of all the other types of yarns. Murata vortex yarns are stiffer than ring and open-end rotor spun yarns while ring yarns possess the highest tenacity values.

![MJS and MVS Spinning System](image)

**Figure 2.1** MJS and MVS Spinning System

### 2.3 REVIEW OF COMPACT SPINNING TECHNOLOGY

It is well known in the textile industry that the limits of conventional ring spinning have been reached in terms of production rates, and since 1970 there has been considerable activity in the development of alternative spinning systems. A major part of the developmental work was directed towards the short staple sector because of the large number of ring spindles in that sector of the market.

Each alternative spinning system has its advantages. These include the elimination of some of the fibre preparation processes and / or the subsequent winding stage; higher yarn delivery speeds; reduced power consumption and improved conditions. Most of the new spinning systems
have carved a niche for themselves with regard to a particular end product and a particular count range. However, the characteristics and appearance of conventional ring spun yarns have not been completely reproduced by any of the new technologies. Due to this, and because of its versatility and flexibility in producing yarns over a wide count range, ring spinning still remains to be the predominant system for the manufacture of staple yarns.

In the production of cotton yarns, the jet spun yarn technology has become commercially significant since 1990. With the development of various types of compact spinning systems, the compact yarns are replacing ring spun yarns. The condensing of edge fibres makes possible the production of compact yarns possible. It was Kalyanaraman (1992) who did a pioneering work in producing a compact yarn in ring spinning by fitting an air jet nozzle in between the front roller nip and lappet.

Vortex spinning was introduced by Murata Machinery Ltd., Kyoto (Japan) at OTEMAS' 97. This has been found to be eminently suitable for spinning 100% carded cotton, and the production rates are quite high compared to ring spinning system. This section summarizes an account of vortex yarns. The principle of vortex spinning is based on false twist mechanism. As a result, structures of these yarns are quite different from each other.

It was Dupont who was credited with the development of fasciated yarn technology. Their invention consisted of a number of spinning methods which included either inserting false twist to a filament bundle or a filament /staple fibre bundle by air jet nozzles and then heat setting. It was found that the latter could be used to produce yarns made from 100% staple fibres with the omission of filament feeding adhesive application, and heat setting sections. The resulting yarn was called "sheaf yarn" which consisted of staple
fibres, tied firmly by other staple fibres along the yarn length at random intervals. In 1963, Dupont carried out another method which was suitable for a tow prepared for stretch breaking. In this method, filament tows were fed into a stretch break unit, simply a robust drafting unit, where they were broken into staple form by stretching and expanding into a ribbon shaped bundle subsequently; an aspirating jet removed the fibres from the front rollers and guided them to a twisting jet unit. The fibre bundle was subjected to a torque by the twisting jet which was found to be effective for core fibres. Beyond the twisting jet, this twist was shifted to the surface wraps.

Dupont patented the Rotofil process, which was very similar to the process mentioned above but in this process staple fibres were used instead of filament tows. This process involved drafting fibre strands and forwarding them to a torque jet by means of an aspirating jet. In the torque jet, the fibres were consolidated into a fasciated yarn assembly by fluid twisting. The drafted fibre bundle was presented to the aspiratory jet as a "spread out" web. The torque applied by the torque jet mainly affected the core part and the "edge fibres" (i.e., those fibres at the outside of the strand) took less twist compared to the fibres at the centre. In view of this, the yarn consisted of highly twisted core and less twisted surface fibres as it entered the air jet. When it left the air-jet unit, the surface fibres because untwisted first and then twisted in the reverse direction, while the core fibres continued to be untwisted. The resultant yarn consisted of surface fibres wrapped around core fibres at varying helix angles ranging from about 10° to 80°. This process was found suitable for staple fibres ranging from 50 mm to 350 mm in length. The fibres used fibres in this Rotofil process were acrylic, and the yarns produced were called "Nandel".

Although the fasciated yarns were produced by Dupont, none of them has achieved success owing to economic reasons. However, some of the
machine builders such as Toray Engineering Ltd., Toyoda Automatic looms works Ltd., Howa Machinery Co., Ltd., Suessen and Murata Machinery Limited, have taken up the idea quite seriously.

2.3.1 Concept of Compact Spinning

Compact spinning is a modification to the conventional spinning process and the principal aim is to alter the geometry of the spinning triangle so as to improve the structure of the ring spun yarn by more effective binding of surface fibres into the body of the yarn.

Another name for compact spinning is condensed spinning and here the fibres leaving the front drafting roller nip are tightly compacted making any sign of a spinning triangle at the twist insertion point virtually imperceptible. Figure 2.2 shows the importance of compact spinning. In the conventional system, the fibres are fed at width W into the zone of twist insertion. This width is the result of the drafting, and this depends on the hank of roving, its twist and level of draft. The higher the draft, the greater the width and vice versa. Stalder and Rusch (2002) have discussed the importance of the spinning triangle.

According to them, the spinning triangle is formed in such a way that many edge fibres are lost or incorporated in the already twisted yarn in a completely uncontrolled way which results in yarn hairiness in consequence. This problem is eliminated by the compact spinning process. By using aerodynamic forces, the drafted fibre sliver is laterally condensed after the main drafting zone with the spinning triangle becoming so smaller and therefore that it almost disappears. All the fibres from the remaining spinning triangle are gripped and integrated fully in the yarn. This results in perfect
yarn structure with greater fibre utilization, better strength and minimum hairiness. The acuity of angle of the spinning triangle in the twist insertion zone is directly proportional to $W_1$, twist level and the spinning tension $T_s$, but it is inversely proportional to the yarn count. That is these factors govern the difference between $W_1$ and yarn diameter $W_y$ at the apex of the spinning triangle. Because of this difference, the leading ends of the fibres at the edges of the ribbon are not adequately covered and twisted into the yarn structure. The result is that these fibres either have a substantial part of their length projecting from yarn surface as hair and thereby contributing little to the yarn strength or they escape twisting altogether as fly waste.

![Figure 2.2 Compact Spinning Triangle](image)

The reduction in width of the spinning triangle will result in the improvement of the control and twisting into the yarn structure of the edge fibres. It should be also noted that, with the problem of incorporating edge fibres into the forming yarn and the resistance to twist propagation from the yarn balloon zone, the strength at the apex of the spinning triangle is generally only one third of the yarn strength. This makes the spinning triangle a
potential weak spot at which breaks occur during spinning. The reason is that the tension induced into fibres by the spinning tension is very small at the centre of the spinning triangle as compared with the edges. Therefore, when spinning fine yarns or yarns with low twist levels, the loss or the poor incorporation into the yarn of edge fibres mean insufficient strength to withstand the spinning tension, and breaks occur. By greatly narrowing the width of the spinning triangle, compact spinning should improve both spinning efficiency and the structure and properties of ring-spun yarn.

Table 2.1 lists the basic features of the four techniques currently used to compact the spinning triangle. All utilize air suction and are essentially either a modification or an attachment to the front of a conventional type of drafting system.

2.3.2 Comfor Spin System

In the Comfor spin process (Figure 2.3) a perforated drum (A) replaces the conventional grooved bottom – front roller of a 3-over-3, double apron (DA) drafting unit. A second top-front roller (C) makes a second nip line with the perforated drum below which the compacted spinning triangle is formed. The nip line of the front drafting zone is made by the contact of the top-front roller (B) with the drum, enabling the fibre mass to be attenuated in the normal way, producing ribbon width \( W_1 \). Suction is applied from within the drum through a slotted tubular screen (S) so that, as the perforated drum rotates, the screen enables a controlled airflow through the perforations passing over the slot to firmly hold the drafted fibre ribbon to the drum surface leaving the nip line at roller B.
<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Manufacturer</th>
<th>Trade names</th>
<th>Basic features</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Rieter Machine Works Ltd.</td>
<td>Com 4 spinner, Com for spin</td>
<td>4 over 3 double apron drafting system with perforated bottom front roller and two top rollers, drafted ribbon compacted by air suction through bottom front roller.</td>
</tr>
<tr>
<td>2.</td>
<td>Spindel fabrik Suessen</td>
<td>Elite</td>
<td>3 over 3 double drafting system with addition roller and special lattice apron moving around slotted air suction tube (tubular profile) for compaction of drafted ribbon.</td>
</tr>
<tr>
<td>3.</td>
<td>Zinser Textilemaschinen GmbH</td>
<td>Air-Com-Tex 700</td>
<td>4 over 4 double apron drafting system with perforated apron circulating around top front roller; drafted ribbon in front zone compacted by suction through perforated apron.</td>
</tr>
<tr>
<td>4.</td>
<td>Maschinen-und Anlagenbau Leisnig GmbH</td>
<td>P4</td>
<td>4 over 4 double apron drafting system with perforated apron circulating around bottom front rollers; drafted ribbon in front zone compacted by suction through perforated apron.</td>
</tr>
</tbody>
</table>
The slot is specially shaped for the drafted ribbon to become compacted from width $W_1$ to $W_2$ by the time it reaches the final nip line roller at roller C. Beyond this, twist is inserted as in conventional spinning.

![Diagram of Comfor System](image)

**Figure 2.3**  Comfor System

### 2.3.3 Elite System

In this system, the basic drafting rollers are retained with an additional unit fitted at the front (Figure 2.4). The added unit consists of a transport apron of lattice weave 3.00 pores/cm², which passes closely over the surface of a specially shaped, slotted suction, tube – tubular profile. Suction occurs at the interstices of the apron moving across the slot of the tubular profile. The plan view shows that the slot can be inclined at $30^0$ to the centre line of the apron, which thereby causes the motion of the apron to effect a rolling of the drafted ribbon as the ribbon is being compacted. This is useful when spinning carded cotton as the very short fibres become more embedded in the final yarn. The additional top roller drives the transport apron via
frictional contact at the nip line. The drafted ribbon is therefore under tension straightening fibres during compaction.

Figure 2.4  Elite System

2.3.4  Air-Com-Tex 700 and CSM Units

These use an alternative apron arrangement to the Elite unit for compaction, but, similar to the latter, compacting occurs after the front-drafting rollers. The alternative arrangement is simply an added conventional apron drafting zone with a line of perforations down the middle of the apron width through which suction is applied. The Air-Com-Tex 700 has only a perforated bottom apron whereas the CSM has double apron of which only the top one is perforated (Figure 2.5).
2.3.5 Maschinenund Anlagenbau Leisnig, MAL(D)

In this system (Figure 2.6), the drafted roving, coming from the front roller of the drafting system passes through another zone which has a top roller and a bottom roller with guide aprons. This guide apron has a series of holes through which an air current is applied on the drafted material. This air current condenses the drafted strand and thereby eliminates the spinning triangle.

2.4 PREVIOUS WORK DONE ON COMPACT YARNS

The literature on compact spinning can be divided into papers which deal with the potential of these yarns which exist as trade literature and papers which deal with the scientific aspects of compact yarns. On the trade literature a number of papers by Artzt (2002, 2003), Stalder (2000), Stalder
and Rusch (2002), Furter (2003), Binternagel (2000), Scheibe and Knecht (2001), Kadoglu (2001), Schneider and Artzt (2003) are available. Particular mention should be made of the research on compact yarns carried out in Turkey recently which has been found to be of high quality. Many papers have been published which have contributed significantly to this area.

Chellamani, Arulmozhi and Vittopa (2000) and Ishtiaque, Salhotra and Akshay Kumar (2003) have reviewed the literature on compact spinning comprehensively.

Bhattacharya (2000) conducted studies on the quality and performance assessment of compact and ring spun yarns and fabrics. All these studies are no doubt useful for the study on compact spinning. However, the reviews are to be updated as a great deal of work on compact yarns has been done. This review tries to fill up the gaps existing in the literature by including all the papers.

Vincent and Gandhi (1976), presented their work on the detrimental effects of protruding and detached fibres in yarns on weaving efficiency. They demonstrated that following singeing of 37 tex open-end-spun cotton yarn, satisfactory weaving efficiency was achieved in the looms.

Hu, Jiang and Postle (2002) reported that when Rotor yarns were subjected to a tensile drawing process they differed from their original form in terms of yarn structure. This paper presents the knitted fabric properties and the authors have reported that comfort properties show a significant improvement besides making the fabric thicker and whiter. This is another way of producing compact yarns by strain-hardening process. Ramkumar et al (2003) has investigated the frictional properties of compact and other yarns by capstan method.
The first scientific study of the compact spun yarns was reported by Cheng and Yu (2003) which included a study on the limitations of this new technology. This work compares the properties of four ring spun yarns vis-a-vis the properties of the compact yarns produced by Rieters Comfor Spin K40; the cotton used for producing all the four counts was extra long staple Supima which was combed. The counts produced were 38s, 50s, 60s and 80s with different levels of twist. The yarns were tested for evenness and imperfections, hairiness, tenacity and elongation. The conclusions reached are that the compact spinning system is effective for counts such as 60s and 80s and for coarser counts it is not suitable as noticed from the tenacity and elongation values.

Although no values of evenness were given, the number of imperfections was found to be higher for compact yarns vis-à-vis regular ring spun yarns. Particularly, the incidence of neps was found to be significantly greater for 50s, 60s and 80s compact yarns in relation to regular yarns.

As regards hairiness, compact yarns displayed less hairiness compared to the regular yarn. An interesting observation is that the coefficient of variation (CV%) of Com 4 yarns was higher compared to the regular yarns. Although the number of protruding fibres with lengths between 1 and 4 mm were greater in 38s regular ring spun yarns, it was noticed that the opposite was the case with longer fibres. For the 50s, 60s and 80s, the numbers of protruding fibres were found to be greater for V6 (regular) yarns than for Com 4 yarns.

Tenacity and elongation values of compact yarns are found to be higher than those of regular yarns. It is noticed that only in respect of 60s, is a significant decrease in the tenacity between a compact and regular ring spun yarn observed. This has been attributed to the highest twist level – 896 TPM
of the Com 4 yarns. The increase in elongation of yarns of 38s produced by compact spinning was attributed to the curliness of fibres in the yarns owing to slower speed of the top roller which leads to lower tension level.

The work done by Cheng and Yu (2003), although is a very useful study on compact yarns, suffers from many criticisms. Only Rieters Com 4 spinning system has been used and the other types of compact spinning systems such as elite, and Air-Com-Tex 700 have not been employed. Also, the selection of cotton used poses a serious problem. It would be useful if cotton mixings which are normally used in the textile mills are processed in the compact spinning frames, and then the yarns are compared for their various properties. The twist which is normally used for producing the yarns should have been used for different counts. In view of this, the findings of the study on compact yarns should be treated with caution. Moreover, data on yarn friction, bending, compression, abrasion, resistance and twist liveliness were not provided which made the work to be of less importance.

Whilst some information exists on the characteristics of cotton yarns, little work has been carried out on the comparative studies between different types of compact spinning systems, and so far as the author is aware, no published information exists on this subject.

Behera et al (2003) have reported that the weavability of compact yarn is much better than the ring yarn irrespective of twist. They have also pointed out that compact yarns require less size add-on.

Dash, Ishtiaque and Alagirusamy (2002) have reported on the properties and processability of compact yarns. They used regular and combed compact which cotton yarns of 24s count. They were wound at speeds ranging
from 1000 to 1400 mpm using both dry and wet splicing. The yarns were dyed in knitted fabric form and their k/s values were determined.

Yarn diameter showed some interesting trends in ring and compact yarns. While in the former, yarn diameter progressively increased, in the latter it reduced up to 1200 mpm and thereafter rose. As far as yarn tenacity and elongation are concerned, they showed a progressive decline in the case of ring spun yarns while the trend was opposite in compact yarns. There was no change in the level of imperfections with the increase in winding speeds either in ring yarn or compact yarn although the number of thick surfaces was less in compact yarn. Yarn hairiness, with the increase in winding speed, showed an increase in short hairs and long hairs. In respect of ring yarn, the increase in long hairs was less, while in compact spun yarn it was significantly high.

Although the strength of spliced portions of compact yarn was higher, the ratio of splice strength to yarn strength was lower due to improper opening of yarn.

Regarding the colour strength of the knitted fabrics produced from ring and compact spinning yarns, it was found that compact yarn samples showed a better colour strength.

Most of the other papers, which have been published in Asian Textile Journal, Melland Textilberichte and Textile Asia deal with the details of the technology and the claims that are made on their advantages. They look like publicity materials and do not contain any scientific content. The publicity generated by the manufacturers and the papers written by authors who presented them is expected to boost their sales.

In one of his papers Stalder (2000) of M/s. Rieter Textile Systems presents the properties of Corn 4 yarn vis-à-vis ring spun yarn. Stahlecker
(2000) discussed the compact or condensed spinning system. Olbrich (2000) has given a description of the Air-Com-Tex 700 condensed ring spinning machine. Scheibe and Knecht (2001) have discussed the requirements of compact yarn on the winding process. The author discusses mean splice strength and fineness related maximum tensile strength of conventional combed ring yarn and compact yarn from which it is noticed that the mean splice strength of compact yarn is lower than that of conventional combed ring yarn.

Artzt (2002), who is credited with a number of papers in spinning, discusses the results of the trials covering the effect of the combing and carding processes on compact yarn quality and process efficiency. It has been reported that with only 10% noil in comber the same quality which is achieved with 20% noil is possible in compact spinning. Also, in compact spinning, 10% of twist reduction is possible compared with the usual twist. It is pointed out that raw material savings are possible by noil reduction combined with gentle carding and combing.

Binternagel (2000), has pointed out the advantages of COM 4 yarns in that better cross wound package, quality manufacture of innovative soft ply yarns, higher weaving efficiency and better knitting performance are obtained. A reduction in sizing can be achieved with compact yarns.

Schneider and Artzt (2003) report on the effects of different ring/traveller system contact surfaces and geometries in compact spinning.

Kadoglu (2001) compared the quality parameters of compact yarns vis-à-vis regular yarns. The experimental work was carried out on ring spinning and compact spinning systems with four levels of twist factors. The cotton was combed, and combed yarns were produced with four levels of twist
factors. That it is possible to produce 60s combed yarns with a lower level of twist factor has been pointed out. Kadoglu (2001) presents extensive data on the yarn characteristics of 40s carded cotton and 60s combed. While in 60s combed count, the hairiness values in 1 mm show some erratic trend for compact yarn, in other classes, there is a substantial improvement. The pattern is the same in 40s carded count. Neps show no consistent trend, and in some cases, there is a small increase in compact yarns. The same comments apply to thick places also. Hairiness determined by using Uster evenness tester shows an allround improvement at all twist levels. The hairiness results obtained from Zweigle hairiness tester, as mentioned above, show somewhat different results. This is in agreement with some of the results obtained by Cheng and Yu (2003).

As regards tenacity, increases range between 4.93 to 11.8% for 60s combed while they are somewhat lower for 40s carded. In particular, 60s combed yarn spun by compact spinning with a twist factor of 105 shows the maximum increase in tenacity, namely 11.8% vis-à-vis normal yarns. There is not much difference in elongation of yarns.

The findings of Kadoglu (2001) that compact spinning gives a better performance with 60s combed cotton yarn are in substantial agreement with those of Cheng and Yu (2003). It is also pointed out that since the width of the roving traversing movement is less than in normal ring spinning, this may result in faster wearing of aprons and roller cuts. Frequent cleaning of compact spinning machine for achieving better yarn quality was necessary and this was also pointed out.

The paper by Stalder (2000) on comfor spin – a new spinning process is also a general paper which describes the advantages of comfor spinning and also in downstream processing. An interesting observation is that
the strength improvement is maximum in 40s and 80s combed counts. The same information is given in his another paper (Stalder 2000).

Brunk (2002) gives the highlights of Elite compact set, which is produced by Suessen. This again is a paper which is meant for publicising the spinning system. Many mills have installed this system and production of doubled yarns is also possible. Another paper by Brunk (2004) describes the ends down distribution in conventional ring spinning and compact spinning. Maninarayan (2004) discusses the structural advantages of compact yarn in knitting. Shrinkage is found to be less in knitted fabrics resulting in net saving of 2% in fabric weight loss.

Furter (2003) has discussed his experience with the quality management of compact yarns with particular reference to optimising yarn clearing. It is pointed out that electronic yarn clearing has to be adapted to the new requirements. For the production of compact yarns, cotton with a high degree of foreign fibre contamination is not recommended. This is a general paper and the technical content is few and does not warrant any special consideration.

Kampen (2000) discusses the advantages of condensed spinning in winding doubling, sizing, weaving and knitting operations. A general description of the various systems of compact spinning is given, and the various advantages that accrue are mentioned.

A paper by Basu, Chellamani and Arulmozhi (2000) is concerned with the yarn quality improvement through application of air in ring spinning. The bottom apron of the drafting zone was modified and also the nose bar was provided with perforations. The nose bar perforations coincide with those in the bottom apron during working of the ring frame. Due to this, the air current
applied through the nose bar perforations passes through the two orifices in the bottom apron. The application of air to the fibrous web in the drafting zone has led to a significant reduction in hairiness of yarns to the extent of 20\%. The abrasion resistance of the yarn is improved by 25 – 40\%. With the reduction in the size of the spinning triangle, more fibres are integrated into the yarn structure and this is responsible for the reduction in yarn hairiness. There was no change in tenacity and elongation for the two types of cotton yarns studied. The parameters employed during air current application, namely, apron orifice diameter, orifice angle and quantum of air pressure all were found to have significant influence individually as well as interactively on yarn quality improvement. Essentially, their technique involves the use of bottom aprons in the ring frame front zone with two rows of orifices (perforations) made at an angular manner and applying air angular manner and applying air through them on the fibrous web. It is pertinent to note that this technique attracted less interest in view of the other compacting systems becoming more popular.

From the above, it is evident that only limited studies have been done on compact yarns and a great deal of work remains to be done. There are no data on the properties of fabrics produced from compact yarns.

Kalyanaraman (1992), Wang and Miao (1997) and Ramachandrulu and Dasaradan (2003) have used nozzles to reduce the hairiness in the cotton yarns; this also produces a compact yarn and is called jet ring spun yarn. Krishnakumar (2004) has reported a novel method of reducing spirality in knitted fabrics using yarns produced by wet spinning in ring frame and called it compact spun yarns.

Some papers on compact spinning were presented in the seminars and conferences held in India and Czechoslovakia. Elite system can also
produce two fold yarns in ring frames and this is possible in comfor 4 spinning system. Also, comparison of the two fold yarns produced by comfor 4 spin has been made by Maninarayan (2004).

Although papers, which have been presented in the seminars on compact spinning held in India and other places, were not published in refereed journals, the rather naive assumption that a technique is unacceptable until hallowed by publication in a refereed publication should not be held and they should be considered to be valuable.

Jackowski, Cyniak and Czekalski (2004) have discussed the characteristics of compact yarns vis-à-vis conventional ring spun yarns. Combed and carded cotton yarns of linear densities 15, 18 and 20 tex were produced both on the compact and conventional spinning frames. The important properties such as tenacity, elongation, evenness, imperfections and hardness were measured. They have found that the Elite compact yarns are characterised by higher tenacity, higher elongation at break, lower U(%) imperfections and lower hairiness. The combed yarns were found to possess higher tenacity and a lower mass irregularity compared with carded yarns. Assessment of the compact yarns with the Uster statistics shows that they can be placed below 5% or 25% of the world production which shows their high quality.

Conventional and compact yarns of 20 tex were knitted to fabrics and it was found that the fabrics produced from the compact yarns were softer than those of their counterparts.

The work carried out by Jackowski et al (2004) shows the potential of the compact yarns in knitting sector.
Mahmood et al (2004) had demonstrated that the factors such as twist multipliers, top roller pressure, and air guide elements had a significant role in the quality of compact yarns. The experiments were performed with 20s (29.5 tex). Three levels of air guide elements, three levels of top roller pressures and three levels of twist factors were used to study the interactions of these on yarn characteristics. It was found that perforated air guide element gave better yarn strength, and as far as top roller pressure was concerned moderate pressure showed better results.

The paper by Mahmood et al (2004) was somewhat novel in that for the first time the effects of some parameters such as air guide element, twist multiplier and top roller pressure on the characteristics of compact yarns were reported.

Cheng and Li (2002) discussed the salient features of jet ring spinning and the impact of it on the yarn hairiness. They used two rovings, one produced from 100% cotton and the other from 100% polyester. The effects of spindle speed, air pressure and twist on yarn hairiness have been examined. They had found that when an air jet nozzle was incorporated below the front roller nip, allowing twisting yarn to pass through the nozzle, yarn hairiness could be significantly reduced. They had hypothesised that this reduction was probably due to the loosening of the yarn structure first before the yarn entered the nozzle, and the subsequent tightening of the structure as the yarn emerged from the nozzle which would result in tucking of the protruding fibre ends into the yarn body through the swirling air current induced by the air jet nozzle. When wrapper fibres increased beyond certain numbers, they could be expected to bind the yarn and decrease the protrusion of fibre ends leading to reduced hairiness. The jet ring spun yarns were found to be superior compared to conventional ring yarns in terms of tenacity. The authors felt that fibre
properties could play a significant role in influencing the effectiveness of the wrapping function.

Rosiak and Przybyl (2004) compared the properties of various yarns including and multi folded threads produced from them. An analysis of the twisting process had been done. The influence of the twist value of yarns and multi folded threads on their processing throughput was examined and presented. This paper is theoretical and is devoid of any experimental results. It is summarised that the advantages which result from manufacturing and applying compact yarns and threads are lower breakage rate, low pilling property of fabrics and higher machine efficiency. It has been surmised that the compact yarns and multifolded threads are eminently suitable for the production of woven fabrics.

Scheibe and Knecht (2001) had investigated the requirements of compact yarn in the winding process. It is pointed out that the average strength of the spliced joint of compact yarn is lower than that of conventional combed yarn due to the increased utilisation of the fibre tenacity in the spinning process. All important aspects of the winding process itself have been examined such as splice quality, yarn quality and package build and adapted to the requirements of compact yarns.

The effects of different ring traveller system contact surfaces and geometries in compact spinning have been examined by Schneider and Artzt (2003). Coating of traveller with oxide coat, chrome coating, and nitrated coat has been discussed. Comparison of ring traveller systems in ring and compact spinning for the study of wear and effect of geometry comparison between T-flange and inclined flange and effect of ring coating and effect of ring geometry and coating on yarn quality and traveller wear has been examined.
Two papers have been published on the properties of knitted fabrics produced from conventional and compact spun yarns. In one of the studies by Ceken and Goktepe (2005) carded ring and compact yarns of 20 tex were produced and plain knitted fabrics with three different loop lengths were made from them. The fabrics were scoured and dyed and tested for abrasion, pilling and bursting strength. It was found that the knitted fabrics produced from compact yarns showed better pilling performance compared to the fabrics produced from regular ring spun yarns. Bursting strength of knitted fabrics produced from compact yarns was found to be higher than those of fabrics produced from regular yarns. In terms of colour strength, fabrics produced from compact yarns displayed higher dye uptake.

A very recent paper by Roy, Sinha and Ambedkar (2005) is concerned with the performance assessment of ring and compact yarns in knitted fabrics.

In the case of the knitted fabrics produced from compact yarns, the numbers of courses per inch were found to be less and Wales per inch were found to be higher mainly due to higher bending rigidity of compact yarns. Air permeability was higher for fabrics produced from compact spun yarns than in fabrics made out of ring spun yarns. Air permeability was lowest at the uppermost setting of the stitch cam and highest at the lowest setting.

Thus it is apparent that only limited properties of knitted fabrics produced from compact yarns have been studied and important properties such as handle spirality and comfort have not been considered.

Artzt (2002) has discussed the advantages of compact spinning. That compact spinning always results in increased raw material utilisation has
been pointed out by him. The possibility of increasing the productivity by reducing twist has been examined.

Chattopadhyay (2005) has reported on the wicking behaviour of compact and ring spun yarns and fabrics. It has been found that the wicking height attained by ring yarns is greater than that of compact yarns and the equilibrium wicking height gained by them is also more. This has been attributed to the greater packing coefficient of compact yarns. The same trend is noticed in fabrics produced from compact yarns. Ring yarn fabrics wick faster than compact yarn fabrics. Close packing of fibres in the yarn he points out, may be detrimental from the point of wicking. This paper lacks in depth as no attempts have been made to validate the models such as Washburn’s equation. Moreover, he has used a reactive dye for his studies which has been objected to by many research workers such as Lord(1974).

Behera, Hari and Ghosh (2003) have reported on the weavability of compact yarn. Ring spun and compact yarns of Nm 34 were produced at three twist levels. Besides this, a doubled yarn of 2/69 Nm was produced from another mixing. The yarns were sized with starch at 2-14% concentrations in the laboratory sizing machine. Weavability was evaluated on the Sulzer-Ruti Reutlinger Web tester. The yarn end after the weavability test was mounted on the stub for studying the nature of breakage on the scanning electron microscope.

The results show that the weavability of compact yarn is much better than the ring yarn irrespective of test. It is pointed out that the compact yarn may need drastically reduced size compared to ring yarn. Weavability of ring yarns increases with increase in size add-on at all T.M. In the case of compact yarns, the improvement in weavability due to sizing is only for lower size add-on (8-10%). The reduction of size in compact yarn helps both in
terms of economy and ecology. Weavability of equivalent single compact yarn is comparable to the 2-ply ring yarn, irrespective of size add-on. This also has great economic significance since doubling of single yarn is a costly process.

The tenacity and elongation of ring and compact yarn increase with the increase in twist. The tenacity and strain of compact yarn is higher than the corresponding ring yarn at any size and twist, level. One interesting aspect is that the tenacity is higher in the case of the sized and un-sized single compact yarn compared to the 2-ply ring yarn. It is interesting to see that sizing contributes more to tenacity of single compact compared to 2 ply ring yarn. This has been attributed to the twisting of the two single yarns in the structure of 2 ply yarn which restricts penetration of size material. This paper is a comprehensive one, and constitutes the single work on weaveability of compact yarns.

Kanthimathinathan (2005) has dealt with the compact spinning process with particular reference to the benefits in post spinning process. It is pointed out that within the counts studied namely 40s, 50s and 60s, there is an overall improvement of 12% in yarn strength, 30% improvement in yarn imperfections, 30% reduction in yarn hairiness index and 6% improvement in yarn elongation.

Warp breaks have reduced as a result of the improvements in strength. In weaving, mills have gone to the level of 350 thread-count in single width looms and 800 thread count in wider width looms. This means that there is high level of packing of yarns in both in warp, and weft ways. It has been pointed out that compact yarns are ideally suitable for fibres having high thread count to improve weaving efficiency as it will reduce yarn-to-yarn friction and yarn to metal friction at reed and healds due to lower levels of
hairiness. There is a saving in sizing cost since 12% size pick up is enough for compact yarn with a clear difference of 6% in comparison to a normal yarn.

The problems associated with compact spinning have been discussed by Ghosh and Sakthivel (2005). Problems such as the coefficient of friction between the rubber cot (top roller mounted with synthetic rubber for better grip) of the delivery top roller and the lattice apron is approximately 10 times higher than between the lattice apron and the profile tube to ensure that all the aprons run at exactly the same speed. Another drawback of compact spinning is its high cost. The other limitations are that the aprons or hollow bodies should have different sizes of opening in order to achieve an optimum condensing effect to avoid undue fibre loss through suction system. Processing of man made fibres and blends is very difficult because the different densities of different types of fibres require different value of suction pressure to have same condensing effect. The other problem is that the better regularity of compact yarn leads to some problems in splicing. Air splicing is difficult as there are no free fibres on the surface that can help to achieve correct opening and blending of the splice. Dhanagopal et al (2005) had discussed the condensed yarn production by mechanical apron condensation method and found that the unevenness, imperfections, tensile strength, elongation at break and hairiness of the yarns produced is better compared to that of normal yarn.

Sudhakar and Gobi (2005) have studied the comfort and low stress mechanical properties of ring and compact yarn knitted fabrics in depth. Both fabrics were tested by using Kawabata Evaluation system, and other properties such as bursting strength, abrasion resistance, pilling, air permeability, water absorption, thermal insulation value were measured. The air permeability of compact yarn fabrics was lower than that of ring yarn fabrics, a result which was already reported by Roy et al (2005) which is contradictory to the findings of the authors. This is due to the fact that whereas Roy et al (2005) carried out
a detailed study by changing the loop size, a single loop was used by Sudhakar and Gobi (2005) in their studies. These authors have shown that fabric weight and thickness are little higher for compact yarn fabrics vis-à-vis regular yarn fabrics. Tensile properties such as WT and RT show a marginal increase for compact yarn fabrics compared to regular ring spun yarn fabrics. As far as bending properties are concerned, with the exception of interlock and Punto di Roma, the values of bending rigidity and bending hysteresis are marginally higher for compact yarn fabrics vis-à-vis regular yarn fabric. Shear parameters G, 2HG and 2HG5 show very marginal differences in fabrics produced from compact yarns compared to regular yarn fabrics. With regard to surface properties, such as coefficient of friction, mean deviation of friction and surface roughness, there is not much difference in these between ring and compact yarn fabrics. In most cases, the values may not be statistically significant.

Abrasion resistance of the various knitted fabrics shows that the fabrics made out of compact yarns are characterised by lower weight losses implying that they have better abrasion resistance. Values of bursting strength show an increase in the case of compact yarn knitted fabrics vis-à-vis regular yarn fabrics. Pilling is found to be less for compact yarn fabrics.

As regards compression properties, no consistent trend has been noticed between the two fabrics. With the exception of Punto di Roma and interlock, RC values are marginally higher showing that the fabrics are harder.

Handle values show a marginal improvement in compact yarn fabrics compared to regular ring spun yarn fabrics.

Nikolic, Stjepanovic, Lesjak and Stritof (2003) have conducted studies on the characteristics of yarns produced by conventional and compact
spinning systems. For this purpose yarns of 20 tex were produced by using Suessen and Zinser spinning machines using 100% cotton and polyester cotton blends. The compact systems produced yarns which showed 20% improvement in strength. A considerable reduction in hairiness of the yarns has been noticed in the compact yarns produced using 100% cotton. There was no appreciable difference in yarn imperfections. In respect of blended yarns, not much difference was noticed and this was attributed to greater bending rigidity of polyester fibres. The reduction in yarn hairiness was not so significant as was noticed in respect of polyester cotton blended yarns. In respect of cotton viscose blends, the improvement in tenacity of compact yarn was significantly higher than that of conventional yarns; the imperfections are unchanged in compact yarns while the hairiness shows an improvement. The increase in tenacity in compact yarn is about 25%. The authors conclude that on the basis of fibre straightening, axial tension and condensing of the fibrous bundle, the compact yarns structure can be defined as near optimal. That the compact yarns have a bright future in view of reduced hairiness, smooth surface high gloss, improved mechanical and physical properties has been pointed out. Ozdil, Ozdoyan, Demirel and Oktem (2005) have presented the characteristics of knitted fabrics produced from conventional and compact yarns. The compact yarns were made on a Rieter spinning machine and that the fabrics knitted from compact yarns exhibit better bursting strength, abrasion resistance, better pilling has been pointed out by them.

Krifa, Hequet and Ethridge (2002) have presented the results of the yarns produced by conventional and compact spinning machines. On the basis of their studies in which they have produced 5 different counts, they conclude that the yarn structure of compact yarns approximates to the ideal yarn. The improvements in yarn strength were found to be greater for short stapled cotton than for long staple cottons. These are contradictory to the results
obtained by Cheng and Yu (2003). Fibres which were inadequate for use in conventional spinning may be spun satisfactorily on the compact system. As expected, compact spinning has produced yarns with less hairiness. It was also found that greater reductions occurred with the short stapled cottons. Compact spinning did not result in significant improvements in yarn evenness as compared to conventional spinning. Finally the authors conclude that compact spinning technology may be helpful in upgrading short staple cotton.

Celik and Kadoglu (2004) have conducted studies on the characteristics of conventional and compact yarns made out of 100% wool, 45% wool and 55% polyester, 50% wool and 50% acrylic fibres and 100% acrylic fibres. In all 22 yarn samples were produced with differences in twist factor and linear density.

The results show that in respect of 100% wool, compact yarn properties are superior compared to conventional yarns. In the case of yarns spun with 45% wool, 55% polyester, 50% wool and 50% acrylic and 100% poly acrylonitrile materials, the differences have not been found to be statistically significant for all yarn parameters. It was found that 100% wool compact yarns had better tenacity, elongation at break, evenness elongation at break, evenness and hairiness values compared to conventional ring spun yarns. But in the case of 50% wool and 50% acrylic blended company yarns have shown better tenacity but lower yarn evenness values as compared to conventional ring spun yarns. In the case of 100% acrylic yarns, the differences between compact and conventional yarns are not statistically significant.

That the compact yarns at low twist level have better yarn properties then those of conventional yarns have been pointed out. This agrees with the findings of Basal (2003). The reduction in yarn hairiness is
considered as an advantage in compact yarns. They have also concluded that fine compact yarns have more advantages since they have less number of fibres in the cross section and during condensation all are incorporated into the yarn body. Thus the paper by Celik and Kadoglu (2004) is an important one as it deals with the compact spinning of long staple yarns. Overall, the compact yarns possess less hairiness, better strength, better uniformity and lower values of thick and thin places and neps compared to the conventional ring spun yarns.

Shahbaz, Jamil, Farooq and Saleem (2005) have made a comparative study of quality parameters of knitted fabrics made from air-jet and ring spun yarns. They have produced the above yarns from blends consisting of polyester and cotton. That the yarn lea strength of 100% polyester is the maximum when compared to the other blend compositions has been pointed out. The results for fabric strength showed that knitted fabric produced from knitted fabric produced from 100% polyester had higher strength. Knitted fabric produced from air jet, yarn had shown a higher fabric weight, and fabric strength of air jet knitted fabric was found to be lowed. These results are in conformity with the findings of Basu (1999).

2.5 HISTORY OF COMPACT SPINNING

Compact spinning was developed by Rieter to adapt a ring spinning frame for spinning from cans. Some modifications to ring frames were made to produce a compact yarn. Dr. Fehrer divided the drafted sliver into two spindles by means of suction and compressed air. Many trials were carried out, and it was found that this method was possible but was found to be very expensive due to large space requirements of cans and long distance sliver feed. The quality of the yarn produced was found to be good even though the
draft employed during spinning was very high, and the fibers were fed from the untwisted sliver. An in depth study showed that the reason for the better yarn quality was the condensation of fibers subsequent to the division of the sliver. This served as an impetus to researchers to concentrate on developing a drafting mechanism with a mechanical / pneumatic fibre condenser unit to obtain to get a very even yarn. At ITMA'99 in Paris, three textile machinery makers, Rieter of Switzerland, Suessen and Zinser of Germany exhibited their compact, or condenser spinning systems. These systems are some what different in each case but all of them are based on the same principle of the elimination of the spinning triangle by pushing the staple fibres together, or condensing them to attain a much smaller spinning triangle than with conventional ring frames. This is achieved by adding an extra condensing process action between front roller and twist insertion. As a result of this condensing, the width of the fibre bundle is reduced significantly by prior to twist insertion, and thus the spinning triangle is nearly eliminated. With the elimination of the spinning triangle, even short fibres are capable of contributing strength and all the fibre are tied up under the same tension. Moreover, the fibre ends are much more tightly incorporated into the fibre mass.

2.5.1 Unique features of compact spinning

Ring spinning accounts for 60% of total production cost in the ring spinning mill. The production speed of the ring spinning frame depends on the traveler and spindle speeds. Although ring spun yarn sets the standard against which all alternative yarn types are measured at present it is far from perfect. If the structure of ring spun yarn is examined under a microscope, it can be seen that integration of many fibres is poor; thus their contribution to the yarn
strength is none or very little. If all fibres were fully incorporated in the yarn, the strength and elongation of the yarn could be increased substantially. Besides the ends of the edge fibres are not always fully included into the yarn. They cause hairiness as they remain separately from the twisted core. Drafting procedure and the yarn formation are the key factors which affect the structure and the quality of yarns. Although the drafting process has reached a very high quality performance, the yarn formation process is further away from the ideal performance level. Thus is mainly due to the spinning triangle.

2.6 SPINNING TRIANGLE

The spinning geometry, which means the path followed by the fibre bundle between the drafting system and yarn in the cop and which involves the drafting arrangement, thread guide, balloon control ring and traveller has a critical effect on the end breaks, tension conditions, generation of fly, yarn hairiness and yarn structure.

Since the width of the fibre bundle emerging from the drafting system is many times the diameters of the yarn to be spun, fibres in the bundle have to be directed inwards and wrapped around, each other. As a result of this, at the exit from the front rollers, there is always a triangular bundle of fibres without twist which is called "Spinning triangle". Since each fibre in the spinning triangle does not contribute to the yarn strength equally during the yarn formation, this contributes to end breaks. In the centre of the spinning triangle, fibres are not subjected to any tension and thus they are bound together without being exposed to elongation whilst the external fibres have to resist the full force of the balloon tension. Short fibres in the spinning triangle can contribute very little to the strength.
Factors such as twist level and the spinning geometry affect the length of the spinning triangle. It has been pointed out by Klein (1993) that a short spinning triangle represents a small weak point and thus fewer end breaks. That if the spinning triangle is too short, the deflection of the fibres on the edges has to be very sharp during binding in has been pointed out by him. This is not possible with all fibres. Besides, with a very short spinning angle, while some edge fibres do not obtain twist and become fly, others might be bound in at one end only and become hair. A long spinning triangle results in a big weak point, and thus high end breaks result. However, with long triangle, fibres are better bound into the yarn, and consequently a smoother and less yarn result.

A potential source of weak point of a ring spinning system is the spinning triangle, and if any improvement can be made, there will be further improvement in the yarn performance. Thus any improvement in ring spinning will entirely depend on the modification of the machine. It is the compact spinning which has eliminated the spinning triangle and the problems associated with it.

Basal (2003) has compared the properties and structures of compact and conventional yarns. 28 yarn samples made from 50/50 polyester/ cotton blend and 100% cotton were spun on the Suessen Elite and the conventional ring machines using five different twist levels. The compact yarns produced from polyester and cotton show a higher tenacity at the lowest twist factor, and the difference between conventional and compact yarns gets narrow down as the twist increases. Thick places are lower for compact yarns while nep shows no significant difference. Hairiness is lower for compact yarns when compared to conventional yarns. As far as migration is concerned, the rate of fibre migration as well as the amplitude of migration was higher in compact yarns and the former can be attributed to minimized spinning triangle in compact
spinning and the latter could be the result of the higher density associated with these yarns. Another important finding is the superiority of compact yarns in terms of tenacity which is more pronounced in lower twist levels and in 100% cotton yarns.

The results obtained by Ganesan and Ramakrishnan (2003) in their work on fibre migration in compact yarn vis-à-vis conventional yarns are quite contradictory to those reached by Basal (2003). Ganesan (2003) has employed only one twist factor for the production of compact and conventional yarns while Basal (2003) has employed five levels of twist factor. Moreover, the differences in the experimental techniques would have contributed to the discrepancy observed.

2.7 WICKABILITY

Wicking is the ability of water dye, etc to move through the textile structures. Wicking is carried out mainly in the capillaries formed by the fibres in the yarn. The speed of water in the capillaries is reduced by the presence of randomly arranged fibres in the yarn, and it is this factor rather than the nature of the fibre material that accounts for the wide range of water transportation properties.

When liquid is taken up in a yarn or fabric, apparently two aspects can be distinguished namely:

i. The amount of liquid absorbed per unit of surface of mass.

ii. The velocity with which this takes place. The vertical wicking test, i.e., the determination of the height of rise H in a yarn as a function of time t, that cover both the above aspects which is
characterized by simplicity and acceptable duration of determination has been selected.

When a liquid wicks in a textile yarn, or yarn system such as a woven fabric under circumstances where the effect of gravity is described by an equation of the form:

\[ S = Kt^{\frac{1}{2}} \]  

where 'S' is the distance travelled \( t \) is the time in seconds, and \( k \) is a constant characteristic of the yarn liquid system.

There are numerous mechanisms that can operate to move fluids through porous materials, but the viscous flow of water by capillary action accounts for the major portion of the flow that actually occurs.

Washburn’s (1921) fundamental work in the hydrodynamics of capillary flow has been used to describe water movement in a number of porous materials including paper, soil and leather.

Norman et al (1956, 1957) have applied Adam's work to develop a theoretical model for water transport in yarns and fabrics and demonstrated with experiments that the model is a good representation of actual condition that can occur in textile materials. They have shown that yarn construction features such as size, number of fibres, fibre size, randomness of the internal structure and twist all affect the rate of water transport insofar as they control the size of the interface capillaries, large capillaries in general producing higher wicking rates, narrow capillaries slowing down and sometimes even stopping the movement of water.
Minor et al (1959) have done work with a number of non aqueous solvents and a number of yarns made from different materials both natural and synthetic and have demonstrated that the work of Norman et al (1956, 1957) is generally valid. They carried out work using to filament bundles as yarn bundles and studied the ease of wicking where the liquid available is limited.

Lord (1974) conducted studies on wicking behaviour of rotor spun yarns and compared it with ring spun yarns. He conducted limited tests, and reached the conclusion that the wicking height is not very sensitive to changes in the twist of the rotor spun yarns.

De Boar (1980) has suggested the three types of measuring methods namely, (i) vertical wicking test (ii) determination of saturation value and (iii) drop test; these cover both the parameters of any amount of liquid absorbed and the rate of absorption.

Sengupta and Srinivasamurthy (1985) investigated the wicking behaviour of ring and rotor with yarns various twist factors and arrived at a general conclusion on the effect of twist on wickability. They have also indicated that hard twisted yarns have a lower wicking tendency than those of soft twisted yarn and the wicking time increases as twist increases. Wicking is, however, less sensitive to twist than in the corresponding ring spun yarns.

Subramaniam et al (1988) have reinterpreted Sengupta’s (1985) results and pointed out that the wicking test is more appropriate for rotor yarns than was previously thought. The only change that has been suggested is that wicking height should be plotted against square root of time.
2.7.1 STRIP TEST

Strip tests can be used for studying wickability of fabrics and yarns. This is performed with a yarn suspended vertically or horizontally with one end dipped into a reservoir or liquid (usually water) then either the time for the liquid to reach a certain level or the height of the advancing liquid front as a function of time is recorded. The amount of water in the yarn also can be measured as a function of time to study wicking.

In most of the previous studies on wicking, dyes were used in distilled water in order to indicate the wicking distance (Cary and Sproles, 1979; Kaswell et al 1961; Minor et al 1959). However, Lichstein (1974) criticised this method because the dye solution would remain a distance behind the actual advancing water front. Lord (1974) pointed out that dye solution does not have the same surface tension and density as water, although it is a useful tracer. Also, dyes vary widely and such tests can be more than comparative.

A simpler capillary – tube flow model is used for studying liquid transport in textile materials. The liquid moves into a porous medium by the capillary pressure. The magnitude of the capillary pressure is commonly given by the Laplace equation as applied to an idealised capillary tube (Adamson, 1967),

\[
P = \frac{2\gamma \cos \theta}{R} \quad \text{ .................. (2.2)}
\]

where \( R_C \) is the capillary radius \( \gamma \) is the surface tension of the advancing liquid.
\[ \theta \text{ is the contact angle at the liquid-solid-air interface.} \]

With an idealised tube structure the volumetric flow rate is given by the Hagen-Poiseuille law, which states that it is proportional to the pressure drop gradient along the tube, (Chatterjee 1985)

\[ Q = \frac{R_C^2 \Delta P}{n L} \] .............................. (2.3)

where \( Q \) is the volume flux,

\( R_C \) is the tube radius,

\( n \) is the fluid viscosity

\( L \) is the wetted length of the tube,

\( \Delta P \) is the net driving pressure (pressure drop across \( L \))

Washburn (1921) transformed equation (2.3) into the following approximate form, which is commonly known as the Washburn equation

\[ L = \left( \frac{R_C \gamma \cos \theta}{2 \eta} \right)^{\frac{1}{2}} t^{\frac{1}{2}} \]

\[ = Ct^{\frac{1}{2}} \] ................................. (2.4)

where, \( C \) is a constant.

The Washburn’s (1921) equation is widely regarded in wicking kinetics while there exists a controversy about its validity for all kinds of porous media. Laughlin (1961) found that the Washburn equation did not hold in general when he investigated the wicking behaviour of wool felt and cotton
fabrics in a light grade of lubricating oil. He made a modification to the Washburn equation, namely:

\[ L = C t^k \]

where \( C \) is a constant.

\( k \) is time exponent.

The logarithm of both sides of Equation (2.4) was taken which gave:

\[ \ln (L) = K \ln (t) + \ln C' \]

\( .............(2.5) \)

which has the form of a straight line.

Kissa (1996) has stated that the limitations of the Washburn equation were frequently overlooked. The equation incorrectly assumes a constant advancing contact angle \( \Theta \) for the moving meniscus (Fisher and Lork 1979) felt that Washburn equation does not take into account the inertia of the flow. It was reported by Kissa (1996) that a variety of liquids had obeyed the Washburn wicking kinetics. Laughlin (1961), Law (1988) and Maroufi (1997) have reiterated the need to improve the Washburn equation. The definition of the capillary radius and the time exponent (0.5) are contentious. Laughlin (1961) demonstrated that the Washburn equation was found to be unsatisfactory when applied to the experimental data of a horizontal strip test for wool, cotton and porous acrylic fabrics. Wicking behaviour of interlock fabrics made out of cotton was investigated by Maroufi (1997), who found that the Washburn equation did not hold true in his research and he derived a modified version of the Washburn equation. The effect of scouring and drying on the wetting of cotton fabric was investigated by De Boar (1980). This work demonstrated that there was a very good linear relation between the logarithm of the height of rise \( H \) and the logarithm of the
duration of time $t$. This relationship was found to be valid for polyester woven fabrics and the values of the time exponent were found to be 0.512 and 0.461 with different scouring methods for a vertical wicking test.

Chen et al (2002) have studied the kinetics of wicking of liquid droplets into yarns. They studied the kinetics of wicking of liquid droplets into yarns by computerised imaging system. A new method is suggested for characterization of the yarn structure by monitoring the droplet absorption. The method is based on the comparative analysis of the time needed for the droplet disappearance as a function of the droplet volume for various yarns. A mathematical model is developed for the description of the wicking kinetics. It is shown that for wetting liquids, the time of droplet absorption $T_w$ is a linear function of the initial droplet volume squared $V_0^2$. For a given, liquid yarn pair, the slope of this relationship provides important information, about the yarn properties. The linear relationship between $T_w$ and $V_0^2$ has been verified by the experimental data with a typical spin finish. The model predicts that droplet wicking could occur even if the advancing contact angle $\theta_a$ is slightly greater than, $90^\circ$. However, for non-wetting liquids, the relationship between $T_w$ and $V_0^2$ is non-linear. A criterion for droplet wicking into non-wetter yarn is obtained.

Wiener and Dejlova (2003) have proposed a model which is based on the thread structure. They have considered fineness of fibres, and number of fibres at the cross section in the bundle and the filling. The formation of the liquid in the longitudinal textile is described in detail, and important parameters are used in the model of wicking. Their model allows a functional dependence of suction height on the parameters of the fibre bundle to be expressed in analytical form.
2.8 SHEAR STRENGTH

A minimum amount of strength is a necessity in any fibre that is to be used to make a textile fabric. Attention has been concentrated, thus on measuring the strength of fibres and the effect of the method of manufacture, chemical treatments etc., on the property. There are various factors that determine fibre strength, namely and test conditions such as relative humidity, rate of duration of loading and test length. Yarns are produced from fibres and are the subjected to tensile and shear strain. It is necessary to investigate the strength yarns since when a fibre, yarn or fabric is pulled, the material is stretching and the amount of stretch is related to its resistance to force. The resistance is determined by incrementally loading or stretching the material and recording the relationship between the load or force and the amount the specimen stretches. The recording is usually in the form of force elongation or stress strain curve. A number of instruments such as the Cambridge Extensometer and the Universal Testing Machine are used for obtaining the stress strain curves. Finalayson (1947) was the first to carry out work on the shear strength of fibres.

In use, textile fibres are also subjected to shear stresses. For example when pressure is applied to the face of a woven fabric, one set of threads will impose as shearing force on the set of threads that cross them. Similarly, shear stresses are setup when threads or fibre are twisted or knitted. In these examples, the stresses are compound, and in order to study the effect of shear stress alone, it is necessary to adopt some simple device.

Textile yarns are usually twisted structures, and their scientific study is concerned largely with the geometrical and mechanical characteristics of such structures. Yarns may be made from continuous filaments or spun
from short staple fibres. In the case of staple yarns, twist provides tensile strength, but is essential for the achievement of satisfactory resistance to lateral abrasion, fatigue or damage associated with the breakage of individual filaments.

2.9 SPIRALITY

Fabric spirality is a complex phenomenon arising from many factors influencing the nature and degree of loop distortion in single-jersey knitted fabrics. Residual torque is believed to be the most important and fundamental factor affecting the degree of fabric spirality. Platt et al (1958) have demonstrated that total torsional stresses in a twisted yarn arise mainly from the effects of fibre bending and twisting. By using the elastic theory, they derived expressions for the yarn torque due to yarn twisting.

Postle, Burton and Chaikin (1964) went one step further and demonstrated that the total yarn torque in a twisted yarn not only arises from the stresses due to fibre bending and twisting but is also influenced by the fibre tension in the twisted configuration. These authors derived an expression for the yarn torque governed by fibre tension. The work of Postle et al (1964) is a significant contribution to torque of yarns.

Davis, Edwards and Stanbury (1934), who did work on spirality, attributed it to twist in the yarn. After experiments in which they knitted fabrics from yarns of different twists they wrote “In every case the spirality increases directly with the yarn twist, takes a left or right direction in accordance with the yarn twist, and is increased by slackening the texture of the fabric”. They found that spirality could be very much reduced by setting
the twist in the yarn before knitting, or by using a balanced yarn consisting of two ends of opposite twist.

2.9.1 **Factors Affecting Spirality**


Several standards are available for measuring the spirality angle eg. The BSI, IWS and ASTM. With the aid of a protractor, the spirality in a knitted fabric can be determined easily. Recently, Celik et al (2005) have developed a method of measuring spirality using image analysis.

Spirality is a regular deformation of the structure caused by each loop twisting over to approximately the same angle (Figure 2.7). The angle between the wales and courses is then less than 90° and when the angle is less than about 83° the distorted appearance of the structure is very obvious and the merchandise is likely to bring customer complaints. Spirality is due to “twist liveliness” the release in torsional potential energy in the yarn. The result of the section of yarn of each loop trying to move into a state of lower strain under the constraint of forces from neighbouring loops is for the loop to twist over. This phenomenon may be seen when the fabric is produced from singles yarns which have not been properly set or from unset two fold yarns which do not have the balancing ratio of singles twist to folding twist.
2.9.2 Effect of Relaxation Treatments

Tao, Dhingra, Chan and Abbas (1997) have investigated the effects of yarn and fabrics construction on spirality of cotton single jersey fabrics. They produced a series of 56 fabrics on a single feeder circular knitting machine using cotton ring spun yarns which covered a wide range of yarn counts, twists and fabric tightness factor. Three yarn counts namely, 18, 21, 24 tex and five twist factors 21, 25, 29, 33, 37 tex$^{0.5}$ tpcm comprising a total of fourteen kinds of yarns were used. Each yarn was knitted at four levels of tightness factor 11, 13, 15 and 17 tex$^{0.5}$ cm$^{-1}$. The fabrics knitted were subjected to dry and wet relaxation treatments. The method of measuring spirality was based on the British standard 2819. It was found that the spirality values in dry relaxed state were lower but accompanied by higher coefficient of variation compared to wet relaxed state. Also, with the increase in tightness factor the spirality values fell while an increase in twist factor led to an increase in spirality. Washed and tumble dried samples showed higher values of spirality compared to either wet relaxed or dry relaxed samples. Correlations were worked out between the various parameters such as yarn
count, yarn twist and tightness factor. The main conclusions reached are that yarn twist factor and fabric tightness factor affected spirality to a greater extent. The work also revealed that the steady-state loop shape for the washed/tumble do dried specimens knitted from ring spun yarns was not unique which was consistent with the observations of Banerjee and Alaiban (1988).

According to De Araujo and Smith (1989), the Figure 2.8 represents the development of spirality in a single jersey fabric knitted with a Z twist yarn on a multi feeder circular machine revolving clockwise;

![Diagram of spirality development](image)

**Figure 2.8** Development of spirality in a single jersey fabric knitted from a Z-twisted yarn on a multifeed circular machine with a clockwise rotating cylinder

Let $DD'$ = Position of a whole when total spirality occurs

$XX'$ = Position of a course when total spirality occurs
\[ X'A = \frac{F}{C} \]  
Displacement between two consecutive courses knitted by the same feed.

\[ XA = \] Position of a course when spirality due to the number of feeds occurs.

\[ XX' = \frac{N}{W} \] open width of fabric.

\[ F = \] Total number of feeds on the knitting machine.

\[ N = \] Total number of needles in the knitting machine.

\[ C = \] Courses per unit length.

\[ W = \] Wales per unit length.

\[ \theta_Y = \] Spirality due to the yarn

\[ \theta_F = \] Spirality due to the number of feeds

\[ \theta_{YF} = \] Total spirality

Course displacement

Then \( \tan \theta_F = \frac{\text{Fabric width}}{\frac{F}{W} \cdot \frac{C}{N}} \)

If \( W = \frac{K_W}{I} \) and

\[ C = \frac{K_C}{I} \]

Where \( K_C \) and \( K_W \) = non dimensional parameters whose value depends on the state of relaxation and \( I = \) loop length (cm) then, loop shape factor = \( KC/KW \) and substituting the above in equation
\[
\tan \theta_F = \frac{F}{NK_C/W}
\]

\[
\theta_F = \frac{\tan^{-1} F}{NK_C/W}
\]

Equation 2.6 shows that the angle of spirality due to the number of feeds on the knitting machine depends not only on the number of feeds, but also on the shape of the loop in a particular state of relaxation of the knitted fabric and on the number of active needles in the knitting machine which in turn depends on machine cut and diameter.

2.9.3 Effect of type of yarn

Postle et al (1964) have demonstrated that yarn torque arises due to fibre tension in addition to fibre bending and fibre torsion.

Total yarn torque comprises three components namely fibre bending, fibre torsion and fibre tension. Platt et al (1958) have ignored the component due to fibre tension in their analysis of yarn torque. Postle et al (1964), who have extended the work of Platt et al (1958), have obtained the following relationship

\[
L_T = L_{FE} + L_{FT} + L_B \quad \text{.................... (2.7)}
\]

where
\[
L_{FT} = \text{Fibre torsion}
\]
\[
L_{FE} = \text{Fibre extension}
\]
\[
L_{FB} = \text{Fibre bending}
\]
\[ L_T = \text{Total yarn torque} \]

Yarn torque component due to fibre tension = \( \pi R_y^3 E_f, e_y f, (\theta_s) \)

where

- \( E_f \) = Fibre tensile modulus
- \( R_y \) = Yarn radius
- \( \theta_s \) = Yarn surface helix angle
- \( \theta_y \) = Yarn tensile strain

In all the processes, the yarn is subjected to considerable amount of stresses which are likely to affect yarn torque.

It is apparent from the above that the basic components of yarn torque are dependent on fibre modulus and yarn tensile strain and helix angle (twist). Stress relaxation in fibres drastically reduces on exposure, to moisture and temperature; they may affect yarn torque considerably. Torsional instability of yarns affects skewness in woven and spirality in knitted structures. The work carried out by Postle (1964), Dhingra and Postle (1974) is very relevant for understanding torsional properties of yarns.

Bennett and Postle (1981) reported that the knitted fabric spirality, as measured by the complement of the angle between the courses and wales in the fabric, not only shows a loop asymmetry due to the interaction of yarn torque and yarn stresses induced by the formation of the knitted loop shape. This factor has to be taken in to account, since plain knitted loop tends to rotate about an axis parallel to the line of the wales to produce an apparently asymmetric loop structure.
2.10 MULTIVARIATE STATISTICAL ANALYSIS

The application of multivariate statistical analysis is becoming very useful in textiles owing to the availability of the computer and software packages to analyze the data.

2.11 GENETIC ALGORITHM AND ARTIFICIAL NEURAL NETWORK IN TEXTILES

An artificial neural network is an information-processing system that has certain performance characteristics in common with biological neural networks. Artificial neural networks have been developed as generalizations of mathematical models of human cognition or neural biology, based on the assumptions that:

1. Information processing occurs at many simple elements called neurons.
2. Signals are passed between neurons over connection links.
3. Each connection link has an associated weight, which, in a typical neural net, multiplies the signal transmitted.
4. Each neuron applies an activation function (usually nonlinear) to its net input (sum of weighted input signals) to determine its output signal.

A neural network is characterized by (1) its pattern of connections between the neurons (called its architecture), (2) its method of determining the weights on the connections (called its training, or learning, algorithm) and (3) its activation function.
A neural net consists of a large number of simple processing elements called neurons, units, cells, or nodes. Each neuron is connected to other neurons by means of directed communication links, each with an associated weight. The weights represent information being used by the net to solve a problem. Neural nets can be applied to a wide variety of problems.

A Genetic algorithm is an optimisation procedure based on the principles of evolution. Just as the neural network shares some terminology with neuroscience, the genetic algorithm does likewise with the language of natural selection and genetics. They combine survival of the fittest among string structures with a structured yet randomized information exchange to form a search algorithm with some of the innovative flair of human search. In every generation, a new set of artificial creatures (strings) is created using bits and pieces of the fittest of the old; and occasional new part is tried for good measure.

Genetic algorithms are different from more normal optimization and search procedures in four ways:

1. Genetic algorithms work with a coding of the parameter set, not the parameters themselves.
2. Genetic algorithms search from a population of points, not a single point.
3. Genetic algorithms use payoff (objective function) information, not derivatives of other auxiliary knowledge.
4. Genetic algorithms use probabilistic transition rules, not deterministic rules.

The most common combinations of genetic algorithms and neural networks occurs in the cases where instead of the back-propagation method, a genetic algorithm is used to evolve either the network’s inter-neuronal
connection weights, or instead to decide upon the network architecture or even indeed the learning rule itself. (Yao 1999)

2.11.1 Previous Work done on Genetic Algorithms and Artificial Neural Networks

The properties of yarns which are important to determine the quality of yarns are strength, evenness and hairiness. Several studies have dealt with the effects of fibre properties and spinning parameters on yarn hairiness (Barella 1983, Barella and Manich 1988, Walton 1968).


Behera and Muttagi (2005) adopted three modeling methodologies based on mathematical, empirical and artificial neural network based on radial basis function for comparing their ability to predict woven fabric properties and found that the artificial neural networks produced the least error.

attempted to apply artificial neural networks for prediction of rotor spun yarn properties.

The idea to hybridise the two approaches, namely genetic algorithm and back-propagation network was followed by Whitely and Coworkers (Whitely and Bogart 1989, 1990, Whitely and Hanson 1989, Whitely and Starkwerthes 1990) who used genetic algorithms to guide back propagation network in finding the necessary connections instead of all connection in order to enhance the speed of training.

Though Kitano (1990) Proposed some evidence to show that genetic algorithm and back-propagation network mating does not provide any advantage over a randomly initialized multiple application of Quick prop (a fast variant of back-propagation) alone, ablest for shallow networks and easy fitness function, successful reports have been reported with a hybrid approach.

Sette, Boullart, Van Langenhove and Kiekens (1997) used method to simulate and optimize the fibre to yarn production process using a neural network combined with a genetic algorithm and shown that simultaneous optimization of yarn qualities was easily achieved as a function of the necessary (optimal) input parameters.

Hugh M.Cart Wright, Les Sztandera and Chih-Chung Chu (2005) have used a hybrid system in which the neural network was constructed first, as a model whose role was to predict the properties of a given polymer from its composition or structure, thereby solving what is known as the forward problem. The second technique was the genetic algorithm, which solves the inverse problem by acting as a search procedure to find the optimum formulation. The overall resulting tool was a hybrid intelligent system in which multiple techniques from Artificial intelligence are combined to take advantage of the best features of each.