Improvement in Yarn Quality for Cotton and Cotton Blend Yarns

by

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Abstract

The aim of this work was to investigate means of improving yarn quality. Quality is a broad term which includes yarn characteristics like tenacity, elongation, hairiness, evenness and abrasion resistance but also a lower cost of production. For a certain raw material any improvement in yarn quality can only be achieved by improving the spinning system's ability to utilise the same raw material more efficiently or effectively.

To achieve this goal, firstly the possibility of improving the distribution of fibres in the yarn was investigated by studying "Drafting against untwisting". Secondly, the possibility of improving locking in of fibres into the yarn structure was investigated. Both an air jet and a rubbing assembly were studied.

Yarns with improved evenness, an improved fibre distribution, will be stronger and therefore can be spun finer and at lower twist factors. Yarns with improved locking of fibres into the yarn structure have the potential of improved strength and less hairiness. Importantly, they can be more resilient to the gradual degradation which takes place due to abrasion, and therefore will have improved downstream performance, ranging from weaving performance to performance after conversion into fabric, thus increasing the quality of the fabric.

Spinning trials and fabric tests have established that not only manufacturing quality but also retention of yarn quality can be improved by combining the advantages of improved fibre trapping and compact spinning.

Dedication

I would like to dedicate this work to my Parents Mr. Muhammad Aslam and Mrs. Shameem Aslam and to my brother Saadi for their endless love and support!

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“There is a way to do it better- find it”

Thomas Edison

“It's not that I'm so smart, it's just that I stay with problems longer”

Albert Einstein

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CHAPTER ONE

Introduction

1.1 Introduction

Since the discovery of the art of fabric making, there has been a quest for finer and higher quality fabrics. From the emperor's new clothes to fashion gurus of the modern era, quality clothing has been a key choice for displaying ones nobility and for distinguishing aristocrats from common people [1-3]. Until a few years ago, this quest for improved fabrics was restricted to aesthetic properties, but it now covers fabrics from the sports field to the battle field [4-6]. This everlasting demand for higher quality fabrics has driven the demand for higher quality yarns. Yarn quality standards are getting tighter and tighter and pressure on yarn manufacturers for higher quality yarns is increasing. Yarn being the basic building unit for any woven or knitted fabrics is considered to be the most important determinant of fabric quality. The very fine fabrics that are being used in the fashion industry, require really high quality yarns, some of which are so fine and delicate that they are hardly spinnable.

The second factor that has pushed the yarn manufacturers for improvement in quality is the cost factor. Cost of manufacturing is increasing very rapidly and markets are getting more and more competitive. One of the easiest ways of reducing this cost of production is to increase the production rates. This quest for higher production rates has led to replacement of shuttle looms by rapier or projectile looms and then substitution of projectile looms by air jet looms. The use of latest techniques has enabled production speeds of up to 1200 rpm on the loom and even at such high production speeds, a yarn having more than two warp breakages per 100 km is considered a below average yarn [7]. These high speed production machines have tested the yarn quality to its highest levels. Although the use of the latest technology in textile machinery has enabled the fabric manufacturing process to absorb some minor short-comings in the yarn, it cannot provide a remedy for a major flaw in yarn quality, and the increase in production speed from 300 picks / min on a projectile loom to 1200 picks / min on an air jet loom requires every inch of the yarn to be virtually flawless.

To keep pace with this demand, the spinning industry has also come up with various developments. These range from modifications to existing spinning systems to the evolution of new spinning techniques. These techniques have addressed both aspects of yarn quality i.e. value addition to the product and reduction in the cost of production.

1.2 Background

1.2.1 Yarn spinning

The term spinning covers both the process or processes used for production of fibres or filaments from natural or synthetic polymers and those used for converting natural or manmade fibres and filaments into yarns by twisting or other methods of binding. The latter provides relatively fine continuous lengths of thread that are suitable for conversion into fabric or for use directly for sewing or rope making. The product achieved by this spinning process is called yarn. A yarn is defined as "an assembly of fibres held together by some binding force usually provided by inserting twist" [8, 9]. This specially is the case for staple fibre yarns, where fibres of small lengths are held together to form a continuous assembly. Filament yarns do not need to be highly twisted as they are already in continuous form, and thus do not need a very strong binding force, but for staple fibre yarns the fibres need to be held together by some force. For this purpose either an adhesive is used as in 'Twilo' process [10] or twist. Use of adhesive did not prove to be commercially very feasible. Up till now the most effective way of binding the fibres together has been by twist insertion. This method of imparting strength has been in use since Palaeolithic times. Although it can be assumed that at that stage twist was inserted by just rolling the attenuated strand of fibres in the palms of hands [11]. Twist increases the frictional forces between fibres and prevents fibres from slipping over one another by generating radial forces directed toward the yarn interior [12]. Based on this principle of twist insertion various yarn manufacturing systems have been developed. Although all these methods use the same basic principle, i.e. twist insertion, for holding the fibres together, the method of twist insertion is different for each technique. The yarns produced by these systems have their own distinct structure and it is this structure which gives the different yarns distinct properties. Among them ring spinning is the most widely used spinning system [13]. The ring and traveller is a remarkable self-compensating mechanism for inserting twist into a fibrous strand and as such has survived for such a long time [14]. The main reasons for the popularity of ring spinning are its flexibility in terms of both the raw material and the count range and especially its optimal yarn structure which results in outstanding yarn strength [12, 15, 16].

The main drawback associated with ring spinning is its low production rate or, in other words, higher production cost. In ring spinning, the whole yarn package has to be rotated for twist insertion. The spindle speeds therefore cannot be increased beyond a certain level. Another factor that limits the production speed in ring spinning is the traveller. During running of a ring spinning machine there is a high contact pressure between ring and traveller. Due to this high contact pressure an excessive amount of heat is generated between ring and traveller. This temperature might reach up to 400 ^{o}C. Currently, the traveller speed is limited to about 50 m/s but most machines seldom exceed 40 m/s [10, 15, 16]. Another approach for reducing the cost of production has been to automate the machinery, but that too has certain limitations. Frey [16, 17] has argued that at present further automation in ring spinning is not economical since the reduction in the number of staff is balanced by an increase in the qualification of the employees. He claims that the economic performance of ring spinning can be improved only by increasing the output per spindle.

A solution to this problem of ring spinning was provided by ‘open end’ spinning systems such as rotor spinning or friction spinning. In this system the fibrous material is highly drafted to individual fibre state. These open fibres are collected on the open end of the yarns, which is rotated to insert twist and form a continuous structure. Rotor spinning gives production rates of about 200 m/min compared to a maximum of 40 m/min for ring spinning. In addition, this process avoids two processes of ring spinning i.e. the roving frame and winding are bypassed, thereby reducing the cost of production [18]. Despite these benefits rotor spinning cannot totally replace ring spinning. The biggest disadvantage of rotor spinning is its yarn structure. Rotor spun yarns can be viewed as having a three part structure i.e. wrapper fibres, sheath fibres and core fibres. The core fibres are densely packed like ring spun yarns, whereas sheath fibres are loosely packed around the yarn core at a low angle and the wrapper fibres are wrapped around the outside of the yarn. Owing to this structure, fibres are less packed than in ring yarns. Rotor yarns are known to be 5-10 % more bulky than ring yarns. The fibres in rotor yarn are densely packed near the yarn axis and this density reduces towards the outer surface of the yarn, compared to the ring spun yarns. The yarn produced from rotor spinning has a harsher feel. The second disadvantage of this technique is that it cannot be employed for the manufacture of finer counts. Its current range is 16 to 120 tex. The range of raw material for rotor spinning is also very limited [19, 20]. In terms of raw material flexibility friction spinning system is more flexible than rotor spinning, which the other commonly used open end spinning system. In friction spinning twist is inserted into opened fibres by two counter-rotating friction rollers which insert twist by rolling the strand [21]. Due to the low spinning tension in the yarn forming zone a high production speed of up to 500 m/min can be achieved. The structure of friction spun yarns is different from ring spun yarns. Fibre orientation of these yarns is very poor as the yarn draw off direction is perpendicular to the fibre delivery direction. The orientation of fibres in yarns is mainly governed by the characteristics of air flow inside the transport channel and by the landing behaviour of the fibres on the friction rollers [21]. The biggest disadvantage of friction spun yarns is lower tenacity, as their fibre strength translation efficiency is very low. The inter-fibre cohesion is also very low. They are inferior in evenness, imperfections and hairiness [21]. The yarns are limited to the range of 42-591 tex. However, practically only coarser are spun. These yarns are mostly used for industrial, technical and speciality purposes, especially where high twist level is required.

Another high production method used for staple yarn spinning by twist insertion is air jet spinning. Air jet spinning offers the fastest commercial production of staple fibre yarns. The main distinguishing feature of the air-jet spinning is the use of a swirling airflow for twist insertion. Yarns produced by air jet spinning, have a special structure. There is a core of relatively parallel fibres which is wrapped by small quantity of surface fibres. The structure has been called “fasciated”[22].

The biggest advantage of air jet spinning is its high production speed. It can produce yarns at up to 500 m/min., about 2 to 3 times faster than rotor spinning and 20 to 30 times faster than ring spinning [22]. Like rotor spinning the steps of roving frame and winding are avoided. Low yarn tenacity is one of the biggest disadvantage of air jet spinning. For 100 % cotton the strength of MJS (Murata Jet Spun) yarn is 40-50 % lower than ring spun yarns whereas for polyester / cotton yarns the difference is 15-20 %. Count flexibility of MJS yarns is also very low. It can only be used for finer counts down to 10 tex. Tenacity decreases as the yarn gets coarser. Some of the shortcomings associated with MJS yarns have been removed by MVS (Murata Vortex Spinning). MVS yarns are claimed to be stronger than MJS yarns due to presence of higher number of wrapper fibres. They are also less hairy and highly abrasion resistant [22].

All these modern spinning systems discussed above offer much higher production rates as compared to ring spinning. In addition to higher production processes like roving frames and winding are also eliminated, which significantly reduces the cost of manufacturing. Despite the cost effectiveness of these systems, they have not been able to totally replace ring spinning. Ring spinning has a clear cut edge over the rest of the technologies. It can use a wide range of raw materials from short fibres to long fibres. With the use of such a wide range of raw material and its inherent flexibility, it can be used over a wide count range, i.e. from coarse to very fine. The structure of ring spun yarns is also very special and enables them to have higher tenacity than those of any other spinning system [23, 24]. These qualities make ring spinning the most widely used spinning system, despite the extra cost of manufacture compared with rotor, friction or air jet spinning.

1.2.2 Yarn quality

In manufacturing, quality is defined as "conformance to requirements", where requirements, or specifications, are established standards, and any deviation from these standards implies a reduction in quality [25]. The ISO 8402-1986 standard defines quality as "the totality of features and characteristics of a product or service that bears its ability to satisfy stated or implied needs" [26]. Thus quality is really the extent to which performance meets customer demands and needs. It also means that something very high in quality for one purpose could be entirely useless for some other task. This applies to yarns as well. Yarn quality standards vary quite markedly according to the customer requirement and are mainly governed by the end use. However, before reaching the customer the yarn has to undergo several manufacturing stages. For a yarn to qualify as a good quality yarn it has to have had satisfactory performance in those manufacturing stages. The first stage is spinning where fibres are converted into a yarn and the next is the conversion of yarn to fabric which is usually achieved by knitting or weaving.

One of the easiest ways of manufacturing a high quality yarn is by using very high quality raw material and processing on very sophisticated machinery, but it can be expensive. In today's competitive environment costs can never be ignored by a commercial organisation. From a commercial point of view it is very important to achieve the highest possible quality at the lowest possible cost. Various spinning systems have been designed to achieve these goals and have their pros and cons but as a general rule it can be said that a spinning system capable of producing yarn over a wide count range and capable of utilising a wider range of raw materials with minimum possible running cost and still having highest possible standards of hairiness, evenness, strength and elongation can be called an ideal spinning system.

In order to quantify the yarn quality and potential for good downstream performance, certain quality parameters have been developed. These parameters are mutually interdependent and modifying anyone of them can affect the others. A brief introduction of the parameters which describe the quality of the yarn, follows.

1.2.2.1 Strength

Strength is one of the most important determinants of a yarn spinning and downstream performance. During spinning and fabric manufacture yarns are exposed to high tensions, and any weak spot in the yarn length being processed, will act as a weak link and may lead to a yarn break. Excessive breakage (ends down) in spinning causes a loss in production. In addition to the loss in production, these end breaks cause lots of fly generation which not only increases the percentage of waste but also pollutes the working environment. This increased fly generation increases the load on the air conditioning plant, which in turn leads to increased electricity costs. Similarly, in weaving a low strength yarn causes excessive warp breakage which results in repeated loom stoppages causing an increase in the cost of production. Besides excessive loom stoppages can cause severe fabric faults like starting marks, missed picks, half miss picks etc.

One of the easiest ways of increasing yarn strength is by increasing the twist level in the yarn but not without sacrificing the production rate and feel of the fabric produced from this yarn. The strength increases with twist up to a certain level and then decreases. This effect is represented by the twist strength curve, as shown in Figure 1.1 [27].

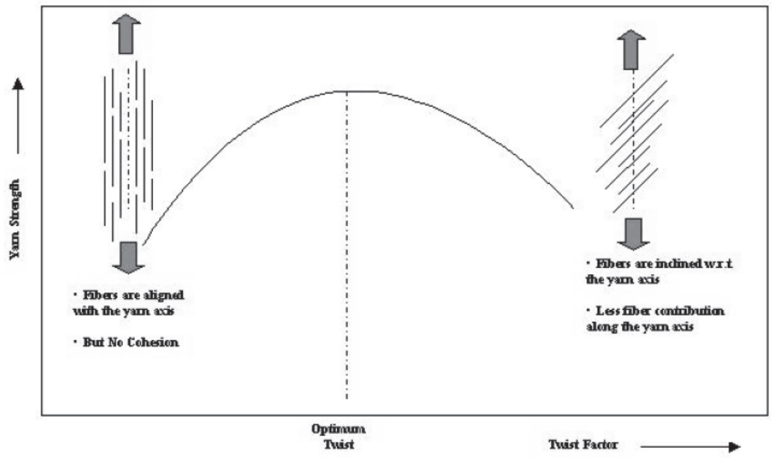


Figure 1.1. Twist strength curve [27]

1.2.2.2 Evenness

Evenness is defined as the uniformity in linear density of the yarn. Linear density is a function of the number of fibres in the cross-section of the yarn and the cross sectional area (for a given density) of the fibres. It can be affected by uniformity of certain other factors such as hairiness and twist [28-30]. Ideally, for a yarn to be even, the fibres should be arranged so that when one fibre finishes another starts and fibres should be laid end to end to ensure a constant number of fibres in the cross-section. However, the best distribution of fibres that can be achieved in a fibre assembly is a random arrangement. This is because none of the processes in yarn spinning process has the ability to add or remove fibres when a thin or thicker region is encountered (except for the auto leveller, which reduces the long term variations). The term index of irregularity is used to measure how close the evenness of a fibre assembly is, to the best achievable. It is defined as the ratio of the measured to the ideal coefficient of variation of thickness (CV %), the latter being given by

$$CV \qquad \frac{*}{\sqrt{}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (1.1)$$

Where n is the number of fibres in the cross section and allows for variation in the thickness of fibres [31].

If the fibres are not evenly distributed along the length of the yarn the resultant yarn will have thick and thin places. Normally a thin place which has fewer fibres in the cross-section will be weaker than the rest of the yarn and since the strength of the yarn depends on the weakest segment in the yarn; the overall strength of the yarn will be lower. Unevenness in the yarn also worsens the appearance of the fabric. It causes a streaky appearance in the fabric and this effect gets more prominent after dyeing.

1.2.2.3 Hairiness

Fibres protruding from the yarn surface, with one end trapped in the yarn core but other end free, are called hairs and the presence of such fibres is called hairiness. The sources of hairiness are lack of incorporation of fibre ends during twisting (i.e. at the spinning triangle) and the friction between yarn and machine parts. Hairiness causes a number of problems during subsequent processing of yarn. First of all, since these fibres are trapped at one end only, they do not play their role in yarn strength as they do not share the breaking load applied to the yarn despite contributing to the count. Second and may-be the biggest disadvantage of hairiness, is that it causes entanglement with neighbouring yarns when they undergo severe rubbing and cyclic tensioning during the shedding process in weaving. To overcome this effect, cotton yarns have to undergo a sizing process to make these fibres stick to the yarn surface. Sizing itself is a very costly process so it has always been a spinner’s dream to make a weave-able yarn without sizing.

Another disadvantage of hairiness is the increase in the pilling tendency of fabrics. These loose fibres when rubbed against some surface can entangle with each other forming a bead or balls of fibres on the surface of the fabric called pills. This pilling destroys the appearance of fabrics.

Despite these disadvantages hairiness does have a small advantage as well. During weaving of fabric on air jet looms the weft insertion is carried out using air jets instead of a shuttle or rapier. Protruding fibres on the yarn surface help the air in carrying the yarn across the whole width of the fabric. Air comes out of the nozzle (relay nozzles) under the yarn and this air provides a cushion for lifting the yarn. The presence of protruding fibres helps the air jet in carrying the yarn by increasing the surface area of the yarn.

Practically it is not possible to spin a yarn which is not hairy, so standards have been developed for acceptable limits of hairiness. It is mainly the longer fibres which cause problems, and the number of fibres that extend more than 3 mm (S3 value) has become a common measure of yarn hairiness.

1.2.2.4 Fibre migration

Fibres in a spun yarn depart from perfect helices and the intermingling or intermeshing of the imperfect helices enable the structure to be self-locking. The change in radial position of fibre elements with respect to fibre length is called fibre migration. The presence of fibre loops, hooks, and tangles affects the yarn performance, and the lack of fibre straightness is described as fibre extent, defined as [32]:

Fibre extent ————————————————………... (1.2)

The ideal helical geometry which is usually used to describe the yarn structure is based on the assumption that a yarn is circular in cross-section and the fibres follow helical paths around concentric cylinders of constant radius. This idealised structure is very difficult to achieve and even if it is achieved, it would be useless at least for staple fibre yarns [33].

Twist is necessary for conversion of staple fibres into yarn. It provides the necessary force of cohesion required to hold the fibres together, but twist alone cannot hold fibres together as the fibres at the surface of the yarn are merely wrapped around the yarn axis so they cannot contribute to the yarn strength. Besides these fibres would start peeling off when exposed to rubbing and eventually the whole yarn would rub away. It was first established by Peirce that fibres appearing on the surface have their ends tucked inside [34].

This behaviour was observed by Morton and Yen [35] and by Morton [36] and the term fibre migration was used to describe this change in position of a single fibre along the length of the yarn. El-Behery [37] and El-Behery and Batavia [38] summarised the factors which affect the fibre position in the yarn into three groups i.e. fibre factors, yarn factors, and factors associated with the spinning process itself.

Most of the research regarding fibre migration in staple yarns is focused on the determinants of fibre migration in yarns and their characterisation. Various techniques have been developed and used to measure the extent of migration and for a variety of fibres, but not much work appears to have been done on the effect of fibre migration on yarn tenacity for ring spun yarns. Some researchers, however, have attributed the low strength in rotor spun yarns to their poor fibre migration and their poor fibre orientation [39-41].

1.2.3 Improvement in yarn quality

The quality characteristics mentioned above are a gauge to measure yarn quality or, in other words, just a means to anticipate yarn performance in spinning and in down-stream processing. Yarn quality is not an absolute term and quality standards vary quite markedly according to customer requirements, end use, cost etc. Therefore a general statement cannot be made about what can be called an ideal yarn. However, there are several targets regarding the yarn characteristics which the yarn manufacturers and researchers are trying to achieve. A brief description of these targets follows

1.2.3.1 Production of finer yarns

Delicate fabrics used in the fashion industry nowadays require finer and finer yarns. Because they have fewer fibres in the cross section, finer yarns are more fragile and are more prone to deterioration in quality, due to any shortcomings in raw material or processing. Therefore, very high quality raw material is required for spinning of finer counts. This high quality raw material is expensive and therefore increases the cost of production. Particularly for natural fibres this effect is very severe, as for them, raw material characteristics cannot be controlled beyond a certain level. Even if a very high quality raw material is used yarns cannot be spun beyond certain fineness.

Among modern spinning systems ring spinning is considered the best spinning system for very fine counts, but even with the most sophisticated modern ring frame, using the very best available raw material, commercially the finest counts produced are 5 tex. At least for cotton, yarns below this fineness level are not spinnable or at least not commercially feasible. The measure of linear density of yarn is called yarn count.

1.2.3.1.1 Yarn count

Yarn Count is expressed in weight per unit length (Direct system) or in length per unit weight (Indirect system). Yarn count depends upon end use. The finer the count, the more difficult it becomes to manufacture and the higher the quality of raw material needed. If there are insufficient fibres, on average, in the cross-section, then the probability of having too few fibres present becomes unacceptably large. The limitation of keeping an average of at least 40 fibres in the cross-section means finer fibres are needed for a finer yarn. For this reason a very high quality raw material with long fibre length and a fine diameter is required. For woollen spinning the relationship between the fibre diameter (D) and average number of fibres (N) is given by [42]:

$$N \quad \frac{*}{\quad} \quad \ldots\ldots\ldots\ldots\ldots \quad (1.3)$$

1.2.3.2 Production of low twist yarns

Up till now twist is the most common way of binding the fibres together in staple fibre yarn spinning. Despite being in use for such a long time it is seen as an unwanted but an unavoidable part of spinning and there have always been efforts to minimise the level of twist in the yarns. There are two main reasons for that. Firstly because the higher level of twist gives a harsher feel to the yarn. Particularly for finer yarns, which usually are used for high aesthetic purposes, where softer feel is a pre requisite, this is a severe problem. Secondly in ring spinning, which is the most widely used method for fine yarns, production rate is inversely proportional to the twist level. Despite having these problems associated with it, the twist level in the yarn cannot be reduced because a reduction in twist level results in a reduction in yarn strength and an increase in yarn hairiness, which reduces the yarn spinning and down-stream processing performance.

Twist inserted in yarns is measured in turns per metre. For different yarn counts different turns per metre are required to achieve the desired strength. For this reason a more generic term called twist factor is used.

1.2.3.2.1 Twist factor

Twist factor is a measure of the spiral orientation of the fibres in a spun yarn or of the filaments in a filament yarn. It links the linear density and the twist. Yarns or rovings composed of the same fibres and having the same twist factor have fibres with the same helix angle and consequently a certain similarity of structure [43]. Twist factor is given by the formula:

$$a \quad \frac{* \;\; \overline{}}{} \ldots\ldots\ldots\ldots\ldots \quad (1.4)$$

Where

a_t = Twist factor expressed in tex system

T = the twist expressed in turns per metre

g = the linear density in tex

1.2.3.3 Production of more abrasion resistant yarns

Abrasion resistance is one of the less emphasised issues in cotton yarn quality. The reason being that cotton yarns are sized before weaving, which accommodates any short-comings in yarn abrasion resistance. In sizing a layer of resins is applied on the yarn surface which binds the fibres to the yarn core and prevents them from being rubbed away. The main reason why cotton yarns cannot be woven without sizing is not due to lack of strength but due to the lack of abrasion resistance. If the yarn abrasion resistance can be considerably improved, yarns might be made weavable even without sizing. Even if the yarn cannot be made weavable without sizing at least it could help reduce the cost of sizing. The shortcoming in abrasion resistance characteristics of the yarn are exposed not only during weaving but are also manifested in the form of reduced service life of fabrics made from such yarn. The plucking out of constituent fibres due to rubbing causes pilling on the fabric surface giving it an unwanted appearance.

1.2.3.4 Reduction in cost of production

A reduction in cost of production might not directly imply an improvement in quality, but for a commercial organisation cost is one of the most important factors to be considered. Apart from that it may allow room for use of some other techniques which are not routinely used but can help improve yarn quality, such as an additional passage on the draw frame, use of finer rovings, or use of better quality (expensive) raw material. Many techniques that have the potential to improve yarn quality significantly have not been adopted commercially just because they are not cost wise feasible.

There have been a number of approaches for reducing the cost of production such as designing a system which can bypass some of the processes (as in open end spinning where processes of roving frame and yarn winding are bypassed) or by increasing the production rate. Production rate can be increased by reducing the twist level in the yarn or by increasing the spindle speed. At the moment spindle speed is limited by traveller speed therefore the most feasible approach to improve the production rate can be by reducing the twist level in the yarn.

1.2.4 Factors affecting yarn quality

Fibre characteristics do not automatically translate into yarn quality. It is also a matter of how these fibres are incorporated into the yarn structure that dictates the quality of the yarn. A brief description of the factors that dictate yarn quality is given in terms of raw material parameters, and machinery and process parameters.

1.2.4.1 Raw material parameters

Selection of raw material is of utmost importance. That is for two reasons. Firstly, because raw material cost constitutes 50 – 70 % of the total cost of the yarn and secondly because the quality of raw material has a direct impact on the quality of the yarn produced. In the case of synthetic fibres it is very easy to alter characteristics of the fibre during the manufacturing process, but in the case of natural fibres it is very complex. The reason is that the quality characteristics of natural fibres cannot be controlled beyond a certain level. Another factor which makes it more complex is the natural variation in quality among natural fibres. Fibre quality varies from area to area, field to field, plant to plant and even within one cotton ball the fibres are not identical. The requirements of raw material characteristics may vary according to the end product but traditionally, the most desirable cotton (Gossypium spp.) is said to be white as snow, as strong as steel, as fine as silk and as long as wool [44], but at the same time the yarn manufacturers want it to be inexpensive [45]. Some of the fibre characteristics which have a direct influence over yarn quality are discussed below.

1.2.4.1.1 Fibre Length

For natural fibres, the length, length uniformity and the length distribution are critical properties, which influence processing and performance [46]. Fibre length mainly depends upon the cotton breed and growing conditions (temperature, water supply, light), but can be affected by ginning as well [45, 47-50].

Fibre length directly affects the spinnability of the fibres and also the strength of the yarn produced. Longer fibre length helps in improving the yarn strength by increased frictional forces with adjacent fibres. During the spinning preparatory processes the fibres have to undergo roller drafting at various stages. The drafting systems are designed to operate efficiently on a very narrow range of staple length. If the fibre length is significantly shorter than the gauge of the drafting zone there will be many floating fibres which affect the quality of drafting. On the other hand, if the gauge of the drafting zone is too short relative to the fibre length it will cause fibres to be damaged.

Longer fibres facilitate the production of yarns with lower twist factors and also yarns produced with longer fibres tend to be less hairy. Excessive fibre length variation (e.g. CV of fibre length, uniformity ratio or uniformity index) result in an increase in process waste and have a negative effect on yarn quality resulting in a deterioration in yarn's spinning and downstream performance [51].

1.2.4.1.2 Maturity

Maturity is defined as the relative wall thickness (i.e. the area of the cell wall to that of a circle with the same perimeter as the fibre, or the ratio of the cell wall thickness to the overall 'diameter' of the fibre).

Immature fibres are flat or ribbon-like in contrast to mature fibres which are rod-like. These immature fibres lack strength and cause variable dye take up. As a result a clear shade variation can be seen on the surface of the fabric. To avoid this problem during dyeing a process called mercerization has to be used, which swells the fibres, improving their dye uptake. However, this process is expensive.

1.2.4.1.3 Fineness

Cotton fibre fineness is governed by both genetic and environmental factors. It affects many aspects of processing performance, including spinning performance, and yarn and fabric quality. Fibre fineness affects the spinning process in several ways. During the preparatory processes where fibres have to withstand severe beating by sharp and pointed needles or wires for opening and cleaning, finer fibres are more prone to breakage. In addition, because finer fibres are more flexible, they are more easily entangled causing nep formation. On the other hand, yarns made from finer fibres have more fibres in their cross-section for a given linear density, which in turn produces stronger yarns, although immature fibres have a negative effect [52], which is more significant for very fine yarns and for rotor and air-jet spinning. Spinning limits, in terms of the number of fibres in the yarn cross section, are 100 or more for rotor, friction and air-jet spinning and about half that for ring spinning. Fibre fineness also plays an important part in governing the ease with which fibres can be twisted together for yarn formation, because of its effect on torsional rigidity [53].

For a spinner the most important effect of fibre fineness is its role in determining the yarn evenness. This is because the uniformity of a yarn is very largely dependent on the average number of fibres in the cross-section. For a given yarn count, the finer the fibres, the more even the yarn is [53].

Finer fibres also enable lower roving and yarn twists to be employed. The yarns and fabrics made from finer fibres are less stiff and have a softer handle. The ideal fineness particularly for rotor spinning and fine yarns is a very fine (< 150 m tex) but fully mature fibre.

1.2.4.1.4 Strength

The strength of an individual cotton fibre is mainly determined by its fineness, whereas the tenacity, which is strength normalised by the fineness of the fibre, is determined by the genetics of the cultivar. Cottons with higher strength values usually give better performance. The effect of fibre fineness and tenacity is more complex. Finer fibres are weaker, and therefore will be more inclined to break during processing, but they may have similar tenacity and when converted into a yarn, they will produce a stronger yarn because of having more fibres in the cross-section. It is therefore always important to make a distinction between absolute fibre strength and fibre tenacity. Fibre tenacity is particularly important for rotor spinning. At optimum yarn twist, fibre tenacity has a greater effect on yarn tenacity than any other fibre property, strength utilization being typically 50 % – 60 % for rotor yarns and 60 %–70 % for ring yarns [54].

1.2.4.1.5 Colour grade

Colour is a fibre quality parameter which does not directly affect the yarn performance in spinning or weaving. However, it has a great influence on the dyeing of fabric made from these fibres. The colour grade is determined by the degree of reflectance (Rd) and yellowness (+b) as established by the official standards and measured by the HVI. Reflectance indicates how bright or dull a sample is and yellowness indicates the degree of colour pigmentation. A three-digit colour code is used. The colour code is determined by locating the point at which the Rd and +b values intersect on the Nickerson-Hunter cotton colorimeter diagram for Upland cotton.

1.2.4.2 Machinery and process parameters

The yarn manufacturing process can be divided into the preparatory processes and the spinning process. As the name suggests the main task of the preparatory processes is to prepare the fibres for spinning by opening, cleaning and improving the orientation of the fibres. The spinning process involves the conversion of the fibrous strand achieved as a result of the preparatory process, into yarn, by twist insertion. The primary target of all these processes is to utilise the individual fibres in the most efficient possible way for yarn manufacturing.

The preparatory process can improve the quality of input material for the ring frame in two ways. Firstly, by removing the inferior quality and unwanted components such as short fibres, mote particles, dust, contaminants etc. in the form of waste e.g. card waste, blow room droppings and comber noil. Secondly, by disentangling the fibres while causing minimum damage to the fibres through optimum settings of various machine settings such as speeds, gauges etc. Removing excessive waste in the preparatory processes can be one of the easiest ways of improving yarn quality but it will have a direct impact on the cost of manufacturing. Therefore the processes are designed in such a way to maintain an optimum level between yarn quality and cost of manufacturing and this can only be achieved by adjusting the machine settings so that they achieve an optimum waste removal while causing minimum damage to the fibres during processing.

1.2.4.2.1 Control over fibre damage during yarn manufacture

Fibre damage may be defined as a substantial change in one or more of the basic fibre characteristics that can result in a loss of fibre contribution to yarn or fabric performance [55]. Fibres have to undergo severe beating during opening, cleaning and carding. Mostly these processes are carried out by mechanical means like beaters, or rollers covered with sharp needles or wires. Some studies suggest that fibres maybe subjected to 10 million contacts with metallic surfaces such as needles or wires during spinning preparatory process (Blow room, carding, combing) [56-58]. When fibres pass through these processes fibre breakage is almost unavoidable, but it can be minimised by using optimum combination of speeds and gauges.

Fibre breakage can occur when fibres are exposed to the harsh treatment caused by high speed sharp needles in carding and the blow room. In addition, fibre breakage can also take place during drafting if the gauge of the drafting zone is set shorter than the fibre length. As a result of fibre breakage the fibre length is reduced, which reduces the spinnability of the fibres.

Apart from fibre breakage there are some other forms of fibre damage too, like over stretching of fibres which reduces the fibre flexibility, and surface alteration of fibres which results in loss of surface cohesion or in some cases excessive fibre clinging.

1.2.4.2.2 Sliver & roving quality

Sliver or roving, which is the input material for spinning machines, is an assembly of a large number of fibres whose position relative to each other, degree of straightening and parallelisation and overlapping are very important in determining yarn quality. These parameters in turn depend upon the quality of the earlier processing. The results of this processing directly affects the quality of yarn produced via the quality of roving that is fed to the ring frame for conversion into yarn.

The most important stage that influences the quality of slivers and rovings is carding [59]. Better carding quality and lower production rates have a direct impact on yarn quality [60]. Faults created at this stage are very difficult to rectify. Fibrous web coming out of the carding machine has some bent or hooked fibres in it [61] . To remove these hooks the fibrous strand is passed through a number of drafting processes, on the drawing frame, roving frame and ring frame. Drafting accompanied by doubling can reduce hooks and improve the evenness of the fibrous strand [62-64]. Drafting alone might improve straightening of the fibres but it causes a deterioration in evenness by reducing the number of fibres in the cross-section [65].

The only process fibres are exposed to, from leaving the card until twist insertion on the ring frame, is drafting (with the exception of combing which is used in production of the combed yarn only). Therefore, anything which affects the quality of drafting will have a direct impact on the quality of sliver and roving. The nature of the irregularity in the input material affects the irregularity of drafting, and some forms of irregularity of the input sliver might also get amplified as a result of drafting [66, 67]. The position and configuration of fibres in the fibrous strand, such as degree of straightening, fibre extent, helix angle, number of residual hooks and direction of presentation of these hooks are important as they directly affect the quality of drafting. Balasubramanian and Bhatnagar claimed that for a drafting system operating under optimum conditions, a wide variation in added irregularities can be found which mainly depend upon the quality of ingoing sliver [68]. Previous research has shown that even direction of presentation of hooks to the drafting system on the drawing frame and roving frame has a remarkable effect on the quality of output material. Trailing hooks give better results in terms of yarn regularity and strength compared with leading hooks [62, 69]. Apart from its effect on irregularity, the presentation direction of hooks in the drafting system also influences the hook removal obtained in drafting. The removal of trailing hooks is more efficient than that of leading hooks [68].

Twist level in the roving also has a significant effect on yarn quality. Yarn tenacity increases to a maximum value then decreases, as the roving twist level increases. Similarly the yarn uniformity first increases and then decreases with increasing roving twist. A certain amount of twist is needed to convey the strand without it drafting, therefore an increase in roving twist increases the inter fibre cohesion, which creates problem during drafting leading to poorer yarn quality [59, 70].

Poorly processed roving and slivers, can directly affect yarn quality and even a very high quality raw material will not be give good results in yarn if not processed properly.

1.2.4.2.3 Spinning quality

The quality of spinning directly affects yarn quality. Spinning is the stage where a fibrous strand, fed in the form of roving is converted into yarn, after reducing the thickness of the strand to the desired level, by introducing twist. Yarn produced through any spinning system has to go through this phase of yarn formation, but since the work in this thesis is focused on ring spinning so the discussion here in this section is with reference to ring spinning only.

The ring department is the most important stage of a spinning mill, as both quality and production of a yarn spinning mill are dictated by this department, which in turn directly affects the productivity and costing of the unit. This stage influences the yarn quality in two ways. Firstly, by the quality of drafting and secondly by how well fibres are incorporated into the yarn.

1.2.4.2.4 Drafting performance

After entering the ring machine roving is attenuated to the desired thickness using a 3-over-3 double apron drafting system. As a result of this drafting the number of fibres in the cross-section is reduced. This drafting can cause an increase in unevenness in the strand if not conducted properly. The results of this drafting depend upon the straightening and parallelization of fibres in input material [62, 71].

Drafting on the ring frame can be divided into two main parts i.e. break draft and main draft. The break draft straightens the fibres before they are exposed to the main draft. It also redistributes the twist in the roving over a greater length. The presence of this twist in the strand provides some control over short fibres during drafting [72]. At very low break drafts the reduction in the twist of the roving may not be sufficient to allow good drafting which may result in the generation of thick places. Too high a break draft on the other hand results in an increase in unevenness (U %) of the drafted roving and lowers the yarn quality [73].

After the break draft the fibres move to the main draft stage where they are exposed to the final draft. This drafting takes place in the second drafting zone which has aprons for fibre control, which allows higher drafts to be used. Usually a draft of 6 to 30 is given in the main draft zone. Lamb demonstrated experimentally and through computer simulation that an imperfect drafting mechanism introduces unevenness in yarns [31, 74]. It was further argued that although a good apron-drafting system introduces only a small amount of irregularity, the quality of drafting on the spinning frame is a more important determinant of yarn evenness than roving quality. The mechanism responsible for increased irregularity becomes stronger at higher drafts but is not much affected by the speed [75].

1.2.4.2.5 Incorporation of fibres

For a constituent fibre to contribute to yarn strength it is very important that the fibre is properly incorporated into the yarn structure. The way the fibres are incorporated during yarn formation depends upon the spinning geometry and the spinning system used for yarn manufacture. In ring spun yarns the fibres are arranged in spirals of variable radii; and they sometimes get entangled, looped, and even protrude from the yarn surface. Therefore, the full length of the fibre cannot contribute to the yarn strength but only the part of fibre length that has been spun in. Apart from not contributing to yarn strength these poorly incorporated fibres also result in an increase in yarn hairiness and they are easily rubbed away when the yarn is abraded during downstream processing. This is especially true for surface fibres in ring spun yarns. The fibres at the yarn core are properly twisted and incorporated into the yarns structure but the surface fibres are loosely bound.

1.2.4.2.6 Spinning-in Coefficient

In order to quantify the average length of each fibre that contributes to yarn strength the term spinning-in coefficient K_{Fi} has been introduced and is defined as the ratio of length of yarn incorporating the spun-in fibre to the actual overall fibre length (i.e. the length bound into the yarn). Mathematically it can be given by the equation [76] :

$$K \qquad \sum \frac{\Delta}{\ } \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1.5)$$

Where

K_{Fi} = spinning in coefficient

Li = length of yarn incorporating the spun-in fibre

$l_{F} =$ Actual overall fibre length

Due to the problems associated with actual measurements of fibre length, an indirect method was devised in which the projection of the fibre onto a plane was used. Spinning-in coefficient K_{Fi} is then given by the equation

$$K \qquad \frac{\sum}{\ } \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1.6)$$

Where,

L_O = overall yarn length between beginning & end of the spun-in fibre

Xi = length of yarn from which fibre protrudes

L = overall length of fibre projection

From this equation it can be derived that if the whole length of the fibre is incorporated into yarn structure then $K_{Fi} = 1$ i.e. maximum and when none of it is incorporated then $K_{Fi} = 0$ i.e. minimum.

This method estimates the average extent of tracer fibres, of a known straightened length, in a yarn, then subtracts the length intervals for which the fibre is on the outside or beyond the yarn surface, however it has some short comings. Firstly it does not take into account the orientation of fibres. If a fibre is straight, and is incorporated into the yarn structure for its whole length, but is slack, then numerically it will have a high value of K_{Fi}, but it will not be able to contribute to the yarn strength unless its whole length is stretched. On the other hand if a fibre lies outside the yarn surface for almost its whole length but is tucked in at both ends and is fully stretched, then it will have a value of $K_{Fi} \simeq 0$ (minimum), but it will contribute very positively in load sharing with other fibres. Secondly it cannot account for the reduction in length of incorporated fibre length due to twist insertion.

Due to the shortcomings discussed above it can be said that spinning-in coefficient is a visual method of estimating how well fibres are bound into a yarn so that they can contribute to yarn strength, but it cannot be considered an absolute gauge for assessing the yarn strength or the extent of fibre trapping in the yarn.

1.2.4.2.7 Spinning triangle

When the fibre strand emerges from the nip of the front rollers it is subjected to twist, running upwards from the spindle. This twist cannot enter the nip due to the pressure between top and bottom rollers. This twist tries to convert the ribbon shaped fibre strand into a round yarn. Now since the fibre ribbon is gripped between the pair of delivery rollers so a delta is formed just in front of the delivery rollers. This triangle is called the spinning triangle [77].

Most of the end breaks occur at this weak point because every fibre in the spinning triangle does not contribute equally to the yarn strength during the yarn spinning. Fibres at the centre of the spinning triangle are subjected to less tension, whereas the fibres on the edge of the triangle are exposed to higher tension. Besides, the short fibres in the spinning triangle cannot effectively contribute to the yarn strength [78]. The length of the spinning triangle is determined by the level of twist and the spinning geometry. High yarn twist produces a short spinning triangle, whereas low twist results in a long one. Klein [15] points out that a short spinning triangle represents a small weak point and therefore fewer end breaks. He also claimed that if the spinning triangle is too short, the fibres on the edges will have to bend very sharply during the binding in. This is not possible for all fibres. Besides, with a very short spinning angle while some edge fibres do not get trapped and become fly others might be bound-in at one end only and become hair. On the other hand, a longer spinning triangle results in a bigger weak point, and thus more ends breaks. However, the fibres are better bound into the yarn with a longer spinning triangle, which produces a smoother yarn and less fly.

The spinning triangle is a weak point of yarn formation in ring spinning system and therefore provides an opportunity for improvement. In order to obtain fundamental improvements in ring spinning, the modification of the ring machine is necessary. Compact spinning sought to improve spinning performance by condensing the strand before twist insertion

1.2.5 How can yarn quality be improved

It can be concluded from the above discussion that yarn quality depends upon two factors i.e. raw material quality and translation of raw material quality into yarn quality. The raw material quality does not automatically translate into yarn quality. The efficiency of a system to translate fibre quality into yarn quality depends upon how the fibres are arranged for yarn formation or in other words 'yarn structure'. The yarn structure depends upon the spinning system used and the spinning geometry and for a certain raw material it is this yarn structure which dictates the yarn quality. Since the raw material quality cannot be improved beyond a certain level (particularly for natural fibres), the only option for improving yarn quality is modification of the yarn structure.

1.2.6 Recent developments for improving yarn quality and spinning performance by modifying yarn structure

Synthetic fibres, despite their advantages, have not been able to totally replace natural fibres. Natural fibres are regaining popularity for many applications [79, 80]. This demand for natural fibre yarns in the market has pushed the machinery manufacturers to research more advanced methods for producing finer and higher quality yarns with the existing raw material. This research has resulted in the development of machinery and spinning systems (Compact spinning, Siro spinning and Solo spinning) that can achieve quality standards which were not previously achievable. These systems have also enabled spinning of yarns whose manufacture was not previously commercially feasible. The improvements in yarn manufacturing can be divided into two main categories. First are those which facilitate the smooth running of yarn during spinning or weaving. Second are the developments which actually improve yarn quality characteristics. Relevant recent developments are reviewed below.

1.2.6.1 Compact spinning

Compact spinning is claimed to offer superior quality and better raw material utilization [81-85]. One of the claimed advantages is the possibility of achieving yarn strength identical to that of conventional ring spinning, but with approximately 20 % lesser twist. This, in turn, means a softer yarn, increased production and a reduction in energy consumption [81]. The properties of fabrics made from compact yarns are better than ordinary ring spun yarns. Sunay Omeroglu and Ulku reported that the tensile strength values obtained in both the warp and weft directions of the fabrics woven from compact yarns were higher than those obtained from fabrics woven from conventional ring yarns. It was also claimed that fabrics made from compact yarns are more pill resistant than those made from ring yarns [86]. The inter-fibre cohesion in yarns, which is an important determinant of yarn strength, was also found to be superior in compact yarns than in conventional ring spun yarns [87, 88].

The idea of compact spinning emerged during the attempts made by Rieter under the direction of Dr. Fehrer [89] to adapt a ring spinning frame for spinning from cans. Although this experiment didn't prove to be feasible but it led researchers to focus on developing a drafting mechanism with a mechanical/pneumatic fibre condenser unit to obtain excellent yarn parameters in ring spinning. These alternatives were patented by other textile machinery makers.

1.2.6.1.1 Principle of compact spinning

An additional drafting zone is added to the standard 3/3 drafting system. This additional drafting zone includes a suction mechanism. This suction force, transferred to the fibrous strand through a perforated surface (rubber apron or a steel drum), causes the fibres to be sucked towards the centre of the strand causing the width of the strand to be reduced. A number of compact spinning methods have been developed by various machine manufacturers and a brief description of these systems follows:

1.2.6.1.2 Suessen compact spinning system

Suessen's Elite® spinning system (Figure 1.2) is based on its Fiomax high speed spinning machines. It is a condensed or compact spinning technique that is claimed to be used universally for all fibres over the complete range [90].

The system consists of an extra drafting zone attached to a standard three roller drafting system. In the extra zone an air-permeable apron runs over a suction duct. The suction duct runs through the length of the spinning machine and is connected to a suction fan. The suction fan produces a negative pressure in the duct. For each spinning position there is a slot in the suction duct, which is tilted in the direction of the flow of material. After achieving the desired linear density through drafting in the main drafting zone, the fibres are guided through the (air-permeable) lattice aprons over the openings of the suction air flow. This helps in condensing the strand by generating a transverse force on the fibre band during its transport over the slot, causing the fibrous strand to rotate around its own axis. The perforated apron carries the fibres attached to it to the delivery nip line [91]. A slight tension force along the direction of flow of material is applied on the strand during the condensation process to improve the straightening of fibres. This tension is achieved by using slightly bigger top roller (driven) than the front bottom roller (driver). This tension force improves straightening of fibres in the strand and therefore supports the condensing effect generated by the negative pressure acting on the fibre band in the slotted area of the suction tube [83, 92].

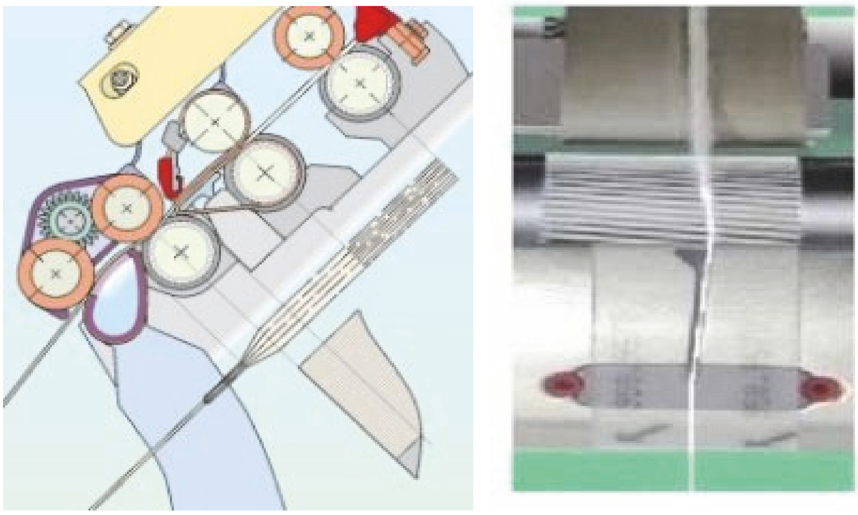


Figure 1.2. Suessen compact spinning system

1.2.6.1.3 Rieter K44 'Comfor Spin'®

In this system, aerodynamic forces are used to condense the fibrous strand after the main drafting zone. It consists of a three-roller, double-apron drafting system. This drafting system is followed by a condensation zone. This zone consists of a suction drum, which is connected to the central suction unit. The fibres coming out of the front drafting roller are held on the surface of the perforated drum. There is an exchangeable stationary suction insert with a specially shaped slot, inside each drum. Due to the suction created by the vacuum inside the perforated drum the fibres are condensed on the surface of the drum, which reduces the width of the strand and therefore the size of the spinning triangle. To prevent the twist from flowing into the condensation zone, an additional nip roller is provided after the front drafting roller. One of the biggest advantages that this system has over other compact spinning systems is its hard wear resistant drum. This enhances the service life of the system. The compacting efficiency of the system is amplified by specially designed air guide element [93]. Optimal interaction of the compacting elements results in good compaction of the fibres. This is claimed to give unique COM4® yarn characteristics [94, 95].

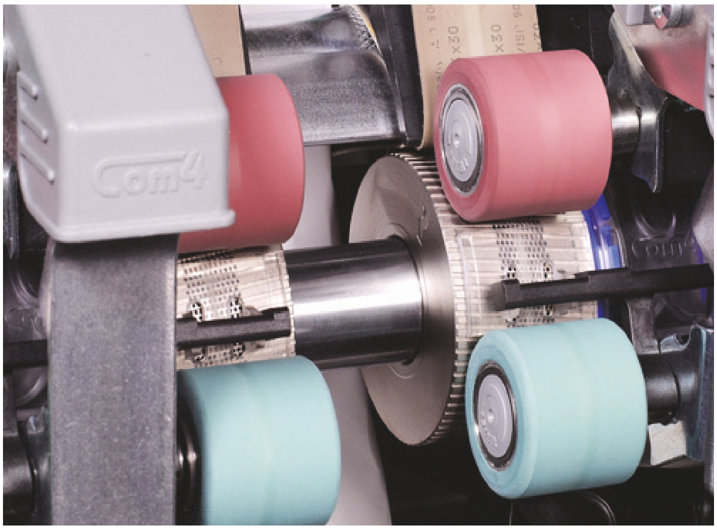


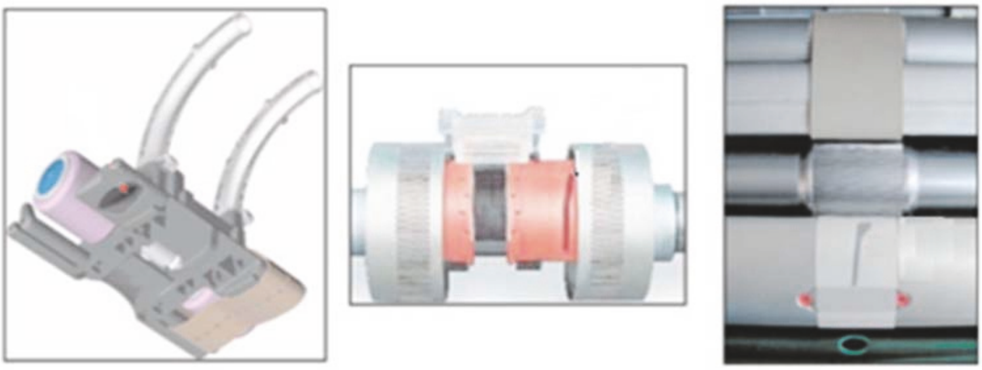
Figure 1.3. Rieter Comfor spinning system

1.2.6.1.4 Zinser AIR-COM.TEX 700 ® system

This system also is based on a similar working principle to the Suessen compact spinning system i.e. a three roller drafting system followed by a perforated belt which runs over a suction tube. The negative pressure acting on the fibrous band through the perforated apron compacts the strand, reducing the spinning triangle. The main advantage associated with this system is its flexibility to accommodate different raw materials. The compacting between the front two cylinders can be influenced by a lower speed of the perforated apron to a maximum of -4.0 %. For the cotton compact spinning process, from 0 to 4 % additional feed is required from a technological point of view. With this spectrum the machine can be set to handle most fibres [91].

1.2.6.1.5 Comparison of various compact spinning systems used commercially

The systems discussed above are the most commonly used compact spinning systems in the textile industry. All these systems have the same basic working principle i.e. reducing the width of the fibrous strand before twist insertion. The implementation however, is different. In the Rieter K44 system the suction is through the bottom roller, whereas the Zinser AIR_COM_TEX 700 and Suessen systems have the suction through top apron and bottom apron respectively, but both driven by top roller. The three devices are shown in Figure 1.4.



Zinser Rieter Suessen

Figure 1.4. Various Compact spinning systems used commercially [96]

Various researchers have compared the results of the yarns produced from these systems. Göktepe et al. [96] observed that Zinser's compact system achieved the highest reduction in yarn hairiness. Suessen's system was found to have highest variation in yarn hairiness. This higher variation was attribution to clogging of the perforated aprons due to dust and fibres. This clogging caused a continuous variation in condensation area which led to poor control over fibres. For yarn evenness the Zinser system gave better results for coarser counts whereas for finer counts the Rieter system gave better results. It was proposed that this reduced effectiveness of the Rieter system in the case of coarser counts could be due to lack of control over fibres with the higher number of fibres in the cross-section of coarser counts. Yilmaz et al. [97] examined the packing density and number of fibres in cross-section for the yarns produced through various compact spinning systems. The packing density of the yarns for different systems was not found to be significantly different. It was found that compact yarns had a packing density of 0.55 to 0.70 compared to conventional ring spun yarns which had packing density of 0.50 to 0.60 and 0.38 to 0.55 for combed and carded yarn respectively. However a trend of decreasing density from centre towards yarn surface was found in compact yarns too, just like conventional ring spun yarns.

1.2.6.1.6 Rotor-craft

Apart from above mentioned pneumatic compact spinning systems some mechanical compact spinning systems are also available. The RoCoS magnetic compact spinning system is one example. It works on the basic principle of compact spinning i.e. to compact the strand before twist insertion, but here compaction is achieved mechanically rather than through pneumatic suction. The effect of pneumatic compacting equipment and its operational cost on the cost of yarn manufacture can be substantial. As a result, pneumatically compacted yarns must get a higher price than their competitors in order to justify the investment and additional costs of labour and replacement parts. The biggest advantage that the RoCoS system has over other compact spinning system is a low operational cost [98].

The RoCoS compaction assembly is a simple clip-on attachment containing a horn shaped condenser zone and an extra roller. After the final draft is achieved the material is passed through a condenser, which pushes the fibres closer. After passing through the condenser the material is pulled forward through final roller, which sits on the front bottom roller. This final roller delivers the material for twist insertion. The Rotor-craft compaction assembly does not have a provision for draft in the compaction zone, like Suessen and Zinser compact spinning systems. This deprives the system of the benefits achieved by straightening of fibres which takes place in other compact spinning systems due to the lateral force created by tension draft [99].

The yarns produced on this mechanical compact system are better than conventional ring spun yarns but inferior to pneumatic compact yarns in terms of tenacity, hairiness and evenness [100]. The fibre migration in the mechanical compact spun yarns is also less than in pneumatic compact yarns [101].

The compaction is achieved by just passing the fibres through a condenser, which pushes the fibres closer to each other. Therefore it can be expected that this method could reduce the spinning triangle and improve the spinning performance, due to better load sharing among the fibres. This system is the cheapest and simplest implementation of compact spinning system, but its effectiveness needs independent validation.

1.2.6.2 Sirospun™

Sirospun can be seen as a pseudo-two-fold yarn in which the two components are untwisted strands rather than twisted singles yarns. To some extent it was built on the concept of self-twist spinning [14], in which cyclic false twist is introduced into two drafted strands of fibres. Then these strands are brought together. To ensure that their twist is out of phase one strand is made to follow a longer path. In attempting to untwist these strands twist about each other, thereby capturing the oscillating twist in each strand. Production speeds of up to 200 m/min could be achieved by this system and the yarn produced could be used for knitting. However, for weaving the yarns had to undergo real twisting in a separate twisting step. The main aim of Sirospun was to manufacture a weavable worsted yarn by capturing the strand twist during twist insertion on the ring frame and to avoid the need for a subsequent twisting as in self-twist spinning [102]. The biggest impediment to the weave-ability of the singles yarns is not their lack of strength, but their lack of abrasion resistance. It is due to this lack of abrasion resistance that yarns no matter how good in quality have to be sized or two folded before weaving. Sizing overcomes this lack of abrasion resistance by forming a protective layer of resin coating over the yarn surface, whereas two-folding achieves this by improved trapping of surface fibres. This more secure binding prevents the surface fibres from being rubbed away during weaving. Since Sirospun was targeted at improving the abrasion resistance of the yarns, the main task of this system was to bind the surface fibres more securely into the yarn structure.

1.2.6.2.1 Mechanism of fibre binding

Two folding dramatically enhances the surface fibre bonding in staple spun yarn. The mechanism of this fibre binding can be explained by Plate's [103] model using two rubber cylinders to represent the yarns. A yellow line is drawn on one cylinder to represent the surface fibre. This is shown in Figure 1.5a. In Figure 1.5b the two strands are Z twisted to represent two singles yarn and the surface fibre now describes a helix on the surface of the singles yarn. Finally in Figure 1.5c the two singles yarns are two folded together with S twist and it is interesting to see how the path of the surface fibre has changed. It is now regularly trapped between the two yarns making up the two fold yarn. This is however important to appreciate that to achieve trapping of surface fibre the two yarns must not only be twisted about one another but also relative to one another. This is shown in Figure 1.5d, where the untwisted cylinders are twisted together. Here the surface fibre can be seen to be on the surface of the two-fold yarn for its entire length.

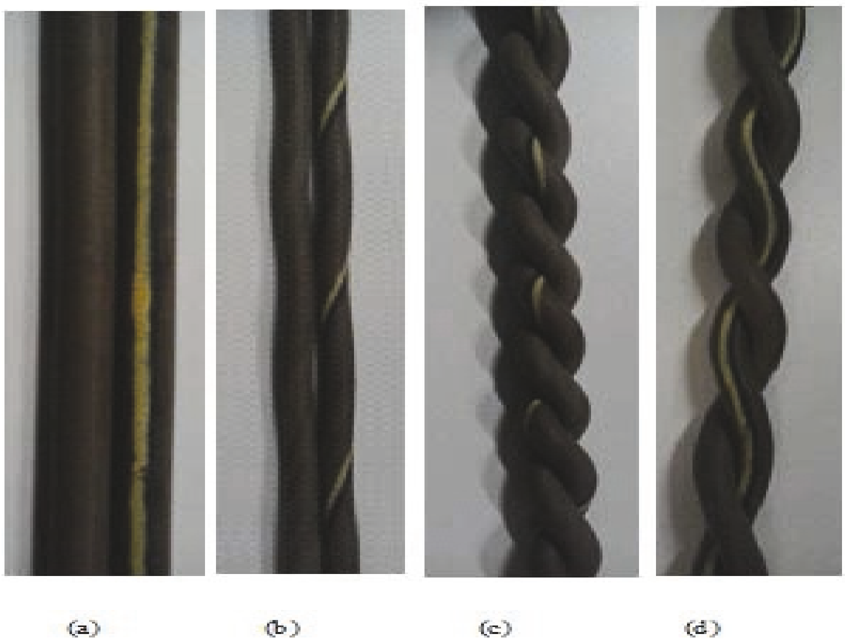


Figure 1.5. Model yarns showing (a) untwisted strands (b) twisted singles (c) two-folded and (d) two-folded of singles.

In the prototype version of Sirospun two drafted strands of fibres after emerging from the front roller were passed through another pair of rollers that intermittently blocked the twist from flowing up to the nip line. The two strands are brought together by the twist to from a large spinning triangle (the 'Vee'). The twist blocking roller causes the twist running into the two strands to increase and decrease. This alternating twist gets trapped in the yarn section below the point of convergence of two strands, which is held fixed by a guide, as alternating twist of the strands relative to the rotating point of contact (i.e. the mean folding twist) [14, 104]. The alternating twist enables the trapping of surface fibres between the two strands. Plate and Lappage [104] demonstrated that the amount of trapping of surface fibres is proportional to the alternating strand twist and is independent of the two-fold twist.

Although twist is observed in the individual strands during two-strand spinning, but none of it is trapped in the yarn if it is constant. Real (net) twist cannot be introduced only alternating twist. If the strand twist is constant then there is no real (alternating) twist of the strands relative to each other. In yarns produced through such a mechanism there will be a small amount of fibre migration due to variation in spinning tensions and movement of the delivery position of fibres, but overall many surface fibres will be poorly trapped and can be easily rubbed up when the yarn is exposed to abrasion. Constant twist above the convergence point only leads to fibres maintaining their relative positions in the two strand yarn; if two-fold twist is removed from such a yarn, then only two untwisted strands will be left. When two strands are held at both ends insertion of real twist is not possible only alternating twist can enable trapping [14].

Later it was discovered that the yarns produced even without the twist-blocking roller were adequately abrasion resistant. It was found that the inherent variation in the linear density of the constituent strands caused sufficient twist variation for surface fibre trapping. This strand twist can be observed but the methods are laborious [104]. The better test for measurement of fibre trapping is the measurement of improvement in abrasion resistance of the yarns produced. Another mechanism responsible for fibre trapping was 'trapping of fibres ends in the vee' i.e. the free fibre ends can have more or less twist than the strand [105].

Spacing between the constituent strands has a significant influence over the yarns produced. It has been shown that abrasion resistance increases and hairiness decreases with increase in strand spacing. For cotton yarns a strand spacing of 7-9 mm was found to be optimal. Above this spacing the number of end breaks increase dramatically. This is because the strand arm starts to draft.

1.2.6.2.2 The working principles of Sirospun

Hereafter, this method of two strand spinning, with or without the patented break-out device (see below) will be referred to as siro spinning. In the siro spinning process the constituent strands are fed side by side through a drafting system and drafted to the desired thickness. After leaving the front delivery roller of the drafting system these strands are twisted through a ring and traveller mechanism like any other conventional ring spinning system. This twist brings the strands together to from a large, long spinning triangle (the ‘Vee’). A schematic outline of the siro spinning system is shown in Figure 1.6 [106].

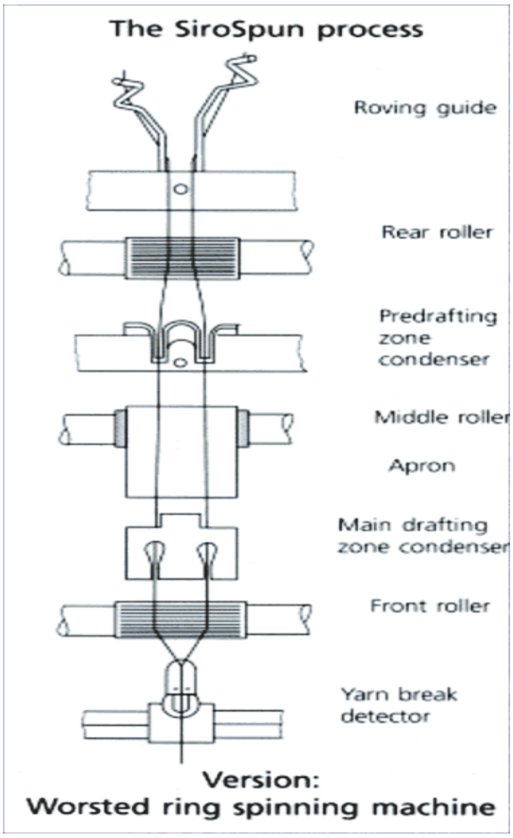


Figure 1.6. Siro spinning system

For producing Sirospun yarns on a ring spinning frame some modifications are required. This includes a double creel (twice the number of running spindles), a double set of roving guides, a wider middle (apron) roller recess and modified front zone condensers (if used). One of the biggest problems with running of Sirospun yarns was that if one of the strands break the yarn could still keep running for a time. This would produce a yarn which is 50 % finer than the desired count. Such a yarn can cause a serious fabric fault. To prevent this from happening, a break-out device was introduced. This device became the core patented part of the Sirospun process. When one of the strands breaks the guiding pair of pins is toppled off its seat forcing the yarn to loop around the pins. This stops the upward flow of twist from the rotating bobbin therefore causing both strands to break.

1.2.6.2.3 Properties of Sirospun yarns and effect of processing parameters on yarn properties

Sirospun yarns have better strength, hairiness and abrasion resistant characteristics than single yarns because of the strand twist. They are also more extensible than single yarns at higher twist multipliers. Coarser Sirospun yarns enjoy better evenness characteristics and have fewer yam imperfections. At all twist levels, Sirospun yams are less hairy and more extensible than two-plied yarns. Whereas in terms of strength Sirospun yams are superior to two-plied yarns beyond medium twist multipliers. Coarser Sirospun yarns are comparable to two-plied yarns in evenness and imperfections, but finer Sirospun yarns are less uniform. As the yarn becomes finer, Sirospun yarns are more abrasion resistant than two-plied yarn. The tenacity, hairiness, and abrasion resistance of all yam types are highly dependent on the level of twist in the yarn [107].

Among processing parameters strand spacing is one of the most important factor that influence the yarn quality. As Plate and Feehan [108] argued that in the absence of deliberate perturbation of the twist equilibrium, inherent thickness variation of the two strands is the only source of creating alternating twist which serves the purpose of binding the fibres together. Cheng and Sun [109] examined the effect of strand spacing on yarn quality. It was found that yarn tenacity increased with the increasing strand spacing from 3 to 11 mm for coarser counts (36 tex). However for finer yarns (28 and 18 tex) best tenacity results were achieved at 9 mm strand spacing. Abrasion resistance and hairiness characteristics were also found to improve with increased strand spacing. This improvement in quality with increased strand spacing was attributed to increased strand twist. Salhotra's [110] work on the effect of fineness of input roving on yarn quality revealed that use of finer roving favours an improvement in yarn evenness and tenacity. This improvement in yarn quality was attributed to two factors. First, yarn irregularity is expected to improve with reduction in draft. Secondly, the compactness of individual strands is better for a lower draft. The width of the emerging strand after drafting increases with increasing draft. The strand from a finer roving will be exposed to a lower draft on the ring frame and consequently will be more compact. It was found that the width of the individual ribbons decreases from 3.5 mm at a draft of 33.6 to 1.5 mm at a draft of 16.0. Subramaniam et al. [111] investigated the influence of twist multiplier and spindle speed on yarn quality for siro spinning. They found an increase in yarn tenacity with increasing strand spacing occurs above a twist multiplier of 55. At a lower twist level, increased strand spacing results in increase in variation in strength, while at a higher twist level, it decreases the variation (CV %) in strength. In general, both the strength and the coefficient of variation in strength seem to deteriorate with increased spindle speed.

1.2.6.3 Some further developments in two strand spinning

Two strand spinning has proven to be an effective method for producing highly abrasion resistant yarns. To further exploit the potential of two strand spinning for producing high quality yarns, some researchers have come up with some simple yet effective techniques and have demonstrated that through these modifications yarn quality can be considerably improved.

1.2.6.3.1 Embeddable and locatable spinning (ELS)

Embeddable and locatable spinning, or ELS, is a method of producing very fine yarns. This method is a combination of siro spinning and core spinning methods, which usually is used commonly in spinning of composite yarn such as those containing Lycra etc., where a filament is inserted into the fibrous strand. Xu et al. [112] proposed this improved method of producing core spun yarns. In this system the two filaments are located at the outer positions and the two staple strands are fed between them. The outer filaments form the larger triangle to reinforce and protect the spinning strands, which are located within this zone. This helps in improving the spinning performance of the system. The biggest advantage of this system is that it can enable the spinning systems to spin very fine yarns which are not even spinnable otherwise. It is claimed that using this system yarns can be spun with as low as 10 fibres in the cross section [112]. Water soluble filaments can be used which can be dissolved later, once the yarn has been converted into fabric.

1.2.6.3.2 Improved fibre trapping with a contact surface during two strand spinning

Xia et al. [113] proposed a modified version of siro spinning, which had a specially designed contact surface attached to the ring frame after the delivery roller. It was demonstrated that yarn hairiness can be significantly reduced, while other yarn quality characteristics such as tenacity and evenness are not much affected. The improvement achieved by this method was attributed to the pre-wrapping of yarn hair onto the single yarn body due to contact surface and inserted twist during the ring spinning. It was also claimed that the efficiency of this system can be further improved by wetting the contact surface.

1.2.6.4 Solo Spinning

Solospun™ technology provides the means of producing a singles yarn that can be woven as either warp or weft without two-folding or sizing. It was invented at CSIRO Textile and Fibre Technology and jointly developed by CSIRO, the Woolmark Company and the Wool Research Organisation of New Zealand (WRONZ). It consists of a modification of the drawing apparatus of the ring spinning frame, which change the yarn structure in such a way that the yarn is more similar to the yarn doubled and plied. The abrasion resistance is comparable to plied yarn [99].

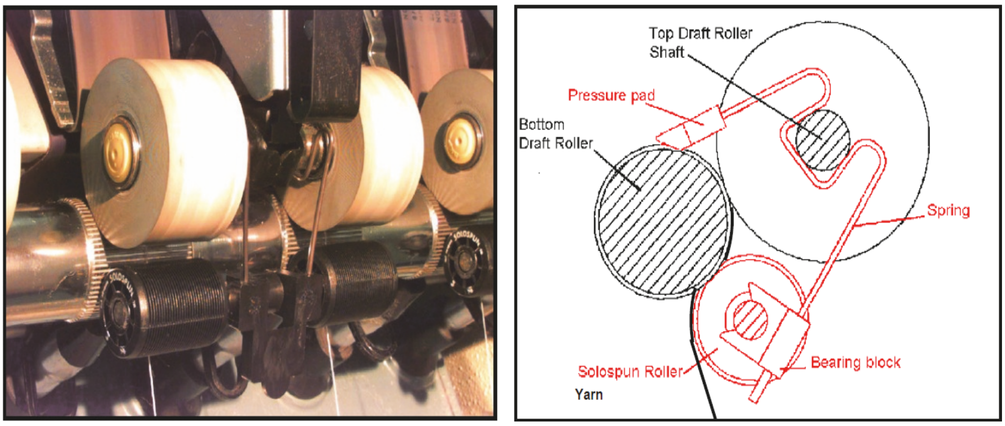


Figure 1.7. Solo spinning system [114]

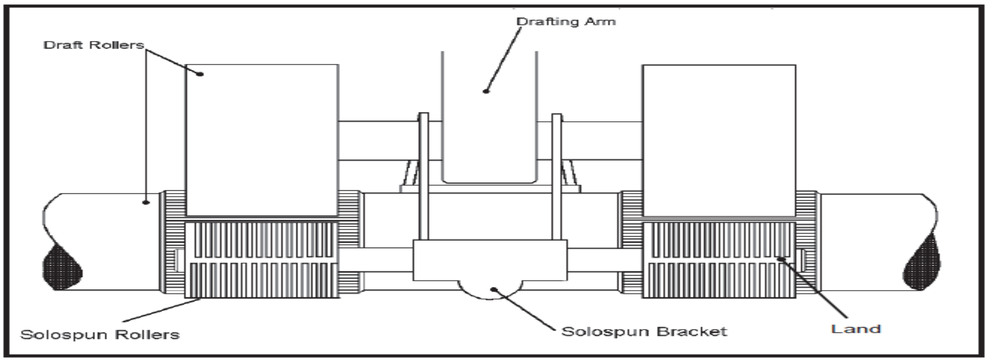


Figure 1.8. Schematic diagram of solo spinning roller [114]

As shown in Figures 1.7 & 1.8 [114, 115], the Solospun system consists of an additional small roller which can be clipped onto the spinning frame so that it is driven by the bottom roller. This additional roller is slotted with the lands and grooves alternating (four times) around the circumference. The purpose of this roller is to split the roving strand into multiple sub-strands that are continually being altered. In this way the fibre trapping mechanisms of Sirospun are enhanced. Significant amounts of strand twist can be captured because the number and size of the strands and the free length into which twist can propagate is being almost continually altered. The rollers act as intermittent twist blocks and prevent the twist from reaching the fibres that are coming out of the front draft roller nip. The strands are not only spread out along the face of the roller but also vary in perpendicular direction as they move in and out of, the slots. Strands can also undergo a form of false-braiding and there is much greater scope of trapping the fibres [14, 115].

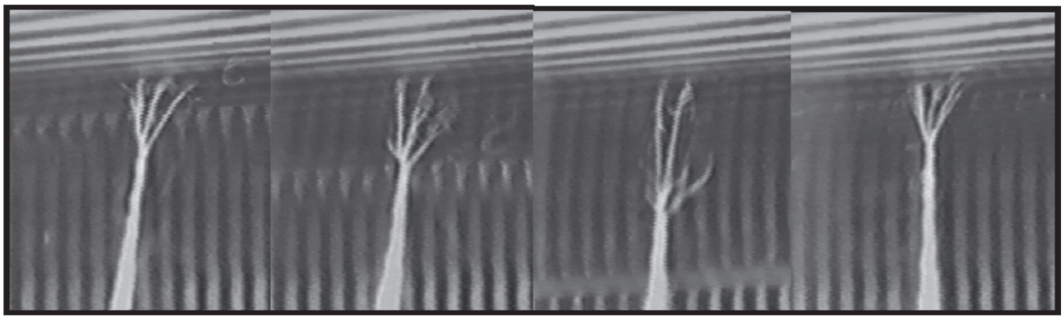


Figure 1.9.Division of strand into mini sub-strands during the solo spinning process [116]

The Solospun technology is a very simple and inexpensive attachment that can be clipped on to standard long staple spinning frames. It consists of a spring wire bracket that can be easily installed and removed from the top front draft roller shafts so that the spinning frame need not be permanently dedicated to Solospun spinning, thereby maintaining versatility. Solospun is cheaper to install than the alternative systems and is a cost effective method of producing weave-able singles yarns without the need for sizing or two-folding. Since the Solospun yarn is spun as singles yarn, the presence larger number of fibres in the cross section provides much better spinning performance than spinning singles yarns for an equivalent two-fold yarn count. Solospun significantly reduces yarn hairiness by pre-twisting of sub-strands and then twisting of these sub-strands into Solospun yarn [117]. Fibre binding is improved to the extent that these yarns can be woven without the need for two-folding. Compact or condensed yarns also produces yarns with reduced hairiness but the fibre security is not improved to the extent that the hairiness stays lower during winding, warping and shedding in weaving.

Compared with Sirospun, finer yarns of lower twist factor can be spun using Solospun. The need for double creel and breakout devices is avoided, spinning performance is improved and fabric streakiness is also reduced. Good weaving performance can be expected from Solospun yarns in a wide range of fabric structures. Fabrics made from Solospun yarns have been shown to have similar performance attributes to fabrics produced from conventional two-fold yarns [114, 115].

1.2.6.5 Some other developments

Apart from the above mentioned commercial developments for quality improvement in yarn manufacturing, some prototype systems have also been developed by various researchers. These systems have been successful at improving certain aspects of yarn quality.

1.2.6.5.1 Use of an air jet for improving yarn quality

The fibres on the yarn surface are not usually strongly bound to the yarn core. Many of the fibres are bound at one end into the yarn structure with their other end protruding out of the yarn core. These protruding fibres do not contribute to yarn strength and they cause hairiness in the yarn. Some researchers have used air jet at the ring or winding stage for reducing the hairiness of yarns.

Jet-ring spinning

Wang et al. [118] proposed using an air-jet on the ring frame after the front delivery roller to reduce yarn hairiness. It was demonstrated using this technique that yarn hairiness can be reduced by 40 %. Cheng and Li [119] worked on the effect of various process variables on the hairiness characteristics of the yarns produced and found that a significant hairiness reduction can be achieved using an air jet after the front delivery roller and he described the direction of air flow in the air jet and the raw material characteristics as the two main determinants of the quality of yarns produced by this method. The reduction in hairiness was attributed to the wrapping of surface fibres due to swirling action of the air jet. It was also claimed that due to direction of the air vortex, the yarn gets twisted and then untwisted. This loosening and tightening of the structure causes the surface fibres to be trapped, thus reducing the yarn hairiness.

Jet-wind process

The jet wind process was a step further along the direction of jet ring. One of the issue associated with jet ring was that one air nozzle per spindle needed to be installed on the ring frame. Since the production per spindle on the ring frame is very low, so installing one nozzle per spindle and the cost of compressed air would be expensive. Therefore it was proposed that an air jet should be installed on the winder. Since per spindle production on winder is very high, this would significantly reduce the cost of manufacture compared to jet ring. Wang and Miao [120] demonstrated that using the jet wind process yarn hairiness can be significantly reduced. Khan and Wang [121] used steam in the nozzle instead of compressed air for worsted yarns and found that this can significantly reduce yarn hairiness. Koç et al. demonstrated that an increase of wrapper fibres generally increases the strength of yarn [122] in rotor spun yarns, which indicates that wrapper fibres can be used to improve yarn tenacity.

1.2.6.5.2 Use of a mechanical false twister for producing low torque yarns

Hua Tao [123] demonstrated that using a mechanical false twister on a ring frame after the delivery roller the fibre arrangement can be modified to produce low torque yarns. It was proposed that yarn torque can be reduced by reducing the twist level in the yarn by changing the fibre tensile stress distribution in the yarn by arranging some fibres in the yarn opposite to the direction of yarn twist. Based on these assumptions he developed a method for manufacturing ring spun yarns using a false twister on the ring frame. He demonstrated that yarns with significantly lower residual torques can be produced.

1.2.6.5.3 Modified yarn path for improvement in yarn hairiness

Wang and Chang demonstrated [124] a simple method for producing yarns with low hairiness for worsted spinning, by using a diagonal path for the yarns on the ring frame. Both left and right diagonal paths were used and it was found that a significant reduction in yarn hairiness can be achieved by using a right diagonal path for spinning. This arrangement, however, did not have a significant effect on yarn tenacity and evenness. This improvement in yarn hairiness was attributed to the increased pre-twisting of the fibres on the right-hand side of the spinning triangle. This was a simple method that could be used to reduce the hairiness of the yarns. The biggest side effect of this method was increased ends down rate, particularly at higher spinning speeds.

1.2.6.5.4 Drafting against untwisting

Drafting against untwisting is a post spinning engineering technique used to improve yarn tenacity by improving the straightening and orientation of fibres. In this method, an already manufactured yarn is temporarily untwisted using a false twisting device. During this temporary untwisted state the yarn is exposed to a drafting force. This stretching of the yarn segment causes the constituent fibres to be straightened and compacted. Fuqian and Oxenham [125] used this technique to enhance the tenacity of friction spun yarns. In production of friction spun yarns, fibres coming from the fibre duct are slowed down and impinge onto a friction drum [126]. When fibres are rolled on the drum surface the fibres are entangled, but the strength of the yarn produced is not very high. To improve this tenacity Fuqian and Oxenham inserted false untwisting into the yarn using a hollow spindle spinning machine. Due to this untwisting the fibres in the yarn were temporarily loosened. At this stage a draft was introduced which caused a tension higher than the spinning tension during yarn formation process. As a result the fibres were stretched and straightened, which improved the load sharing among the fibres. They showed that yarn tenacity can be improved by 10 % using this method.

Similarly, Khan [127] demonstrated that this technique can be used to improve the strength of woollen, worsted and rotor spun yarns as well. Instead of using a mechanical untwister he used an air jet untwister for false untwisting. It was demonstrated that a significant improvement in yarn hairiness and tenacity can be achieved using this method. Another advantage is that yarns can be thinned down with this method giving three potential advantages. Firstly, spinning a coarser count and then thinning it down can increase production rate. Secondly, fine yarns that are not spinnable otherwise might be produced. Thirdly, softer yarns can be produced because the yarn thickness is reduced by drafting spreading the twist over a longer length which facilitates the manufacture of very fine yarns at lower twist factors.

1.2.6.5.5 Pin spacer for improving yarn evenness

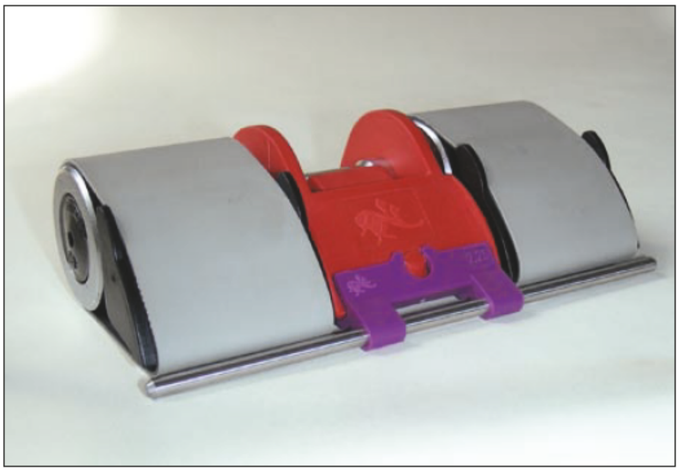


Figure 1.10. Pin spacer introduced by Suessen [128]

The pin spacer introduced by Suessen, as shown in Figure 1.10, is a very simple clip-on attachment. All the conventional double apron drafting systems have spacers installed at the sides of the apron cradle. The special feature of the pin spacer, which distinguishes it from conventional spacers is that it is fitted with a highly smooth polished metallic bar in front of the aprons, so that when the fibres exit the aprons and enter the main draft zone, they pass under this bar. The presence of this bar provides additional control over floating fibres which results in an improvement in yarn evenness. The working principle of this bar is the same as the presser bar used in drawing frames for control over floating fibres. Claims have been made by the manufacturer that this spacer improves yarn evenness by around 10 %. It is also claimed that this spacer substantially raises the quality level of almost all yarn parameters which are influenced by the drafting process [128]. However, these claims require neutral validation. Passage of the fibrous strand through main drafting zone with and without pin spacer is shown in Figure 1.11.

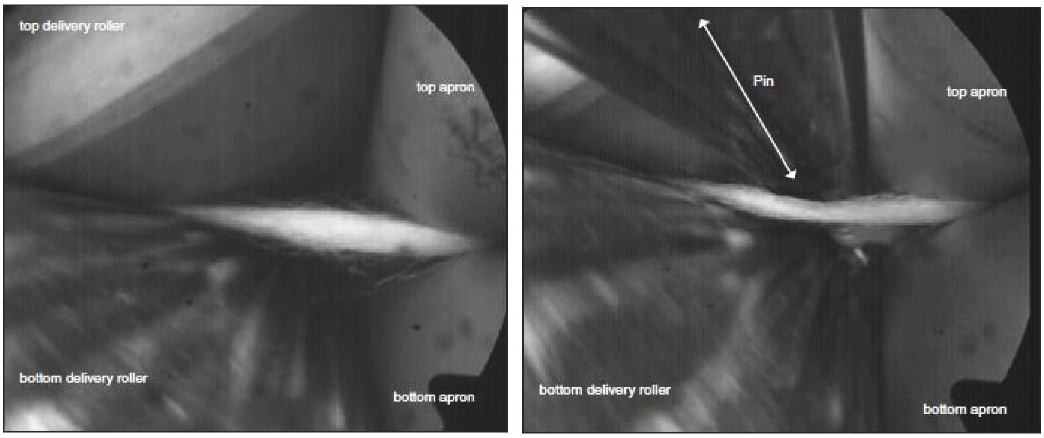


Figure 1.11. Fibre passage through drafting system with (left) and without pin spacer (Right) [128]

1.2.6.5.6 Auto leveller in spinning for more even yarns

Among the existing spinning systems the auto-leveller is the only system capable of improving yarn evenness by preferential drafting of thicker places. Usually in commercial spinning lines auto levellers are used at carding machines and drawing frames to control long term variations. Johnson [28] proposed using an auto leveller at the ring frame. The prototype machine used by him consisted of a specially designed drafting system which had an extra drafting zone (i.e. 5 drafting rollers). Use of this two zone drafting system allowed the roving thickness to be reduced to a desired level before entering the final draft zone. This was necessary because the final zone had a variable draft depending on the sensed thickness. The evenness of the strand in this final zone was monitored using highly sensitive sensors. Just like any other auto levelling system the speed of the back roller was increased or decreased according to requirement, using a specially designed gear box. Using this system he demonstrated that significantly more even yarns can be produced with an auto leveller. Due to such a high level of evenness this system could be used to spin finer yarns that are not spinnable otherwise. The problem however with this system was that this system was too prone to faults and cost of installing such costly equipment on every spindle was very high.

1.2.6.6 Facilitators of improved yarn performance

These are the developments in textile processes which do not directly improve yarn quality, but facilitate the yarn in having a smooth performance during spinning or weaving. When an end breaks on the ring frame the broken end starts generating lots of fly. This fly or loose fibres start settling on the drafting rollers and are absorbed into the yarn during drafting and spinning. These unwanted fibres cause thick places, which can lead to excessive cutting in winding, resulting in increased splices, thus creating weak places and winding faults. Therefore by reducing the number of breaks these process facilitators, indirectly improve the yarn quality. Some such facilitators are:

1.2.6.6.1 Spin finishes

To compensate for some of the damage to fibres during preparatory processes sometimes some spin finishes are used. A spin finish is a liquid or solid that is applied to the surface of the fibres in order to improve processing in short staple or long staple spinning [129]. Spin finishes are mostly applied to eliminate the development of static charge. These finishes achieve this target firstly by reducing the friction between fibres, and with machine surfaces, which decreases static charge generation, and secondly by facilitating the dissipation of charge by making them hydrophilic. This friction can also cause local fusion of fibres, especially at points where the fibres rub guides and other machine parts during high speed winding [130].

The type of spin finish to be used depends upon many factors [131, 132] i.e. the chemical properties of fibres, the type of spinning process, the technique used for applying the finish. For example the spin finish used for cotton, compensates for the loss in natural waxes found in cotton fibres. The surface of cotton fibres is covered with 0.3 to 0.6 % of natural wax [129]. This wax protects the fibres and aids processing. The presence of waxes helps in drafting of fibres during subsequent processing. This also helps in reducing the development of static charge and the moisture content of fibres is retained.

1.2.6.6.2 Devices for reducing spinning tension

The tension in the yarn during spinning is an undesirable but still an unavoidable feature of the ring spinning process. This particularly is the case with modern spinning machines where spindle speeds of up to 22,000 rpm are achieved. Whenever this tension exceeds the yarn strength, the yarn breaks. As a result, production speeds cannot be increased beyond a certain level. The spinning tension is not constant throughout the whole length of the bobbin. At the bottom-most and top-most positions of the bobbin, spinning tension is maximum. Use of inverters has enabled variable speeds during spinning, i.e. to have higher speeds at points where spinning tension is low (centre of bobbin) and lower speeds at zones of higher tension (top and bottom positions). As a result higher average production speeds can be achieved. Another benefit of using inverters is that at the start of the doff when the bobbin and travellers start from rest, the inverters enable a gradual increase in spindle speed, resulting in a significant reduction in ends down at the start of the doff.

Similarly balloon control ring is another auxiliary which is used for reducing the yarn tension. Tang et al. [133] demonstrated that a right size and correctly positioned balloon control ring, can reduce the yarn tension by up to 2/3.

1.2.7 Improvements in yarn structure achieved by recent developments

For a certain raw material, the only option for improving yarn quality is by modifying the yarn structure. Therefore, all the improvements in yarn manufacturing have been targeted at improving this yarn structure. These improvements are either achieved by modifying the spinning geometry of the spinning systems or by adding certain accessories to the existing spinning lines. The structural changes induced in yarns in order to improve yarn quality are therefore reviewed:

1.2.7.1 Improved incorporation of fibres into yarn structure

Many of the recent developments in ring spinning have focused on improving the yarn quality by improving incorporation of fibres into the yarn structure. Hearle and Bose indicated that the pattern of fibre migration within the yarn must influence its properties, and controlling fibre migration during spinning is a possible way of altering yarn properties [134]. Techniques like solo and siro spinning have targeted this very area. Researchers have claimed that by improving the incorporation of fibres these methods provide a means to produce weavable singles yarn without the need for plying or sizing [114, 116, 117]. The most significant advantage of Solospun yarns is that the fibres are securely bound within the yarn structure, due to this the yarn has a very high level of resistance to abrasive forces imposed by the weaving process [116]. Similarly in compact spinning too, most of the improvement in yarn quality is due to improved incorporation of fibres into the yarn structure, which has resulted from reduction in the size of the spinning triangle. Some other experimental setups discussed above such as a diagonal path on the ring frame and use of a contact surface during spinning of two-ply yarns, have also achieved an improvement in quality by improving the incorporation of fibres.

1.2.7.2 Wrapping of surface fibres for reduced yarn hairiness

The fibres, whose total length has not been incorporation into the yarn structure, appear on the yarn surface in the form of hairiness. Once the twist insertion has been executed the incorporation of these fibres cannot be enhanced unless the twist is removed. A simpler and cost effective method to reduce these fibres could be to wrap them fibres around the yarn core. Although this wrapping might not incorporate the fibres into the yarn structure and therefore might not improve the load sharing among the fibres, it would prevent these protruding fibres from causing other hairiness related problems such as entanglement with neighbouring fibres, resistance to absorbency during sizing etc. This technique has been applied by some researchers in the form of the jet-ring and jet-wind processes and has been demonstrated to be able to reduce yarn hairiness by up to 40 %.

1.2.7.3 Improvement in fibre migration

An improved migration means that more fibres starting on the outside will move to the inside and vice-versa. This lateral movement through several layers of fibres provides a binding mechanism. Improved fibre migration provides a locking mechanism for the fibres which prevents the yarn from disintegrating when exposed to an abrasive force.

Solospun and Sirospun yarns enjoy higher fibre migration than conventional ring spun yarns and compact yarns [135]. It is due to this improved migration that these yarns have much superior abrasion resistance and lower yarn hairiness. The effect of fibre migration in compact yarn is, however, more complex. In ring spinning the spinning triangle is believed to be the biggest source for inducing fibre migration in yarns. During the twist insertion, fibres are subjected to different tensions depending on their radial positions. Fibres at the core are under minimum tension due to the shorter fibre path, while the fibres on the surface are exposed to maximum tension. According to the principle of the minimum energy of deformation, fibres lying near the yarn surface will try to migrate into inner zones, where the energy is lower. This leads to a cyclic interchange of fibre position. However, in compact spinning the spinning triangle is eliminated by compaction of the strand. Therefore, it should cause a reduction in fibre migration as well. If that is the case then the yarn quality should also be worsened, as fibre migration is one of the biggest determinants of yarn quality. Various researchers have worked on fibre migration in compact yarns. Ganesan and Ramakrishnan [136] found that due to the elimination of the spinning triangle the fibre migration in compact yarns was inferior to conventional ring spun yarns. Ishtiaque et al. [137] studied the inner structure of compact yarns. It was reported that these yarns exhibit lower mean fibre position but higher RMS (root mean square) deviation and mean migration intensity than conventional ring spun yarns. Basal and Oxenham [81] also compared the structure of compact and conventional ring spun yarns. They reported that the rate of fibre migration as well as amplitude of migration is higher in compact yarns. This improvement in fibre migration despite having reduced the spinning triangle can be explained by Basal and Oxenham's [81] work where the improvement in rate of migration was attributed to a smaller spinning triangle and increase in amplitude of migration was attributed to higher yarn density.

1.2.7.4 Improvement in yarn evenness

For a certain twist level yarn evenness is the biggest determinant of yarn strength. Therefore, most of the recent developments in ring spinning have ensured that as a result of the processing, yarn evenness should be improved or at least not deteriorated. Compact spun yarns have fewer imperfections than conventional ring spun yarns. This improved evenness enables them to have improved spinning performance and allows them to be spun finer and at lower twist factors. Similarly Siro and Solo spun yarns are more even than conventional ring spun yarns. Work by Johnson [28] was also targeted at improving yarn evenness and has demonstrated that by improving yarn evenness very fine yarns can be produced, which are not spinnable otherwise.

1.2.7.5 Improved fibre orientation for better load sharing among fibres

Relative fibre orientation means the position of fibres with reference to each other. Improving this orientation can improve load sharing among the fibres, which results in improved yarn strength and better utilisation of fibre strength. Khan [127] has demonstrated that by improving the straightening and orientation of fibres by employing drafting against untwisting, yarn strength can be improved significantly. Similarly in some compact spinning systems a slight tension draft is applied in the processing zone to improve straightening of fibres.

1.3 Problems, gaps & opportunities

Various spinning machinery manufacturers and researchers have come up with solutions to improve aspects of yarn quality. These systems, their working principle, their advantages and disadvantages have been discussed in detail in preceding sections. From the analysis of this information it can be said that all these developments have targeted certain segments of yarn quality and have achieved some success in improving them. Despite these advancements the yarns produced still lack in some areas and provide an opportunity for improvement.

Yarn quality can be segregated into its spinning performance and downstream performance. Smooth spinning performance means fewer end breaks in ring spinning. The breakage in spinning takes place when the spinning tension exceeds the yarn strength. The end breakage in spinning can only be reduced by improving yarn strength or by reducing spinning tension. With the increase in production speed of modern machines the spinning tensions cannot be reduced beyond certain levels. Therefore, the only option for improving spinning performance is to increase the yarn strength so that it can endure these forces successfully. Improvement in yarn strength not only improves spinning performance of the yarn but also will improve downstream performance. At a given twist level yarn evenness is the biggest determinant of yarn strength. Some of the developments in spinning systems have targeted improvement in yarn evenness. Work by Johnson [28] is one such effort and a significant improvement in yarn evenness was shown to be possible. This is the only case where it has been shown that the evenness limit imposed by the random positioning of fibres can be beaten. All other improvements to drafting can only lead to a closer approach to the random limit. However, such an auto-levelling in spinning is too prone to faults such as drift, and the cost of installing such equipment on every spindle will be too high. Similarly, the evenness properties of compact yarns have been demonstrated to be better than ring spun yarns, but critical analysis of compact spinning systems reveals that they do not have a provision for improving yarn evenness. The reason is that the processing zone of compact spinning is installed after the drafting has been completed. After this stage the thickness of any segment in the strand can neither be increased nor decreased. Therefore, theoretically it is not possible to improve the evenness of the yarn. A possible explanation for the superior evenness of compact yarns could be reduced fibre loss. Due to compaction of the strand before twist insertion the fibres come closer to each other and fibre ends are more easily trapped as the emerging strand rotates so there is less chance for the fibres to be lost as fly. However, this needs a separate validation by accurate measurement of the counts of two strands of nominally the same liner density on compact and conventional ring spinning systems. An alternative explanation is that the hairs either form slightly thicker places or affect the measurement of the apparent linear density by the evenness sensors. Another development that claims to improve yarn evenness by providing more control over short fibres is the pin spacer introduced by Suessen, but these claims made by manufacturers need neutral validation. It can therefore be concluded that despite the fact that yarn evenness is such a major determinant of yarn quality, there still is room for further improvement. This provides an opportunity for improvement in yarn quality and this gap can be exploited by designing a system that has the potential for improving yarn evenness but at the same time is not operationally very complex.

Unlike spinning performance the downstream performance of the yarns does not depend solely on yarn strength. There are several other factors that influence yarn performance. It can be said that downstream performance depends a lot on the quality retention ability of the yarn. Immediately after the yarn is manufactured the process of gradual degradation in yarn quality starts due to abrasive forces acting on the yarn. These forces tend to rub away constituent fibres out of the yarn structure causing the yarn to become more hairy, less even and weaker. The ability of yarn to be resilient to this slow but sure degradation lies in how well the fibres are locked into the structure.

Among recent developments in cotton ring spinning, compact spinning can unarguably be declared the most successful method. This can be seen from its commercial success. Some critics have even declared it a revolution in ring spinning, but if looked at closely it can be seen that even compact yarns lack certain characteristics. The modified spinning geometry does help in improving the incorporation of fibres into the yarn structure and this improved incorporation helps in reducing yarn hairiness and improves spinning performance of the yarns, but the question that "does this improved incorporation helps in improving the locking of these fibres into yarn structure?" still needs further analysis. Although there is some evidence that compact yarns have higher fibre migration values, which implies that fibre trapping should be stronger in them than in conventional ring spun yarns, the inability of compact yarns to be woven into fabric without sizing implicitly points towards the fact that the degree of fibre locking in compact yarn is not satisfactory. Siro and Solospun yarns on the other hand do have improved locking of fibres but they have their own draw backs. The siro spinning system can produce more abrasion resistant yarns but its biggest disadvantage is the use of two rovings. First of all these extra rovings need extra creel space, secondly roving frame production is reduced which means extra roving frames will be needed to feed the ring frame, thirdly the strand breakage detection device needs to be installed. If an extra creel is not attached to the ring frame then smaller diameter roving packages have to be used, which implies excessive doffing on the roving frame. The solo spinning operates on a single roving but has not had significant penetration in cotton spinning. The reasons for this probably need further investigation. However, in cotton spinning, there are not the cost savings of avoiding two-folding and the slotted roller probably needs to be adjusted to match the finer rovings and shorter finer fibres. Besides the working principle of solo spinning does not allow it to benefit from the advantages of compact spinning, as the strand has to be split into sub-strands before twist insertion. Therefore, it cannot enjoy the benefits associated with a small spinning triangle. Some other systems discussed above for improving locking of fibres also cannot enhance the incorporation of fibres into the yarn structure because they all are installed after the twist insertion process. Although these systems have been demonstrated to be able to reduce the yarn hairiness they cannot induce trapping of fibres, because after the insertion of twist, the fibres are locked in their designated places and any processing without removing the twist cannot enhance the interlocking of fibres.

The shortcomings associated with the developments in spinning techniques are a setback but at the same time they do provide an opportunity for further improvement in spinning systems. These opportunities can be exploited by combining the advantages of various systems. It has already been demonstrated in the past that combining the two different systems does help in further improving yarn quality [138]. If a spinning system can be designed that can produce a yarn with significantly improved evenness, a small spinning triangle like compact spinning, and fibre trapping like siro or solo spinning and still does not require two strands like siro spinning, then it has great potential. The key is to find a system which is simple, cost effective and yet can achieve a considerable improvement in yarn quality.

1.4 Conclusions

It is concluded that for a certain raw material, the only way yarn quality can be improved is by improving the arrangement of fibres in the yarn, or in other words by modifying the yarn structure. From the analysis of the literature it was found different systems have targeted different aspects of yarn quality eg improvement in yarn strength, evenness and hairiness and have achieved significant improvements, but still the available systems have some shortcomings such as raw material limitations, high running costs and complex operational mechanisms. These shortcomings provide an opportunity for further improvement. The summary of proposed work in this thesis towards improving yarn quality by exploiting these shortcomings is given in the following flow chart.

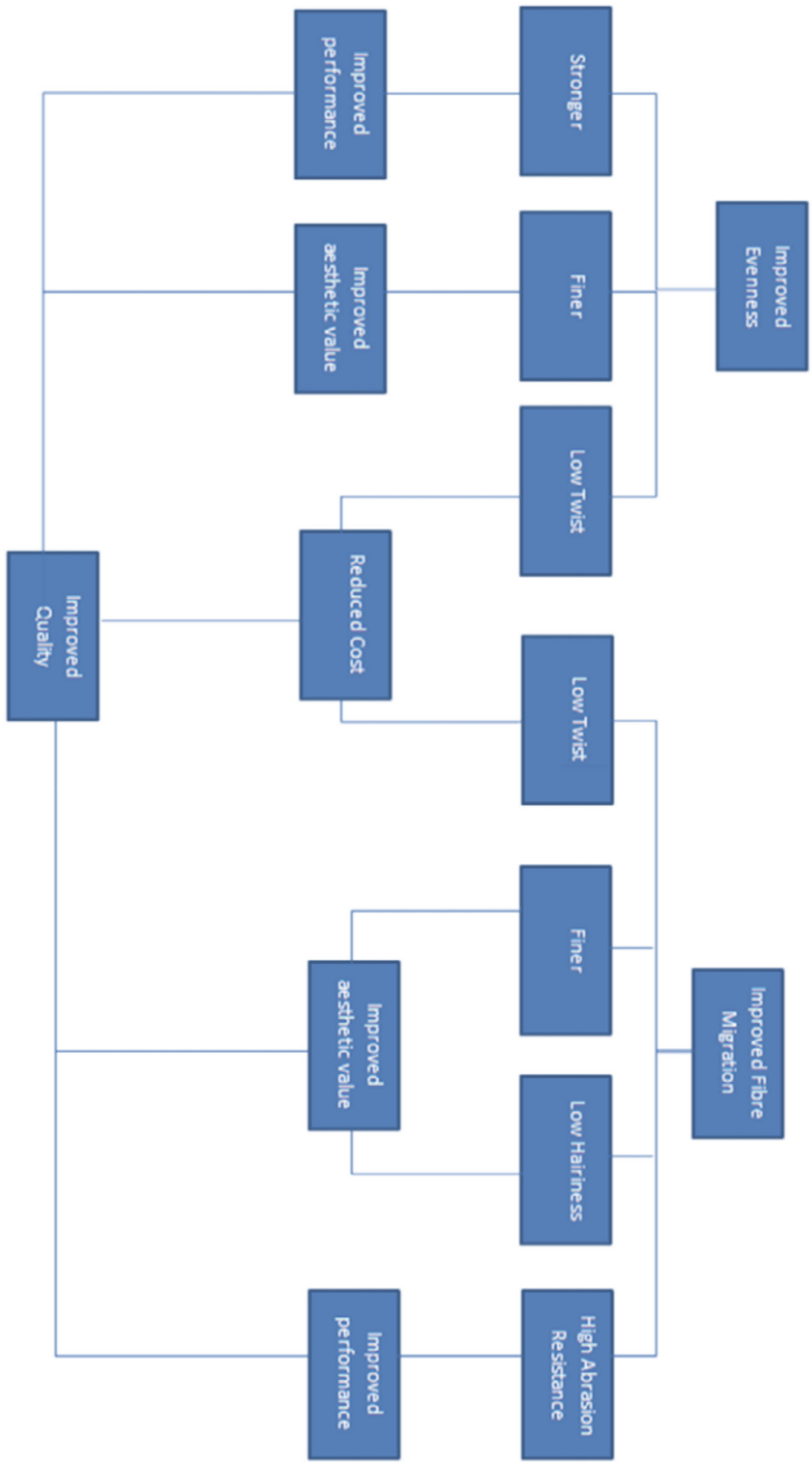


Figure 1.12. Flow chart of how yarn quality can be improved by proposed work

To improve the shortcomings of existing spinning systems some modifications to the spinning systems were proposed and investigated. Two main aspects of yarn quality i.e. yarn evenness and trapping of surface fibres were targeted for improvement, as shown in the flow chart diagram above (Figure 1.12). Improved yarn evenness would help in improving the yarn strength, which in turn would facilitate the spinning of finer and lower twist yarns. This would not only improve the yarn quality but also would reduce the cost of production by reducing the twist level in the yarn. Improved trapping of surface fibres would not only improve the manufacturing quality of the yarn, but also will improve the quality retention ability of the yarn. Improved incorporation of fibres into the yarn structure will make more constituent fibres contribute to the yarn strength. The yarns thus produced will be stronger, less hairy and more abrasion resistant. These yarns can be spun finer and at lower twist factors, therefore reducing the cost of production.

Chapter 2 gives a detailed description of the machines used in the experimental work for manufacturing and testing of the yarns.

At a given twist level yarn evenness is the biggest determinant of yarn strength, so first of all (Chapter 3) the potential of improving the yarn evenness by employing a post spinning processing technique “drafting against untwisting” has been investigated. This process has already been demonstrated to be a successful method for producing finer and low twist yarns. The study here aimed to develop an understanding of how this system works and if it could be used to improve yarn evenness by preferentially drafting thicker places. For this purpose a modified yarn winder fitted with a two roller drafting system was used. For evenness measurement two short but sensitive capacitive sensors, aided by specially designed computer programs were used. This setup not only enabled the measurement of yarn evenness immediately before and after the processing zone but also provided the means for monitoring the effect of processing on a particular thick or thin place.

It was concluded from these and previous studies that a significant improvement in yarn evenness is not easily achievable, or at least not commercially viable. This led to the conclusion that those aspects of yarn quality which needed to be targeted were those which can be improved without improving yarn evenness. Therefore an attempt to improve the downstream processing of the yarns by improving their abrasion resistance was made. This would be achieved by improving the incorporation of fibres into the yarn structure, by creating intertwining among the fibres. An air jet was used in spinning but separately and prior to twist insertion, installed in a specially designed drafting system, which had an extra processing zone. It was hypothesised that the swirling action of the air jet would twist and untwist the strand to create an intertwining of fibres which would not only lock the fibres more securely into yarn structure but also would compact the strand. This would enable the system to achieve the benefits of a smaller spinning triangle like compact spinning and more secure locking-in of fibres like siro or solo spinning, and still using a single strand. The work is reported in Chapter 4.

The air-jet compacted the strand but just twisting and untwisting of the strand created, by the air vortex was insufficient for creating the desired intertwining among fibres. Apart from this, a side effect of this processing was worsening of evenness. To make up for these short-comings the system was improved by replacing the air jet with a mechanical "rubbing assembly" that could provide more vigorous treatment to the fibres. This was based on the observation of the way strands are consolidated on a rubbed roving frame and was achieved using a custom designed rubbing assembly. The investigations are reported in Chapter 5. The aim was to reduce hairiness and improve downstream performance and was particularly aimed at improving weave-ability. However, weaving trials are complex and lengthy so some new methods of measuring yarn abrasion resistance have been proposed and investigated.

CHAPTER 2

Experimental Details

This chapter gives details about the machinery setups used in this work. The equipment falls into two main categories

a) Machinery for modifying the yarn manufacturing process.

b) Instruments used for testing yarn quality characteristics.

2.1 Machines used to manufacture modified yarn

To achieve the desired fibre arrangements in yarn, experiments were conducted at two different stages of yarn production. The first experiment modified the structure of an already manufactured yarn and the second made alterations to spinning. For this purpose three different machinery setups were designed. The details of these machines are given below.

2.1.1 Modified winder for drafting against untwisting

The process of drafting against untwisting was carried out on a modified yarn winder. One single spindle yarn winding machine was modified for this purpose. It was fitted with a two roller drafting system to carry out drafting on the untwisted yarn. For untwisting a three pin untwisting head was used. The spindle was also equipped with an online evenness monitoring system. This was achieved by using two highly sensitive capacitive sensors. The data collected by these sensors was processed through a custom designed computer program. The drafting system, fitted with untwisting mechanism is shown in Figure 2.1.

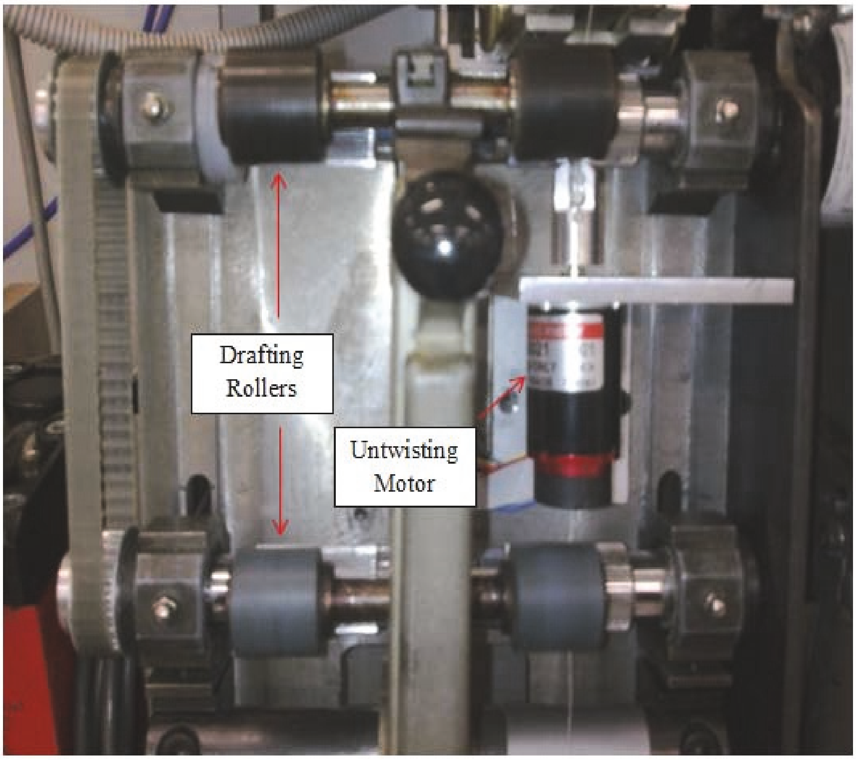


Figure 2.1. Drafting system fitted with untwisting motor

2.1.2 Spinning frame with added air-jet for improved fibre trapping

The spinning frame used for this work was an SDL spin-tester. This is a common laboratory scale spinning machine with 6 spindles. The draft and twist can be easily altered by rotatable dials and a digital display which provides continuous, online monitoring of the spindle speed, twist and draft. A five-roller drafting system was specially fitted to this machine. This provides an extra processing zone in which the air jet was inserted for creating intertwining among the fibres and compacting the strand. The drafting system fitted with the air-jet is shown in Figure 2.2.

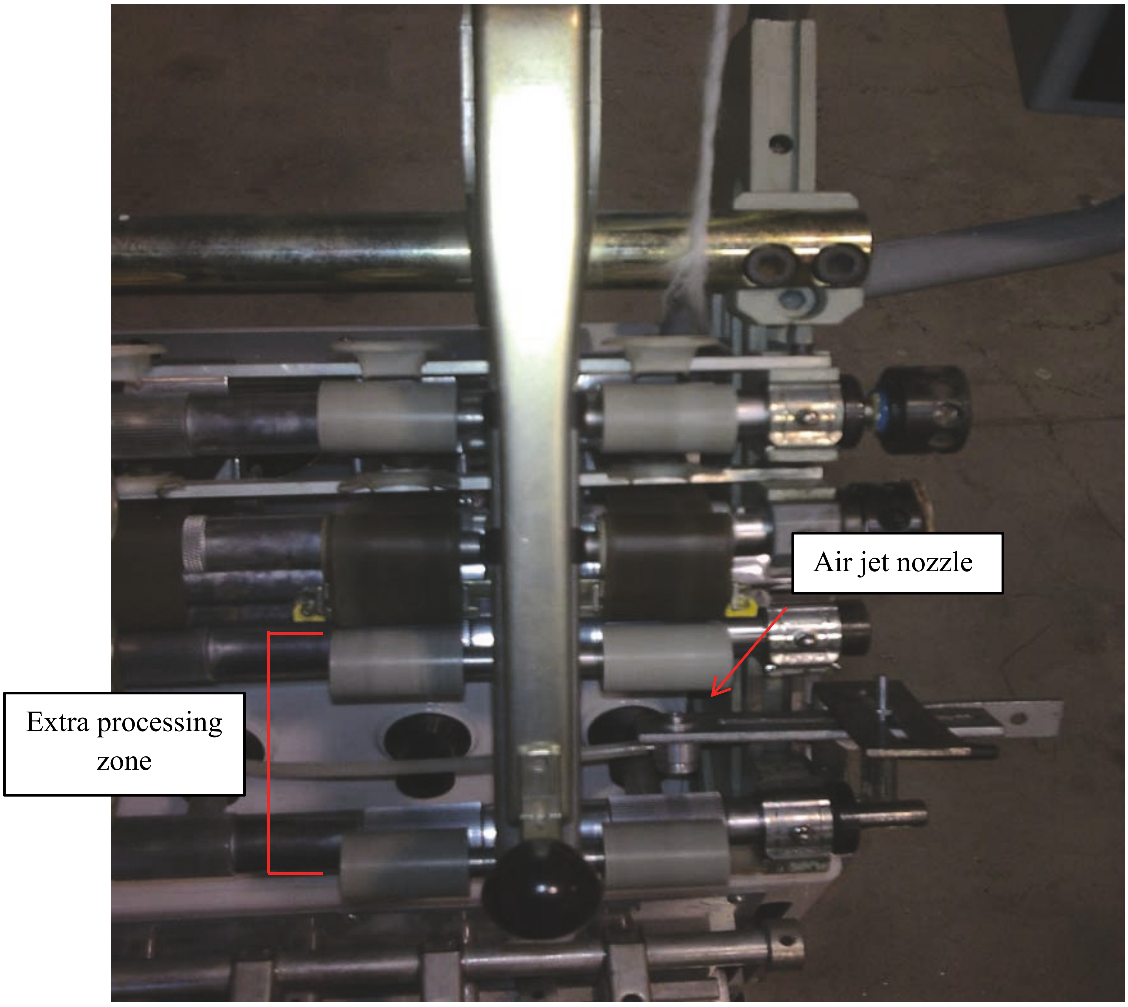


Figure 2.2. Drafting system fitted with the air nozzle

2.1.3 Spinning frame fitted with rubbing assembly for improved trapping of fibres

The third set-up involved fitting the spin-tester with a custom designed rubbing assembly for creating intertwining among the fibres for improved trapping of the fibres. The spin-tester fitted with the drafting system containing the rubbing assembly is shown in Figure 2.3.

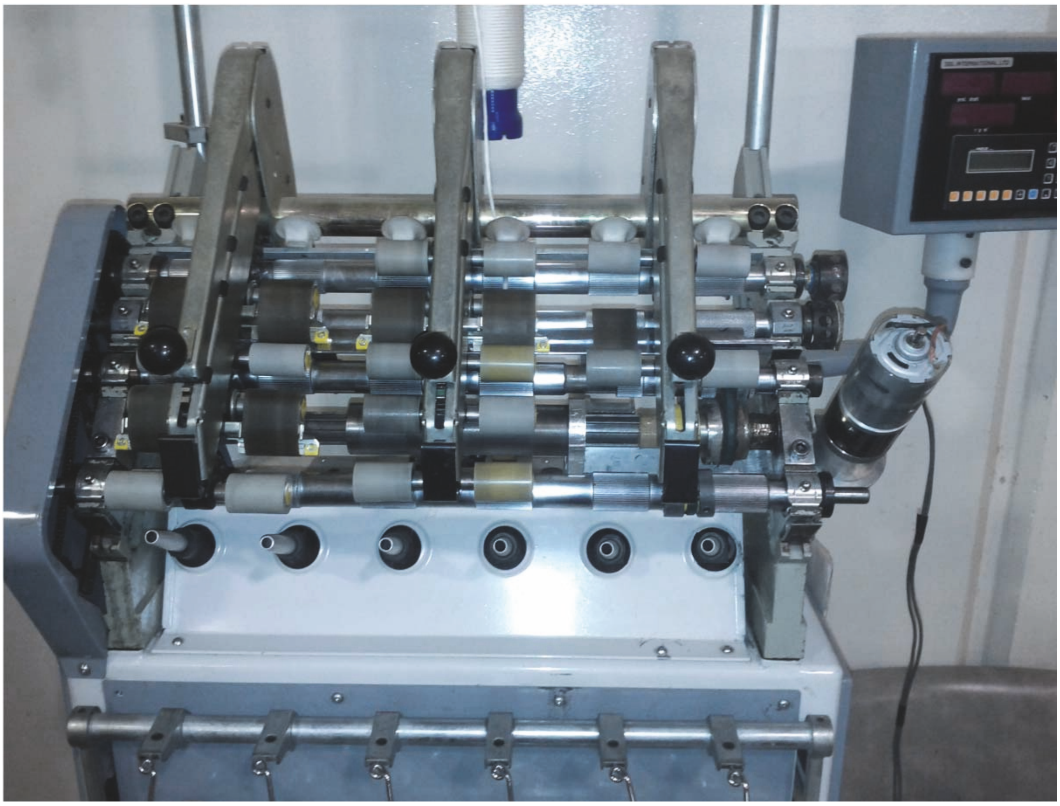


Figure 2.3. Spin-tester fitted with the drafting system

2.1.4 Rubbing assembly

The rubbing assembly was designed keeping in view that it was to work on a running spinning frame therefore it had to have two motions at the same time i.e. transverse oscillations, for rubbing of strand and rotary motion, for delivering the material forward. For this purpose the rubbing sleeve was mounted on a spline shaft as shown in Figure 2.4.

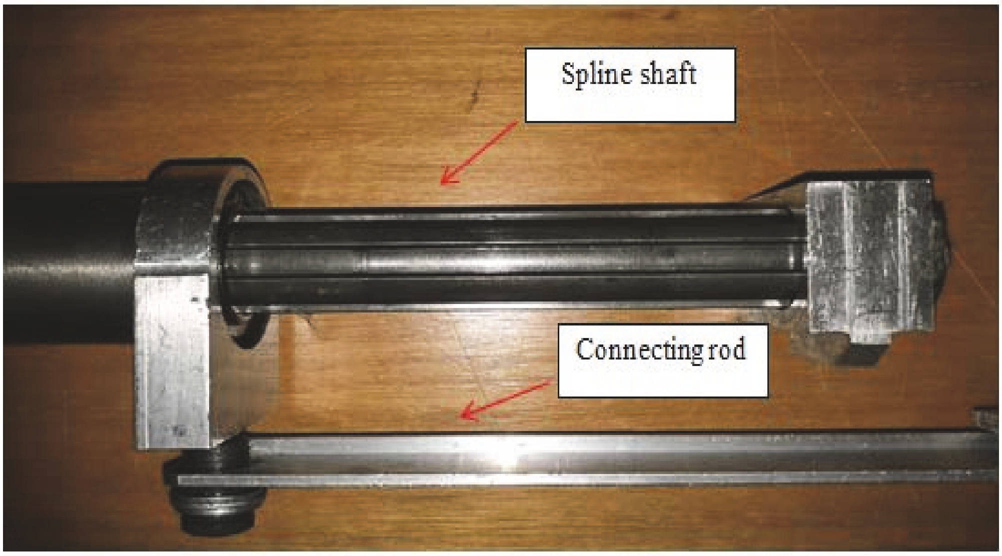


Figure 2.4. Rubbing sleeve mounted on the spline shaft

The forward drive was provided from the preceding roller using a belt and the oscillatory motion was provided through a separate motor. The rubbing assembly along with the drive motor is shown in Figure 2.5.

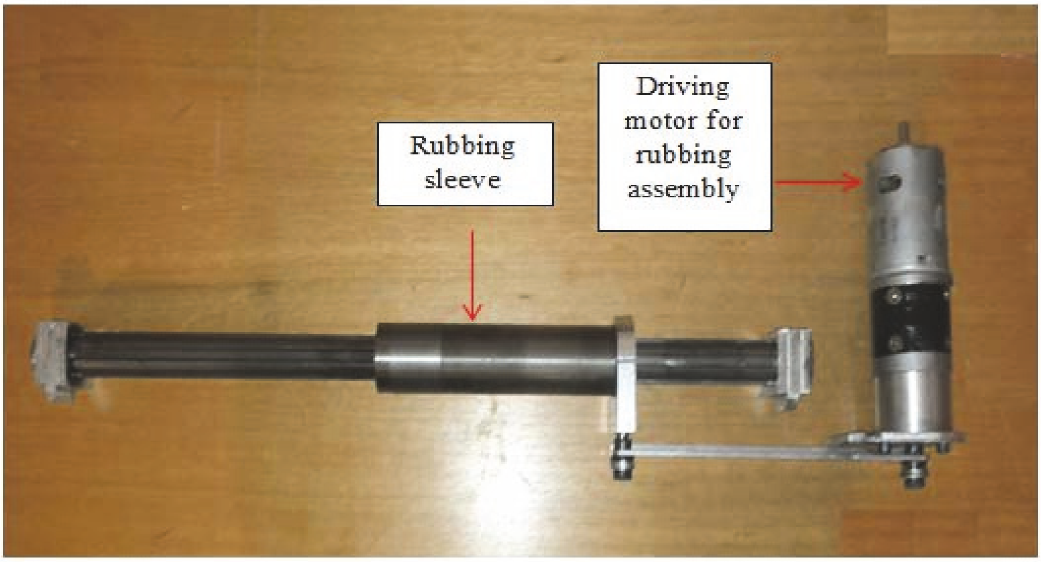


Figure 2.5. Rubbing assembly fitted the drive motor

As seen in the Figure 2.7, the rubbing assembly was connected to the drive motor through a crank shaft. This served two purposes, firstly it converted the rotary motion of the driving motor into oscillatory motion and secondly the crank shaft was designed having holes at variable distance from the centre. By selecting the suitable hole in the crank shaft, the amplitude of the rubbing stroke could be adjusted. The crank shaft with adjustable holes is shown in Figure 2.6.

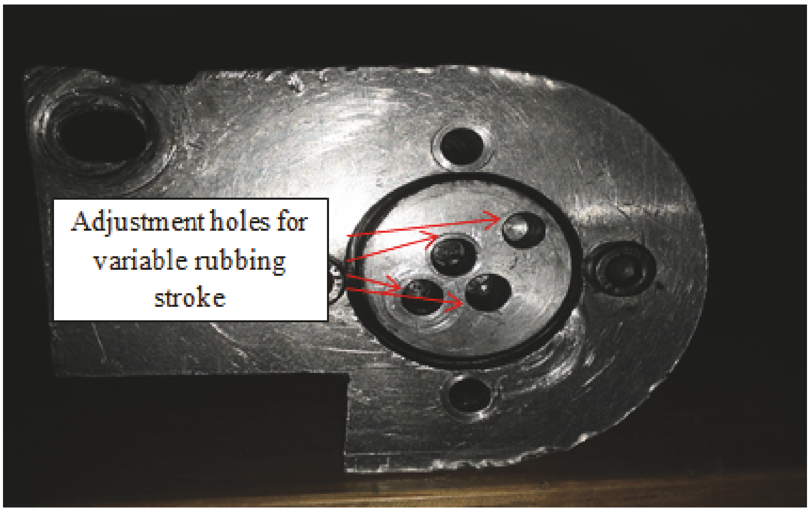


Figure 2.6. Crank shaft with different holes for adjustable stroke length

To make the machine flexible in terms of frequency of oscillation the drive motor of rubbing motor was provided through a variable DC power supply. A MP 3097 power supply having two outputs of Voltage of 0 – 32 volts and 0 – 3 amp was used.

2.2 Testing instruments

The second group of machines used was those used for yarn testing. Standard yarn tests were carried out on standard lab machines; however, some machines were designed for non-routine testing as well. Their details are given below:

2.2.1 Manual abrasion tester

Due to the unavailability of standard equipment for testing abrasion resistance of the yarns a manual abrasion resistance tester was designed. This was a simple frame containing a rack fitted on a rail. Any desired abrading configurations such as 3-pin, knife edge, smooth bar etc. could be attached to the rack and mounted on the rail. The abrasion resistance tester fitted with 3-pin abrader is shown in Figures 2.7 and 2.8.

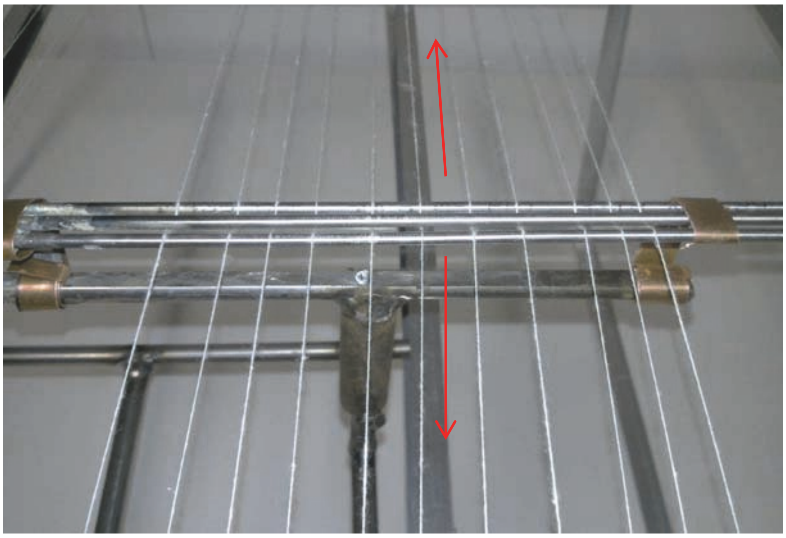


Figure 2.7. 3-pin abrasive surface

Figure 2.8. Abrasion tester fitted with 3-pin abrader

The yarns samples were clamped on one end and then after passing them through the abrasive pins, a dead weight for introducing the desired tension was attached to the yarn end. To prevent the weights from rotating and untwisting the yarns, the end of the yarn after attaching the dead weight was clamped. Yarn ends with the dead weights attached are shown in Figure 2.9.

Figure 2.9. Yarn end with dead weight attached

2.2.2 Equipment for repeated winding

A second method for testing the abrasion resistance of yarns was to test yarn hairiness after repeated windings. For this purpose a winder was used which could wind the yarn exiting the hairiness tester, so that the hairiness of the same segment of yarn could be tested again. The winder is shown in Figure 2.10.

Figure 2.10. Winder used for winding of yarn exiting the hairiness tester

The winder had a variable take up speed, which could be adjusted to match the yarn testing speed of the hairiness tester and a traversing mechanism so that during unwinding the yarn does not slough off. The hairiness tester fitted with winder is shown in Figure 2.11.

Figure 2.11. Hairiness tester fitted with winder

CHAPTER 3

Drafting Against Untwisting for Improved Yarn Evenness

3.1 Introduction

There has been a long history of methods to improve yarn evenness and strength. For a given fibre, these properties are primarily governed by the quality of drafting and average number of fibres in the yarn cross-section. Even "ideal" drafting where fibres are individually accelerated only when their leading end reaches the front nip, still leads to a yarn whose variations in thickness follow a random (Poisson) distribution governed by the average number of fibres in the cross-section [139, 140].

If an improvement in yarn evenness can be achieved, it can greatly improve yarn's spinning performance, besides there is a lot of room for improvement in yarn evenness. Uster experience statistics of yarn evenness show that the majority of yarns produced may be considerably less regular than it is practicable to spin [141]. A more even yarn can afford to have lower average twist, so if yarn evenness can be improved it can help in manufacturing low twist yarn, which in turn will lead to a reduction in cost of production and the manufacture of softer and finer yarns.

3.2 Effect of evenness on yarn strength

The weakest spot in a yarn segment determines the strength of that segment. The thinner a place gets the weaker it becomes. A thinner portion in a yarn segment will have fewer fibres in the cross-section and will consequently have lower tenacity. A major cause of yarn breakage during spinning is yarn unevenness

[142-144]. Studies on the effects of yarn irregularity in spinning and weaving of weavable singles (Solospun) yarns have shown that a relatively small improvement in yarn evenness can significantly reduce end breaks [145, 146]. Mandl claimed that if coefficient of variation of tenacity of a yarn can be reduced from 11.3 % to 10.0 %, the probability of a weft break on a weaving machine is reduced from 6.5 to 1.4 per 100,000 picks, or by a factor of 5 : 1 [147]. Many researchers have worked on the correlation between the breaking spot in the yarn and thin places. Cybulaska et al. claimed that yarn linear density and its uniformity has a great influence on breaking load and elongation of the yarn. The higher the yarn linear density, the greater the breaking load and elongation [148]. Stout claimed that a very regular yarn can afford to have a lower average strength than a less regular one [149]. Penava and Oreškovi found that in 61 % of the cases studied the breakage point was the thinnest place. It was also claimed that as the length of the thin place grows, the breaking force falls [150]. Studies [151-153] elsewhere have shown that yarn strength decreases when yarns are spun with eccentric rollers. Bragg demonstrated that yarns made with more eccentric rollers yielded higher warp breakages than those with lower eccentricity [154]. This reduction in yarn tenacity and increase in warp breakage due to increase in eccentricity of the rollers is because an increase in irregularity of the yarn linear density reduces yarn strength by creating more thin places.

Thin places despite having a higher twist factor than neighbouring thick places [155] are a weak link in the yarn and provide an opportunity for improvement in the yarn strength. By reducing the frequency of occurrence and magnitude of these thin places yarn performance can be improved. Mandl described the occurrence of weak places in worsted yarn due to the unevenness of linear density (yarn evenness) and related the yarn evenness and tenacity by the equation [147]:

$$R \;\; L \qquad K.T. \;\; 1 \qquad 0.80 \;. \underline{\qquad} \qquad \text{......................................} \; (3.1)$$

$$CVR \;\; L \qquad \underline{\qquad\qquad} \; .CVB \;\; L \qquad \text{..} \; (3.2)$$

where:

L = Length of yarn

R (L) = average tenacity (N)

K = specific tenacity (N/Tex)

T = Yarn count

CVw (L) = CV of yarn evenness within the length of yarn

CV_B (L) = CV of yarn evenness between the lengths of yarn

CV_R (L) = CV of yarn tenacity

3.3 Principle and hypothesis

In mule spinning improved evenness is achieved by employing draft against twist. Some initial twist is introduced into the yarn segment and then as the new yarn is introduced more twist is introduced. This may help in improving evenness of the yarn by preferential drafting of thicker places in the segment [156]. According to Catling a mule spinner can produce a yarn more even than the input slubbing [157].

Hand spinners have been credited with producing some incredibly fine yarns which probably were more even than the random limit [28]. This may be because the spinner can monitor when the strand reaches the desired thickness and then lock this section by letting twist flow into it, before drafting the following section.

It has also been shown theoretically and experimentally that using a sensor to monitor the number of fibres immediately behind the front draft roller in ring spinning and then altering the front roller speed, and hence the draft, can also allow the random limit to be beaten [28]. However, the method is too expensive and probably too prone to problems such as drift, to be practical.

3.3.1 Drafting against untwisting

Wang proposed taking an existing yarn and temporarily but continuously removing the twist in the yarn, using an air-jet, as it passed through a drafting zone. The principle of the method is shown in Figure 3.1.

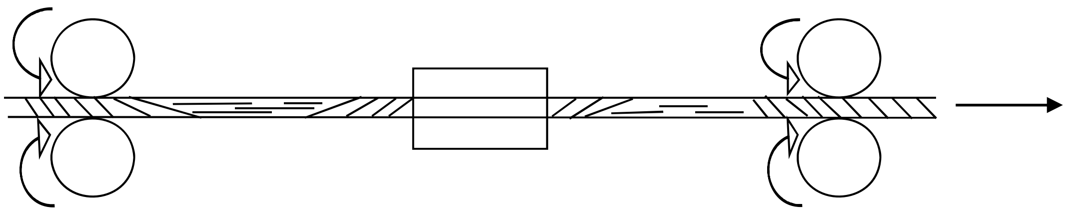


Figure 3.1 Schematic diagram of drafting against untwisting

The principle of this method was to pass an already spun yarn through a false-twist zone that acts to temporarily remove the real twist in the zone behind the false twist device. As a result of this untwisting, the yarn, which is already under tension introduced by the difference in surface speed of front and back rollers, gets drafted. It was proposed that this method was a promising one for making finer rotor yarns. One of the inherent problems associated with rotor spinning is that it cannot be used to spin finer yarns. By using this technique an already manufactured rotor yarn can be drafted into a finer yarn.

Improved yarn evenness gives improvement in tenacity and as discussed earlier, drafting against untwisting may improve yarn evenness. Khan [127] demonstrated that this technique, using an air jet, could be successfully used to improve yarn quality parameters like strength and hairiness for rotor spun and worsted yarns. This method could also enable increased production on the spinning frame by producing a coarser yarn and then converting it into a finer yarn during winding [127]. The potential cost savings would depend on a number of factors. If the final twist is kept constant, the production of the spinning frame increases by roughly the mean draft during winding (assuming spinning speed is maintained). Ends down should be reduced but doffing frequency increases. However, winding will cost more as production is slowed and a continuous supply of air is needed. Another potential problem is the high untwisting speed required for processing. Modern yarn winders run at around 1500 metres per minute. To keep up with this winding speed the untwisting device will have to run at around 750,000 rpm to remove 500 turns per metre, which is an enormous speed. Some modern yarn texturing machines are capable of achieving this speed by use of disc twisters, but installing such equipment on every spindle might not be commercially feasible.

The amount of untwisting introduced by an air-jet is difficult to determine. In order to understand the process it is important to determine the optimum level of untwisting required for improving evenness using drafting against untwisting. The point at which a yarn section will draft is primarily determined by the twist factor. Therefore, several methods were devised to find out the optimum amount of untwisting required to achieve the best possible yarn quality. In other words, the effect of the amount of untwisting on the drafting performance and the properties of the processed yarn was investigated. The minimum amount of untwisting required to allow drafting, can be related to the minimum twist of cohesion in the yarns. However in case of an already manufactured it could be different due to setting of fibres in the twisted state as they are already in that state for quite some time. Rotor spun yarns might also behave differently due to presence of wrapper fibres. Some work has already been done on the cohesion of yarns and rovings as a function of twist. Barella and Sust defined the minimum twist of cohesion as the number of turns per unit length existing in the yarn at the moment it breaks as a result of fibre slippage when it is submitted simultaneously to traction and untwisting [158].

Gokarneshan et al. also investigated the minimum amount of twist required for cohesion [88]. These results provide a guide for investigating the minimum amount of untwisting that would allow the fibres to slip past each other and thus allow drafting to take place, but do not necessarily give the twist value that will give the best drafting for strength and evenness. Lord and Nichols measured the untwisting level required for drafting and its effect on the yarn produced They found out that best results regarding yarn tenacity are achieved at 60 % untwisting, but did not investigate going beyond 100 % untwisting [32]. Also they did not investigate the effect of such drafting on yarn evenness.

3.4 Materials & experimental details

3.4.1 Static rig

The initial method for examining drafting as a function of untwisting was a simple static test in which the yarn was untwisted and drafted on a standard laboratory yarn twist tester (Quadrant Twist Tester 73 AMX/98/1303). Yarn samples were first untwisted on the twist tester in steps of 10 % of the nominal initial yarn twist. The sample was then manually drafted by 10 % by pulling one of the clamping jaws away. After the yarn was drafted it was twisted back on the same twist tester (The same number of turns that were taken out of the yarn was put back during retwisting, but since the length of the yarn was increased by 10 %, as a result of drafting, the resultant twist per metre in the yarn will be reduced). The tenacity of the retwisted yarn was then tested on a Lloyd strength tester.

During untwisting the yarn was kept under the standard pretension force (for untwisting during twist testing) given by the equation [159]:

$$\text{Pre} \quad \text{tension force} \;\; g \qquad \frac{\quad\quad\%}{\qquad\qquad} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.3)$$

Three different yarn counts of 100 % cotton, rotor spun yarn were tested (17, 25 and 30 tex). Raw material details are given in Table 3.1. To aid the comparison all three counts had approximately the same initial twist factor.

Count (Tex)	**Twist factor**	**Staple length**	**Fibre fineness Micronaire**
17	36.8	28 mm	4.7
25	38.5	28 mm	4.7
30	37.8	28 mm	3.5

Table 3.1 Fibre and yarn properties for the three yarn counts

The idea was that when the yarn is untwisted sufficiently the fibres will be able to slip past each other. When the amount of untwisting is insufficient and the yarn is exposed to a drafting force the yarn would snap apart instead of drafting. So the tenacity values were only recorded when the yarn had not snapped or fallen completely apart during drafting. Samples in which the yarn was untwisted beyond the 100 % untwisting level were also tested. This untwisting beyond 100 % will be referred to as "over-untwisting". For every untwisting level 5 samples were tested. The gauge of the drafting and untwisting zone was 10 cm.

3.4.2 Twist contraction

One problem during this untwisting and drafting process was to determine the effect of twist contraction and its effect on net draft achieved. As the yarns are untwisted they increase in length as the helical angle of the fibres decreases. This means that when the yarns are drafted by 10 % by pulling the clamping jaws apart, they do not actually get drafted by 10 %, instead some part of the induced draft is covered by extension caused in the yarn segment due to the reversal of the twist contraction. The yarns were processed on a gauge of 10 cm. Upon untwisting these yarns increased in length by 2 - 4 mm (depending upon their inherent twist contraction). The yarns were extended to a total length that was 10 % greater than the original (twisted) length, so the actual draft that took place during the initial extension was only the remaining portion of the length which was left after twist contraction reversal i.e. the actual draft that takes place during extension was 1.06 to 1.08. The rest of the drafting takes place during retwisting when twist contraction takes place. Since the yarn sample was held at both ends not allowing it to contract, some additional drafting must occur. The twist contraction for the yarns was calculated theoretically and experimentally.

3.4.3 Calculated twist contraction

Twist contraction in yarns is given by the equation [33] :

Cy ——— .... (3.4)

where:

= angle of helix of outside fibres

Cy = Ratio of untwisted length to twisted length

From equation 5 it can be seen that the twist contraction of the yarn depends only on the angle , which the fibres make with the yarn axis.

The twist factor is given by the equation:

$$K \quad 0.5 * \tan \quad \frac{}{*} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3.5)$$

$$\tan \quad \frac{}{\frac{}{*}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3.6)$$

where:

= Helix angle of fibres

= Yarn Density

K = Twist factor = ($turns/\ m * \sqrt{tex}$)

Using equation 5 & 6 the twist contraction in the yarn at various turns per metre values is shown in Table 3.2

Turns/m	**(angle in degrees)**	**Sec**	**Cy**	**% contraction**
500	11.8	1.02	1.01	1.0
600	14.1	1.03	1.01	1.5
700	16.4	1.04	1.02	2.0
800	18.6	1.05	1.02	2.5
900	20.7	1.06	1.03	3.0
1000	22.8	1.08	1.04	4.0

Table 3.2 Calculated twist contraction for various twist factors

The actual twist contraction was measured by untwisting the yarns under the standard pre-tension force, without any other external drafting force applied. The yarns were allowed to increase in length as the result of untwisting. This increase in length in the yarn samples was then measured. Results for these experimental measurements are given in the Tables 3.3, 3.4 and 3.5.

Untwisting%	Turns/10cm removed	Calculated extension (mm)	Actual Extension (mm)
10	8.9	0.0	0.5
20	17.8	0.0	1.2
30	26.7	0.4	1.5
40	35.7	0.5	2.0
50	44.6	1.0	2.2
60	53.5	1.0	2.5
70	62.5	2.0	2.7
80	71.4	2.0	2.7
90	80.3	3.0	2.7
100	89.3	4.0	3.0

Table 3.3 Actual Twist contraction for 17 Tex

Untwisting%	Turns/10cm removed	Calculated extension (mm)	Actual Extension (mm)
10	7.7	0.0	0.7
20	15.4	0.1	1.1
30	23.1	0.4	1.5
40	30.8	0.5	2.0
50	38.5	1.0	2.5
60	46.2	1.0	3.0
70	53.9	2.0	3.5
80	61.6	3.0	3.7
90	69.3	3.0	4.0
100	77.0	4.0	4.0

Table 3.4. Actual twist contraction for 25 tex

Untwisting%	Turns/10cm removed	Calculated extension (mm)	Actual Extension (mm)
10	6.9	0.0	0.7
20	13.8	0.1	1.2
30	20.7	0.3	1.5
40	27.6	0.5	1.7
50	34.5	1.0	2.0
60	41.6	1.0	2.0
70	48.3	2.0	2.0
80	55.2	2.0	2.0
90	62.1	3.0	2.0
100	69.1	4.0	2.0

Table 3.5. Actual twist contraction for 30 tex

The measured twist contraction in the yarn was different for different counts and it was found to be less than the calculated twist contraction in most cases. The minimum measured twist contraction was found for the 30 tex yarn. This lesser actual twist contraction could be due to the effect of wrapper fibres. Since wrapper fibres are wrapped around the fibre axis, sometimes even with opposing twist they may not open up and consequently prevent the yarn segment from increasing in length without the introduction of an external drafting force. Actual twist contraction was found to be higher than calculated contraction at lower untwisting levels. This could be because fibres have the opportunity to take up straighter paths under the tension of the dead weight.

3.4.4 Dynamic rig

The behaviour of a yarn in a dynamic situation might be different from the static situation, because in continuous untwisting and drafting the yarn is constantly under a load which is capable of drafting the fibres apart. In the case of the static rig it was observed that the first place to start drafting, keeps getting drafted, but that will not necessarily be the case in a dynamic situation where new yarn and new twist is continuously entering the processing zone. The point at which a yarn section will begin to draft is primarily determined by the twist factor, which can be expected to vary roughly as $\frac{1}{\text{tex}}$ [155], i.e. the thin places will have significantly higher twist factors. It was also expected that thick places in a yarn being untwisted under tension will be drafted before thin places as they have less twist to lock the fibres compared to neighbouring thin places. Due to tension in the yarn caused by the drafting force the resulting torque should cause the remaining twist to re distribute with thin places having higher twist factors. So as the thick places draft the twist will tend to flow from neighbouring yarn segments so other regions will get closer to the point where they can draft. As a result the spot in the yarn which will be drafted may keep changing. It was therefore important to investigate the behaviour of yarn in a dynamic situation because if this technique is to be applied industrially then it would be on a machine where yarn is continuously untwisted and drafted. For this purpose a dynamic rig was used which is shown in Figure 3.2.

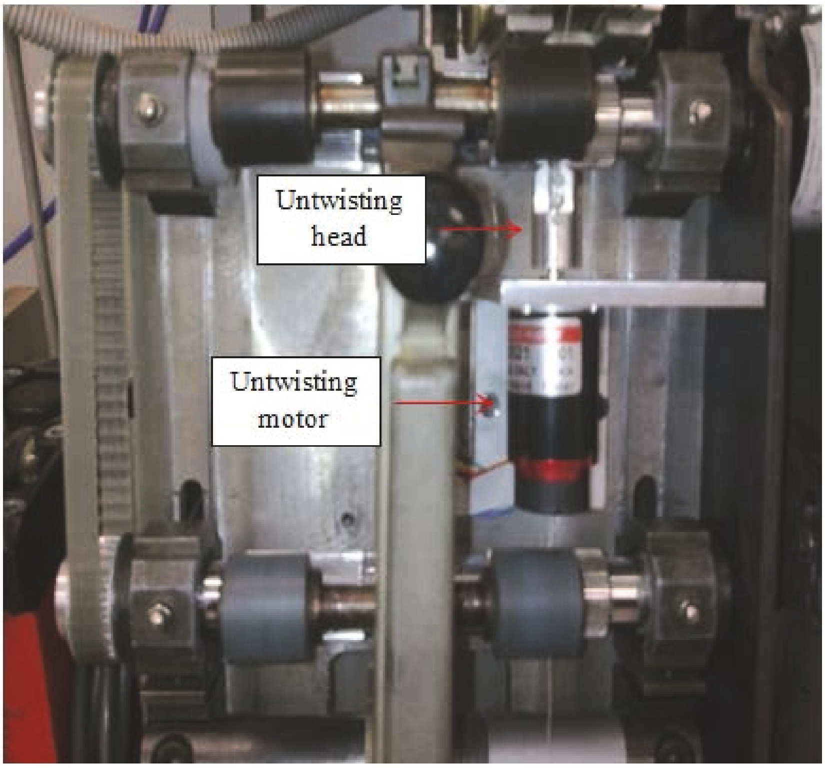


Figure 3.2. Apparatus for drafting against untwisting with mechanical untwisting device

The dynamic rig consists of a standard winding unit fitted with an untwisting and drafting mechanism and sensors to monitor yarn irregularity before and after treatment. In previous studies an air nozzle was used for untwisting, but the problem with an air nozzle was that its level of untwisting was uncertain and could not be easily controlled. A mechanism that gave a known and controllable level of untwisting of the yarn was needed. Yarn was passed through the untwisting and drafting mechanism and its evenness was measured before and after treatment in the drafting zone. Drafting was carried out using two pairs of rollers, with a nip to nip spacing of 10 cm. The aim was to have the twist in the yarn to give fibre control during drafting.

3.4.5 Untwisting mechanism

Untwisting with an air jet is potentially capable of much higher speeds and reduced wear relative to a mechanical untwister and may provide additional wrapping of loose fibres, but the amount of untwisting imparted by an air jet is uncertain and not easily controlled. It depends upon several factors such as fibre type, yarn linear density, yarn tension, twist level, air pressure and degree of set. But here a precise mechanism for untwisting was required that could impart a controlled amount of untwisting to the yarn. For this purpose a mechanical untwister was used. A schematic of the untwisting mechanism is shown in Figure 3.3.

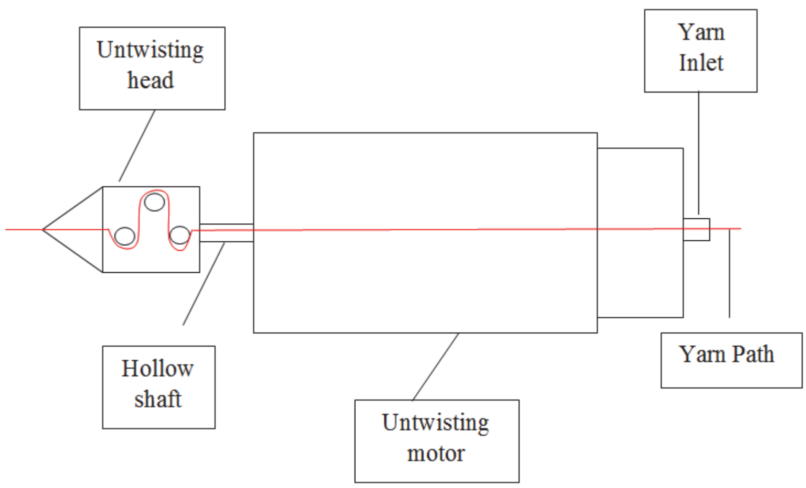


Figure 3.3. Schematic of untwisting motor

The key requirements were to have a high-speed system that nevertheless imparted a known amount of twist to the yarn. The solution was to use a high-speed DC motor with a hollow rotor and light-weight gripping mechanism. The yarn was made to pass through three horizontal ceramic pins held in an aluminium casing which prevented twist propagating past the pins when the yarn was under the tension imposed by drafting during untwisting. The casing was designed so that one end of the second and third pins was exposed so that the yarn could be easily looped over the central pin. The casing, with pins, was then dynamically balanced. The motor contained an in-built shaft-encoder so that the speed could be synchronised with the front roller of the drafting system, using a second encoder on one of the front rollers. The level of untwisting could be controlled according to twist level in the yarn. The untwisting motor and three pin head is shown in Figure 3.4.

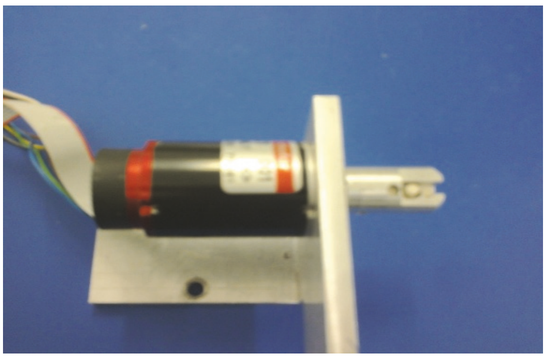


Figure 3.4. Untwisting motor and three pin head

The maximum speed that the untwisting motor could achieve was about 8000 rpm. The rotation speed of the motor depended upon the turns per metre to be removed. The highest twist level yarn used in these experiments was 893 turns per metre for the 17 tex yarns. Untwisting this yarn to 180 % untwisting level means that the untwisting motor will have to make 1607 revolutions for every metre of yarn being processed. Since the untwisting motor could not exceed 8000 rpm, the maximum delivery speed that could be achieved for the extreme was 0.5 metres per min. Although for lower untwisting levels the yarns could be processed at higher delivery speeds all the yarns were processed at same speed to eliminate the effect of processing speed on the results.

3.4.6 Evenness measurement

As discussed above, the key requirement for improved tenacity is improved evenness. In principle, yarns could have been produced under different untwisting and drafting conditions and then tested off-line, but here online evenness measurement was chosen. Firstly this was because it was not possible to wind the yarn on a package like a standard winding unit which has a variation in take up speed of the yarn due to the varying point of contact of take up tube with the winding drum. Normally this is accommodated by small changes in speed of withdrawal of the yarn from the bobbin. However, the solid nip and fixed speed of the inserted drafting unit meant this was not possible. Also the length of the path, the yarn followed, varied when the yarn moved across the width of the drum. When the yarn moved to the extreme ends of the drum the length of the yarn increased and when in the centre, the length reduced. This change in path length caused the yarn to get slack and tight, and therefore caused a tension variation of the yarn, which was also not acceptable here. Apart from these limitations there were some advantages too, which caused this mechanism to be used instead of standard commercial evenness testers. A great potential advantage of monitoring yarn thickness on-line is that the yarn profile before and after treatment can be compared so that the effect on particular thick and thin regions can be compared.

Existing, commercially available, optical and capacitive sensors cannot be used, however, because they filter the sensor signal to remove long-term variations. This, so-called AC coupling, overcomes problems due to drift and contamination build-up but does not allow an absolute thickness or linear density to be determined. The solution was to use two special high-resolution capacitive sensors placed before and after the treatment zone. The sensors are shown in Figure 3.5. These sensors had a resolution of 2 mm in the direction of yarn travel and a frequency response of 20 kHz or more. The sensors output a voltage that is proportional to the mass of the material even at very low speeds [160].

However, there were potential problems with these special sensors which require some care and monitoring to produce accurate and repeatable measurements. The sensor empty signal did not remain zero but drifted depending on the ambient conditions or a build-up of dust and dirt. The drift in their output voltage is mostly due to temperature and humidity changes. To ensure that the results of the tests were accurate, the empty sensor readings were taken at the beginning and end of each test. If the values varied significantly then the particular measurement was rejected.

During running of yarn through the system the yarn moved sideways as it followed the path introduced by grooves in the drum. Due to this sideways movement the yarn could push the brass plates in the sensors. As the sensors were very sensitive, even a slight movement of these plates could significantly affect the results. To avoid these errors ceramic guides were attached on top of both the sensors. So that if some sideways movement occurred in the yarn, its effect was absorbed by the yarn guides and could not affect the sensing gap.

3.4.7 Data acquisition

A computer program was developed to monitor the effect of processing on thick and thin places in yarn. At the end of every trial the programme also calculated the overall evenness of the yarn segment before and after the processing.

This program consisted of three sub program which were run in sequence for complete acquisition and manipulation of the data.

The first program was "Display sensor values". This program took readings from both sensors at 1 milliseconds intervals and displayed the values on the screen after each block of "loop" points. The programme was used to help set the sensors to have empty values (i.e. no yarn present) between +0.5 V and preferably +0.1 V. After the sensors were adjusted their values were monitored for some time as they tend to drift more in the minutes immediately after the adjustment.

The second program was "Take yarn data". This command takes readings from both sensors with the yarn removed. Then the yarn is inserted and data taking is initiated. The program then takes a single reading from each sensor each time it detects a change in the encoder counter. The signals and position along the yarn are stored. Data taking continues until it is stopped. The data is then output to a file. Then the yarn is removed and empty sensor values are taken and included in the output file. During data taking the recent sensor values are displayed on the front panel. After data taking is complete the complete set of values is displayed.

The third part program was "Output file conversion". This programme was designed to take data from the output file and prepare it for subsequent analysis by subtracting the mean sensor empty signal. It also calculates the yarn evenness (CV %) measured by the two sensors for just the yarn that passes through both sensors, normalises the data of the two sensors to the same mean value and overlays the two signals. The capacitive sensors used for evenness measurement are shown in Figure 3.5.

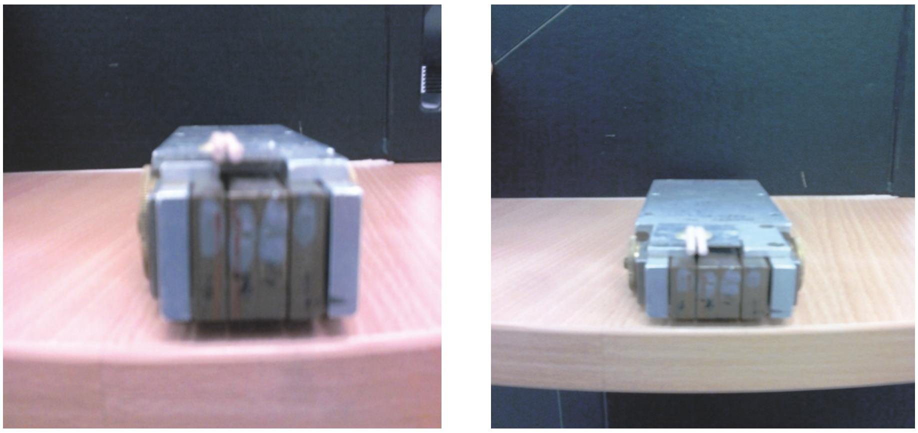


Figure 3.5. Capacitive sensors for evenness measurement

To minimise the chances of errors due to difference between the two sensors it was very important that the drift in both the sensors (due to dust and ambient conditions) does not influence the results. Therefore before every test yarns were passed through the two sensors without any untwisting and drafting. The output signals from both the sensors were overlayed for comparison and it was found that output signals from the two sensors overlapped each other, which suggests that both the sensors were measuring the evenness with same sensitivity. A representative section of output signals for 17 tex yarn is shown in Figure 3.6.

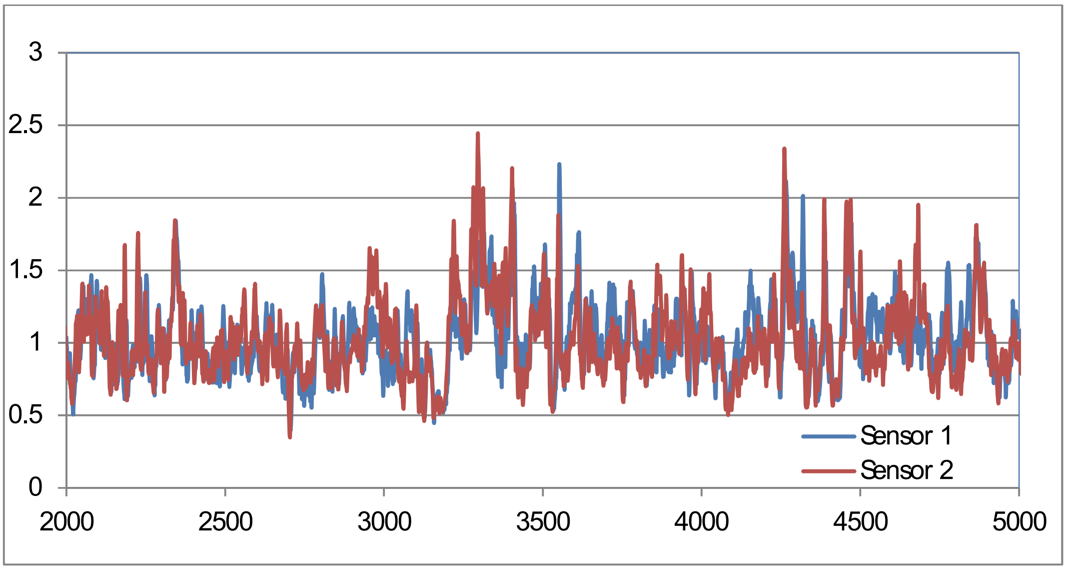


Figure 3.6. Section of overlayed yarn for 17 tex yarn for sensors calibration

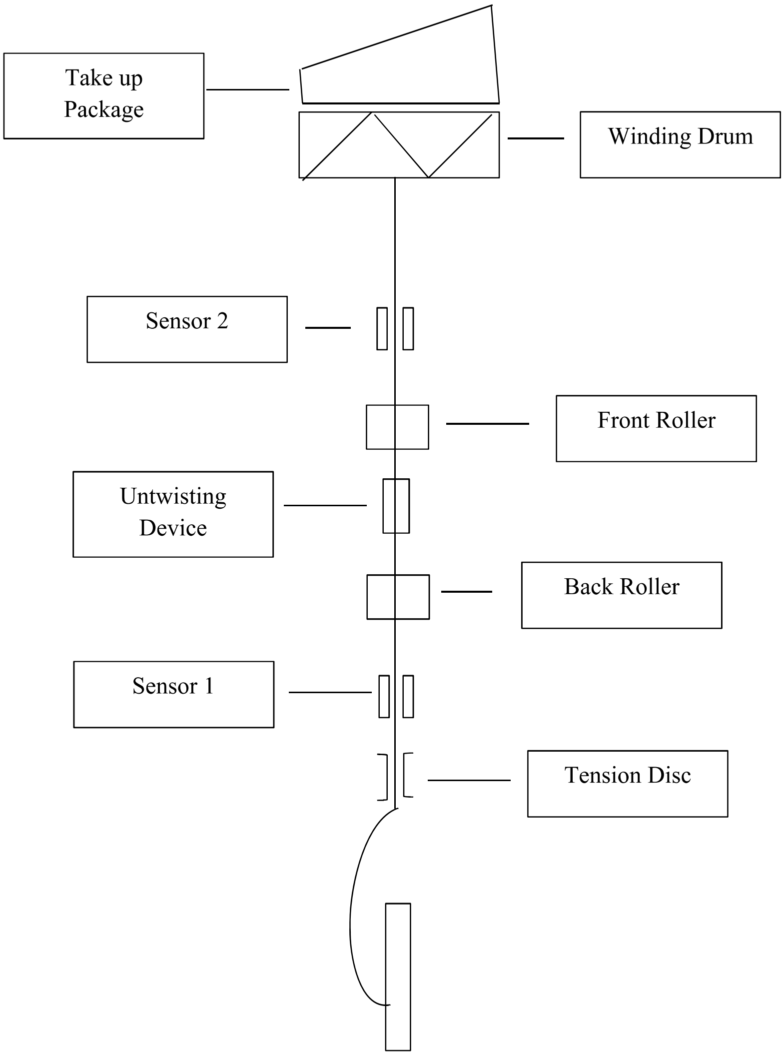


Figure 3.7. Schematic of untwisting and drafting system and sensors.

A schematic diagram of the yarn path through the sensing and processing zone is shown in Figure 3.7. A yarn package was placed on the bobbin holder of the winder. After passing through a yarn tensioner the yarn passed through the first sensor which measured its linear density. From there the yarn was taken up by the back pair of drafting rollers and through the untwisting motor. After passing through the ceramic pins of the untwisting device the yarn entered the front pair of rollers which are running at a higher speed than back rollers thereby causing drafting to take place in the yarn segment. This processed yarn then passed through the second sensor which measured its post processing linear density and was then wound on to a take up tube via the winding drum. Untwisting and drafting took place simultaneously in the yarn. The untwisting motor was made to run at different speeds according to the level of untwisting to be imparted to the yarn during this untwisting and drafting process.

3.5 Results & discussion

Yarn tenacity and its dependence on the level of untwisting of yarn was the main yarn characteristic targeted in this study. It was examined under static and dynamic conditions. The tenacity values for 17, 25 and 30 tex yarns, tested using the static method, are given in Figures 3.8, 3.9 and 3.10 respectively. The negative sign with the values indicates over-untwisting of the yarn. The original twist factor (tpm*√ tex) i.e. twist factor of the parent yarn was around 3700 to 3800 for all three yarns.

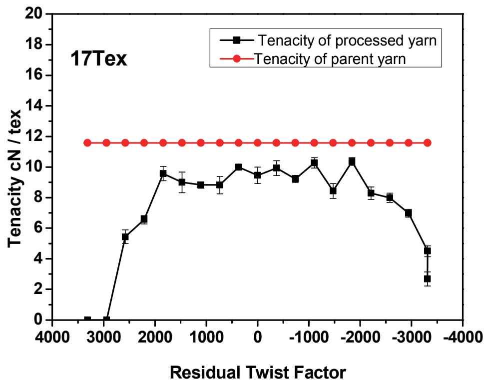


Figure 3.8. Tenacity of 17 tex yarn on static rig

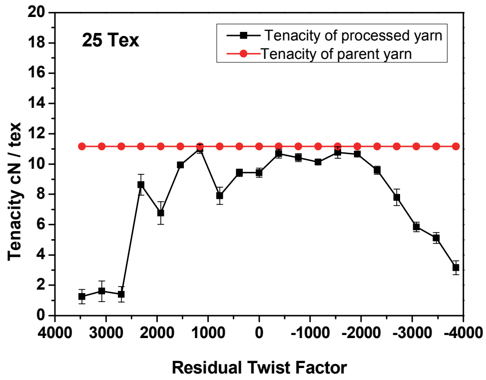


Figure 3.9. Tenacity of 25 tex yarn on static rig

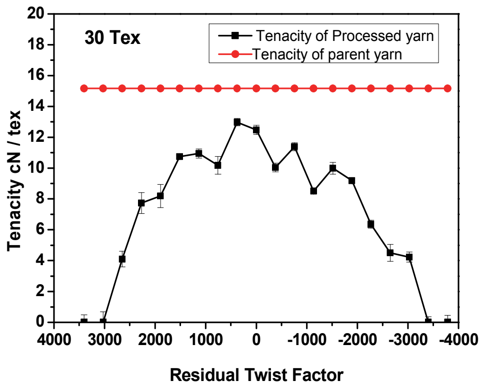


Figure 3.10. Tenacity of 30 tex yarn on static rig

Yarn tenacity is plotted against residual twist factor (i.e. twist factor of the yarn after removing twist in intervals of 10 %). It can be seen that the tenacity of the processed yarn never reaches the tenacity of the parent yarn (except for a few points in the case of the 25 tex yarn). A drop in tenacity was expected because of the reduced twist per metre in the yarn. The yarns were drafted by 10 % after untwisting but when they were retwisted, the same number of turns was put back in the yarn, as were removed. However, since the length has now increased by 10% the net turns/m in the yarn is reduced.

Although yarns had different parent yarn tenacities (with coarser yarns having higher tenacity values), but same drafting behaviour was exhibited by all counts. At the initial untwisting levels, i.e. till around a twist factor of 3000 and above, the fibres are held too strongly and do not allow drafting to take place. As the level of untwisting increases the fibres are loosened, allowing them to be drafted. At around a residual twist factor of 2500 the yarns started getting drafted and they kept getting drafted up to the same value in the opposite direction. Beyond twist factor of -2500 and below 2500 yarns did not draft in most of the cases and they snapped apart if pulled excessively. In some cases the yarns did survive drafting at higher levels of over untwisting but the tenacity values of the resultant yarns were very low which indicates that fibres were not loose enough to be properly drafted, rather they were damaged by the drafting force applied to them. However the force required for conducting drafting could be different at different untwisting levels. Higher the amount of residual twist in the yarn higher would be the force required to draft the fibres apart, as at higher twist factors fibres are held tightly by twist present in yarn.

When a semi twisted strand of fibres is exposed to a drafting force some fibres that are loose enough to slip past each other, allow drafting of the yarn, whereas other fibres which are locked by the twist are broken or damaged. This explains the shape of graph where the tenacity of resultant yarn increases as the level of untwisting increases.

Although draft-ability of yarns increased with untwisting, one interesting behaviour was exhibited by all the yarn counts. The highest tenacity values were recorded at residual twist factors of about 1000 and -1000, that is when there was some twist present in the yarn. This can be explained by the presence of some twist in the yarn providing fibre control during drafting, which helps maintain yarn evenness. This better tenacity results from the better yarn evenness, as discussed earlier.

The results shown here in graphs are for a draft of 1.10, but as discussed earlier all the drafting did not take place during the drafting step. Some drafting took place during the retwisting stage when the yarn tried to contract due to twist insertion but since it was clamped at both ends so it could not contract which caused the fibres to be drafted.

In the second part of the experiment the yarns were processed on the dynamic rig, where they were continuously untwisted, for a range of twist levels differing in steps of 10 % and given a draft of 1.10. All three counts were untwisted from 10 % to 150 %, and their evenness results recorded. The results for the dynamic rig are shown in Figures 3.11, 3.12 and 3.13. All three counts were processed on the dynamic rig and the CV % immediately before and after the processing zone was measured. The negative sign with residual twist factor represents over-untwisting.

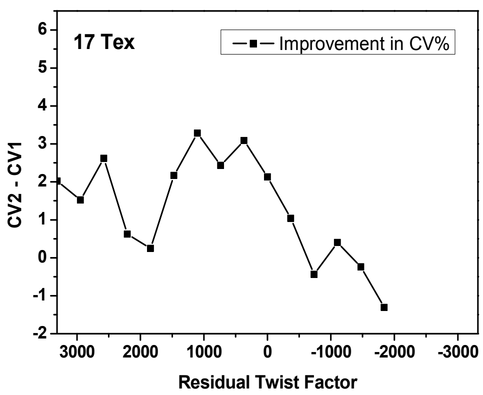


Figure 3.11. Evenness of 17tex yarn on Dynamic rig

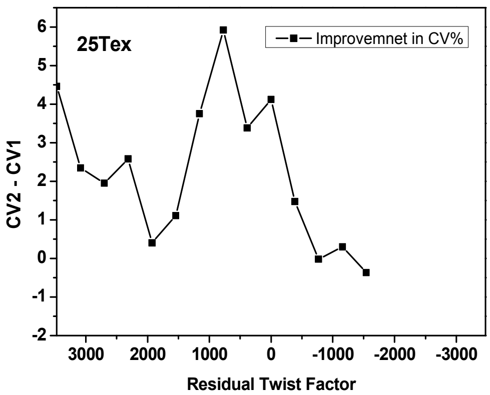


Figure 3.12. Evenness of 25tex yarn on Dynamic rig

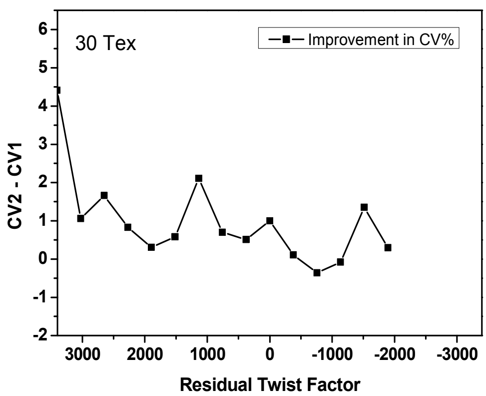


Figure 3.13. Evenness of 30tex yarn on Dynamic rig

The graphs clearly illustrate the dependence of yarn evenness on level of untwisting. Change in CV % of yarn i.e. CV2-CV1 at various levels of untwisting are plotted. Here CV1 is the CV % of the yarn before processing and CV2 is the CV % of the same segment of yarn after processing. For all three counts the coefficient of variation of the processed yarn was similar to or less than the parent yarn at some level of untwisting. Here again, as with the static rig, the presence of twist appeared to help in improving the yarn evenness. Zero twist led to a deterioration in yarn quality in terms of evenness. The presence of some twist in the fibrous strand provided some control in drafting. It is proposed that the presence of some twist in the yarn also helped in improving evenness by locking up the thin places and forcing the drafting to take place in neighbouring thick places with relatively lower twist. Although the results seemed to be following the same pattern for all three counts in some aspects some interesting results were exhibited by the 30 tex. The curve for the change in CV % of the yarn is lower for the 30 tex yarns compared to the finer counts. A possible reason could be that it did not actually get drafted by the 10 %. It was proposed that when the 30 tex yarn was untwisted the yarn may have been gripped so strongly between the ceramic pins of untwisting head due to the capstan effect that it could not be drafted. To test this hypothesis the processed yarns were checked for changes in their linear density and the results are shown in Tables 3.6 to 3.8:

Residual TF	**Processed yarn Count**	**Parent yarn count**	**Actual Draft**
No Untwisting	19.68	19.68	1.00
3405	19.68	19.68	1.00
3027	20.27	19.68	1.03
2648	20.66	19.68	1.05
2270	20.46	19.68	1.04
1892	20.66	19.68	1.05
1513	21.05	19.68	1.07
1135	21.45	19.68	1.09
756	21.64	19.68	1.10
378	21.64	19.68	1.10
0.00	21.45	19.68	1.09
-378	21.45	19.68	1.09
-756	21.64	19.68	1.10
-1135	21.05	19.68	1.07
-1513	21.05	19.68	1.07

Table 3.6. Change in count of processed yarn for 17tex yarn

Residual TF	Processed yarn count	Parent yarn count	Actual Draft
no untwisting	23.60	23.6	1.00
3469	24.07	23.6	1.02
3084	24.78	23.6	1.05
2968	24.30	23.6	1.03
2313	24.54	23.6	1.04
1927	25.01	23.6	1.06
1542	25.72	23.6	1.09
1156	25.72	23.6	1.09
771	25.96	23.6	1.10
385	25.96	23.6	1.10
0.00	25.72	23.6	1.09
-385	25.96	23.6	1.10
-771	25.96	23.6	1.10
-1155	24.78	23.6	1.05
-1540	24.78	23.6	1.05

Table 3.7. Change in count of processed yarn for 25 tex yarn

Residual TF	Processed yarn count	Parent yarn count	Actual Draft
No untwisting	34.70	34.7	1.00
3312	35.94	34.7	1.02
2944	35.04	34.7	1.01
2576	34.35	34.7	0.99
2208	34.35	34.7	0.99
18840	35.74	34.7	1.03
1472	35.04	34.7	1.01
1104	34.70	34.7	1.00
736	35.40	34.7	1.02
368	34.70	34.7	1.00
0.00	35.04	34.7	1.01
-368	35.74	34.7	1.03
-736	35.04	34.7	1.01
-1104	35.39	34.7	1.02
-1472	34.70	34.7	1.00

Table 3.8. Change in count of processed yarn for 30tex yarn

From the tables it can be seen that in case of both 17 and 25 tex yarns actual draft is almost same as theoretical draft, but the count testing of 30 tex yarn revealed that 30 tex yarn did not draft.

3.6 Effect of drafting against untwisting on thick and thin places

For all three counts the best results in terms of yarn evenness were recorded at residual twist factor of -740. Drafting against untwisting has no provision for adding fibres to the yarn segment being processed hence existing thin places in the yarn cannot be removed or made thicker, so the only way the processing could improve the evenness was by reducing the amplitude and frequency of thick places. Therefore the effect of processing on specific thick and thin places in the yarn at the optimum residual twist factor of roughly -740 was examined.

17tex

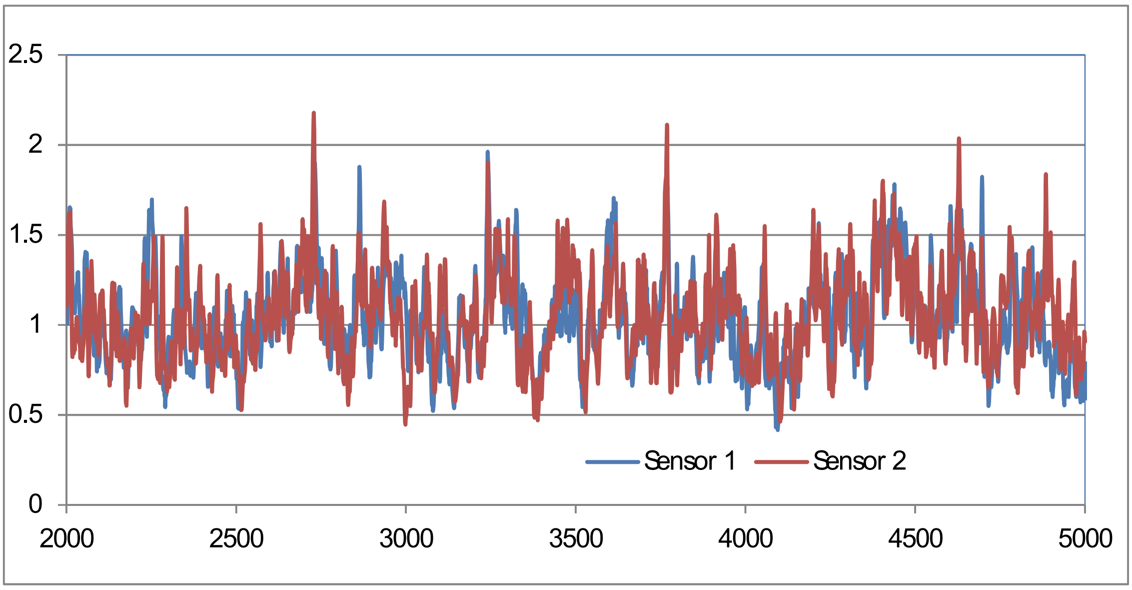


Figure 3.14. Section of overlayed yarn signal for 17 tex yarn

25tex

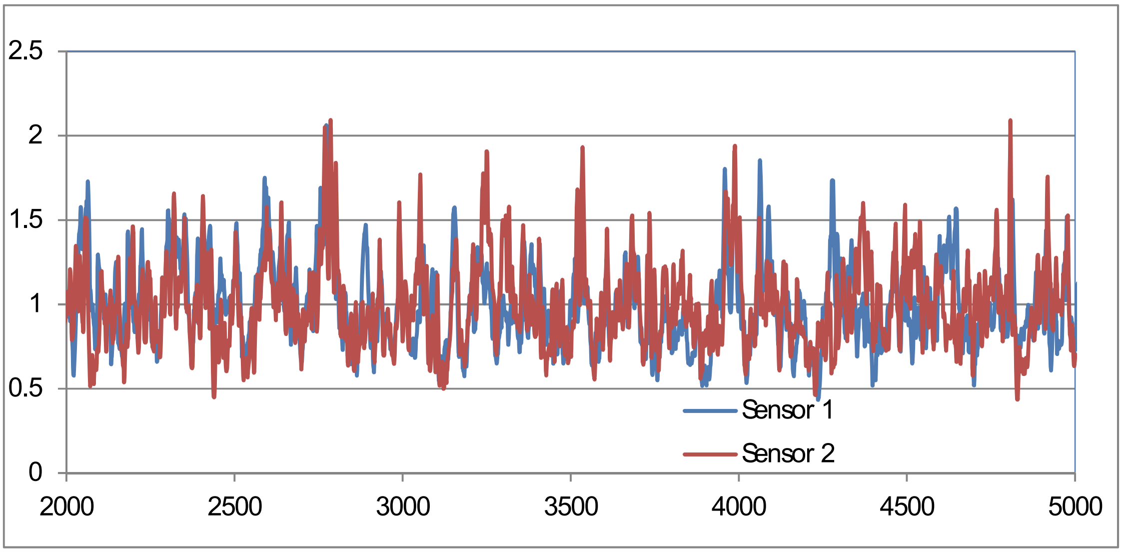


Figure 3.15. Section of overlayed yarn signal for 25 tex yarn

30tex

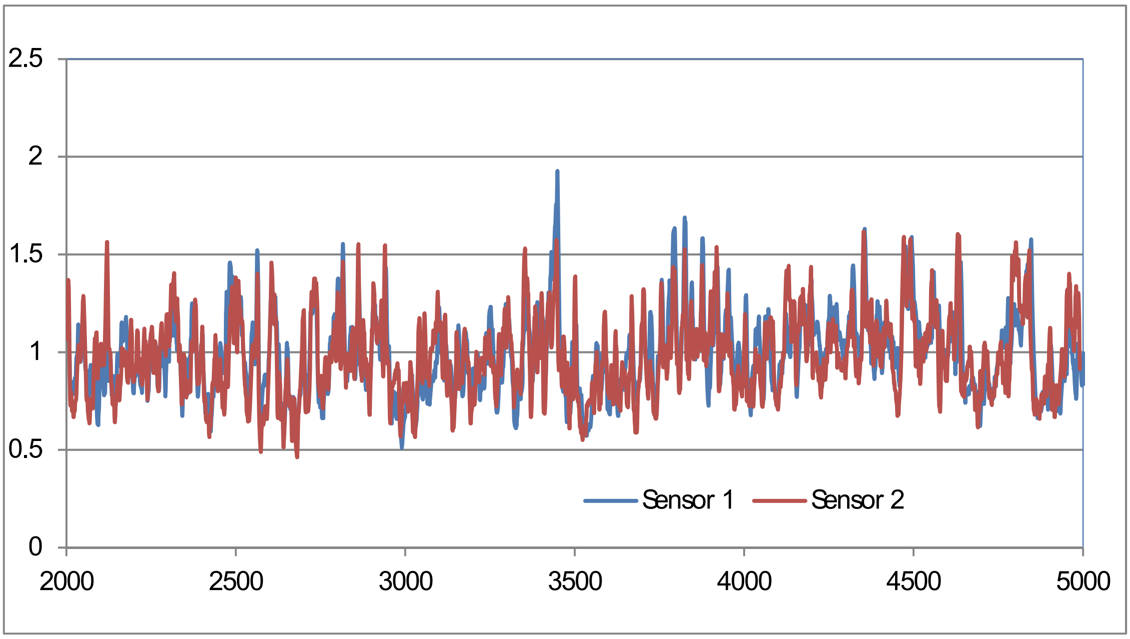


Figure 3.16. Section of overlayed yarn signal for 30tex yarn

A representative section of roughly 3000 points approx. (0.9 metres) along all the yarns at an untwisting level of 120 % are shown in Figures 3.14 to 3.16. The average CV of the processed yarn for all these tests was better than the CV of the parent yarn. The signal from sensor 1 i.e. before processing is in blue the signal from sensor 2 i.e. post processing is in red. It appears that the effect of processing on the thick and thin places is more or less random.

Ideally the drafting should take place in the thick places if yarn evenness is to be improved. On some places the drafting did take place on thick places causing the magnitude of that thick place to reduce, but that is not always the case, as some thick places stayed the same and did not get drafted and in some case even the already thin places were further thinned down, which can be seen from the overlayed yarn section.

3.7 Conclusions

Yarn evenness greatly influences yarn tenacity. A yarn with better evenness can afford to have lower average twist and still have better performance in spinning and in weaving. A post spinning technique “drafting against untwisting” has been investigated, to find if and how this method can be employed for improving yarn evenness. This method has already been demonstrated to be a potential technique for manufacturing finer and low twist yarns. The only way this process can improve yarn evenness is by locking up the thin places and forcing the drafting to take place in a thick place. The decisive factor which dictates, where the drafting occurs, is the twist in the yarn. Therefore yarns were processed at different untwisting levels and the effect of this processing on yarn tenacity and evenness was measured to find the optimum level of untwisting for processing. It was found that fibres start slipping as soon as the yarn goes below twist factor of 2500.

Contrary to the conventional belief, that for better drafting there should be minimum surface contact among the fibres, it was found that best results were achieved when there is some twist present in the yarn. The presence of some twist provides control over fibres.

One of the most important findings was that over untwisting (untwisting beyond 100 % untwisting) always gives better results than the corresponding normal untwisting. These findings seem to explain the results achieved by previous researchers with this work. Khan [127] used an air jet for untwisting and attributed the improved hairiness and tenacity to wrapping of fibres and to improved straightening of fibres. At the start of the processing the yarn is under maximum tension, so the possibility for the air jet to untwist it are at a minimum, but as soon as the yarn starts untwisting it gets slack and it becomes easier to untwist it. Therefore it will keep untwisting the yarn and will take it past 100 % untwisting level, until the torsion in the yarn will stop it from doing so.

During the processing the yarn would have two points with zero twist. The first is when the yarn is going from 100 % initial twist to over untwisting and the second is when the yarn is returning to its original twist direction. This stage with zero twist is the weakest spot in the yarn segment being processed and therefore is most prone to drafting. It can therefore be said that drafting does not necessarily take place in the thick places only. For this system to work for improving evenness, it is very important that a control system be used which does not take the yarn to 100 % untwisting, so that there is always some twist present in the yarn. This twist will distribute itself according to yarn thickness and will lock up the thin places.

Another important finding of this work is that for preferential drafting of thick places, continuous introduction of fresh yarn is very important. During drafting on the static rig it was observed that a place that starts drafting keeps getting drafted. For drafting to take place in another place in the yarn it is important that fresh yarn is continually introduced, so that drafting takes place in a new thick place, which is governed by the level of twist in the yarn.

Apart from explanation of the working principle of this technique, the following conclusions are also drawn from the work:

Rotor spun cotton yarns can be drafted below twist factor of 2500. The force required to draft the fibres can be different for different twist factors but if a fibrous strand with a twist factor of less than 2500 is exposed to a drafting force, the fibres are loose enough to slip past each other or in other words yarn can be drafted.

For 30 tex yarns the yarn could not be drafted as the yarn was gripped very strongly in the pins of the untwisting head due to the Capstan effect. This indicates that for processing of coarser yarns some other mechanism needs to be devised for executing untwisting in the yarn. It could be two small metallic discs pushed against each other by a spring. But the problem with that would be that when the motor will turn at high rpm the plates would tend to move away from each other due to centrifugal force. On the other hand if a very high pressure spring is used its pressure would be too high at low rpm. So a self-compensating mechanism which is capable of maintaining the gripping force of the untwisting head is needed. This can be achieved by attaching a small dead weight across one of the gripping discs so that when the rpm of the motor increases the dead weight tends to push outwards, thereby increasing the gripping force on the discs.

CHAPTER 4

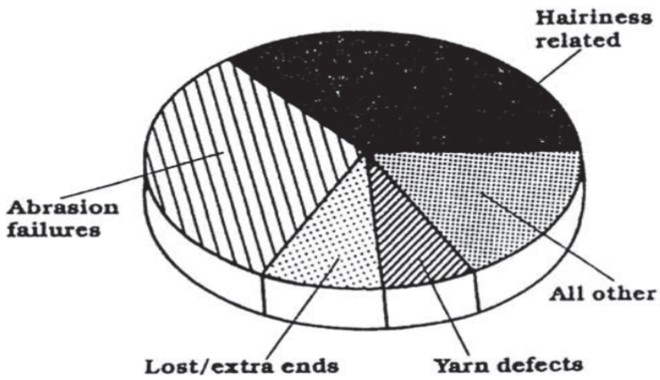
Improved Incorporation of Fibres for More Abrasion Resistant Yarns Using an Air Jet

4.1 Introduction

It has been fairly well established that to improve the yarn strength its evenness should be improved, or at least not be worsened. The yarn evenness can be improved in only two ways, either by making thin places thicker or by making thick places thinner. The former is not achievable at least with existing spinning machines, as no machine in the existing spinning line has the ability to add fibres to the strand. So the only other option is to thin down the thicker places, which can be achieved by preferential drafting of thick places. This is practically done in drawing by the use of an auto-leveller. It has also been demonstrated by the work of Johnson [28], that significantly more even yarns can be produced by using an auto-leveller at the ring spinning stage, but that system was too complicated and too prone to faults. Another method considered to be able to achieve this preferential drafting of thick places i.e. drafting against untwisting has also been investigated. It was a simpler method but it was found that this could not significantly improve yarn evenness.

Having established that a significant improvement in yarn evenness cannot be easily achieved, it was recognised that for a certain raw material the options for improving yarn quality are very limited, and the aspects of yarn quality which needed to be targeted were those not directly influenced by yarn evenness.

Yarn quality can be thought of in terms of spinning performance and downstream performance. Any modification in yarn structure cannot easily improve yarn spinning performance without improving yarn evenness, as yarn evenness is the biggest determinant of end breakage rate during yarn spinning [140, 146]. Downstream performance on the other hand, which ranges from the yarn performance during winding, to weaving or knitting, to the appearance of the fabric or garment, depends upon quality attributes. Various researchers have worked on the fatigue behaviour of yarns during weaving and have questioned the use of tensile strength as the only decisive factor in deciding the performance of a yarn during weaving [161-165].



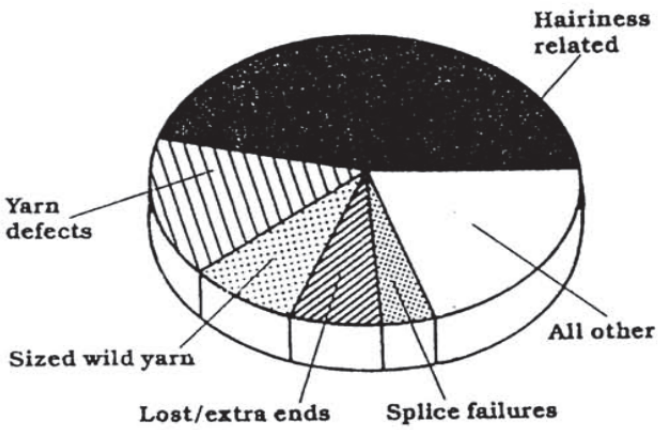


Figure 4.1. Break up of reasons of warp breakage in weaving [166-168]

It can be seen from the Figure 4.1, that for these particular cotton yarns, hairiness and abrasion resistance were the two biggest contributors in the warp breakage, which were responsible for about 60-80 % of the total breaks [166-168]. Their influence is so strong that, at least in short staple spinning, yarns no matter how good in quality, have to be sized before weaving. Both hairiness and lack of abrasion resistance are a result of poor incorporation of the constituent fibres into the yarn structure and are mutually dependent. The fibres that are not firmly attached to the yarn can be abraded from the yarn surface by the action of the droppers, the heald frame, and the reed. These fibres tend to build up in knops on the yarn, which continue to grow until they finally cause the yarn to break [104]. They can also entangle with the protruding fibres of neighbouring yarns and prevent the shed from opening cleanly.

Incorporation of the fibres into the structure depends upon the spinning system used for yarn production. Among existing spinning systems ring spun yarns are considered to have the best structure for efficient utilisation of fibre characteristics and consequent yarn quality, but even ring spun yarns have some short comings. In conventional ring spun yarns many of the surface fibres are bound to the yarn structure only at one end, having much of their length protruding from the yarn surface, causing hairiness. These protruding fibres do not play their role in the load sharing when the yarn is exposed to a breaking force. For a yarn to perform better during spinning and in downstream processing it is very important that all the constituent fibres should play their role in load sharing. Another disadvantage of having these loose surface fibres is that they get caught with the neighbouring yarns which cause the yarns to break. Even after the yarn has been converted into fabric or a garment this process of gradual degradation continues and manifests itself in the form of pilling and excessive hairiness of the fabric surface, which not only diminishes the appearance of the fabric but also reduces its service life.

The gradual degradation in yarn quality, due to lack of abrasion resistance starts at spinning. Despite the fact that the winders are designed to cause minimum abrasion to the yarn, they still increase hairiness. Depending upon various factors such as winding speed, condition of guides, winding tension etc. the hairiness of the yarns was found to increase by up to 55 % as a result of winding [169-171].

The key to manufacture a yarn that is low in hairiness and is resilient to this slow but sure degradation lies in how well the fibres are incorporated and locked into the yarn structure. Some of the recent developments in ring spinning such as compact spinning, siro spinning and solo spinning have addressed these issues. Although compact spinning was mainly targeted at improving the spinning performance of the yarns by reducing the size of the spinning triangle, a positive side effect of this reduction in spinning triangle was that fibres which would otherwise protrude as hairs in conventional ring spun yarns were incorporated into the yarn structure. As a result more fibres contributed to yarn strength. It appears that the abrasion resistance characteristics of compact yarns has not been assessed, however, some researchers have compared the abrasion resistance of fabrics made from compact and conventional ring spun yarns and found that both knitted and woven fabrics made from compact yarns were more abrasion resistant than conventional ring spun yarns [86, 172]. The technique used by siro and solo spinning is quite different from compact spinning. That may be because they were targeted specifically at improving abrasion resistance characteristics of the yarn. They improved the binding of fibres by trapping the constituent fibres into the yarn structure, as a result the yarns produced were found to be significantly more abrasion resistant and less hairy.

In cotton industry compact spinning is widely used because it offers improved spinning performance, reduced hairiness and slightly improved tenacity, but they do not possess enough abrasion resistance to be woven without sizing. Since in cotton yarn industry, sizing is a routine before weaving, therefore any shortcomings in abrasion resistance are compensated. Solo and Sirospun yarns are much more abrasion resistant, but are not widely used in short staple spinning because solo spinning cannot be used for cotton fibres due to finer fibres, whereas siro spinning can be and is sometimes used in cotton industry, but does not offer any cost savings if the yarns have to be sized. Mostly, in cotton spinning, siro spinning is used only when spinning multi coloured yarns, because there, two strands have to be used anyways. For short staple spinning a solution to this problem can be to combine the advantages of the two systems. This has already been attempted by some researchers where the effect of combining solo and siro spinning and siro and compact spinning was investigated. It was found that a further reduction in yarn hairiness can be achieved by combining the two systems [138]. The system developed by combining these two mechanisms will have the spinning geometry of compact spinning i.e. smaller spinning triangle and the improved fibre trapping of Siro and Solospun yarns.

4.2 Fibre migration

Fibre migration, as discussed in the introduction chapter, is defined as variation in fibre radial position within the yarn. It is this fibre migration along with twist that is necessary if the fibres are to be bound together in a yarn. Ideal migration has been proposed to be one in which a fibre migrates regularly and uniformly from outside to the centre of the yarn and then back to outside. However, the key requirement is that fibres are trapped by other fibres close to their ends so that most of their length contributes to yarn strength.

One of the mechanisms which cause fibre migration is the tension differences between fibres at different radial positions in a twisted yarn. During twist, fibres are exposed to different tensions depending on their radial positions. Fibres at the core are under minimum tension due to their shorter fibre paths while fibres on the surface are exposed to the maximum tension. According to the principle of the minimum energy of deformation, fibres lying near the yarn surface will try to migrate into inner zones where the energy is lower. If fibres can move freely past each other, then this will lead to a cyclic interchange of fibre position. If not, then the yarn will be distorted from a straight cylindrical shape.

4.3 Principle and hypothesis

The abrasion mechanism in staple spun yarns can be demonstrated by rubbing a finger and thumb forwards and backwards over a lightly gripped singles yarn. This will cause loose fibres to be rolled into fibre balls and the yarn will eventually break [14]. This same effect takes place on a loom due to rubbing of yarns against loom parts and against neighbouring yarns. Brorens et al. studied the mechanisms of yarn failure due to abrasion and cyclically applied tension using a simulated weaving mechanism, and found that abrasive failure occurs when yarn incrementally drafts apart under the cyclic stresses imposed [173]. When a yarn surface is abraded the fibres that are not bound to the structure tend to rub away making the yarn segment thinner and therefore weaker.

The poor abrasion resistance of yarns arises because when the fibres are fed into the drafting zone they are approximately straight and parallel to each other and, unless there is a mechanism for changing fibre positions, there will only be a low level of migration. A fibre situated initially on the surface of the yarn will have a high probability of lying on the surface for a substantial part of its length and can be readily abraded away from the surface.

The basic rule therefore for improving the abrasion resistance of the yarn is to prevent the constituent fibres from being rubbed away. This has been done by using chemical methods such as corona treatment of cotton fibres, which increases the cohesion among the fibres [174]. The same effect is achieved in sizing where a film of resin is applied to the yarn which not only binds the fibres to the yarn core but also prevents the surface fibres from being exposed to abrasive surfaces by forming a protective layer over the yarn. The main disadvantage of these processes is the use of chemicals which not only increases the cost of manufacture but also these chemicals are hazardous to the environment.

Another method of binding the surface fibres is two folding. In the two folding process due to twisting of yarns about one another and also relative to one another the path of a surface fibre changes and it is regularly trapped between the two yarns [104]. It is this trapping of fibres which keeps them locked in the structure and prevents them from being rubbed away.

This principle of locking the fibres is used in siro and solo spinning as well. In siro spinning two mechanisms are responsible for trapping of fibres. The first is due to alternating twist in the constituent strands. The second is due to fibres ends being caught in the vee of the strands [14]. If there is no twist in the strands relative to each other the fibre trapping will be no different than in ordinary singles yarn. Initially this alternating twist was introduced by using twist blocking rollers and also by using a vertically oscillating roller. However, later it was discovered that even without any intermittent roller the yarns produced were significantly more abrasion resistant. That is because even in the absence of an intermittent roller the level of twist in each strand varied relative to the other, because of inherent variation in strand thickness [14].

Spinning techniques like siro spinning and solo spinning have demonstrated that by securing the fibres more strongly into the yarn structure, the abrasion resistance of the yarns can be significantly improved. However, the ability of these systems to trap the fibres between the strands depends upon the relative rotation of the strand. This effect was demonstrated by Plate and Lappage, who showed that the amount of trapping is proportional only to the alternating strand twist and is independent of the two-fold twist [104]. Similarly in the work by Choi and Kim, it was demonstrated that the average length of surface fibres, between migrations away from the surface, was strongly correlated with the abrasion resistance characteristics of the yarn. The shorter the length the higher the abrasion resistance [175]. The length was determined by how long tracer fibres were visible on the surface. This inward and outward movement will lock surface fibres.

Although the techniques like siro or solo spinning are not being commonly used in cotton spinning, possibly because sizing is routinely used before weaving, the principle involved i.e. securing the fibres into the structure by improved migration, can be employed to manufacture more abrasion resistant yarns. Based on his experience with weavable singles yarn (Solospun), Lappage claimed that the resistance of yarn to abrasive failure depends upon the twist and geometry of fibre paths in the yarn. In ordinary singles worsted yarns, the fibres lie in highly parallel helical paths which are more prone to drafting. In woollen yarns there is a high degree of inter-fibre entanglement, which resists incremental drafting [145].

This phenomenon of locking fibres by getting them entangled with each other is used in “needle punching” of non-woven textiles [176]. By entangling the fibres with each other sufficient strength is achieved to convert a sheet of fibres into a multi-layer fabric. In yarn spinning this entanglement can be seen in terms of improved fibre migration in the yarn. Improving intertwining or fibre migration means that the fibres will be more strongly secured into the yarn structure.

For practical yarn formation in staple spun yarns, some degree of fibre migration is necessary. As Hearle [33] pointed out that in the absence of migration the fibres on the surface will not be wrapped by any other fibres and so will not be able to exert any inward force on the underlying layer of fibres. When such a yarn is exposed to a breaking force the fibres will slip past each other. Furthermore, when such a yarn is exposed to abrasive forces the fibre layers will start peeling off the surface, eventually leading to yarn failure. Therefore it can be concluded that some fibre migration is present in yarn, but if the magnitude of this fibre migration can be enhanced, it can help in improving the binding of fibres to the yarn core. This will lead to yarns that are more abrasion resistant, stronger and less hairy.

4.4 Air jet for improved trapping of surface fibres

Various researchers have demonstrated that processing the yarn through an air jet can help in improving the trapping of surface fibres. They have used an air jet at the ring frame or in post spinning processes like winding and found that a significant improvement in yarn hairiness can be achieved [118-120, 177]. This improvement in yarn hairiness has been attributed to improved trapping of surface fibres. Wang et al. used an air jet immediately after the front delivery roller on the ring frame and found that yarn hairiness can be reduced by 40 % [118]. Similarly Cheng and Li [119] demonstrated that using an air jet on the ring frame can help in reducing yarn hairiness. This improvement in hairiness was attributed to improved trapping of surface fibres which takes place due to loosening and tightening of fibrous structure as it is being processed through a false twister having a swirl in the direction opposite to the direction of yarn twist. Similarly significant improvement in yarn hairiness has been reported by various researchers using an air jet in winding [120, 121, 178].

From the findings of these researchers it can be inferred that using an air jet as a false twister, yarn hairiness can be significantly reduced. One issue, however, with these systems was that in all these systems the air jet was used after the twist insertion. As a result the air jet may not easily modify the arrangement of constituent fibres, as they were already locked in the yarn structure due to twist. This shortcoming can be rectified by using the air jet before the twist insertion stage, when the fibres are in loose state. Therefore it was proposed that if an air jet is inserted into the spinning system before the strand has exited the front roller, it can potentially be more effective in improving the trapping of surface fibres, and will also compact the strand. The yarns thus produced will have the secure fibre binding due to processing through an air jet and also will have the spinning geometry of compact spinning, i.e. a smaller spinning triangle.

Using an air jet for compacting has three advantages. Firstly, it will compact the strand and therefore lead to a smaller spinning triangle. Secondly, it will act as a false twister, because of which the fibrous strand will be first twisted and then untwisted. As a result, the fibres will be first tightened and then loosened. This tightening and loosening of the structure may allow the protruding fibre ends to be tucked into yarn structure. This will provide trapping of surface fibres. Thirdly, the processing of a loose strand of fibres through an air vortex may create an intertwining among fibres which will lead to interlocking. This method has been used commercially in the manufacturing of intermingled filament yarns where a number of filaments are processed through an air nozzle which entangles the filaments with each other binding them together.

4.5 Prototype machinery setup

The machine used for the experiment was a laboratory scale 6 spindle spin-tester, fitted with a custom designed drafting setup.

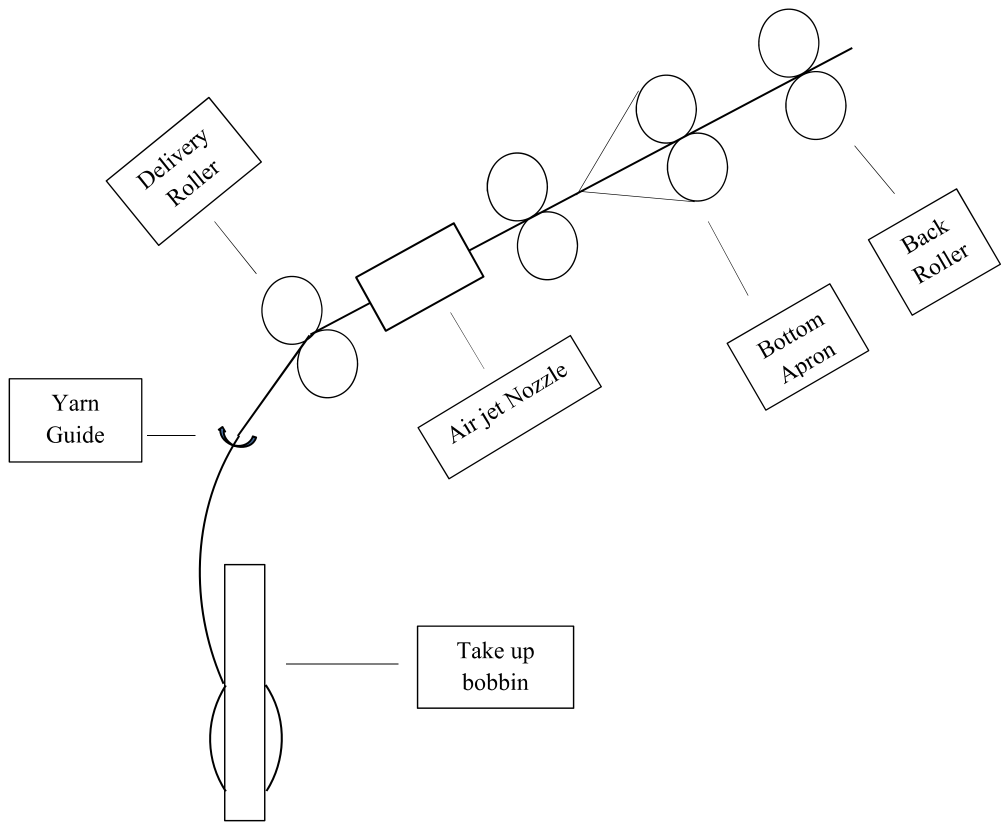


Figure 4.2. Schematic diagram of ring spinning system fitted with air jet nozzle

4.5.1 Drafting assembly

As discussed earlier, for improving the yarn quality, yarn evenness should be improved, or at least should not be worsened. The evenness is very much dependent on the quality of drafting. So it was very important that the processing must not interfere with the drafting process. For good drafting there should be minimal contact between the fibres so that the fibres can slide past each other individually. If the strand is compacted before drafting, the fibres may be drafted in clumps rather than individually. Therefore for this work a specially designed drafting system was used that had an extra processing zone, so that the processing could be carried out after the desired thickness of the strand had been achieved.

A 4 by 4 drafting system was used in which first two zones were just like any other standard apron drafting system. The strand was drafted to the desired thickness in the first two processing zones. Then this drafted strand was passed through the air vortex, to induce the desired entanglement and compaction in the strand. The drafting system used is shown in Figure 4.3.

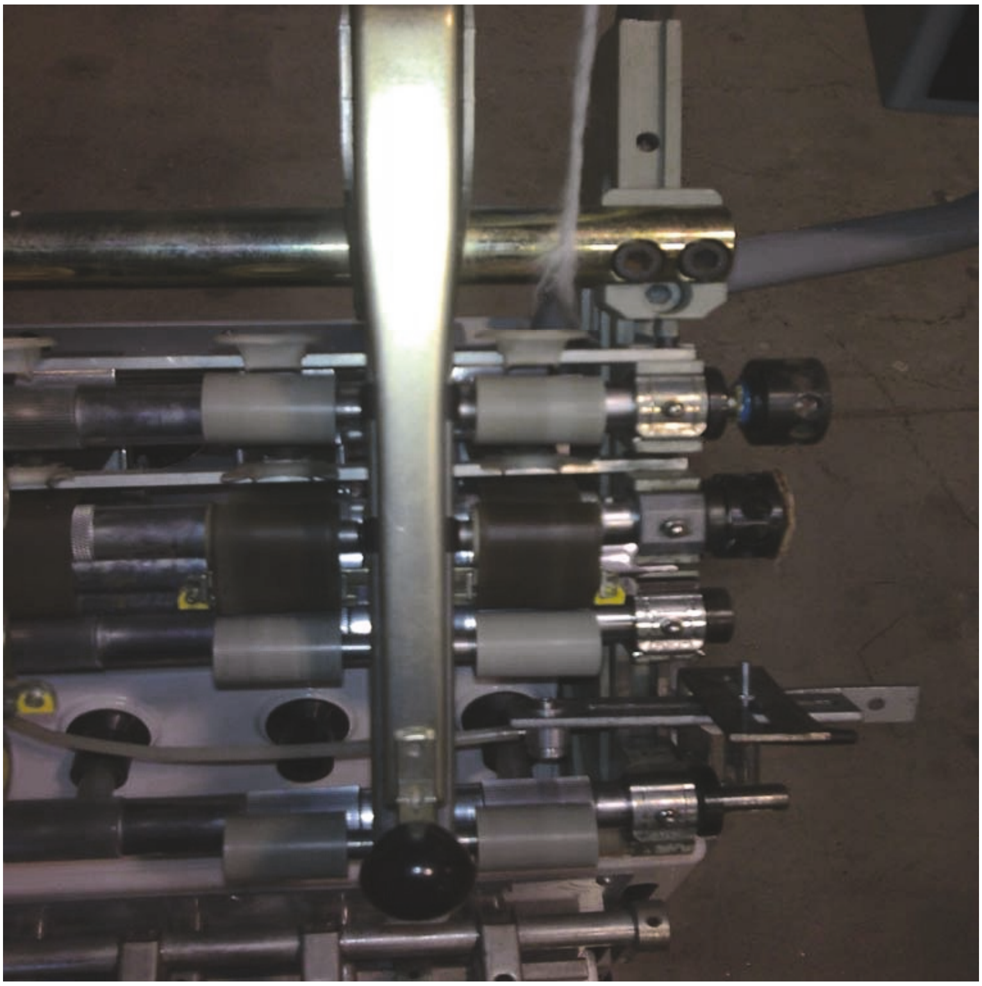


Figure 4.3. Drafting system use for processing

The roving was fed to the drafting system through a roving guide located behind the back roller of the drafting system. After the break draft the material was fed to the aprons where main draft occurred. This fibrous strand with the desired linear density is then fed into the processing zone containing the air jet nozzle. From here the strand is finally delivered through the front roller of the drafting system. The technical details of the drafting system are given in the Table 4.1.

Pairs of drafting rollers	4
Top Roller	Rubber coated
Bottom Roller	Fluted steel roller
Gauge of First drafting zone	3 mm
Gauge of last drafting zone	80 mm
Loading of Top delivery roller	Green
Drafting system	SKF
No of pairs of drafting aprons	1
Spacer colour	Yellow
Break Draft	1.20

Table 4.1. Technical details of the drafting system

4.5.2 Draft distribution among drafting zones

The draft distribution among the first two zones was the same as a standard three roller drafting system i.e. a break draft of 1.2 in the first zone and a main draft from 25 – 50 (depending upon the output count) in the main drafting zone. In the extra processing zone a small tension draft was used. Ideally there should have been no draft in the processing zone as the fibres were uncontrolled and introducing any draft at this stage would worsen the yarn evenness, if fibres moved in bursts. The only reason for applying this draft was to keep the strand in line. The strand was twisted by the false twister, which caused it to contract but in the second half of the processing zone i.e. after the nozzle, the strand was untwisted which caused it to become slack. This caused the strand to deviate from its “straight line” path and move sideways. To prevent this from happening a slight tension draft of 1.10 was needed.

4.5.3 Design air-jet nozzle

The simple design of the air jet nozzle used in the work is shown in Figure 4.4.

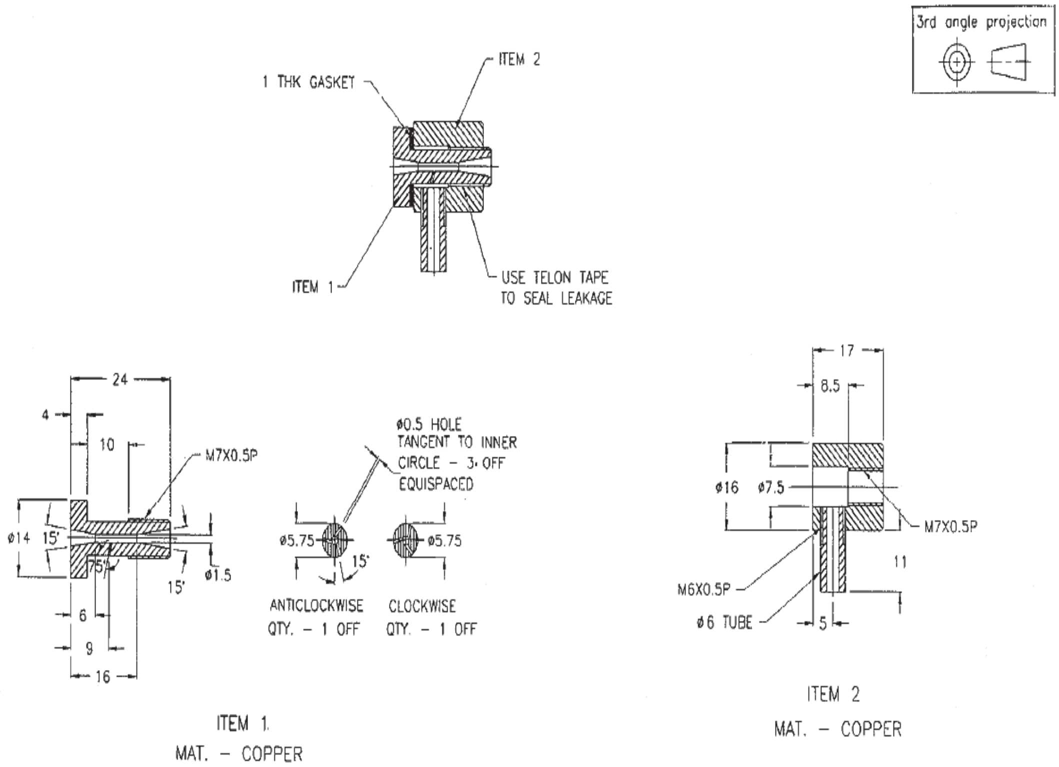


Figure 4.4. Design of nozzle used for air jet

This nozzle was cylindrical with a central hole with the compressed air being fed in perpendicular to this hole. The diameter along the direction of flow gradually increased to create a venturi effect, so that the air exits in that direction only.

4.5.4 Direction of air flow

The nozzle was designed to make sure that air flow in a way that it should exit along the direction of flow of material. This was achieved by creating a winch effect in the design of nozzle. It was important because if the air had flown against the direction of flow of material it would have caused fuzziness in the material and therefore would deteriorate the yarn hairiness.

4.6 Materials & method

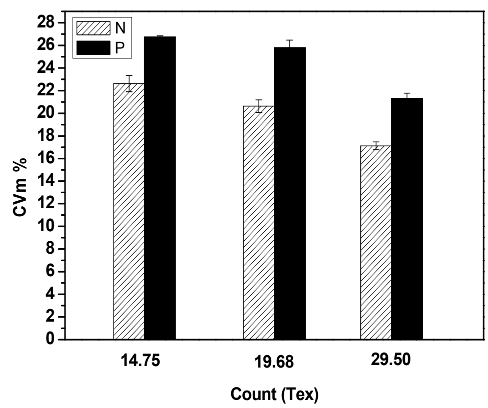
All the yarns were manufactured on the SDL spin tester. To investigate the influence of yarn linear density and twist level on the processing, three counts i.e. 29.50, 19.68 and 14.75 tex were spun at twist factors of 3340, 3820 and 4290. All the yarns were spun at a spindle speed of 7000 rpm, from 430 tex and 57 tpm roving made from 100 % Australian carded cotton of 3.9 mic. and 32 mm staple length.

4.7 Results and discussion

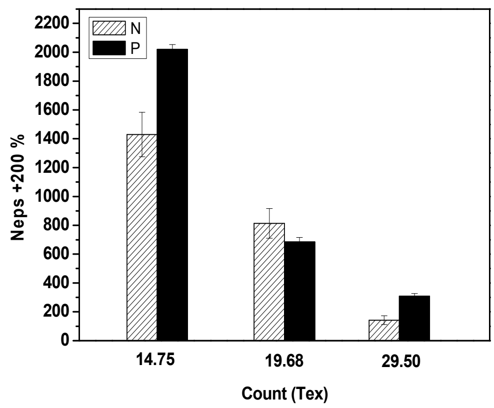
Yarns were tested for improvement in the quality parameters of tenacity, evenness, hairiness and abrasion resistance. All the testing was carried out in standard testing conditions i.e. 20$\pm$2 ^{o}C and 65$\pm$2 % RH. In the tables and graphs the yarns with the Air jet on will be referred to as ‘Processed yarns’ (P) and the yarns without the processing assembly will be referred to as ‘Normal yarns’ (N). The results are given below:

4.7.1 Evenness results

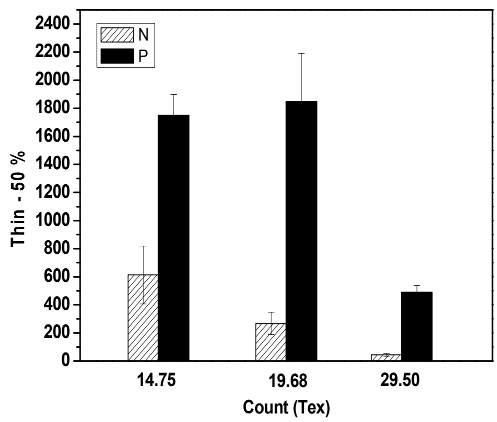
Yarn evenness was tested on a Zellweger Uster Tester III (UT-3). Three samples of 250 metres each were tested.



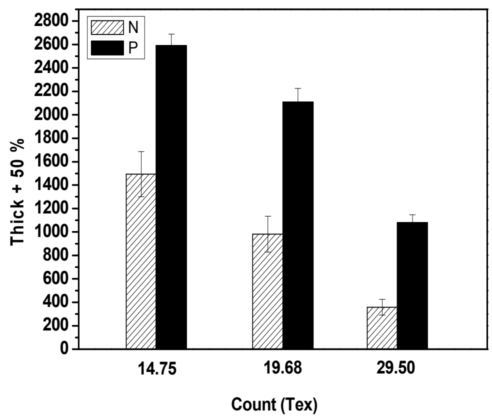
CVm % for three counts



Neps +200 % for three counts



Thin -50 % for three counts



Thick +50 % for three counts

Figure 4.5. Evenness results for various counts

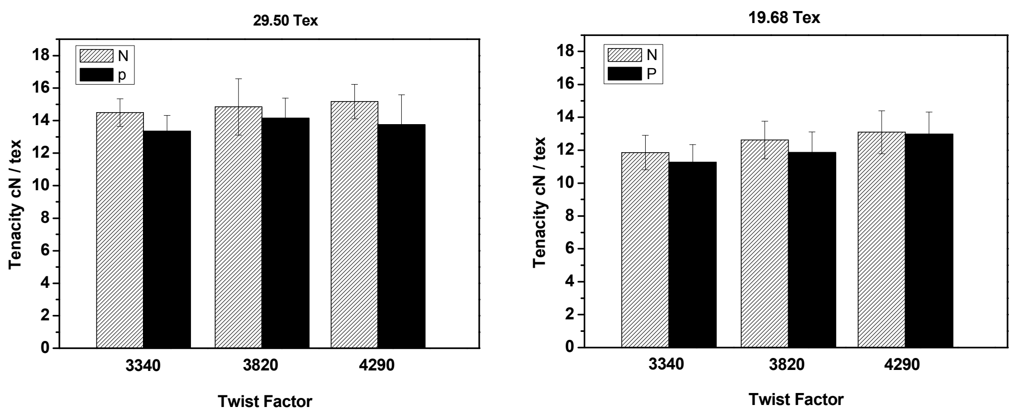
	29.50 tex		**19.68 tex**		**14.75 tex**	
	(N)	**(P)**	**(N)**	**(P)**	**(N)**	**(P)**
U %	13.38	16.66	16.14	20.26	17.64	20.87
Std. Dev.	0.3	0.3	0.4	0.7	0.5	0.1
CVm %	17.12	21.33	20.63	25.79	22.62	26.74
Std. Dev.	0.3	0.4	0.5	0.6	0.7	0.1
Thin-50 %	43	490	266	1848	612	1750
Std. Dev.	10	47	80	343	205	147
Thick+50 %	358	1080	981	2110	1493	2592
Std. Dev.	66	65	152	115	192	96
Neps +200 %	141	309	813	684	1429	2019
Std. Dev.	30	16	102	30	154	34

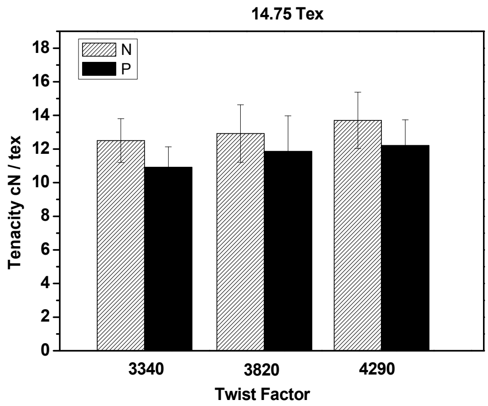
Table 4.2. Evenness results for various counts

Various parameters of yarn evenness are shown in Figure 4.5. All aspects of yarn evenness can be seen to have deteriorated as a result of processing. The CV % of the processed yarn is around 20 % higher. There were several factors that could be responsible for this deterioration in yarn evenness. Firstly, the air jet, could have blown off fibres. However, the linear density of the two yarns was not significantly different. A second factor that could have caused the evenness to deteriorate is the draft in the processing zone. The high inter-fibre contact could lead to bursts of drafting. The effect should be small because the draft was only 1.10, but should show up as a short wavelength drafting wave in the evenness histogram. The most likely cause of this deterioration in evenness is the looping, entanglement and disorientation of fibres in the turbulent airflow of the air jet.

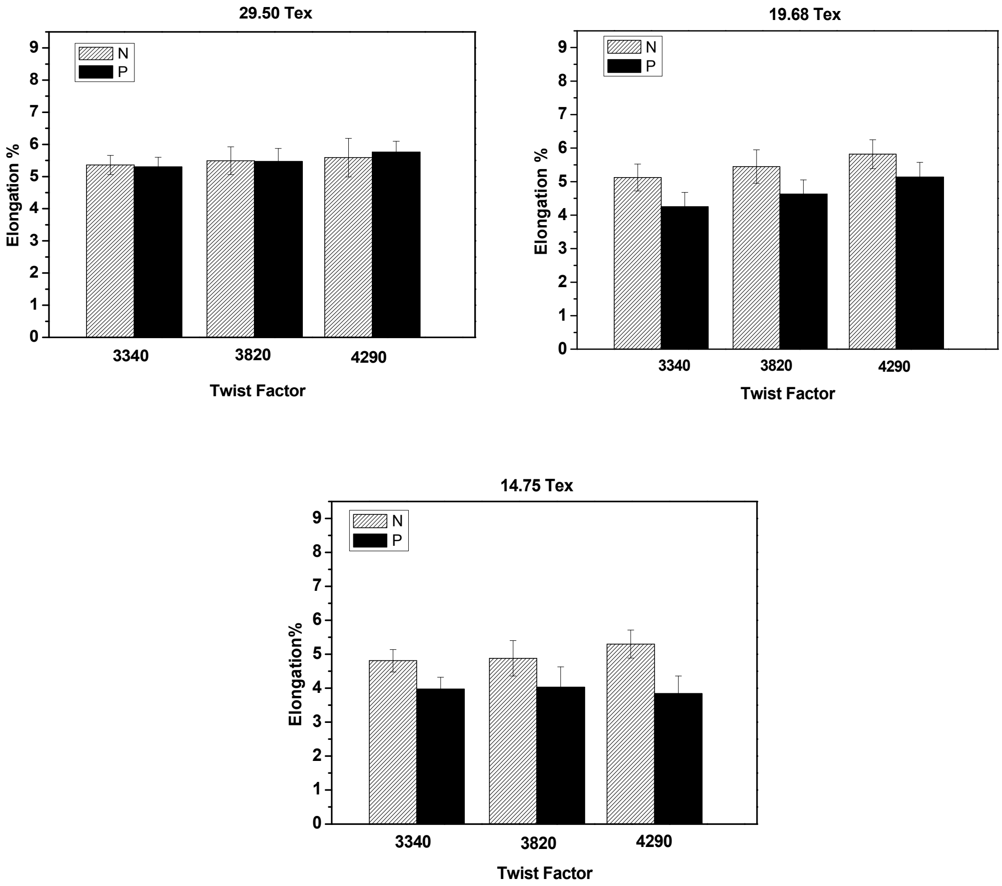
4.7.2 Yarn strength and elongation

The mean yarn tenacity results, determined using 50 tests per sample group at a gauge length of 500 mm, on an Uster Tensorapid-3, are shown in Figure 4.6.

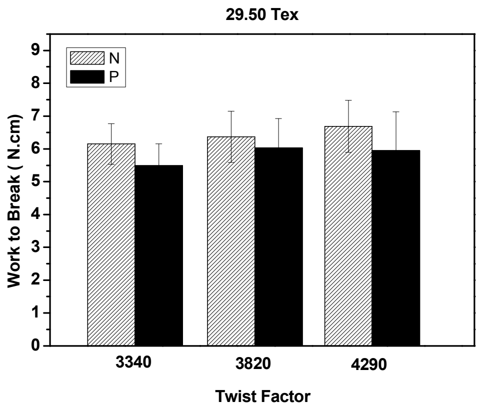


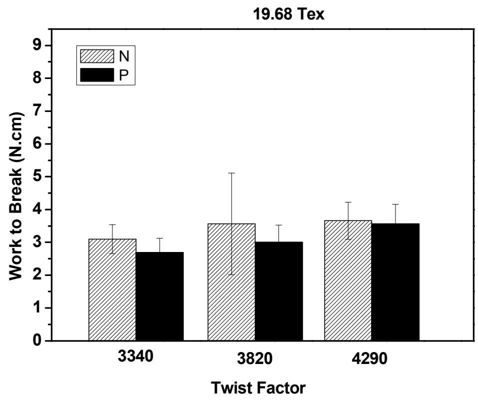


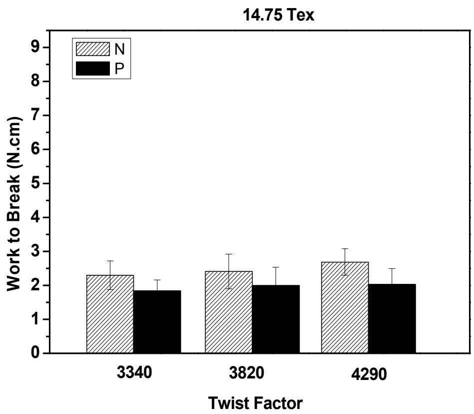
a) Tenacity for three counts at three twist levels



b) Elongation % for three counts at three twist levels







C) Work-to-break for three counts at three twist levels

Figure 4.6. Yarn strength results for various counts

29.50 tex						
	(N)			(P)		
Twist Factor	**Elongation (%)**	**Tenacity (cN/tex)**	**Work-to-break (N.cm)**	**Elongation (%)**	**Tenacity (cN/tex)**	**Work-to-break (N.cm)**
3340	5.36	14.50	6.15	5.30	13.33	5.50
Std. Dev.	0.3	0.8	0.6	0.3	0.9	0.6
3820	5.50	14.85	6.37	5.47	14.15	6.05
Std. Dev.	0.4	1.7	0.7	0.4	1.2	0.8
4290	5.76	15.17	6.70	5.60	13.76	5.95
Std. Dev.	0.3	1.0	0.7	0.6	1.8	1.1

19.68 tex						
	(N)			(P)		
Twist Factor	**Elongation (%)**	**Tenacity (cN/tex)**	**Work-to-break (N.cm)**	**Elongation (%)**	**Tenacity (cN/tex)**	**Work-to-break (N.cm)**
3340	5.12	11.85	3.10	4.25	11.27	2.70
Std. Dev.	0.4	1.0	0.4	0.4	1.0	0.4
3820	5.45	12.62	3.56	4.63	11.87	3.00
Std. Dev.	0.5	1.1	1.5	0.4	1.2	0.5
4290	5.82	13.10	3.66	5.14	13.00	3.56
Std. Dev.	0.4	1.3	0.5	0.4	1.3	0.6

14.75 tex						
	(N)			(P)		
Twist Factor	**Elongation (%)**	**Tenacity (cN/tex)**	**Work-to-break (N.cm)**	**Elongation (%)**	**Tenacity (cN/tex)**	**Work-to-break (N.cm)**
3340	4.80	12.50	2.30	3.97	10.90	1.85
Std. Dev.	0.3	1.3	0.4	0.3	1.2	0.3
3820	4.90	12.92	2.41	4.05	11.85	2.00
Std. Dev.	0.5	1.7	0.5	0.6	2.1	0.5
4290	5.30	13.70	2.70	3.85	12.20	2.03
Std. Dev.	0.4	1.6	0.3	0.5	1.5	0.4

Table 4.3. Yarn strength results for various counts

A drop in all aspects of yarn tenacity can be seen at all twist levels, whereas compacting of the strand was expected to improve yarn strength. Over all yarn tenacity was found to be dropped by around 8 %. This drop in yarn strength can be attributed to the deterioration in yarn evenness. For a given twist level, yarn evenness is the biggest determinant of yarn strength. As the yarn evenness has deteriorated by around 20 % a significant drop in strength was expected. Errors were calculated based on standard deviation and z-test was applied under null hypothesis and the results were found to be statistically significant for all counts at all twist levels.

4.7.3 Hairiness results

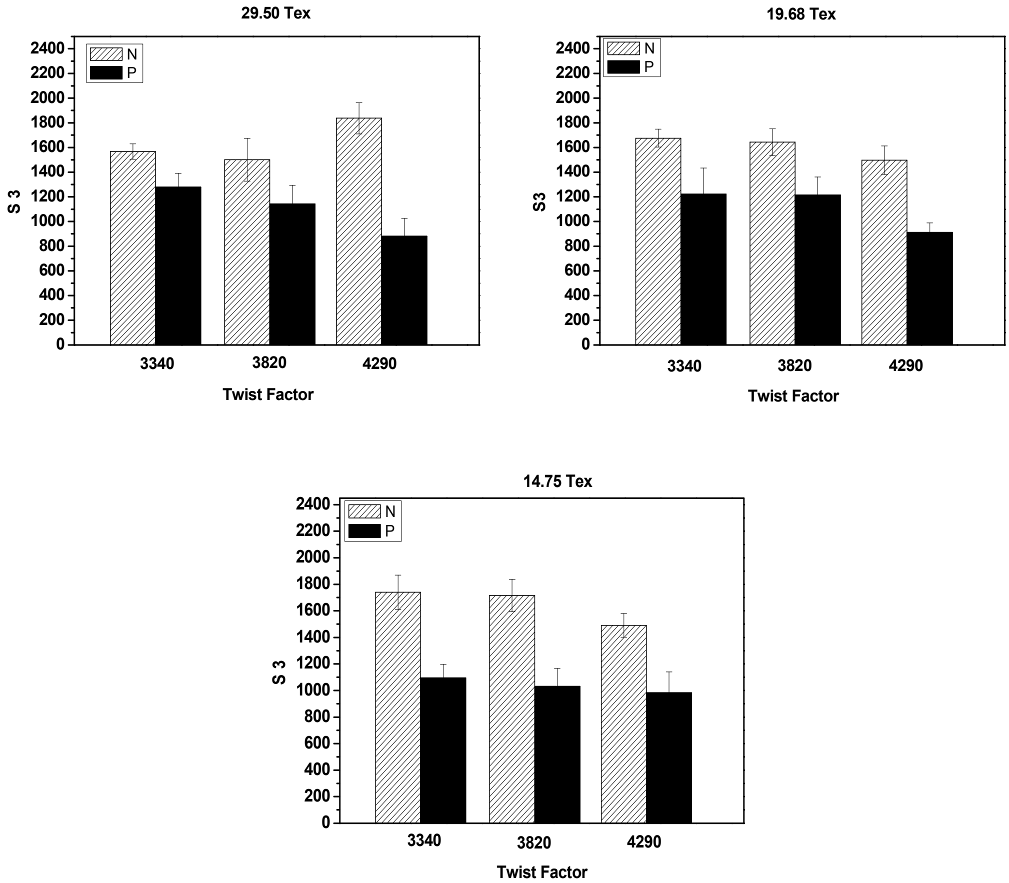


Figure 4.7. Hairiness results (S 3 values) for normal and processed yarns

The S3 (hairs longer than 3 mm) values from a Zweigle Hairiness 565 tester are shown in Figure 4.7. It can be seen that hairiness for all the counts at all twist levels was significantly lower in the processed yarns than in normal yarns. The yarn hairiness was reduced by around 30%. The reduction in yarn hairiness can be attributed to the reduction in spinning triangle and wrapping of loose surface fibres around the yarn core by the air jet.

4.7.4 Abrasion resistance

Generally during the assessment of yarn quality the abrasion resistance of the yarn is not given much importance. This could be because, in short staple spinning, sizing is routine and would compensate any short-comings in abrasion resistance.

The standard testing report of any commercial yarn consignment to a customer includes the quality parameters of strength, hairiness, evenness and elongation. However, these do not guarantee downstream performance if the yarn deteriorates in further processing. In this work abrasion resistance was the most important determinant of success. An improvement in yarn abrasion resistance implies an improvement in incorporation of fibres into the yarn structure and could be used as a measure of likely downstream performance.

The abrasion of yarns involves gradual loosening of surface fibres, which are not securely bound to the yarn core. If the air jet has successfully improved the interlocking of fibres then it should enhance the resistance to abrasion. In previous research a number of different techniques have been used to assess yarn abrasion resistance [173] [179-184]. The basic principle of all these methods has been to rub the yarn over a surface until failure. The number of rubs to break is usually taken as the measure of abrasion resistance.

The different surfaces used have included a knife edge, three pins and a wire. The geometry of the abrading surface, the tension imposed during abrasion, and the speed of oscillation are generally considered key factors that influence the results. Plate pointed out another factor which had a remarkable effect on the measured abrasion resistance of the yarn. He claimed that unless a small traverse is introduced to the yarn during testing, a significant difference between an unweaveable yarn and a yarn with a good weaving performance cannot be recorded by any of the testing methods mentioned above [185]. He attributed this effect to the pushing of a sheath of surface fibres by the traversing mechanism and the formation of fibre pills behind the abrasive mechanism. A yarn abrasion testing rig was designed taking these factors into consideration.

4.7.4.1 Abrasion resistance on manual abrasion resistance tester

An abrasion tester was designed that was flexible in terms of length of abrasion zone, tension applied on samples and abrading surface used. The equipment used is shown in Figure 4.8.

Figure 4.8. Manual abrasion tester

As shown in the Figure 4.8., it was a simple design. The yarn samples can be laid on the top by clamping them at one end and attaching a dead weight on the other end to keep them tensioned. The attached weight could be varied to introduce different tensions on the samples according to the yarn linear density. The abrasion surface was attached to the rack, which had adjusting screws to accommodate any variation in height of abrasive surface. An abrasive surface of any design could be attached to this rack. The rack was installed on a track to keep it in line during running.

A three pin head was used as an abrading surface in this experiment. These pins were of 3 mm diameter steel and attached to a steel support at a centre to centre distance of 5 mm. The yarns were laid down on the top head, passed through the three pins and then the dead weights were attached. A tension of 6.5 mN/tex was used, because this is the maximum tension normally applied to the yarns during weaving [173, 186]. It was observed that when the dead weight was attached to the yarn they started untwisting. This twist removal from the yarns could severely affect the results of the experiment. To prevent this from happening, the yarn end after having the dead weight attached to it was clamped. Ten samples each of processed and normal yarn were installed on the testing rig side by side. Once the setup was completely installed, the rack was moved to and fro by hand. The appearance of yarn after every 100 cycles was recorded to compare the results for normal and processed yarns.

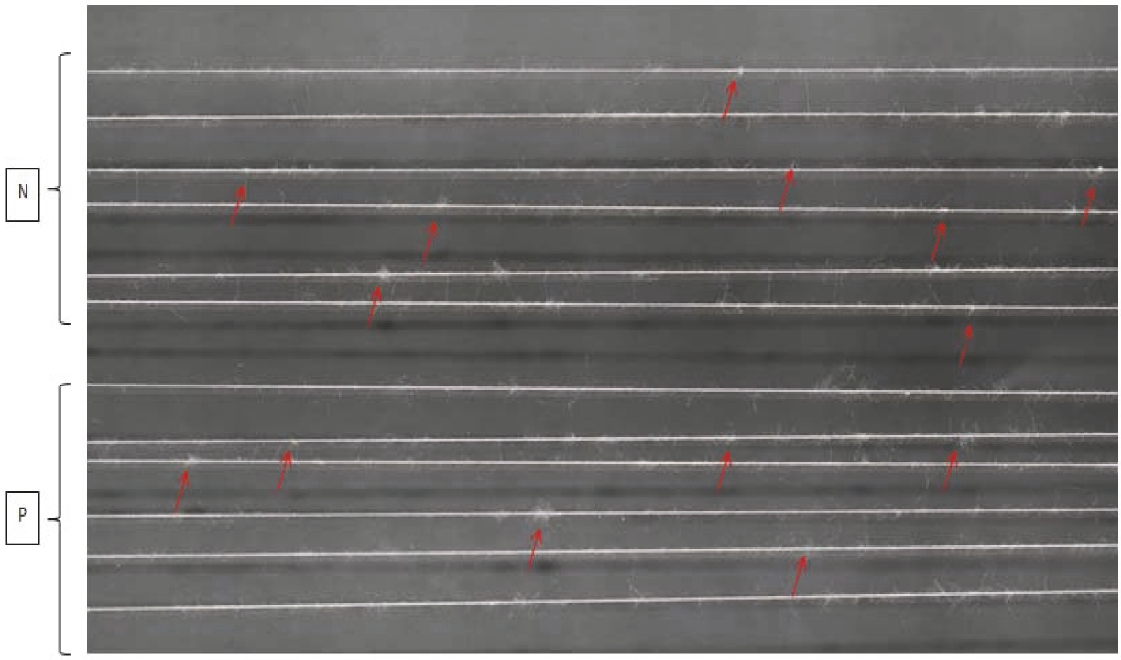


Figure 4.9. Appearance of yarns after 500 cycles

The appearance of yarns after 500 cycles is shown in Figure 4.9. The yarns in the top half of the picture are processed yarns, whereas ones in the bottom half are normal yarns. It can be seen that the deterioration in yarn appearance due to abrasion, after 500 cycles is not much different. This indicates that the system used could not significantly improve the trapping of surface fibres. It did help in improving the yarn hairiness by reducing the width of the emerging strand and also by wrapping of loose surface fibres, but could not improve the binding-in of these fibres.

4.8 Conclusions

A new method for improving the yarn abrasion resistance has been proposed and investigated. The main aim of the work was to improve the surface fibre trapping but it also gave the advantages of a reduced spinning triangle. An air jet has been used to reduce the width of the fibrous strand and bind the surface fibres. It was proposed that due to the swirling action of the air currents the strand will be compacted and the protruding surface fibres will be tucked and locked inside the yarn structure. The aim of the work was to produce a yarn with reduced yarn hairiness and improved binding of surface fibres.

Three yarn counts, 29.50, 19.68 and 14.75 tex each with twist factors of 3340, 3820 and 4290 were manufactured and tested. The yarns produced were tested for evenness, tenacity, hairiness and abrasion resistance. The following results were found:

Yarn hairiness was found to improve by around 20-30 %. This is in agreement with the hypothesis and findings by previous researchers by use of an air jet in jet ring or jet wind.

Yarn evenness was found to have deteriorated by around 20 %. All aspects of yarn evenness were found to be worse. It was proposed that this deterioration in yarn evenness could be due to the tension draft applied during processing and also due to disorientation of fibres. Another factor responsible for this deterioration in evenness could be the nozzle design.

Yarn tenacity was found to drop by around 10 %. The drop in tenacity was more severe at lower twist levels. This drop in tenacity can be attributed to the deterioration in yarn evenness.

A significant improvement in yarn abrasion resistance was not observed. Abrasion resistance was tested on a manual abrasion tester, using three horizontal stainless steel pins. It was found that rate of deterioration in processed yarn was the same as for normal yarn. This suggests that the reduction in yarn hairiness may have been due to wrapping of surface fibres around the yarn core without trapping. For improving the abrasion resistance there has to be a mechanism to lock the surface fibres into the yarn structure.

4.9 Recommendations for future work

The nozzle design might be improved so that it not only compacts the fibrous strand but also creates intermingling among the fibres so that the locking-in of fibres into the yarn structure can be improved. Such improved fibre migration would help improve locking in of surface fibres. This might be achieved by using the kind of nozzle used in manufacturing of intermingled filament yarns.

CHAPTER 5

Improved Incorporation of Fibres for more Abrasion Resistant Yarns by Rubbing of Strands

5.1 Introduction

It has been discussed in detail in previous chapters that the options for improving yarn quality for a certain raw material are very limited. The main area targeted for improvement was the downstream performance of the yarn. It was proposed that if the surface fibres can be bound to the yarn structure more strongly, it will prevent them from being rubbed away and therefore will improve the yarn's abrasion resistance. The first method tried was to use an air jet for improved trapping. It was found that the air jet did help in reducing the yarn hairiness but did not successfully enhance the binding of surface fibres. As a result, the yarn produced did have lower hairiness to start with, but the abrasion resistance was not found to be significantly different from conventional ring spun yarns. Another side effect of this processing was that yarn evenness had deteriorated quite badly. Consequently the yarns produced were inferior in terms of tenacity.

In the light of these findings it was deduced that if the abrasion resistance has to be improved a system needs to be designed that can bind the surface fibres more strongly into the yarn structure not just wraps them around yarn surface, but at the same time does not cause a deterioration in yarn evenness. This locking of fibres into the yarn structure can be achieved by making the fibres pass through lateral layers of fibres, or in other words, by improving fibre migration.

5.2 Principle and hypothesis

In the preparatory processes of yarn spinning mills, twist insertion is seen as a necessary evil. It is seen as necessary to prevent drafting in handling of the sliver but has associated problems such as the limiting of production rate and extra energy consumption (particularly on roving frame). Due to these inherent problems there has always been a quest to find a substitute for twist insertion for developing cohesion among the constituent fibres so that the strands can be conveyed to the next process. In woollen spinning some such substitutes are used. During carding prior to woollen yarn spinning the fibres exit the carding machine in the form of a web. These fibres are collected and divided into strands of fibres called slubbings. These slubbings are collected onto a package and then converted into yarn on a ring frame. To impart enough strength into these slubbings so that they can be unwound on a ring frame, the strands are rubbed between two aprons [187]. This rubbing introduces interlocking among the fibres which inhibits the fibres from slipping. Similarly on a rub rover frame used in the worsted spinning process the drafted strand of fibres is made to pass between two custom designed surfaces which rub against each other [188, 189] . As a result of being rubbed between these surfaces the fibres get entangled. This entanglement creates a structure strong enough to endure the downstream processing tensions, which in this case is the tension during unwinding of roving from bobbin. The rubbing aprons of rub rover are shown in Figure 5.1.

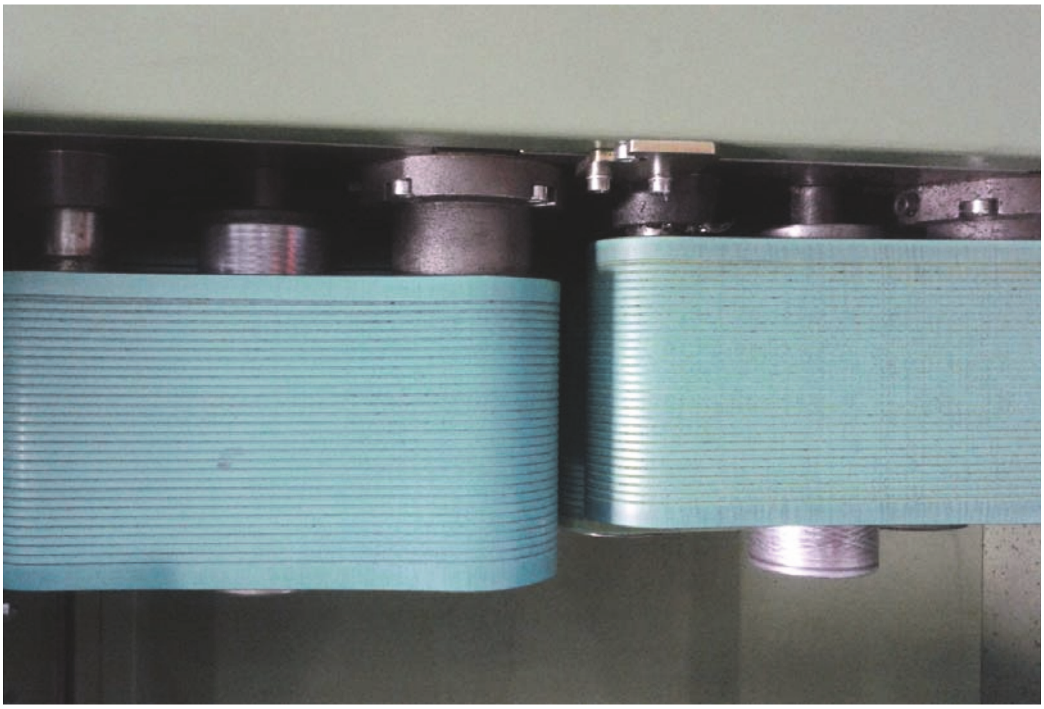


Figure 5.1. Rub rover aprons

It was hypothesised that if the drafted strand of fibres is processed in the same way before twist insertion, i.e. it is rubbed between two suitable surfaces, then interlocking among fibres will occur. This interlocking among fibres will serve three purposes. Firstly, it will trap the surface fibres better, which will reduce yarn hairiness and enhance the abrasion resistance of the yarns. Secondly, as a result of this interlocking, the yarn produced will be stronger and more elastic. Thirdly, it will compact the strand which in turn will reduce the size of spinning triangle and achieve the advantages of compact spinning.

On a ring spinning frame when the drafted strand of fibres emerges from the nip of the front rollers the fibres are more or less perfectly straight and parallel to each other. This straightening of fibres takes place as a result of repeated drafting, which the strand has to undergo in order to achieve the desired thickness. This straightening is a desirable feature for proper drafting of the material. However, as discussed earlier, for practical yarn formation there has to be an intermingling of the fibres for the yarn structure to lock-up. Among existing spinning systems there is no provision to induce this migration among fibres and twist insertion is the main stage where this migration takes place. If a rubbing system like the one discussed above is added to the existing spinning system then it might greatly help in improving yarn quality by improving fibre migration in the yarns.

5.3 Prototype machinery setup

The setup is a ring spinning machine fitted with a customised drafting assembly. This is the same drafting system used in the previous chapter. Here instead of an air nozzle a rubbing assembly has been used. A schematic diagram of the yarn passage through the spin tester fitted with drafting set up and rubbing assembly fitted in the drafting system are shown in Figure 5.2 a and Figure 5.2 b.

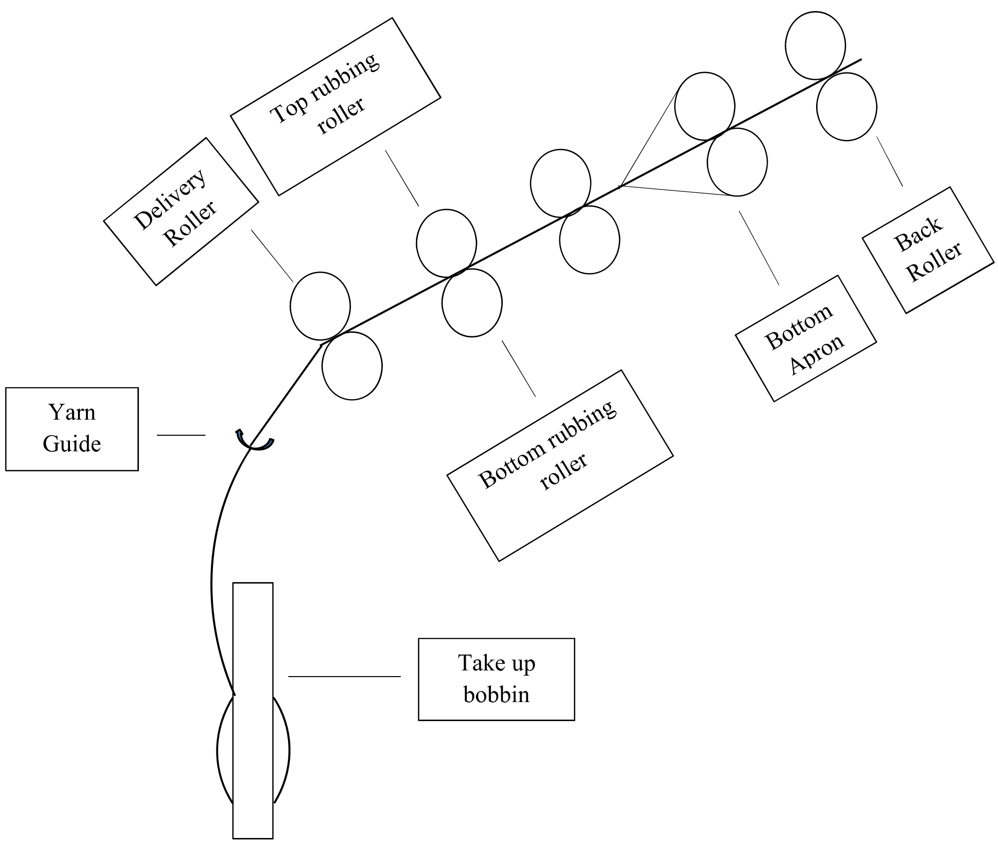


Figure 5.2a. Schematic of yarn passage through spin tester

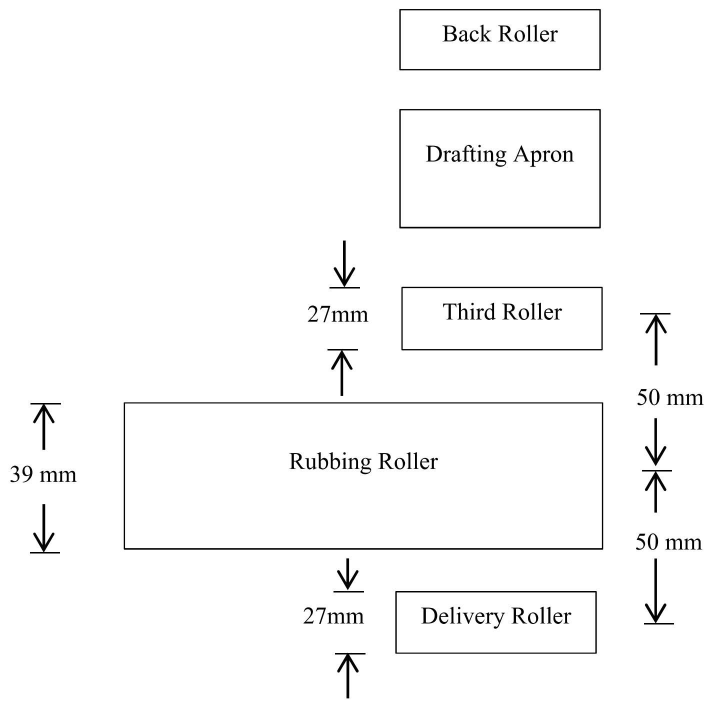


Figure 5.2b. Schematic of rubbing assembly fitted in drafting system

The technical details of the processing parameters and settings on the machine are given in the Table 5.1.

Pairs of drafting rollers	04
Top Rollers	Rubber coated
Bottom Rollers	Fluted steel roller
Gauge of First drafting zone	3 mm
Gauge of processing zone	100 mm
Loading of Top delivery roller	Green
Drafting system	SKF
No of pairs of drafting aprons	01
Spacer colour	Yellow
Break Draft	1.20

Table 5.1. Technical specifications of the machine.

5.3.1 Drafting assembly

The drafting system used in this work is a 4 by 4 apron drafting system with an extra processing zone for carrying out rubbing to achieve improved fibre migration and compaction in the strand. The drafting system is shown in Figure 5.3.

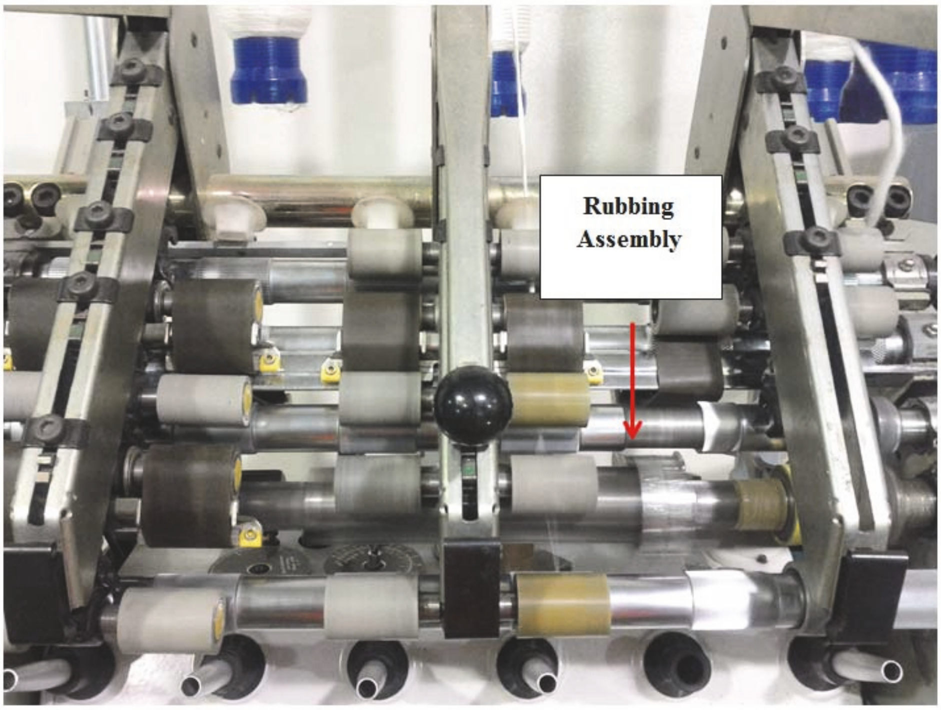


Figure 5.3. Drafting system

5.3.2 Rubbing assembly

A special rubbing assembly was designed to intermingle the fibres in the strand. A pair of rollers was used to perform the rubbing. The tricky part about this system was that it had to simultaneously perform two tasks, i.e. it had to rub the strand, for which an oscillatory motion was required, and at the same time it had to deliver the material forward, for which rotatory motion was required. This dual motion of the rubbing roller was achieved by mounting the rubbing roller on a spline shaft. The oscillatory motion of the roller was imparted by connecting the bottom roller to a separate motor through a crank shaft, whereas for rotary motion the spline shaft was connected to the main drive of the drafting system. A separate DC power supply with variable output power was attached to the oscillating motor so that the speed of oscillation of the compacting roller could be varied according to requirements. The top roller however was kept stationary and was pressed against the bottom roller like other top rollers in the drafting system and was driven by surface contact with the bottom roller. The rubbing assembly is shown in Figure 5.4.

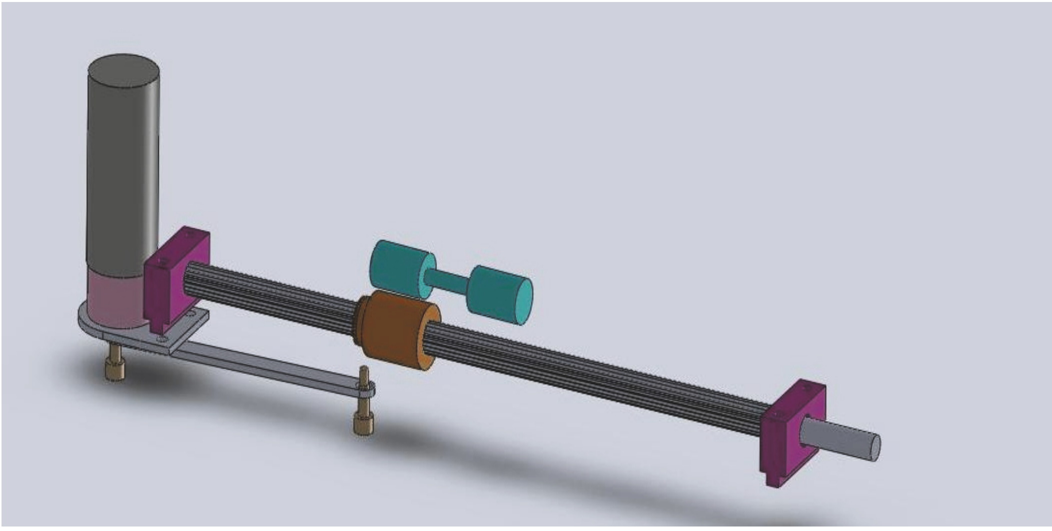


Figure 5.4. Rubbing assembly used for compacting the strand

5.3.3 Rubbing surfaces

One of the most important factors that could influence the outcome of this experiment was the selection of a suitable surface for rubbing the strand. It was a pre-requisite for the surfaces to be rough enough to grip fibres but at the same time to be smooth enough to allow the surfaces to rub past each other. As a general rule it can be said that gripping efficiency of surfaces will increase with an increase in roughness of the surfaces and pressure between the rubbing surfaces [190]. However, a negative side effect of having two highly rough surfaces rubbing against each other would be generation of too much heat and excessive power-consumption. In addition, surfaces that were too rough might damage the fibres being processed. To achieve this desired action, different surfaces were used on top and bottom rollers.

5.3.4 Bottom roller

A number of surfaces were experimented with and analysed for achieving the desired rubbing efficiency. As discussed earlier the main inspiration for this idea was the rub rover, so first of all a surface similar to that of rub rover aprons was tested. This surface is shown in following Figure 5.5.

Figure 5.5. Surface inspired by rub rover apron.

This surface was manufactured by machining grooves, similar to those of the rub rover aprons, on a plastic sleeve. This sleeve was then mounted on the oscillating roller. This surface could not substantially compact the strand. Due to lack of cohesion among fibres in the output strand, the material failed to be delivered to the next roller and eventually started lapping around the rubbing roller. From the analysis of this failure it was found that the major reason for these aprons being successful on a rub rover and not here was the difference in the thickness of the strands being processed. On a rub rover these aprons deal with a thicker strand, having a lot more fibres in the cross-section. When this thick strand of fibres is pressed between the surfaces, some of the fibres sit in the grooves of the aprons and fill up the space in the grooves. This laying in of fibres serves two purposes. Firstly, they fill in the gap in grooves and prevent the rest of the fibres from entering the grooves. Secondly the top layer of fibres sitting in the grooves provides a rough surface to grip the remaining fibres in the strand for their rubbing. On the next stroke the fibres under the effect of the false twist imparted in them due to rubbing, lock these fibres that were sitting in the grooves, and carry them along with the strand being pushed forward. In cotton ring spinning the number of fibres is much reduced, so all the fibres sit inside the grooves and escape the rubbing action. As a result they start lapping around the rubbing roller.

To deal with this issue the geometry of the rubbing surface had to be modified and a new surface capable of accommodating this reduction in thickness had to be designed. The design and size of grooves should be that some fibres in the strand should sit in the grooves while the rest should go with the compaction stroke of the roller. The shape and size of grooves was designed based on the following premises:

The size of the grooves should be such to allow only a few fibres to sit in during the compaction stroke, so that rest of the strand can be exposed to rubbing.

The shape of grooves should be such that the fibres can easily enter and escape the grooves. Because if the shape is not appropriate enough then there is a chance that fibres might enter the groove but get stuck in there. This would result in lapping of material around the roller.

Like many other scientific discoveries some inspiration was taken from nature as well. The most ancient way of making yarn was by rubbing a drafted strand of fibres between the palms of your hands. The pattern of grooves on the inside of a human hand provides an ideal surface for gripping the fibres to twist or rub them. So an attempt was made to engrave a surface that is much closer to the pattern of lines on the inside of the hands.

Based on these principles a variety of new surfaces were manufactured and tested. After establishing that the grooves had to be reduced in size the next question was the optimum fineness for achieving the desired compaction. It was argued that the size of grooves needed to be large relative to the fibre thickness. Various surfaces were then put on trial and the size of grooves was gradually reduced, until the best possible results for compaction were achieved.

The surface roughness was varied by engraving grooves of different pitch and depth on metallic sleeves. The reason to use metallic surface was because the design engraved on a metallic surface would be more resistant to any wear and tear, which these surface will undergo when exposed to rubbing. Microscopic images and groove details of various surfaces tested are shown in Figure 5.6.

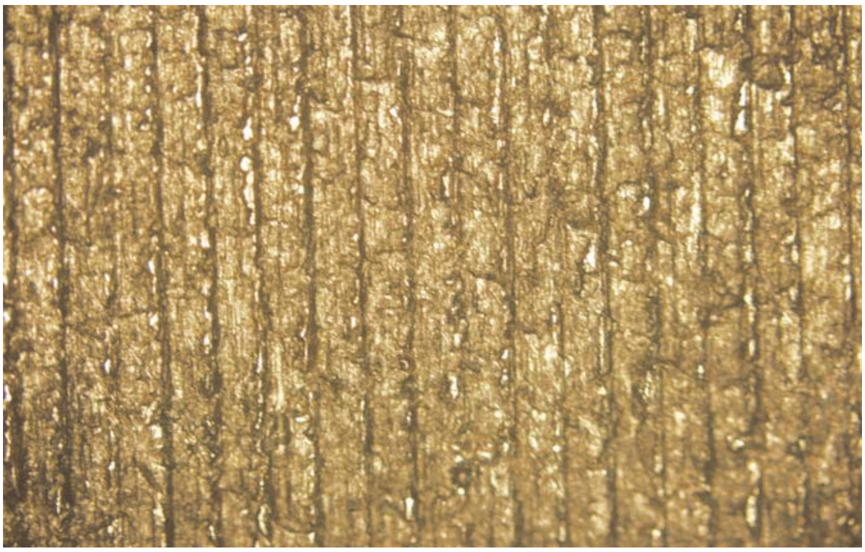


Figure 5.6. Microscopic image of surfaces used for bottom roller

The testing of surface roughness was carried out on a Taylor and Hobson Form Talysurf 50, 2D Profilometer using a cut-off length (lc) of 0.8 mm and a bandwidth of 300:1. Three samples each 10 mm long were tested. The surface roughness measurements are given in Table 5.2 [191, 192].

	Ra (µm)	RHSC	Rda (°)	Rp (µm)	Rv (µm)	Rz (µm)
Surface #1	51	296	51	268	117	151
Surface #2	14	49	17	48	27	21
Surface#3	9	65	14	55	24	30

Table 5.2. Roughness values for surface experiment with

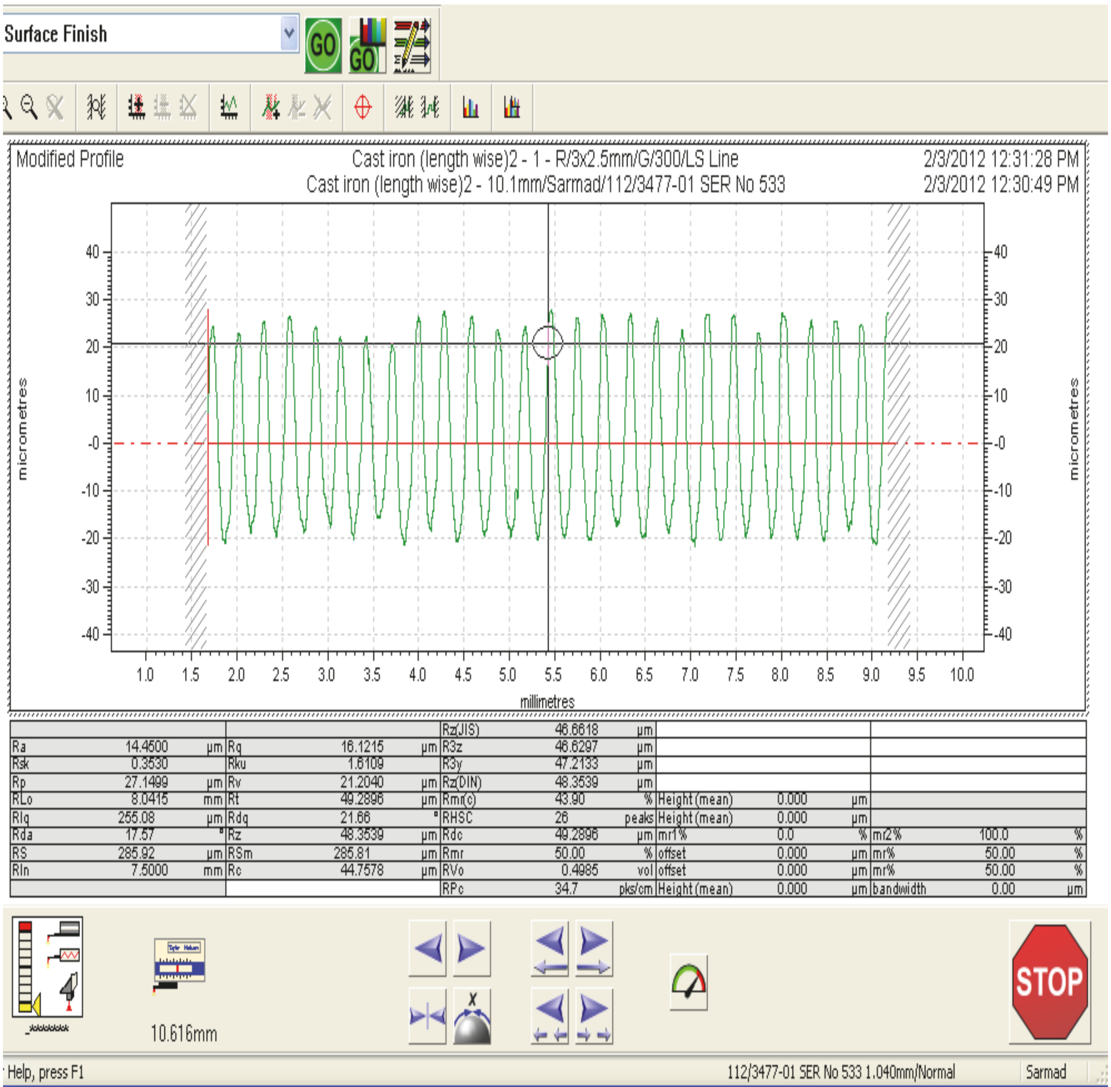


Figure 5.7. Specification of surface used for rubbing

Where,

Ra = Average roughness of the surface.

Rt = the vertical height between the highest and lowest points of the profile within the evaluation length.

Rda = arithmetic mean slope of the profile that it makes with the line parallel with the centre line.

Rz = average of the maximum peak to valley height within the sampling length

Rp = Average of height of highest point above the centre line.

Rv = Average of depth of lowest point below the centre line.

After testing different surfaces it was found that a surface having grooves just above the average fibre diameter was most suitable. This surface was prepared by engraving very fine grooves on a cast iron sleeve. The surface used had an average roughness of Ra = 14 μm. Reducing the surface roughness any further reduced the quality of rubbing.

Since there are no standard methods for assessment of quality of compaction, various assessment techniques were improvised. These methods are discussed in detail in section 5.5.1 of this chapter.

5.3.5 Top roller

A rubber coated roller of 85 Shore surface hardness was used as the top roller. The reason for using a rubber top roller was to improve the gripping ability of the rubbing surfaces to achieve better rubbing efficiency. First of all a rubber coated roller with a smooth outer surface was tested. However, the friction of the surface was not enough to grip the fibres to be rubbed. To overcome this lack of friction very fine grooves perpendicular to the direction of oscillation were engraved on the top roller. The top roller surface used in the experiments is shown in the Figure 5.8.

Figure 5.8. Microscopic image of surface of top roller used

5.3.6 Top roller pressure

The gripping action of the surfaces and therefore the rubbing efficiency can be increased by increasing the pressure between the surfaces but it will have side effects. This has been fairly well established by Russell and Dobb's work with a rub rover [190]. Firstly, too high a pressure between the surfaces would lead to excessive heat generation which will make the process unsuitable for longer runs. Secondly, too high a pressure would lead to wearing out of the rubbing surface. This high contact pressure might also damage the fibres. Too low a pressure on the other hand might lead to insufficient gripping of fibres for efficient execution of rubbing, besides the top roller was driven through surface contact with the bottom roller which therefore needed sufficient pressure. So an optimum pressure was sought, which was just enough to grip the fibres and also rotate the top roller. This pressure was applied using a spring loaded arm as in conventional drafting systems.

5.3.7 Speed and amplitude of oscillation

The bottom roller was made to oscillate at around 100 rpm. The idea was to have at least one oscillation per fibre length so that every fibre in the strand would face at least one stroke of oscillation. Too little oscillation might lead to insufficient compaction of the fibres whereas too high a frequency of oscillation might cause damage to the fibres by excessive heat generation. The frequency of oscillation could be varied by varying the speed of the driving motor of the oscillation assembly.

The amplitude of oscillation could be adjusted by changing the slot in the crank shaft. The amplitude of oscillation was kept at 10 mm (i.e. 5 mm on either side from mean position). A larger oscillation amplitude might have yielded better results in terms of rubbing quality, but would have taken the strand out of the processing zone by pushing it sideways out of the roller width. Too low an amplitude of oscillation on the other hand would have helped in keeping the strand straighter and in line, but not without compromising the quality of rubbing.

It was observed that during this rubbing process the fibrous strand could be carried sideways by the bottom roller. The reason for this was that it was being rolled between two surfaces, one of which, i.e. the top roller, was stationary. As the strand moved away from the centre, its length increased. The nip to nip distance between rubbing roller and front roller was 50 mm, and the amplitude of rubbing stroke was 5 mm on either side of the mean position. This stretched the strand by about 0.5 % during every rubbing stroke. The shape achieved by the strand during a complete rubbing cycle was much like a triangle. This effect is shown in Figure 5.9.

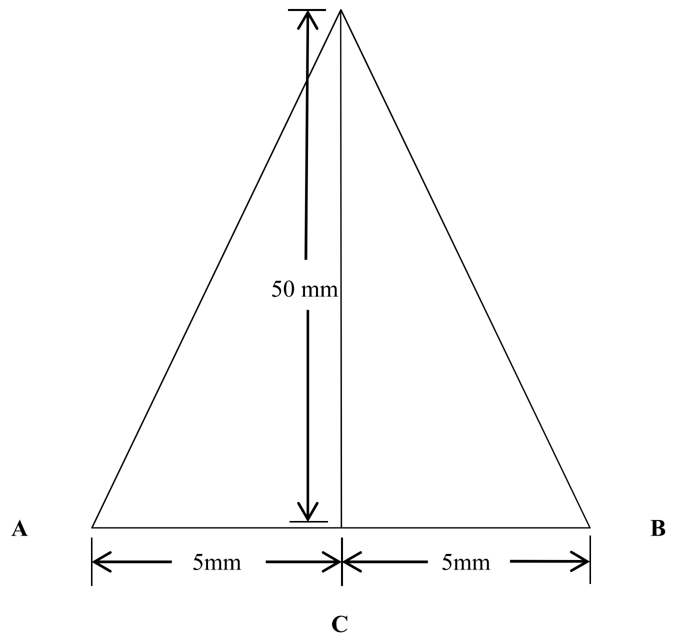


Figure 5.9. Path of fibrous strand during rubbing stroke

Point A and B are the extreme positions of the strand during rubbing, whereas Position C is the centre point of rubbing amplitude. The path of the strand forms the hypotenuse of a triangle when it is at the extreme ends of rubbing, which means that its length increases at the extreme positions. However, the length of material supplied from the delivery rollers is constant, so the strand will be stretched when it reaches its extreme positions, possibly causing drafting of the strand. Similarly, on its way back towards the centre, the roller will take the fibres with it, causing the strand to get slack. Since there is no mechanism to compensate this tension variation in the strand, this repeated stretching and slackening of strand can result in uneven drafting. This would be detrimental to yarn strength. So it was important to run the machine at optimum amplitude where there is enough compaction and rubbing achieved but at the same time without compromising the evenness. Values of amplitude of oscillation and pressure were chosen that gave good compaction of strand. A more careful optimisation in terms of fibre binding while minimising any deterioration in evenness would be desirable.

5.3.8 Draft distribution among drafting zones

In the processing zone a slight negative draft of 0.98~0.99 was introduced in the strand. The reason for this negative draft was to facilitate fibre intermingling. If the strand is under tension the fibres will be stretched and will not inhibit intermingling. Too high a negative draft would cause the material to get too slack and will induce lapping. Introducing a slight tension draft could have improved delivery of material to the front roller by keeping it straight and in line, but an uncontrolled drafting over a wide gauge would cause the yarn evenness to deteriorate. The entanglement of fibres as a result of rubbing might also mean that applying any tension draft would cause the fibres to be drafted in the form of small lumps rather than as single fibres which would generate thick and thin places.

5.4 Materials

Three different counts (29.50, 19.68 and 14.75 tex) at three twist levels (Twist factor of 3340, 3820 and 4290) were manufactured and tested for improvement in quality. All yarns were spun on the SDL spin tester at a spindle speed of 7000 rpm, from 430 tex and 57 tpm roving made from 100 % Australian carded cotton of 3.9 mic. and 32 mm staple length.

To draw a clear comparison all yarns were first spun on the spinning frame without the rubbing assembly and then with the rubbing assembly installed and the results were then compared. The yarns manufactured without the rubbing assembly will be referred to as ‘Normal yarns’ (N), whereas the ones with the rubbing assembly on will be referred to as ‘Processed yarns’ (P).

5.5 Results and discussion

The primary target of this work was to improve yarn quality parameters such as tenacity, elongation, hairiness and abrasion resistance. To achieve these primary targets some secondary targets were set. These secondary targets were to interlock the fibres into the strand before twist insertion. For a comprehensive analysis of this experiment it was important to investigate the two effects separately. So the experiments were carried out to investigate the following two aspects of this work:

1. To find out how effective the rubbing was, in achieving the desired arrangement of fibres in the yarn structure.
2. How this modified fibre arrangement affected the overall quality of the yarn produced.

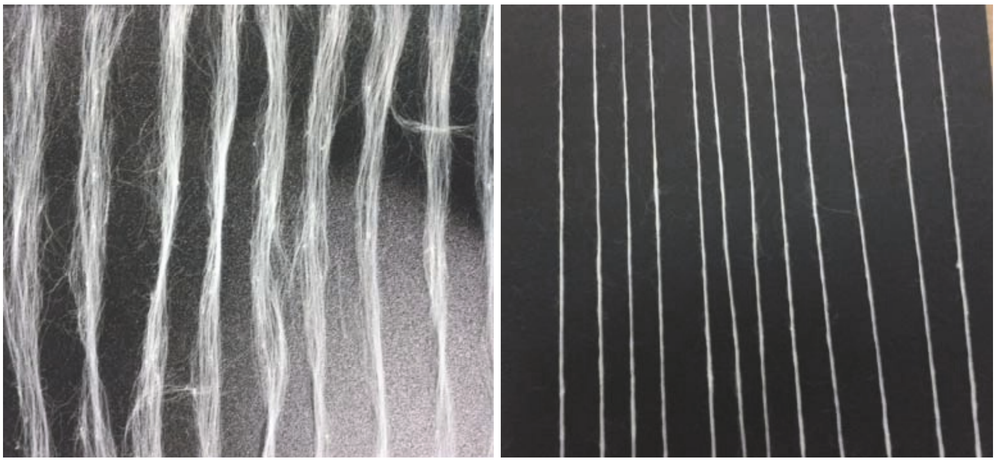
The latter is easier to analyse, as standard testing equipment is available for testing of various aspects of yarn quality, but the former is more complicated because there are not many systems available for testing and analysis of this kind of processing. Various experiments were designed and carried out to assess the effect of processing.

5.5.1 Assessment of efficiency of rubbing

The success of the proposed hypothesis, that fibres can be locked more securely into the yarn structure by rubbing the strand before twist insertion, was entirely dependent on how efficiently and effectively the rubbing had been executed. The most common way of assessing fibre orientation in the yarn is by the tracer fibre technique. However, because of the practical difficulties (too laborious and time consuming) and limitations of the tracer fibre techniques in quantifying the level of trapping, some novel methods of examination were adopted. The details and the results of the novel approaches are as follows.

5.5.1.1 Appearance of strand before twist insertion

After the insertion of twist into the strand there are a number of factors that can influence the orientation and locking in of fibres into the yarn structure. To separate the influence of twist and to estimate the effect of the rubbing only, it was important to develop a method that could differentiate between the "processed strand" and "normal strand" before twist insertion. For this purpose the drafted strand of fibres was collected from the front rollers before twist insertion for both normal and processed yarns and analysed. These collected strands are shown in Figure 5.10.

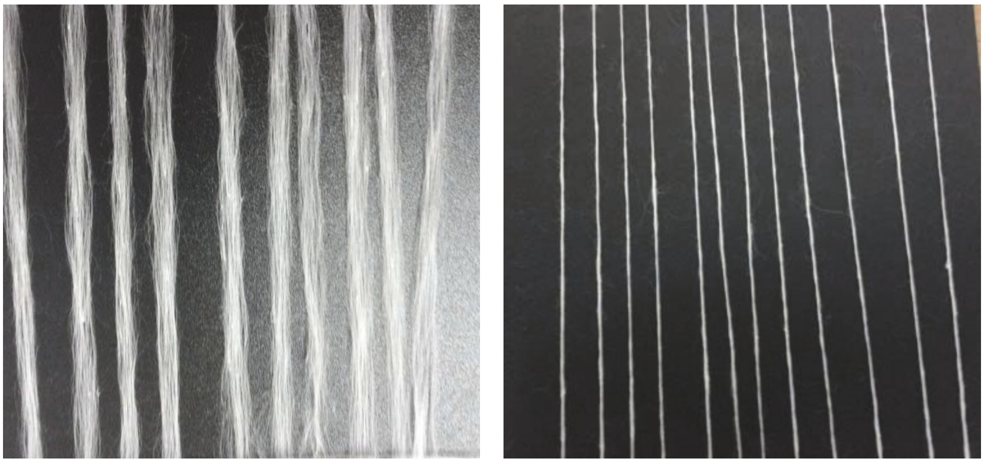


Normal Strand　　　　Processed strand

Figure 5.10. Drafted strands of normal and processed yarns

It can be seen that the processed strands are much more compact and have a rope-like shape as compared to the normal strand, which are much like loose ribbons. This ability of the strand to retain a yarn-like shape without any twist insertion implies improved interlocking of fibres. If there was no intertwining among the fibres, the processed strand would also have emerged in the shape of a ribbon, just like the normal strand.

However, the question arises as to whether this apparent interlocking is a significant improvement over that achieved by compact spinning methods, Could the appearance of the strand be mostly because the fibre array is condensed but without significant interlocking of fibres? Therefore the "processed strand" was compared with the emerging strand of same linear density from a standard compact spinning system. The strand from a Rotor- craft compact spinning system was used for this comparison. The drafted strands for "processed yarn" and rotor craft compact system are shown in the Figure 5.11



RoCoS Strand Processed strand

Figure 5.11. Drafted strands for processed yarn and RoCos yarn

The compaction achieved in the rotor craft compaction system faded away as soon as the strand emerged from the system and the strand reverted back to ribbon shape rather than retaining its yarn shape. The "Processed strand" on the other hand kept its yarn shape even after the compacting force had been removed. Hence, some locking of the fibre structure has occurred. These findings clearly indicate that a conventional compact spinning system such as the RoCoS system does not have a significant mechanism that intermingles or entangles the fibres. The fibres are just pushed together or condensed rather than compacted.

5.5.1.2 Strength of strands

Having established that the fibres were interlocked with each other, the second question was how well they have been interlocked. To test this interlocking, an indirect method was used. Based on the presupposition that the strength of the strand should increase with improved interlocking of fibres, the strengths of strands of different thickness were measured. For this strength measurement, 6 inch long samples of both ‘normal strand’ and ‘compact strand’ were taken. The reason for using very short samples was because “normal strands” were too weak to support their own weight if any longer. The strands were clamped at top and small dead weights were attached at the bottom of the strand. The weights were increased in small increments (0.05 grams) until failure. The value of the weight just before the strand broke was recorded. Results for this testing are shown in Table 5.3.

	Weight (grams)	
Tex	**P**	**N**
29.50	0.55	0.005
19.68	0.40	0.005
14.75	0.25	0.005

Table 5.3. Strength values of strands for normal and processed yarns

5.5.1.3 Visual observations

Apart from these measurements, some visual observations were also used to gauge the efficiency of rubbing. The first was that when the strand was sufficiently rubbed the strand transfer from, into and out of, the processing zone was very smooth. It was observed that when the fibres were not rubbed properly the strand was pushed in one direction and out of the processing zone as it followed the compaction stroke. To prevent the strand from going out of track, a small tension draft of about 1.02 ~ 1.04 had to be applied, whereas when the rubbing was carried out effectively the strand could be processed even at a slight negative draft (about 0.98 ~ 0.99). Better interlocking of fibres provided a sufficient binding force among the fibres, which compacted the strand and therefore prevented the strand from getting slack by improving cohesion among the fibres and helped in keeping the strand in line.

The second visual observation was the deposition of loose fibres on the delivery roller. When rubbing quality was good the fibres emerging from the delivery roller were caught in the strand as soon as they emerged from the delivery roller. When the rubbing was not carried out properly the fibres on the extreme ends of the strand remained loose and uncontrolled, so they followed the rotation of the roller, i.e. were wrapped. This effect was so strong that after running for some time the material started lapping around the roller. To prevent this, a small scavenger brush had to be used under the delivery roller for collection of these loose fibres. This scavenger mechanism is shown in the Figure 5.12.

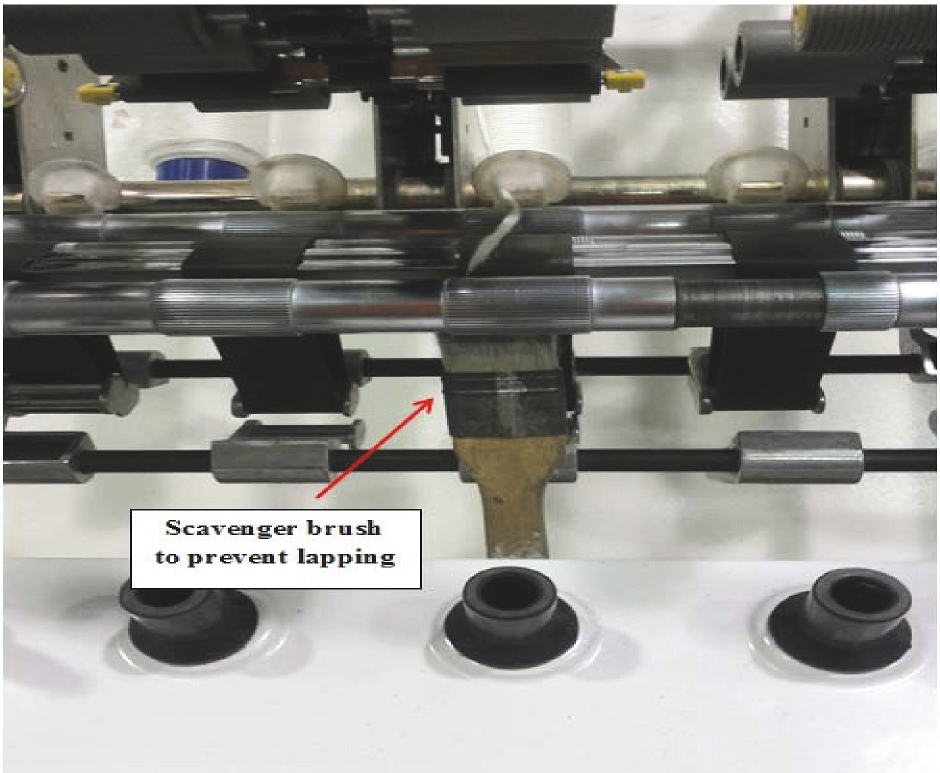
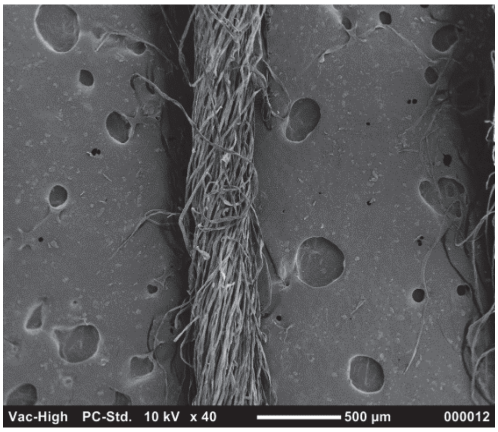


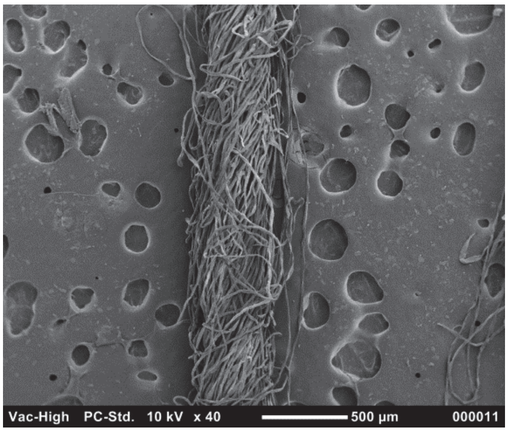
Figure 5.12. Bottom roller fitted with scavenger brush

These visual observations enabled rapid fine tuning of the machine parameters for the strongest rubbing performance and compaction of strand by improved interlocking and trapping of fibres.

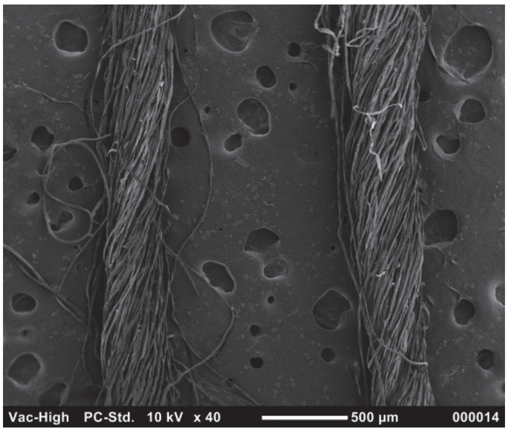
5.5.1.4 Microscopic analysis of normal and processed yarn

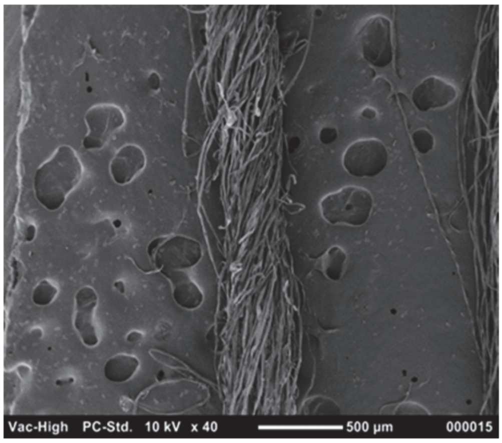
For a detailed analysis of yarn structure of normal and processed yarns it was very important to see what effect the processing had on fibre orientation. Therefore both normal and processed yarns were observed under a microscope. For this analysis a scanning electron microscope (JEOL Neoscope) was used. Yarn samples before and after the twist insertion were observed under the microscope. The SEM images of normal and processed yarns before and after twist insertion are shown in Figure 5.13.



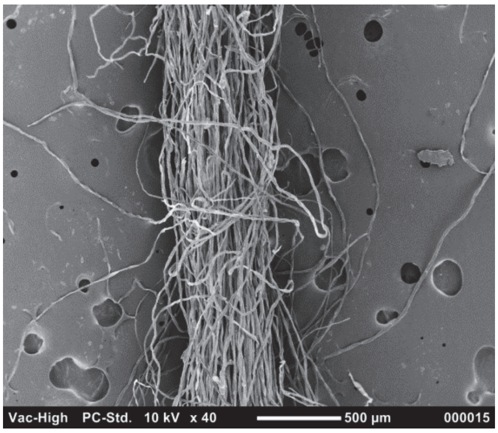


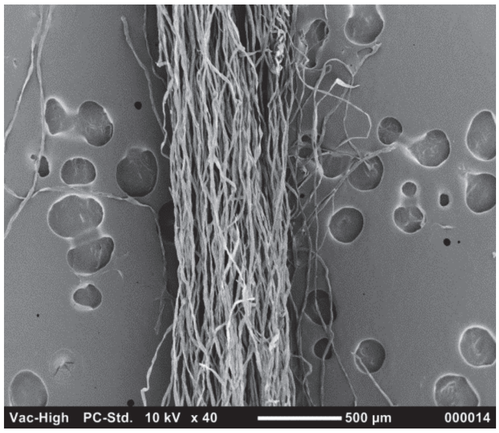
Processed yarns



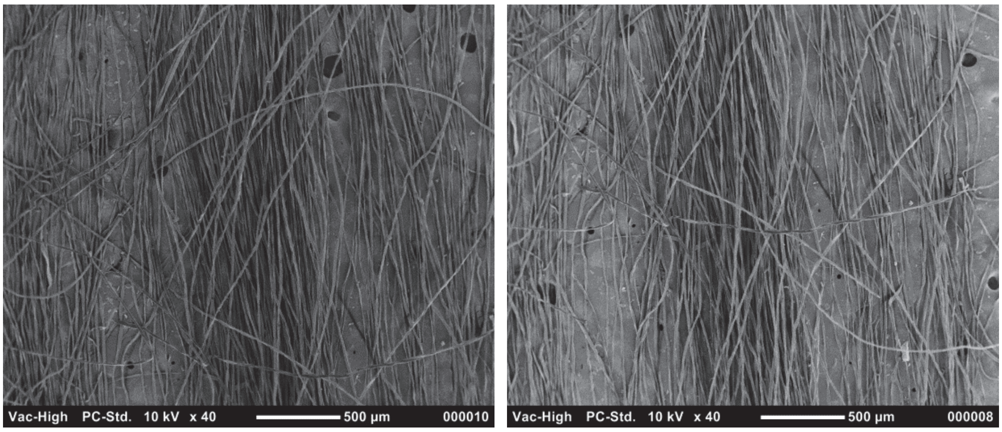


Normal Yarns





Processed strands without twist



Normal strand without twist

Figure 5.13. SEM images of normal and processed yarns and strands

From the images it can be clearly seen that rubbing has effectively introduced intertwining among the fibres. This effect can be clearly seen in the strands before twist insertion, where the strands are very compact as compared to their equivalent normal strands and also a clear intertwining and even some entanglement can be seen among the fibres. Similarly from the yarn images it can be seen that processed yarns have less hairs on their surface and fibres can be seen to be interlocked with each other. However some of the fibres can be seen to be wrapped around the yarn. This could be a side effect of the rubbing process and ideally this should not have been the case. For the fibres to be locked-in into the yarn structure and still maximum fibres contributing to the yarn strength there should be an intertwining among the fibres not an entanglement or looping of the fibres.

5.5.2 Abrasion resistance

The main aspect of yarn quality targeted in this work is an improvement in abrasion resistance of yarns. It has been discussed in detail in the previous chapter that there is no agreed standard testing method for such assessment. A number of yarn abrasion testers have been developed, but since these were not readily available some improvised methods were developed. The details of test methods and the results of testing are given below.

5.5.2.1 Abrasion resistance on manual abrasion tester

The yarns manufactured were tested for improvement in abrasion resistance on the manual abrasion tester described in the previous chapter.

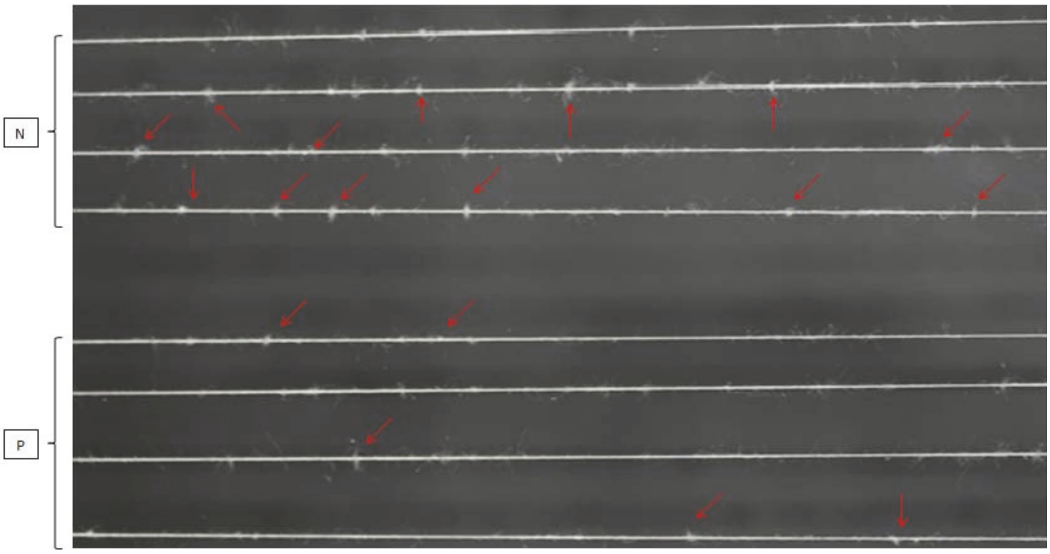


Figure 5.14. Normal and processed yarns after 500 cycles

From the Figure 5.14 it can be seen that the degradation in yarn appearance due to abrasion was much higher in normal yarns than in processed yarn. The yarns in the top half of the picture, i.e. normal yarns, are much more hairy and a lot more beads of fibres have accumulated on the surface. These beads are the loose surface fibres which are not bound to the yarn core and which accumulate into a pill-like fibre balls on the yarn surface. The yarn group in the bottom half, i.e. processed yarns are significantly less hairy and have much fewer pills on their surface. This explicitly demonstrates that, by rubbing the strand before twist insertion, the binding of surface fibres can be improved. This improved trapping of fibres results in a decrease in a yarn's tendency to gradually deteriorate as a result of abrasion.

5.5.2.2 Abrasion resistance by measurement of hairiness after repeated windings

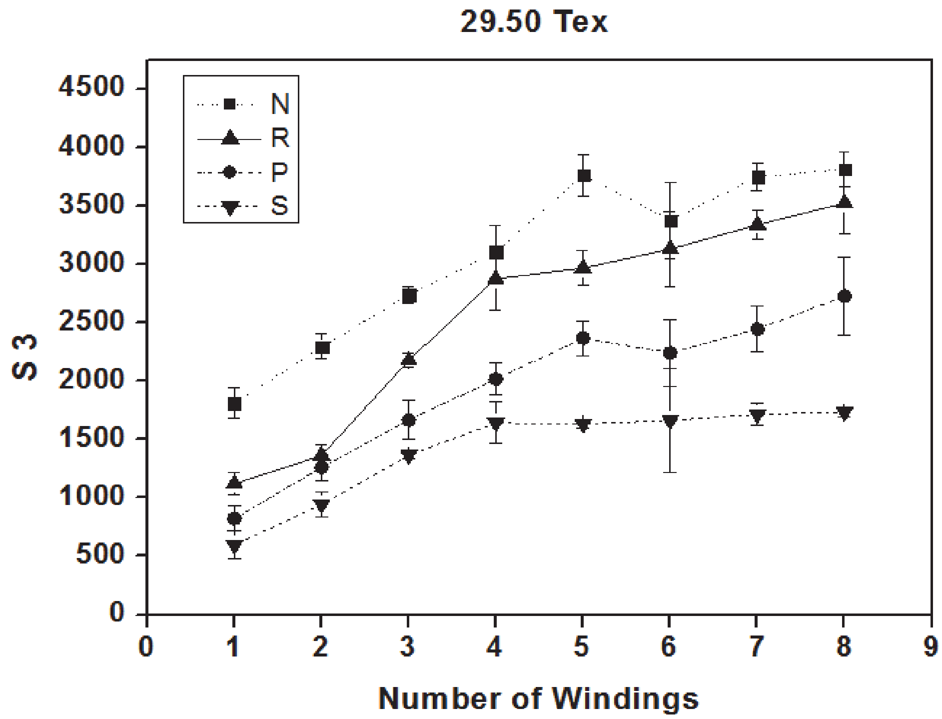
Another method used to test the ability of this system to bind the fibres into the yarn structure is changes in hairiness with repeated windings of the yarns. During winding the yarn rubs against a number of surfaces. Although these surfaces are designed to cause minimal abrasion in the yarn, they still increase hairiness. As the yarn runs against these guides and tensioning devices any loose fibres on the yarn surface tend to emerge from the yarn structure and protrude from the surface. These jutting fibres result in an increase in the number of hairs counted in the yarn. If the fibre trapping has been improved then the rate of increase of yarn hairiness with repeated windings should be lower. If this is the case this process of repeated winding can be employed as a test to assess the abrasion resistance of the yarns.

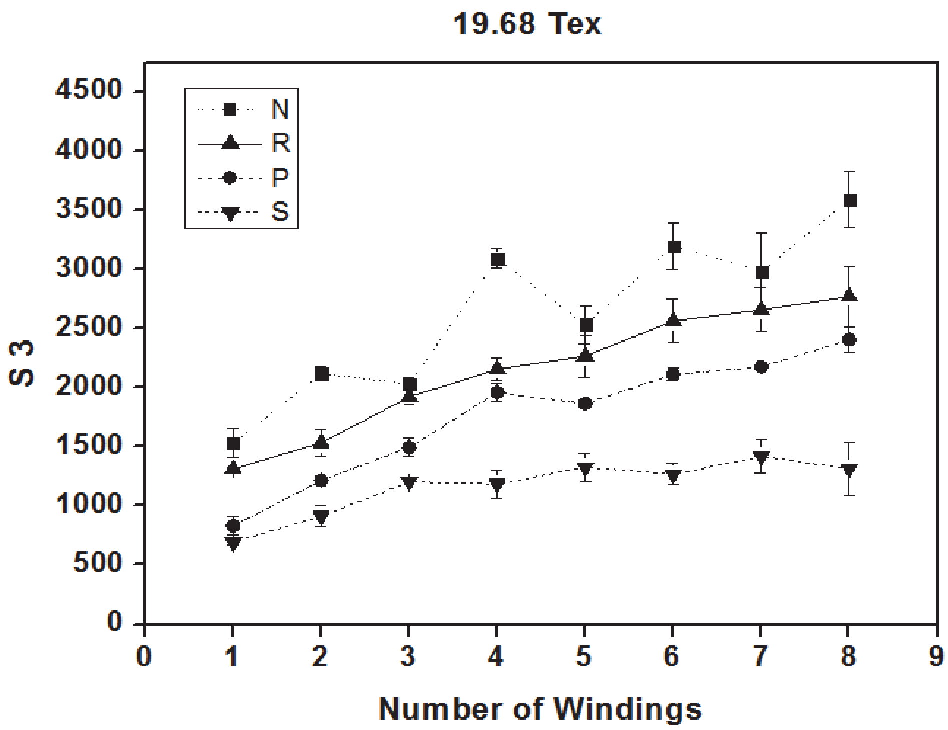
To establish the credibility of this test it was important to compare the results of processed yarn against a yarn that has proven superior abrasion resistance. For this purpose the test was conducted on Sirospun yarns (S) as well. All the three counts were spun on a siro spinning assembly at a strand spacing of 8 mm. The yarns were then exposed to repeated winding just like other yarns.

The testing was carried out on a Zweigle 565 Hairiness tester. Yarn from the bobbin was passed through the hairiness tester and its hairiness was recorded. The same length of yarn was then passed through the tester again and its hairiness was recorded again. This process was repeated for eight windings. One issue for this test was the collection of yarn exiting the hairiness tester. If the same length of yarn is to be tested repeatedly then the yarn exiting the hairiness tester should be collected on a package so that it can be tested again. For this purpose a winder was attached to the hairiness tester. The take up speed of the winder was synchronised with the delivery rate of the hairiness tester. Testing was carried out at a speed of 50 m/min. Three samples of 100 metres each were tested for each count. The hairiness tester fitted with the winder is shown in Figure 5.15.

Figure 5.15. Zweigle Hairiness tester fitted with winder for tested yarn take-up

The results for repeated windings are shown in the Figure 5.16.


29.50 Tex
N
R
P
S
S 3
Number of Windings
0
500
1000
1500
2000
2500
3000
3500
4000
4500
0
1
2
3
4
5
6
7
8
9


19.68 Tex
N
R
P
S
S 3
Number of Windings
0
500
1000
1500
2000
2500
3000
3500
4000
4500
0
1
2
3
4
5
6
7
8
9

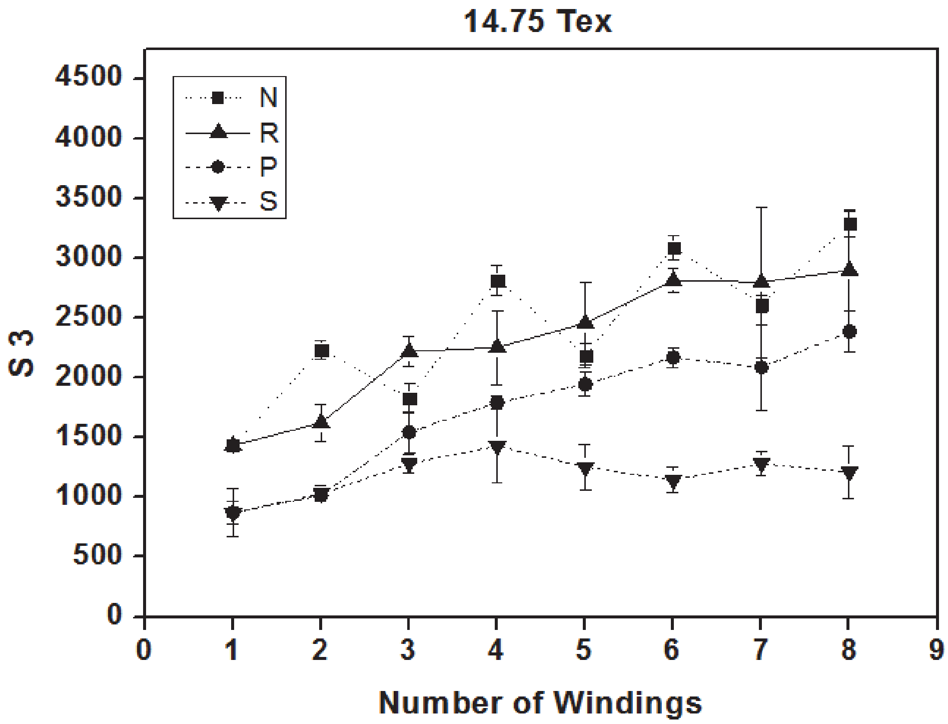


Figure 5.16. Hairiness values for repeated windings

A trend of a gradual increase in hairiness with increasing number of windings can be seen for all the yarns samples. The rate of increase in hairiness with each winding is much lower in the 'processed yarns'. At any number of windings the hairiness index (S3 value) of processed yarn was less than normal yarn. This lower rate of degradation in appearance can be attributed to better trapping of fibres in the yarns. It can also be seen that the rate of increase of hairiness is much higher at the start of the test for both normal and processed yarn, i.e. for the first three to four rewindings. After that the rate of increase dropped. This is in agreement with previous work by Barella and Vigo [193] and by Xia et al. [194] where the same trend was seen.

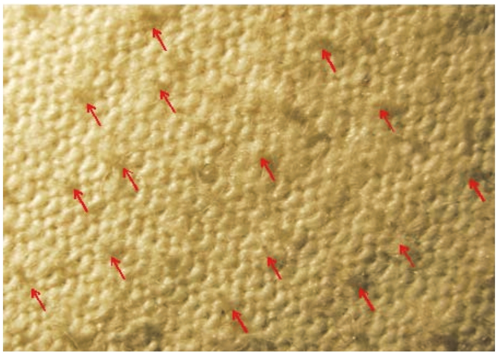
Summarising the results it can be said that Sirospun yarns were the most abrasion resistant of the four types. Processed yarns were found to be second best. Compact (R) and normal yarns had almost the same abrasion resistance qualities, although the hairiness of normal yarns tended to be higher after an even number of windings. Since the winder was installed after the hairiness tester, trailing fibre ends were raised on the odd number of winding and were detected in even numbered windings. This suggests that normal yarns have more trailing fibres ends which are pushed out by the winding step and then detected in the next pass. The presence of these trailing fibres can be attributed to wider spinning triangle in normal yarns, which resulted in poor incorporation of fibres into the yarn structure. Another factor responsible for this zigzag effect could be the presence of more fibres in longer hair groups in normal yarns. Longer the length of the fibre protrusion, more prone it is to be laid along the yarn axis and escape detection and then raised again in the next passage.

On the basis of these results it can be said that, by processing the fibrous strand by rubbing it between two suitable surfaces, the incorporation of fibres into the yarn structure can be improved and this can help in improving the abrasion resistance of the yarns.

5.5.2.3 Abrasion resistance by testing the yarn for pilling in fabric

Cotton yarns, no matter how good they are in quality, are sized before weaving. This coating of size covers the yarn surface and conceals any shortcomings in abrasion resistance of the yarn. The first stage where the weakness in a yarn abrasion resistance is exposed is after it has been converted into a fabric. Any deficiencies in yarns abrasion resistance characteristics manifest themselves in the form of excessive pilling tendency in the fabrics made from them and therefore this can be used for assessment of abrasion resistance characteristics of the yarn [195]. The yarn is woven or knitted into a fabric and then it is tested for its pilling propensity. The results of this test do not necessarily demonstrate the yarn's characteristics regarding its abrasion resistance, because there are several other factors that can influence the results. These include the fabric weave, ends and picks per inch, cover factor etc. These effects however can be minimised, if not eliminated, by using the same weave design, same cover factors, production speeds and other machine settings for all the samples manufactured. The main advantage of using this test (as compared to direct abrasion testing of yarns) is that it is more reliable and convenient to perform because there is standard testing equipment available for carrying out these tests.

Due to difficulties involved in weaving a fabric, the testing was only carried out on knitted fabric. Both normal and processed yarns were manufactured with a knitting twist i.e. at a Twist factor of 3500. The yarns were then knitted into fabric (single jersey) on F.A.K single end, laboratory scale knitting machine. The fabric samples were then tested for pilling tendency on an ICI Pilling Box Abrasion Tester. The microscopic images of the fabric surface for normal and processed yarn fabrics, before and after testing are shown in Figure 5.17.



Normal yarn Fabric

Processed yarn fabric

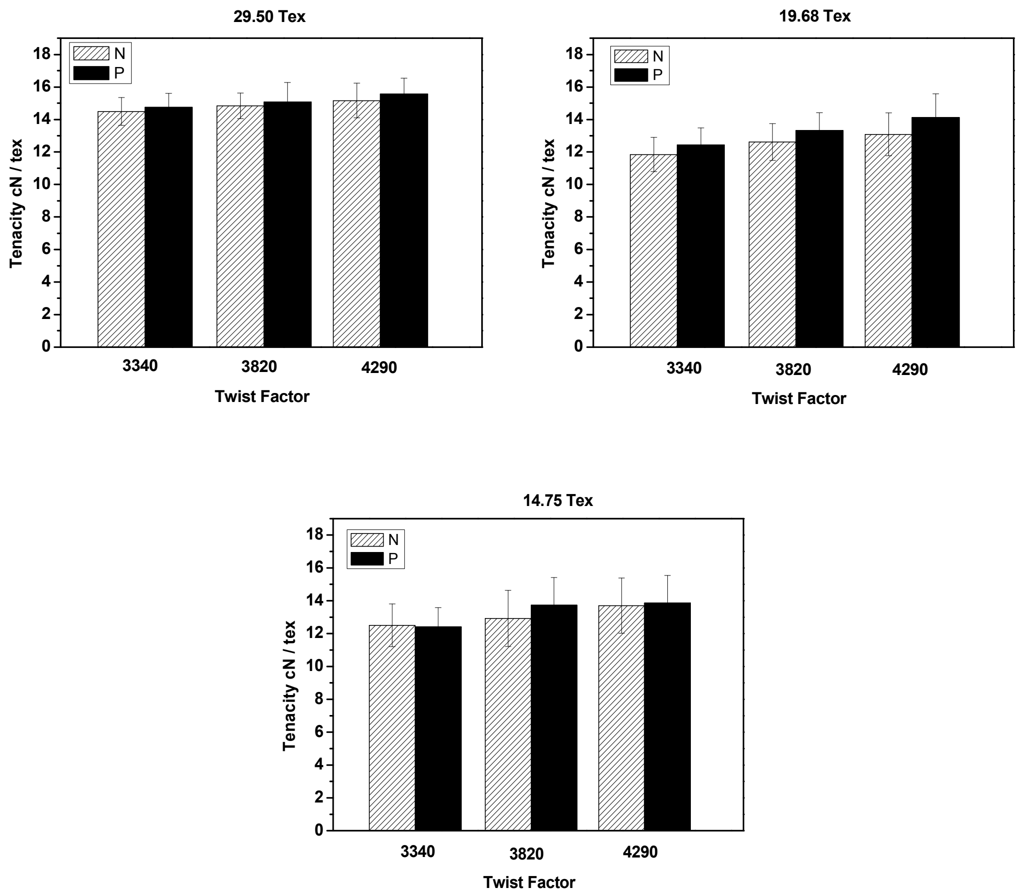
Fabric without Abrasion

Figure 5.17. Pilling results for normal and processed yarns

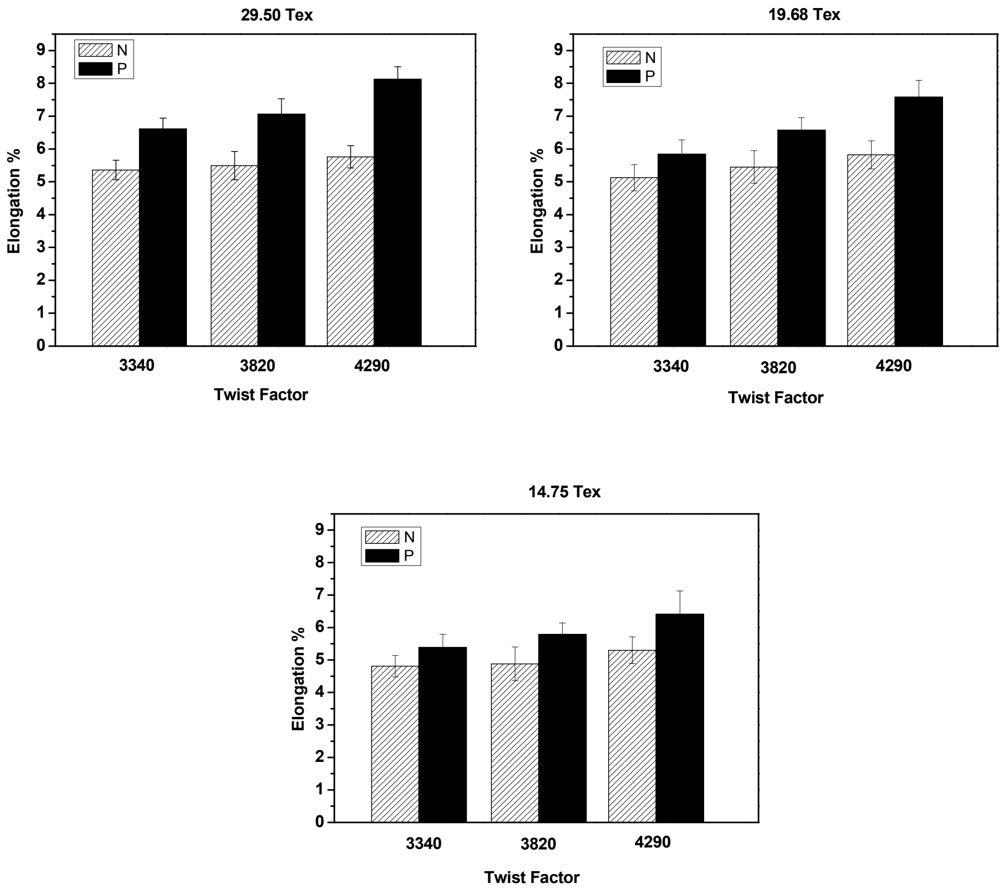
Both normal and processed yarn fabric samples were put in the pill box and were rotated for 5 hours at a rotational speed of 60 rev / min. It was found that processed yarn fabrics had significantly less pills than normal yarn fabrics. Apart from pilling their surface was less hairy and more uniform than normal yarn fabrics. The fabrics were also compared with the standard charts for fabric grading for pilling propensity and processed fabrics were found to be closer to standard 2, whereas normal fabrics were closer to standard 3 [196].

5.5.3 Yarn strength and elongation

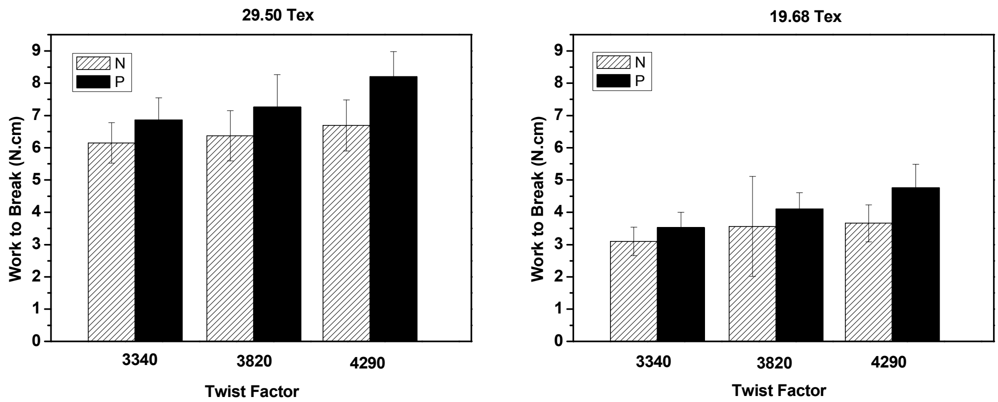
The processing of fibrous strands by rubbing before twist insertion should improve yarn strength in two ways. Firstly, it should give better incorporation of fibres into the yarn structure. These fibres would otherwise be protruding from the yarn surface and would not contribute to yarn strength. Secondly, it should improve their interlocking with each other and into the yarn structure. Theoretically this effect should be more pronounced at lower twist levels and if that is the case it should help in manufacturing yarns at lower twist factors. To verify this hypothesis yarn samples ranging from coarse to fine counts were manufactured and tested for yarn strength. Yarn tenacity, elongation at break and work-to-break were determined using an Uster Tensorapid-3. Fifty samples per yarn group were tested, at a gauge of 500 mm under standard testing conditions (RH = 65±2 % and Temperature = 20±2 ^{o}C). The results are shown in Figure 5.18.

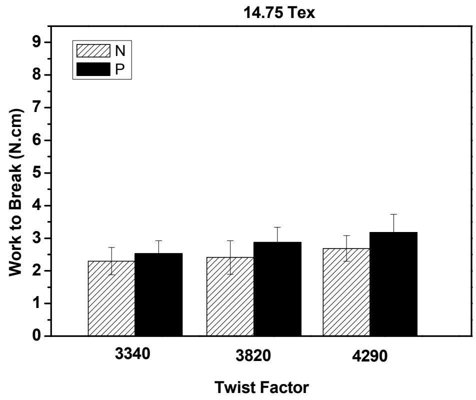


a) Tenacity for three counts at three twist levels



b) Elongation % for three counts at three twist levels





c) Work-to-break for three counts at three twist levels

Figure 5.18. Yarn strength results for various counts

29.50 tex						
	(N)			(P)		
Twist Factor	**Elongation (%)**	**Tenacity (cN/tex)**	**Work-to-break (N.cm)**	**Elongation (%)**	**Tenacity (cN/tex)**	**Work-to-break (N.cm)**
3340	5.36	14.50	6.15	6.61	14.74	6.86
Std. Dev.	0.3	0.8	0.6	0.3	0.8	0.6
3820	5.50	14.85	6.37	7.06	15.08	7.26
Std. Dev.	0.4	1.7	0.7	0.4	1.2	1.0
4290	5.76	15.17	6.70	8.13	15.58	8.20
Std. Dev.	0.3	1.0	0.7	0.3	0.9	0.7

19.68 tex						
	(N)			(P)		
Twist Factor	**Elongation (%)**	**Tenacity (cN/tex)**	**Work-to-break (N.cm)**	**Elongation (%)**	**Tenacity (cN/tex)**	**Work-to-break (N.cm)**
3340	5.12	11.85	3.10	5.84	12.44	3.53
Std. Dev.	0.4	1.0	0.4	0.4	1.0	0.4
3820	5.45	12.62	3.56	6.58	13.33	4.10
Std. Dev.	0.5	1.1	1.5	0.3	1.0	0.5
4290	5.82	13.10	3.66	7.58	14.12	4.76
Std. Dev.	0.4	1.3	0.5	0.5	1.4	0.7

14.75 tex						
	(N)			(P)		
Twist Factor	**Elongation (%)**	**Tenacity (cN/tex)**	**Work-to-break (N.cm)**	**Elongation (%)**	**Tenacity (cN/tex)**	**Work-to-break (N.cm)**
3340	4.81	12.50	2.30	5.40	12.41	2.53
Std. Dev.	0.3	1.3	0.4	0.4	1.1	0.4
3820	4.88	12.92	2.41	5.78	13.72	2.87
Std. Dev.	0.5	1.7	0.5	0.3	1.6	0.4
4290	5.30	13.70	2.70	6.41	13.87	3.17
Std. Dev.	0.4	1.6	0.3	0.7	1.6	0.5

Table 5.4. Yarn strength results for various counts

The strength comparison is for 29.50, 19.68 and 14.75 tex yarn at twist factors of 3340, 3820 and 4290. From the graphs it can be seen that the improvement in elongation was more significant than in tenacity. Although an improvement in tenacity can also be seen it is not as significant as the improvement in elongation at break. On average, the tenacity values improved by around 3 ~ 5 % but the improvement in elongation were around 20 %. The net result of this improvement in tenacity and elongation can be seen in the improvement in work-to-break of around 15 %. This increase can only result from an increase in the number of fibres which contribute, or the extent to which each contributes, to the yarn strength. The standard errors were calculated based on standard deviation and statistical significance level of the results was calculated using z-test under the null hypothesis. It was found that the improvement in elongation at break was statistically significant for all counts at all twist levels. However, the change in yarn tenacity was found to be not statistically significant for all results.

		Elongation (%)		
Tex	**Twist Factor**	**3340**	**3820**	**4290**
	N	5.36	5.49	5.76
	P	6.61	7.06	8.13
29.50	**% improvement**	**23**	**29**	**41**
	N	5.12	5.45	5.82
	P	5.84	6.58	7.58
19.68	**% improvement**	**14**	**21**	**30**
	N	4.81	4.88	5.30
	P	5.39	5.79	6.41
14.75	**% improvement**	**12**	**19**	**21**

		Tenacity (cN/tex)		
Tex	**Twist Factor**	**3340**	**3820**	**4290**
	N	14.49	14.84	15.17
	P	14.74	15.08	15.58
29.50	**% improvement**	**2**	**2**	**3**
	N	11.85	12.62	13.09
	P	12.44	13.33	14.12
19.68	**% improvement**	**5**	**6**	**8**
	N	12.50	12.92	13.70
	P	12.41	13.72	13.87
14.75	**% improvement**	**-1**	**6**	**1**

		Work-to-break (N.cm)		
Tex	**Twist Factor**	**3340**	**3820**	**4290**
	N	6.15	6.37	6.69
	P	6.86	7.26	8.20
29.50	**% improvement**	**11**	**14**	**23**
	N	3.10	3.56	3.66
	P	3.53	4.10	4.76
19.68	**% improvement**	**14**	**15**	**30**
	N	2.30	2.41	2.69
	P	2.53	2.87	3.17
14.75	**% improvement**	**10**	**19**	**18**

Table 5.5 Effect of yarn twist and linear density on yarn strength

Although the improvements in various aspects of yarn strength were different for different counts and twist levels, over all it can be said that the effect of this improvement was more pronounced at higher twist factors. This effect can be clearly seen from Table 5.5., where elongation % at break, tenacity and work-to-break results are tabulated for comparison. A clear trend can be seen that the maximum improvement in all parameters of yarn strength is achieved at the highest twist levels. However, the effect of linear density on the strength parameters is not the same. The elongation at break has a trend of increase with increasing linear density. The other parameters, i.e. tenacity and work-to-break do not show a trend with linear density. This might be because the improvements in tenacity were not statistically significant. This further suggests that rubbing parameters might need to be fine-tuned according to yarn linear density.

The higher extension of processed yarns may be explained by the presence of folded or looped fibres. Some of the fibres (Figure 5.13) are folded and looped by rubbing. These folded fibres will not share the load with neighbouring straight fibres until they are also straightened. However, by the time these fibres get straightened some of the already straight fibres would be broken under the applied load. These recently straightened fibres would now take the load and the yarn will have to be stretched further before it completely breaks, thereby increasing the elongation at break values. This effect is in agreement with the findings of Hearle & Lord, where they attributed higher extension in rotor spun yarns to the presence of folded and entangled fibres. It was claimed that these entangled and folded fibres act as an extensible component of the system [40].

Another factor responsible for the less significant improvement in tenacity is the deterioration in yarn evenness which is discussed in detail below. This deterioration in yarn evenness was a side effect of this processing and might be avoided using a modified design which is discussed later in this chapter.

5.5.4 Yarn hairiness

A more accurate comparison of hairiness prior to winding was also made. Hairiness results for the normal and processed yarns are shown in Figure 5.19.

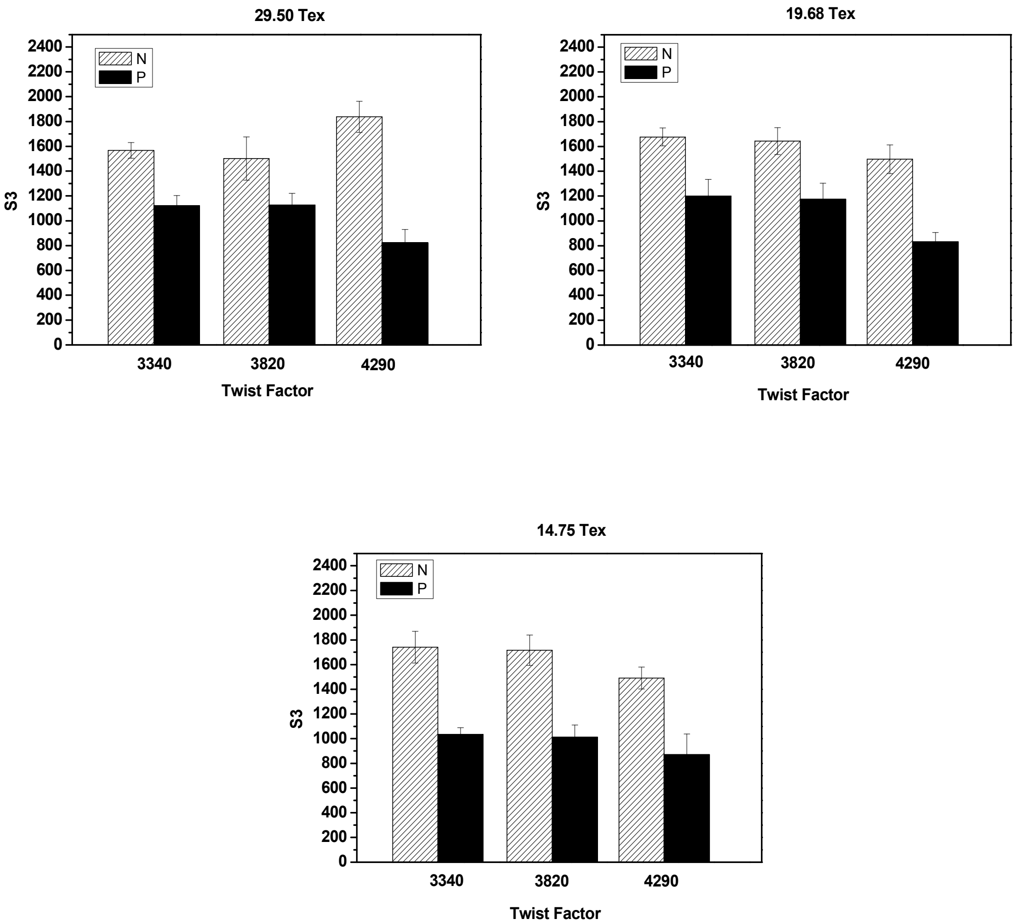
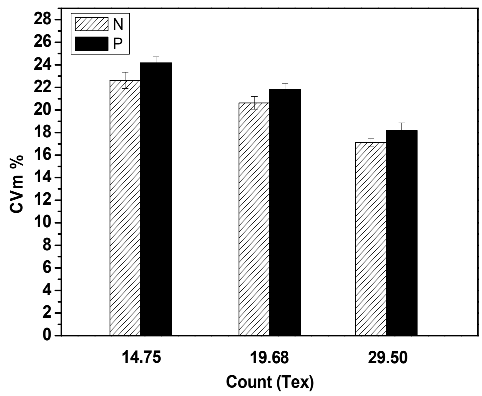


Figure 5.19. Hairiness results (S3 Values) for normal and processed yarns

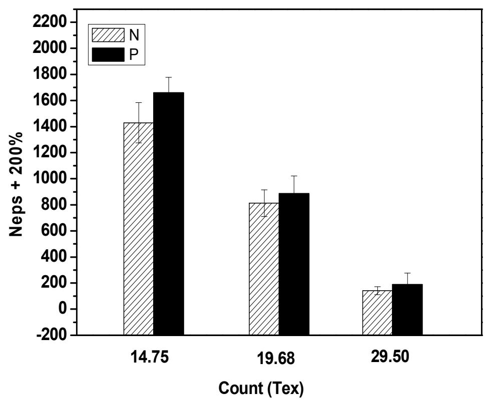
The initial S3 hairiness values are significantly lower for processed yarns. On average, the hairiness values are around 25 % lower. In the 29.5 tex yarn, the hairiness was reduced by 35 %, whereas for finer counts the improvement was around 20 %. The reason for bigger improvement in coarser counts could be because coarser yarns have more fibres in the cross- section so there is a higher probability for more fibres to be trapped into the yarn structure.

5.5.5 Yarn evenness

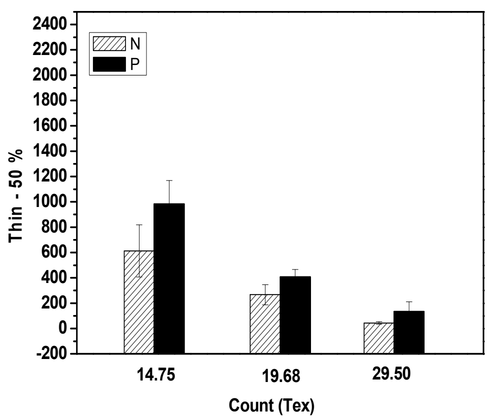
Although compaction of the fibres should not directly influence the evenness of the yarn produced, there were some side effects of this processing that could affect the evenness. Firstly, yarn evenness could be affected because of the rubbing stroke of the compaction assembly (this effect has been discussed in detail in section 5.3.7 of this chapter). Secondly, there could be some fibre loss during processing which could lead to increased unevenness. Yarn evenness was measured on an Uster Tester 4 (UT-4), using three 250 metre samples per lot. The results are shown in Table 5.6 and Figure 5.20.



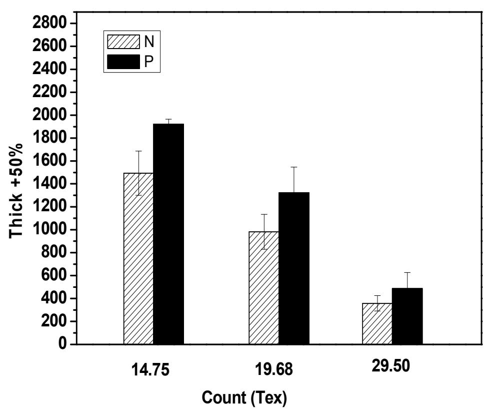
CVm % for three counts



Neps +200 % for three counts



Thin -50% for three counts



Thick +50% for three counts

Figure 5.20. Evenness results for various counts

	29.50 tex		19.68 tex		14.75 tex	
	(N)	**(P)**	**(N)**	**(P)**	**(N)**	**(P)**
U %	13.38	14.27	16.14	17.13	17.64	18.85
Std. Dev.	0.3	0.5	0.4	0.3	0.5	0.3
CVm %	17.12	18.16	20.63	21.84	22.62	24.16
Std. Dev.	0.3	0.6	0.56	0.5	0.7	0.5
Thin-50 %	43	135	266	407	612	984
Std. Dev.	10	75	80	58	205	184
Thick+50 %	358	486	981	1322	1493	1921
Std. Dev.	66	141	152	244	192	42
Neps +200 %	141	188	813	886	1429	1659
Std. Dev.	30	87	102	135	154	118

Table 5.6. Evenness results for various counts

Figure 5.20 clearly shows the poorer evenness of processed yarns. All aspects of yarn evenness can be seen to be poorer as a result of processing. As discussed earlier, two possible causes of this deterioration could be fibre loss during processing and stretching of the strand during rubbing. So both possibilities were investigated. To check the extent of fibres loss during processing, the yarns were manufactured on the drafting assembly without the rubbing assembly attached and then keeping the draft level unchanged the same count was manufactured with the rubbing assembly installed. The yarns produced were checked for count. If there was a large fibre loss taking place then the count produced with the rubbing assembly attached should be finer. However, no significant difference between the count of normal and processed yarns was found. So it can be said that there was not a significant fibre loss taking place during processing. Drafting of the strand by stretching at the extremes of the compaction stroke should also lead to a reduction in count and a short wavelength periodicity in the evenness spectrum. This effect can be seen in Figure 5.21., where mass spectrograms for normal and processed yarns for 14.75 tex yarn at all twist levels is shown. The short wavelength variation, just under 10 cm, appear to be slightly higher in processed yarn, which is equal to the length of the processing zone (i.e. 10 cm). However a peak in the spectrum cannot be observed, which suggests that this worsening of evenness was random, which could be mainly due to disorientation of fibres and not due to stretching of strand. Had that been the case, it would have appeared as a peak (periodic variation) equal to the amplitude of the rubbing stroke.

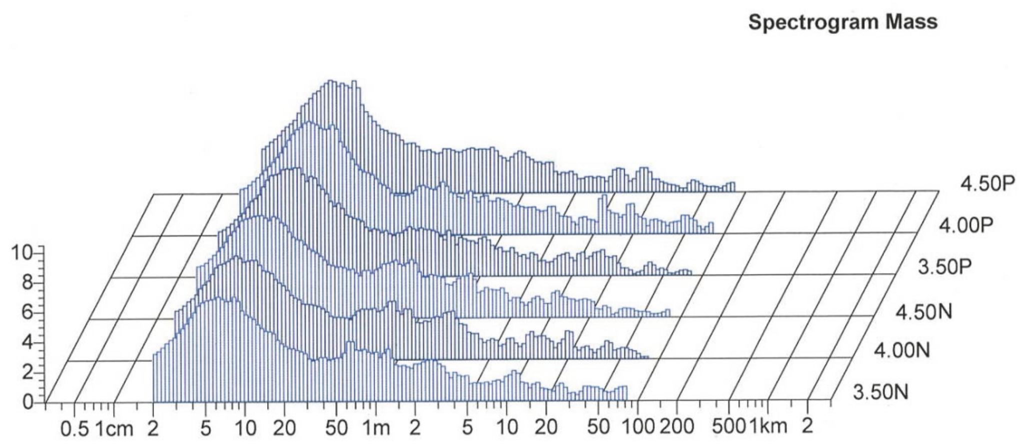


Figure 5.21. Mass spectrogram for 14.75 tex normal and processed yarn

Over-all the measured CV % (of linear density) of the yarn was about 6 % worse. Other possible explanations seem to be i) that some surface fibres are wrapped or entangled over a short distance by rubbing (seen in Figure 5.13) when they would be pulled straight in normal spinning, or ii) that the measurement is sensitive to variations in packing density of the fibres. However, such effects would be expected to be small.

Some suggestions which might be investigated and could potentially eliminate or at least minimise this deterioration in yarn evenness are proposed in section 5.6.

5.6 Discussion

The yarn testing results revealed that as a result of the rubbing, the abrasion resistance and hairiness of the yarns has significantly improved, but a significant improvement in yarn tenacity could not be recorded. The yarn tenacity was found to improve only by 3~5 %. The deterioration in yarn evenness, which was a side effect of this processing, deprived the yarn of this improvement in strength. The linear dependence of yarn tenacity on evenness has already been established by previous researchers, where a drop of 15 % in yarn tenacity was observed (for worsted yarns), for a change in yarn evenness by 25 % [197].

However not having a drop in tenacity despite having a drop in evenness, still was a significant improvement. To ensure the credibility of these results, a repeat of yarn strength testing was carried out. Fifty samples per yarn group were manufactured and tested on under standard laboratory testing conditions. The results of repeat test are shown in Table 5.6.

29.50 tex						
	(N)			(P)		
Twist Factor	**Elongation (%)**	**Tenacity (cN/tex)**	**Work-to-break (N.cm)**	**Elongation (%)**	**Tenacity (cN/tex)**	**Work-to-break (N.cm)**
3340	6.73	15.21	6.95	7.00	15.08	7.04
3820	7.47	15.97	7.62	7.76	15.79	7.83
4290	7.70	15.26	7.55	9.20	16.40	8.96

19.68 tex						
	(N)			(P)		
Twist Factor	**Elongation (%)**	**Tenacity (cN/tex)**	**Work-to-break (N.cm)**	**Elongation (%)**	**Tenacity (cN/tex)**	**Work-to-break (N.cm)**
3340	5.50	11.80	3.23	6.06	12.20	3.52
3820	5.87	13.07	3.70	6.62	12.95	3.93
4290	6.19	12.69	3.67	6.78	14.02	4.41

14.75 tex						
	(N)			(P)		
Twist Factor	**Elongation (%)**	**Tenacity (cN/tex)**	**Work-to-break (N.cm)**	**Elongation (%)**	**Tenacity (cN/tex)**	**Work-to-break (N.cm)**
3340	5.47	14.38	2.92	5.58	12.98	2.66
3820	5.64	14.14	2.89	6.32	14.14	3.13
4290	5.80	13.75	2.86	7.06	14.62	3.50

Table 5.7. Recheck strength results for various counts

The rechecking results showed the same trend i.e. yarn elongation at break was improved, whereas the tenacity stayed more or less unchanged. This clearly suggests that rubbing can potentially improve yarn tenacity, if the worsening of evenness can be eliminated. One possible solution to this problem can be to use a top surface which is oscillating at the same speed as the bottom roller but in the opposite direction. This arrangement will prevent the strand from rolling sideways. As a result of this, the effect of stretching and slackening will be removed. It would be desirable to test whether this solves the unevenness-problem. However, the current arrangement was adopted in order to keep the system simple and low cost as possible. The alternative that could be investigated is to reduce the variation in path length by increasing the distance between the rollers and rubbing zone or increase the frequency of rubbing while reducing the amplitude.

An increase in the surface area of the rubbing surfaces may improve the quality of rubbing. In the equipment used in this work the rubbing was carried out by two rollers so the area of contact was just the nip of the rollers. If this rubbing is performed with flatter surfaces having a wider contact area, the quality of rubbing might be improved. More effective rubbing per stroke can help in achieving better rubbing or allow fewer or smaller strokes per unit length. This wider area of contact can be achieved by using a roller and apron or two aprons rather than rollers for rubbing.

The optimisation of the rubbing process was carried out, mainly based on the premise that, the better the compaction of the strand, the better the quality of rubbing. However this might not necessarily be the case. Ideally, for improved fibre trapping, a regular intertwining among the fibres is required. If every fibre regularly migrates from the outside to the inside and vice-versa, then the fibres will be locked into the yarn, as for Sirospun yarns. This kind of fibre arrangement might not result in a very tightly packed output strand, but the advantage of this kind of strand would be that fibres will be less disoriented and entangled. This would be improve the load sharing among the fibres and would also help in eradicating the worsening of yarn evenness caused due to looping and disorientation of fibres.

The results presented in this work are for carded cotton yarns. Different raw materials with different fibre characteristics need to be tested on the rig to investigate the effect of raw material characteristics on the quality of yarns produced.

5.7 Summary

Improved incorporation and interlocking of fibres into the yarn structure can help in improving various aspects of yarn quality like elongation, hairiness and abrasion resistance. This incorporation can be achieved by rubbing the fibrous strand between two suitable surfaces. To avoid any disturbance in the drafting process and therefore to the evenness of the yarn, the rubbing process should be carried out in an extra processing zone. The yarns produced by this method were tested from two perspectives. The first was whether the rubbing introduced the desired arrangement of fibres in the yarn structure and the second was to find out what effects this new arrangement of fibres had on yarn quality parameters. To find answers to these questions yarns were spun over a count range from coarse to fine. These yarns were first tested to check if the desired interlocking of fibres had been introduced and then they were tested to find out what effect the rearrangement of fibres had on their quality parameters such as strength, evenness, hairiness, elongation, abrasion resistance.

From these experiments following conclusions could be drawn about the process:

The most important factor that influences the effectiveness of the processing is the geometry of surfaces used for rubbing.

Grooves, slightly deeper than the average fibre diameter were found to be the most suitable for carrying out rubbing.

The processing should be carried out without tension in the processing zone. Instead it would be desirable to have a slight negative draft in the processing. The presence of this negative draft can serve as a buffer to absorb any stretching and slackening of the strand during rubbing.

The work-to-break of the yarn was improved by 10% although a significant improvement in yarn tenacity was not recorded. The improvement in the total work needed to break the yarn establishes that more fibres must be broken and therefore that more fibres are bound in and contributing to yarn strength. The elongation at break was found to improve by around 20%. This effect of having an improvement in elongation and work-to-break but not in tenacity can be explained by the poorer evenness being countered by more fibres contributing but these fibres having a wider spread in their degree of straightness (so that fibres take up the load at different elongations).

Yarn evenness was found to be poorer for all counts at all twist levels. Over-all it can be said that yarn evenness was found to be around 5% worse. The most likely causes of the deterioration in evenness seem to be stretching and slackening of the strand during the rubbing stroke and an increase in wrapped and entangled fibres.

Yarn hairiness was improved by around 25%. This improvement was due to trapping of surface fibres, which would otherwise protrude from the yarn surface.

The abrasion resistance of the yarn, as determined by several improvised tests was improved quite significantly. This abrasion resistance translates into improved pilling resistance of fabrics made from these yarns.

CHAPTER 6

Conclusions and Future Work

Summary and conclusions

Yarn quality can be seen in terms of both spinning and downstream performance and an improvement in one or both can be called an improvement in yarn quality. The final verdict on quality depends upon the customer's perception of its performance. By the time the yarn reaches the customer, its quality is lower than its quality at manufacture, and it keeps on deteriorating during downstream processing. The reason for this decline in quality can be found in the self-locking structure of staple fibre yarns. This degradation in quality negatively affects the downstream performance of the yarn. Retrospectively, it can be said that, for a yarn to have a smooth spinning and downstream performance it is very important that it should have a good manufacturing quality and at the same time should have the ability to retain this quality. Therefore, in this thesis an effort is made to systematically develop new methods that can not only improve the yarn quality but also improve its ability to resist any deterioration in quality.

Prior to conducting an investigation into the ways of improving yarn quality, the initial part of this thesis was devoted to a critical literature review of the work by previous researchers in this field. Various determinants of yarn quality have been discussed and it was found that yarn quality depends upon raw material quality and the arrangement of fibres for yarn formation or in other words 'yarn structure'. Every yarn spinning system has its own distinct yarn structure, which primarily depends upon the spinning geometry. For a certain raw material yarn quality can only be improved by modifying the yarn structure. Some of the recent relevant developments in yarn manufacturing sector have also been studied. This included commercially used techniques such as compact, siro and solo spinning, as well as some of the methods which have been demonstrated on a laboratory scale to be able to significantly improve yarn quality, but have not been big commercial successes. The working principles of these systems, what modifications they have induced in the yarn structure, how these modifications are induced and what effect they have on yarn quality, has been examined and presented. This critical appraisal of the published literature led to the conclusion that these systems have achieved improvements in yarn quality such as reduced hairiness, improved evenness, and increased strength by improved incorporation and locking of fibres into yarn structure, more even distribution of fibres along the yarn length, reducing the spinning triangle and wrapping of loose surface fibres. Despite having achieved significant improvement in yarn quality, there are certain shortcomings, which, on one hand are a drawback to these systems, but on the other hand provide an opportunity for further improvement.

In the light of the findings of the literature review a hypothesis was developed about what structural modifications can be introduced to improve yarn quality. Ideally, any modification targeted at improving the yarn quality should improve all aspects of yarn quality, but practically so far this has not been possible. Therefore two aspects of yarn quality, yarn evenness and fibre migration were targeted in this work. An improvement in yarn evenness will improve yarn strength and spinning performance and should facilitate spinning of finer yarns at lower twist factors. This will not only improve the aesthetic value of yarns but also will also increase the production rate and therefore reduce the cost of production. The second aspect of yarn quality targeted in this work was to improve fibre migration or the trapping of surface fibres. Improving the intertwining of fibres can be perceived in terms of improved fibre migration in the yarn, which binds the fibres more securely and makes the yarn more abrasion resistant. Another advantage of this processing was the compaction of the strand before twist insertion. Therefore the method enjoys the benefits of compact spinning, i.e. small spinning triangle, as well. The yarns thus produced can be spun finer, at lower twist factors and will be more resistant to the degradation in quality which takes place due to abrasive forces acting on the yarn during winding, shedding, beat up etc.

Three approaches to improving yarn quality were investigated.

The first approach was to try and understand if and how “drafting against untwisting” could be employed to improve yarn evenness. Drafting against untwisting had previously been demonstrated to be an effective method for producing softer and finer yarns by improved orientation of constituent fibres. It was proposed that the working principle of this method, which is to simultaneously untwist and draft an already spun yarn, can be used to improve the evenness of a yarn. By employing this technique, the natural affinity of the twist for thin places (due their lower torsional rigidity), could be used as a detection mechanism for thin places and preferential drafting of thicker places. Such a mechanism can be the simplest most economical auto levelling mechanism. For this purpose special equipment was designed (which is discussed in detail in chapter 3) and different yarn counts were tested on this rig. The results from this testing led to the following conclusions:

Yarns can be drafted below a twist factor of 2500.

Although yarn quality in terms of both strength and evenness was always poorer the best results are always obtained when at least some twist is present in the yarn. This twist provides control over fibres during drafting.

Use of this system with an air-jet may help improve yarn hairiness and tenacity, by improved fibre orientation and wrapping of loose fibres, but an improvement in evenness does not seem possible using an air-jet as untwister. The reason is that with an air-jet there will always be two zero twist spots in the yarn segment being processed. These spots, being the weakest point, are most prone to drafting. For this system to work the drafting should preferentially occur in the thick places. Therefore this system can only work if an untwisting mechanism is used which introduces a controlled amount of untwisting and balances this with the delivery speed of the material. These findings are in agreement with findings by previous researchers where they have attributed the improvement in yarn quality to improved fibre orientation.

The next approach (chapter 4), was to try and combine the advantages of siro/solo spinning (improved trapping of fibres) and compact spinning (small spinning triangle), for improved spinning and downstream performance. An air-jet was installed before twist insertion in a specially designed drafting system, which had a provision for an additional processing zone. The intention was that the air jet would act as a false twister which twists and untwists the fibrous strand. This might intertwine and improve the locking-in of fibres and also would wrap protruding fibres around the yarn core. An additional benefit of this processing was that the emerging strand was compacted too, and thus will have a small spinning triangle like compact spinning. Yarn counts ranging from coarse to fine, with twist levels ranging from hosiery to weaving were spun. The results from yarn testing led to the following conclusions:

Use of an air false twister can compact the emerging strand and results in a reduction in yarn hairiness, but (at least for this air jet) did not improve the fibre incorporation. That is why when these low hairiness yarns were tested for abrasion resistance they were not found to be significantly superior to equivalent conventional ring spun yarns.

A worsening in yarn evenness was found at all twist levels in all counts. This could be because of the tension draft applied in the processing zone and disorientation of fibres by the air-jet.

Yarn tenacity was found to be slightly lowered by processing.

The final approach (chapter 5) was to try and overcome the short-comings of the air-jet system. This time the intertwining was introduced through rubbing of the strands. The drafted strand was rubbed between two specially designed surfaces (a rubber coated top and a grooved metallic bottom roller). Yarn counts over a range from coarse to fine at twist levels from hosiery to weaving were spun and compared with their corresponding conventional ring spun yarns for tenacity, hairiness, evenness and abrasion resistance. Some new methods of abrasion resistance testing were also developed and investigated. The following observations were made about the use of rubbing to induce fibre migration:

Yarn evenness was found to be slightly-poorer. This worsening may be due to disorientation of fibres and stretching of strands, which takes place as a side-effect of rubbing.

A significant improvement in yarn tenacity could not be achieved; however, not having a drop in tenacity despite a drop in evenness clearly indicates that this processing technique would improve the yarn strength if the drop in evenness can be overcome.

Rubbing the fibrous strand before twist insertion helps in manufacturing of yarns that are significantly less hairy than conventional ring spun yarns.

The biggest advantage that the yarns produced by this rubbing method, have over conventional ring spun yarns is that these yarns have their constituent fibres more securely locked into the yarn structure. The yarns thus produced are significantly more abrasion resistant. This was verified by microscopic analysis of the yarns and also by exposing the yarns to physical abrasion on an abrasion tester and by repeated winding of the yarns. There is less deterioration in the quality of these yarns during winding and other downstream processing. The higher abrasion resistance of the yarns can improve weave-ability and can help reduce the cost of sizing of the yarn.

Another potential advantage of having improved abrasion resistance and reduced hairiness in the yarns would be reduction in pilling tendency of the fabrics made from these yarns. This will increase the service life of the fabrics made from these yarns.

Rubbing significantly compacts the strand and the yarns produced through this method enjoy the benefits of compact spinning i.e. a small spinning triangle. Rubbing actually compacts the strands by interlocking of constituent fibres, compared to existing compact spinning systems that just condense the strand.

This method does not need a double strand like siro spinning and therefore the need for an extra creel and break out device can be eliminated.

With more fibres contributing to the yarn strength, and an improved elongation at break, this method may also help in improving the spinning performance of the yarns.

The use of rubbing for improving abrasion resistance of yarns might be too complicated and expensive to be adopted commercially. The additional cost of a drafting system with an extra processing zone, rubbing assembly, wearing of rubber cots of rubbing assembly during processing and the drive required for driving the rubbing rollers, might only be compensated if the yarns produced are abrasion resistant enough to be woven without sizing. However the findings of this work demonstrate that fibre trapping and therefore the abrasion resistance of the yarns can be improved by creating intertwining among the fibres and rubbing can be a potential way of achieving this intertwining. These findings can be helpful in development of a highly abrasion resistant yarns or even sizing free yarns, if a simpler method can be developed for creating intertwining among fibres or if a simpler and inexpensive rubbing system can be developed.

Recommendations for future work

The following observations are made and possible directions are suggested:

Further investigations into the potential ability of drafting against untwisting to improve evenness would require, a new mechanical untwister which can apply a variable grip, which is strong enough to untwist the yarns but at the same time loose enough to allow drafting to take place. This would need to be combined with a sensing and feedback arrangement that measured tension and adjusted draft or untwisting accordingly. However, it is difficult to envisage a system which could operate at a commercially acceptable speed and cost.

The use of an air-jet to improve the fibre trapping requires an improved design of the air-jet possible in combination with a false twister to allow intermingling. Any vigorous system such as the nozzles used for manufacturing of intermingled filament yarns is likely to blow the yarn apart or some fibres away. Air-jets of this type used in vortex spinning [198] still wrap trailing fibre ends.

A further improvement in quality of rubbed yarns might be achieved by improving the quality of rubbing. This may be achieved by:

Use of rubbing surfaces with a wider surface area. This can be achieved by using an apron or aprons instead of rollers for rubbing and will help in introducing more agitation in the fibres per rubbing stroke and will facilitate the reduction in the amplitude of the rubbing stroke.

Use of softer material for both top and bottom roller, may help improve the gripping of fibres but is likely to be at the expense of excessive heating and wear.

Counter oscillating the top and bottom surfaces. This may improve the rubbing quality, by eliminating the stretching effect caused by the use of a stationary top roller but would be more complex and costly.

Further investigations into the best ways of interlocking the fibres without degrading yarn evenness offer significant potential for producing higher quality yarns.

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