MECHANICAL METHODS FOR THE REDUCTION OF SPIRALITY IN WEFT KNITTED FABRICS

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The Candidate confirms that the work submitted is his own and that appropriate credit has been given where reference has been made to the work of others.

ABSTRACT

A mechanical method for reducing the spirality of single jersey tubular weft knitted fabrics is described. Initial attempts, using a false twisting device, did not prove successful. A later, successful method was developed, based on changes in yarn torque produced by a steaming and untwisting method. The new method is shown to be very effective in reducing spirality. Microscopic examination of changes in yarn structure, including characteristics of fibre migration have also been carried out.

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To my parents
Nicholas **and** *Maria*

and to
Helena

this Work is dedicated

If, as it is said:
"Necessity is the mother of invention",
let necessity be now.
Invention must not become an orphan!

H.E. Knobil

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Abbreviation: **TF** : Twist Factor (turns.cm^{-1}.tex^{½})

INTRODUCTION

A knitted fabric may be regarded as a particular configuration of a yarn or yarns, where the yarn is both the raw material and the finished product: "In a knitted fabric, the original raw material has not been greatly altered in form; the yarn as such has not been destroyed and it maintains its thread-like identity even in the finished fabric" [1]. For instance, a plain-knit fabric (single jersey), the simplest of the weft knitted structures, is made up of a single length of yarn formed into a repeating pattern or matrix of interlocking loops [1] (Fig. I.1a). This rapid process of "making a fabric from yarn by the formation of intermeshing loops" [2] is also called "one yarn process". Such a fabric, which is produced on a plain knitting machine having a single bed of needles, demands regularity of both yarn count and twist. This is because, the knitted article is frequently used for providing an indirect indication of the yarn regularity. As Webster [3] pointed out, "a plain knitting stitch (loop) involves four diameters of yarn whereas a plain weaving intersection involves two diameters only, and this increases the "sensitivity" of knitted fabrics to visual faults caused by uneven yarns".

In the stressed state on knitting needles, a plain knit loop has almost perfect bilateral symmetry about a vertical axis (Fig. I.1b) which would be retained during subsequent relaxation of the structure if the yarn was a torque-free uniformly dense, cylindrical rod [4]. Unfortunately, this is never the case and the relaxation of a fabric towards its state of minimum internal energy is accompanied by changes in the three dimensional configuration of the constituent loops to varying degrees.

These changes are responsible, in some cases, for totally unacceptable appearance of fashionable knit goods, produced on any kind of knitting machines (flat V-bed, circular, "Cotton"). The exact adjustments of the machine, the knowledge and the monitoring of the yarn behaviour, yarn characteristics and construction effects, can predict the fabric behaviour [5], but do not eliminate the faults in the knits [6].

Some knitted goods are specially processed for "permanent" structural and dimensional stability. The stabilising processes are inadequate because after washing, loop distortion occurs, resulting in changes in the shape, structure and texture of the knitwear. This is particularly evident in single jersey knitted fabrics [6-8].

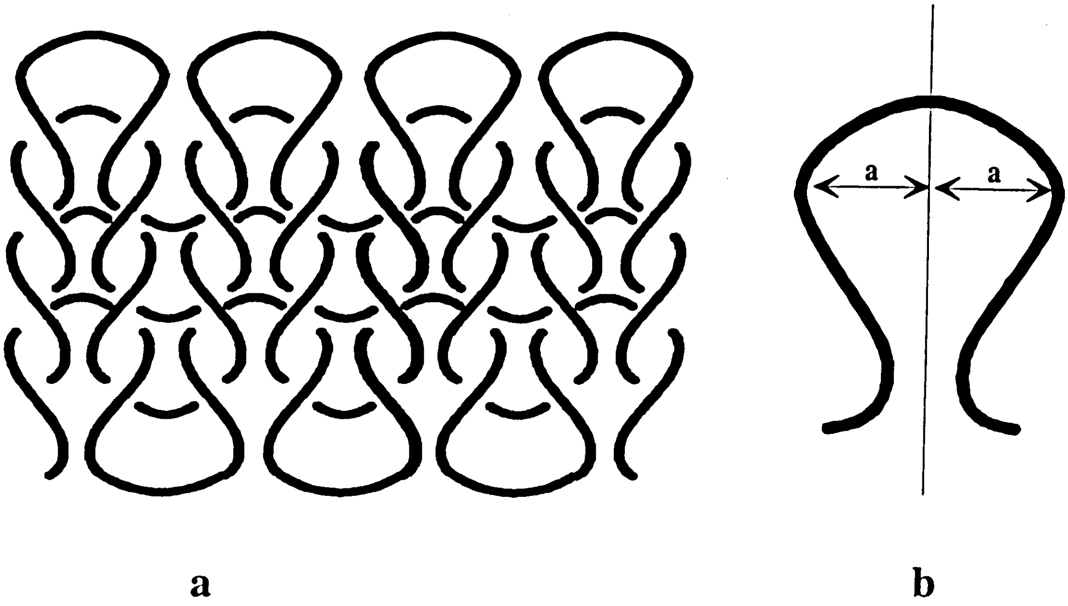


Fig. I.1 Plain Knitted Fabric (Single Jersey) and Its Repeating Pattern (Loop)

It is widely accepted that the main effects of the loop distortion, appearing in the knitted fabrics, are the *cockling* and *spirality* effects. Spirality is a problem that appears not only in knitwear articles, in terms of shape and pattern distortions [9], where the majority of consumers make complaints, but also in the making-up industry [10] where it causes great trouble to the manufacturers of knitwear.

Textile technologists and knitwear manufacturers attached great importance to possible permanent solutions to the problem of spirality (skewness). This is because spirality affects the *quality* of the knitwear, which is a predominant factor in today's global market. The work reported in this thesis begins with a review of previous experimental and theoretical studies into the phenomenon of spirality. Both the effects of spun yarns and continuous filament yarns are discussed and a brief overview of the published theoretical models are given. The review shows that for such models to be any practical value it is necessary for a useable yarn model to be devised which more accurately predicts the yarn behaviour than the current classic helix model. Owing to a lack of such a model, it was considered appropriate to conduct any possible work in the area aimed at the prevention of spirality.

CHAPTER 1

SPIRALITY EFFECT OF SINGLE JERSEY KNITTED FABRICS

1.1 THE NATURE OF SPIRALITY

In many tension-free, tubular single-yarn fabrics, knitted in a plain stitch on a circular one needle system [11] knitting machine, the lengthwise rows of loops (stitches) called needle lines or *wales*, should normally occupy a truly vertical line, parallel to the edges of the fabric and at right angles (90°) to the crosswise rows of loops called *courses*, when the fabric is undistorted. In practice, however, an undesirable phenomenon becomes vividly apparent, where the wales show a pronounced bias towards the left or the right [9,11-18]. This fault occurs particularly in single jersey knitted fabrics and garments [19] which have a dissymmetry of the loop between the face and back of the fabric [12]. This results in *seams* which do not run parallel to the edges of garment made up from such material, although the line of courses remains perpendicular to the edges of the fabric [15]. This defect has been appropriately termed by Davis, Edwards and Stanbury [20] as "***spirality***", since it occurs chiefly in tubular fabrics, where the wales follow a spiral path around the axis of the fabric, forming an angle with the perpendicular. The comparable defect on a flat knitted fabric is referred to as *wale spirality* [21] where the wales follow a sideways direction forming an angle with the perpendicular. This angle is termed as the "*spirality angle*" and is a measure of the fabric spirality [22].

If the loops of each course on the technical face of the fabric, which has been produced on a knitting machine, are examined closely, an inclination to lean slightly to the right (or left) is observed, indicating an excess of yarn on the left or right hand side respectively of the loop, i.e., the formation of each loop is just a little lopsided [23]. The lifting of the one side of the knitted loop from the plane of the fabric [22] is the cause of the appearance of an almost rib-like structure form, as the wales are bunched together [15].

When the fabric is on a knitting machine, the magnitude of this distortion is unpredictable because of the imposition of strains on it due to the *take-down* tension [24]. As the fabric is released from the stress due to this tension, a complete change occurs in the shape of each of its unit cells (loops). This rearrangement of the fabric structure results in an initial fabric distortion. If the fabric undergoes a process of wetting (immersing in water, dyeing, washing), there is a further distortion of the fabric which is mainly a result of reappearance of the forces in the yarn which have been "relaxed" in the earlier steam setting of yarn [25]. This factor must be recognised in producing a commercially acceptable washable product [26,27].

Many workers [7,9,12,17,28-31] who dealt with this phenomenon of spirality agree that the main reason for this defect "is the unbalanced torque within the yarn, shown by its ***twist-liveliness***, the release of torsional potential energy in the yarn" [4], rather than just the presence of the twist alone. In combination with the unbalanced active torque in the yarn, there is the contribution of fabric geometry. The degree of freedom of yarn movement in the fabric structure contributes significantly to the rise of spirality [32]. The more slack the fabric structure, the greater the spirality. This slackness can be achieved by two ways: by changing the tightness factor or, by changing the linear density of the yarn. It has been stated [4] that the loop twisting, over to approximately the same angle as the spirality angle, is the result of the section of yarn in each loop that is trying to move to "a state of lower strain under the constraint of forces from neighbouring loops" [33]. It has been shown [34,35] that much of this distortion arises from the residual torque in the yarn. Newly produced ring spun yarns exhibit a tremendous tendency to untwist, before being treated with any dry or wet relaxation method. This phenomenon could be explained by taking into consideration that, elastic stresses as well torsional forces (torque), set up in the component fibres by the twisting action during the spinning process, attempt to be relieved. This tends to cause an opening up of the yarn and gives rise to yarn and fabric defects (e.g., snarls, spirality, cockling) [12,22]. Hence, "the greater the twist-liveliness, the greater the spirality" [15]. At this point it is necessary to mention that, although this statement is generally acceptable, it was found in the literature that there is a confusion between the *twist amount* in the yarn and the *yarn torque* [20,36,37]. Some statements which reflect this, are given below:

"...the degree of spirality is related to the twist factor (number of turns per length of the yarn)" [18];

"Yarns with lower turns per unit length, tend to develop less spirality in the fabric than yarns with high twist levels..." [22].

"...spirality increases with the turns per inch ..." [38];

"...spirality is often due to an excess amount of twist in the yarn from which the fabric is knitted..." [39];

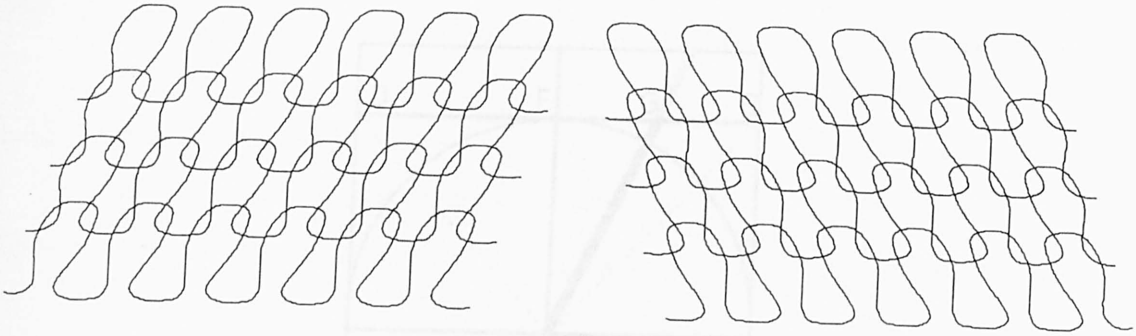
"...spirality which coincided with twist in the yarn..." [40].

1.2 DIRECTION OF SPIRALITY

It is well known that the direction of the spirality in fabrics knitted from singles short staple yarns is normally determined by the direction of the yarn twist [6,9,11,14]. If a Z-twisted yarn is used for the production of a knitted fabric, the technical face of the fabric exhibits spirality in the Z direction and vice versa [17] (Fig. 1.1, Plate 1.1).

1.3 MEASUREMENT OF SPIRALITY

The angle of spirality can be measured with the help of a protractor, or by using a specially designed transparent plastic board as is illustrated in Figure 1.2. The line EF, which is perpendicular to the sides AB and CD of the rectangle ABCD, plays the role of the reference line of a wale in the ideal perpendicular relation that exists between wales and courses in an undistorted knitted fabric. If the line AB tallies with a course and the line EG lies along the actual line of the wales, then the angle FEG is the angle of spirality. Using the distances AD = 10 cm and FG (**h** cm), Oinuma and Takeda [29] calculated the "*percentage spirality*" (PS %) which is expressed by the following equation: $PS(\%) = (h/10)\times 100$, and it is considered as the sum of the "*net*" spirality caused by the yarn torque and the "*additional*" spirality caused by all other factors.



Z Spirality

S Spirality

Fig. 1.1 Direction of Spirality (Wale Skew)

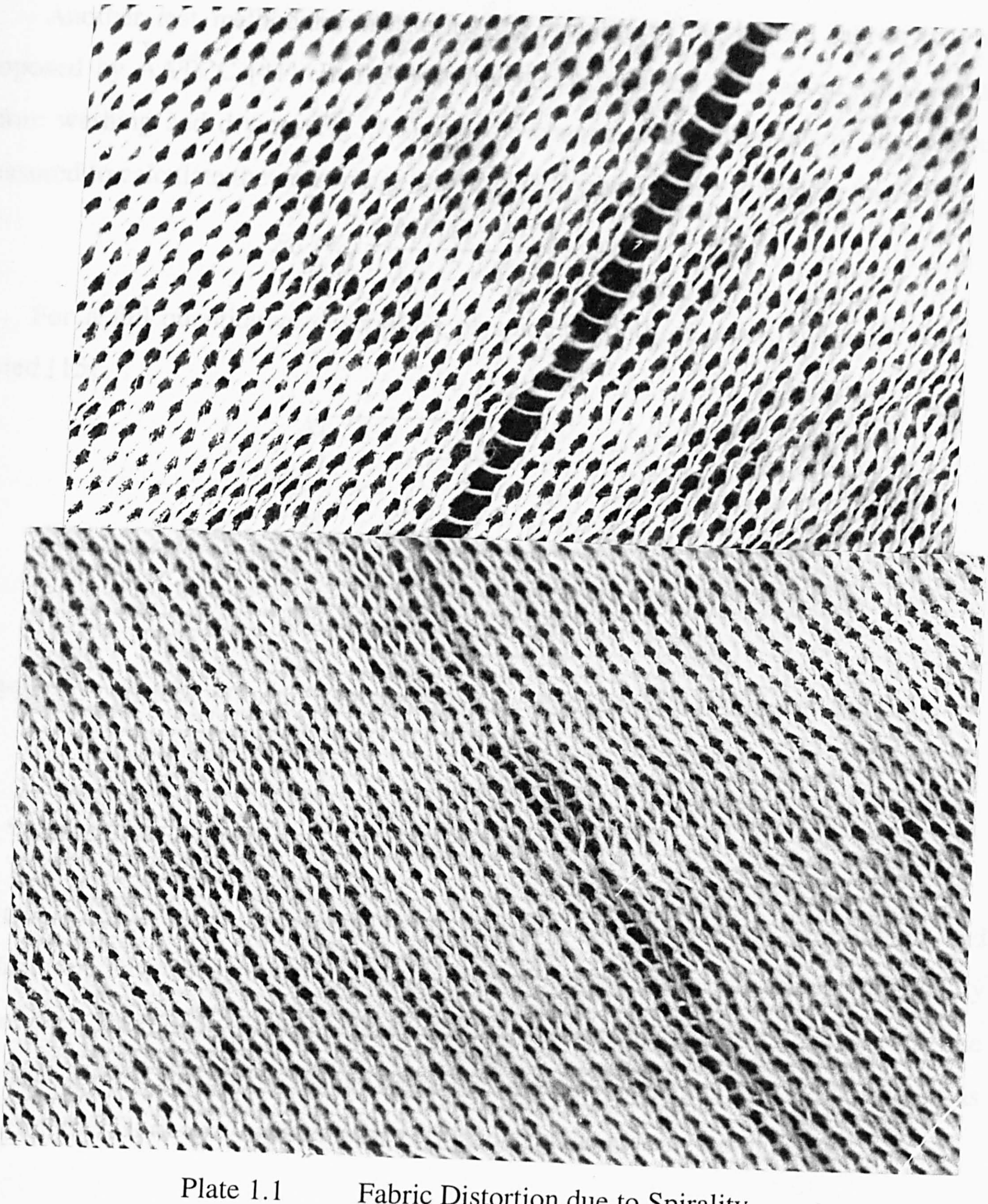


Plate 1.1 Fabric Distortion due to Spirality

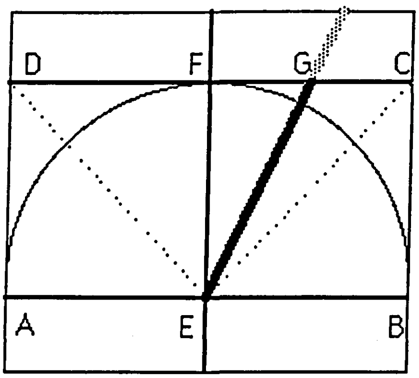


Fig. 1.2 Transparent Board Having a Protractor Configuration on It

Another test method for measuring the spirality of the knitted fabrics has been proposed by AATCC [41]. In this test, the fabric samples are marked with a square before washing and drying (Fig. 1.3) and the change in the diagonals of the square is measured to calculate the *percentage spirality* (*PS*) given by the following formula:

$$PS\ (\%) = \frac{2(B'D - A'C)}{(A'C + B'D)} \times 100$$

For a full quantitative description of spirality, both direction and angle must be quoted [15].

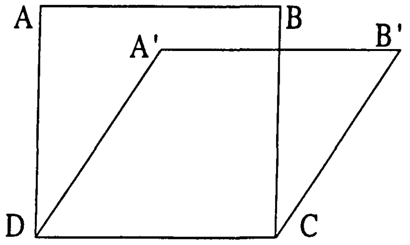


Fig. 1.3 Method for the Calculation of the Percentage Spirality (by AATCC)

1.4 "ACCEPTABLE" SPIRALITY

Over many years in dealing with spirality, many workers, researchers and manufacturers have set limits of spirality acceptability. For some, the maximum spirality angle of 5° is acceptable [32,42] whereas for some others the angle of 7° is taken as the upper limit [4,33]. In United States [43] a *percentage spirality* of 8% is considered as the maximum a fabric may exhibit to be acceptable by the making-up industry.

1.5 EFFECT OF KNITTING MACHINE FACTORS ON FABRIC DISTORTIONS

1.5.1 FABRIC DISTORTIONS

A point worthy of consideration is the effect of the knitting action on fabric distortions. Some aspects of the effect of knitting machine parts and their operations may also prove of interest.

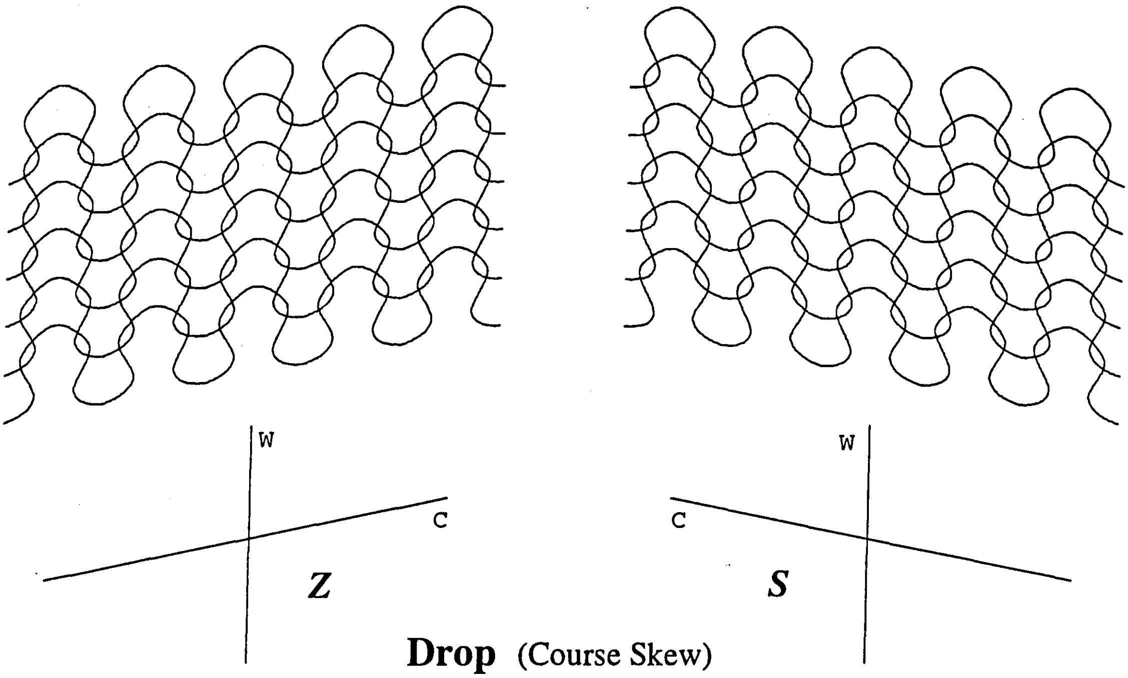
First, a distinction between the "spirality" and the "drop" or "corkscrew" [44] phenomena should be made to avoid any possible confusion.

"If the wales are skewed from the vertical, the resulting configuration is called a "wale skew" (Fig. 1.4a). If the courses are skewed from the horizontal, the resulting configuration will be called "course skew" (Fig. 1.4b)" [41].

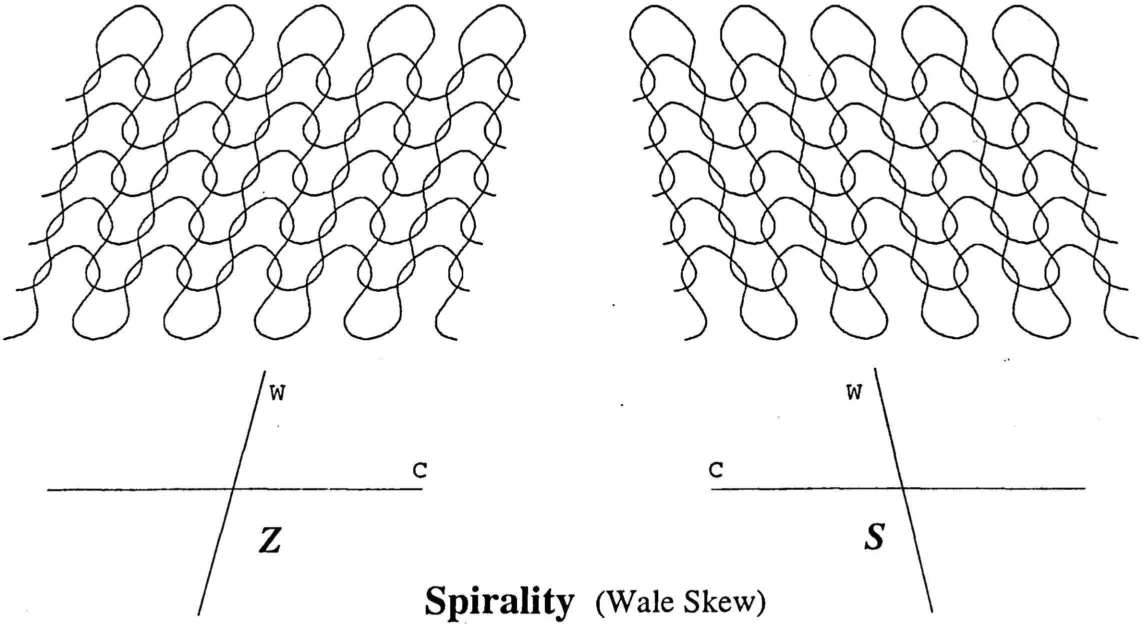
"Wale skew", widely accepted as the well-known term "spirality", is due to the twist liveliness [11,17,41,44]. "Course skew" has been described as the "drop" effect [29] and is inherent in the process. This occurs due to the helical disposition of the courses [12] and depends on the fact that articles produced with a spiral configuration have a "start" and an "end" of a *coil* not on the same plane.

In weft circular knitting machines, fabrics present a course skew because the yarn is knitted in the circumferencial direction [17]. The degree of the course skew or drop depends on the number of feeders used on the knitting machine [11,17,18,29,41]. It is true [12] that in recent years, the machine manufacturers tend to increase the number of feeders. For this reason, the problem is likely to become more acute. The degree of drop is a function of the step S of the helix (Fig. 1.5) due to the number of courses knitted per revolution of the machine, to the number of courses per centimetre [12] and the machine circumference. The direction of the inclination of the drop depends on the direction of either the revolving cam box or the rotating cylinder.

In some papers [11,17] there is the suggestion that both the spirality and the drop effect contribute to the final distortion or "total" spirality of the fabric. It becomes essential therefore, to describe the effect of the number of feeders on the drop phenomenon as well as to investigate the contribution of the drop to the "total" spirality of the produced fabrics.



Drop (Course Skew)



Spirality (Wale Skew)

Fig. 1.4 Compárison between Drop and Spirality Effects

1.5.2 DROP EFFECT

In order to investigate the influence of the number of feeders on the drop effect, the model illustrated in Figure 1.5 has been used.

Assumptions: The height of a course (stitch - loop row) or the distance between the central lines of two adjacent courses (step S of the helix) is one millimetre. In the Figure 1.5a one feeder is used while in the Figure 1.5b, four feeders are used. The diameter of the tubular "fabric" is assumed to be 23 cm. The various curved (spiral) lines represent a possible ideal position of the central lines of the successive courses.

"Opening" the fabric (cutting along a wale) it can be seen that the length of a course in the first case (Fig. 1.5a- one feeder) is smaller than that of the other case (Fig. 1.5b- four feeders).

Following simple geometrical analysis it can be seen that:

$$\mathrm{OL} = \sqrt{((23\times\pi)^2+1)} \Rightarrow \mathrm{OL} = 72.2567 \text{ cm}$$

Also, $\mathrm{OM} = \sqrt{((23\times\pi)^2+4^2)} \Rightarrow \mathrm{OM} = 72.2577 \text{ cm}$

The difference 0.001 cm of the length of the courses due to the insertion of three more feeders can be neglected since the nominal width OK of the opened fabric is 72.2566 cm ($\pi\times d = \pi\times 23$ cm).

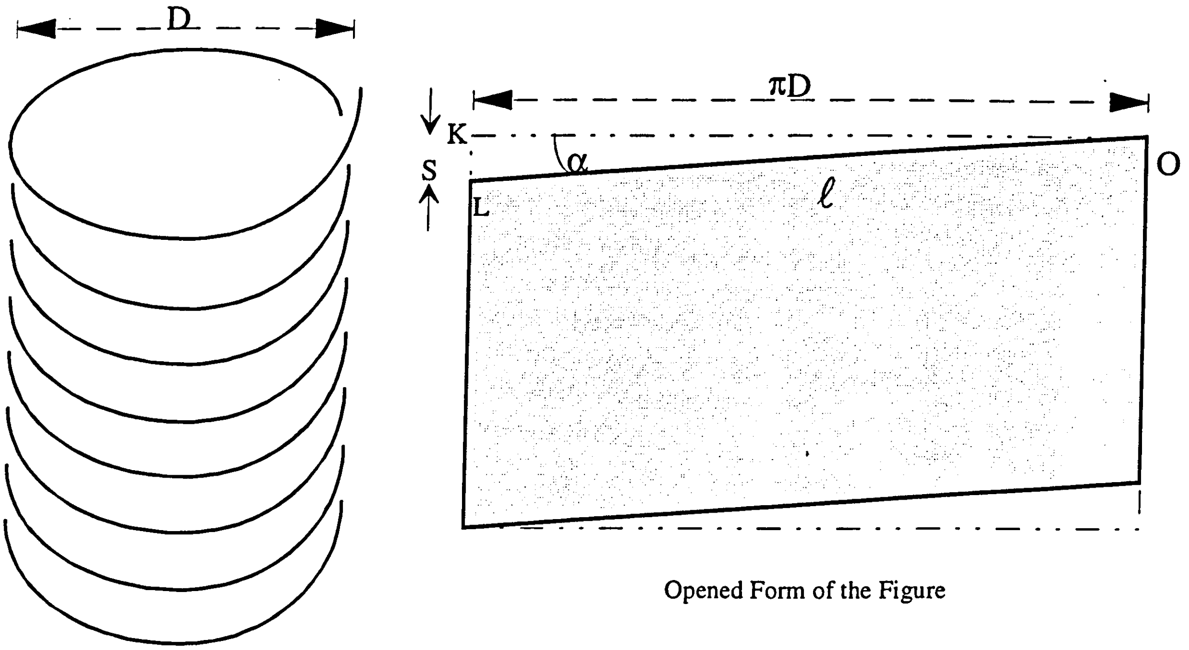
Furthermore, the inclination of the course in the fabric can be:

- for one feeder → 0.00138 % or $\alpha = 0.0793°$ ($\alpha = \tan^{-1}(S/OK)$)
- for four feeders → 0.00152 % or $\beta = 0.317°$
- for 144 feeders → 0.14375 % or $\gamma = 3.038°$

Note: Machines with 144 feeders usually have a diameter of 86.36 cm (34 inches). Therefore the length of a course will be $\mathrm{OX} = \sqrt{((86.36\times\pi)^2+144^2)} \Rightarrow$ $\mathrm{OX} = 271.69$ cm. The width of the opened fabric is $86.36 \times \pi = 271.3$ cm and the angle will be $\gamma = \tan^{-1}(14.4 / 271.3) \Rightarrow \gamma = 0.053$ rad or 3.038°.

The angle of inclination in all the cases is negligible, although the insertion of three extra feeders, in the second case, increases the angle by 75 % (angle β).

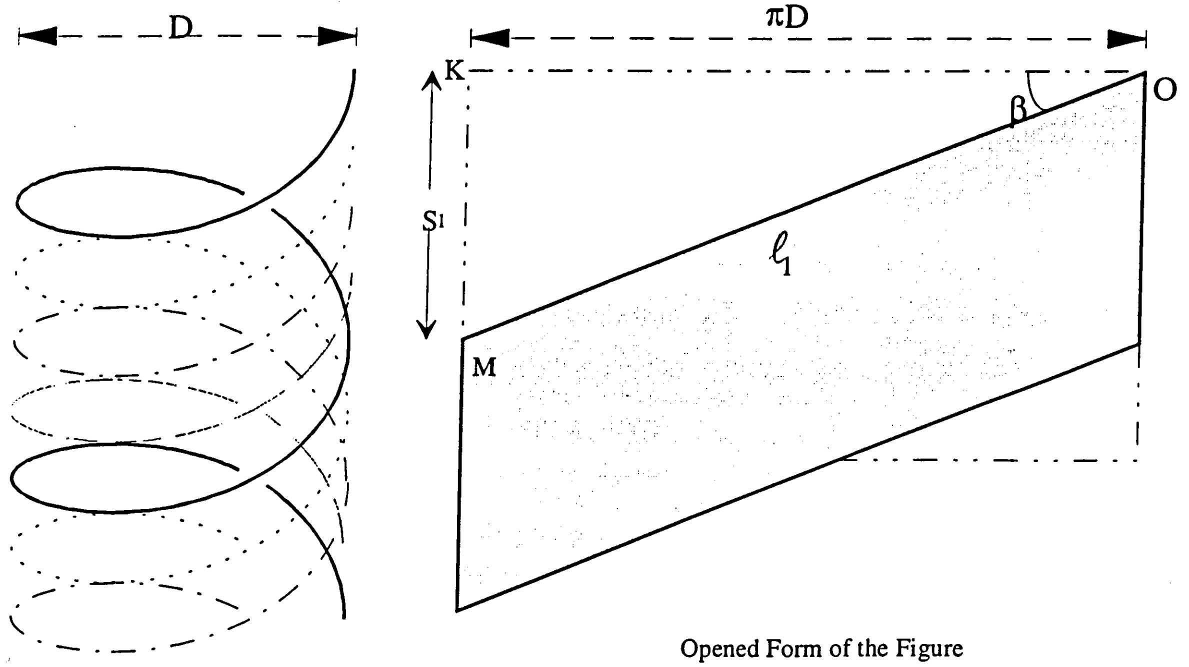
In the extreme case of machines with 160 feeders [45], the inclination in terms of angle degrees could be considered as contributing to the "total" spirality, leading to a first conclusion that a large number of feeders alters, although slightly, the spirality.



Arrangement of a Course in a Knitted Fabric (One Feeder)

Opened Form of the Figure

(a)



Arrangement of a Course in a Knitted Fabric (Four Feeders)

Opened Form of the Figure

(b)

Fig. 1.5 Effect of the Number of Feeders on the Fabric Drop (Course Skew)

Araujo and Smith [11] attempted to explain their statement of "total" spirality by carrying out the following analysis:

Figure 1.6 represents the development of spirality in a single jersey fabric knitted with a Z-twisted yarn on a multifeed circular machine with an anticlockwise rotating cylinder.

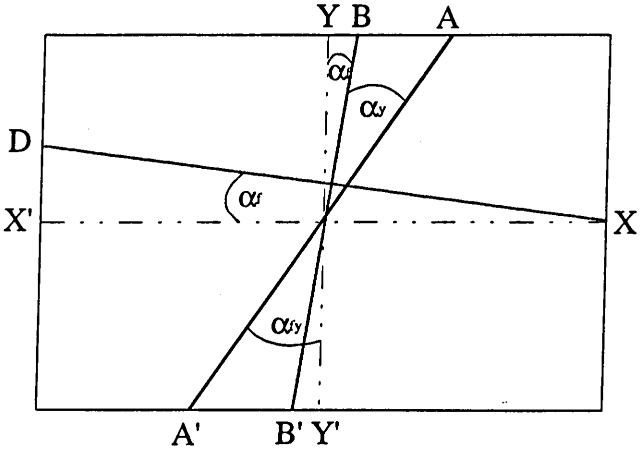


Fig. 1.6 Development of Spirality in a Single Jersey Fabric Knitted from a Z-Twisted Yarn on a Multifeed Circular Machine with an *Anticlockwise* Rotating Cylinder.

XX' = Position of a course due to the total spirality = N / W (open width of fabric);

AA' = Position of a wale due to the total spirality;

BB' = Position of a wale when spirality (drop) due to the number of feeders exists;

XD = Position of a course when spirality (drop) due to the number of feeders exists;

X'D = Displacement between two consecutive courses knitted by the same feeder = F/C;

F = Total number of feeders on the knitting machine;

N = Total number of needles in the knitting machine;

C = Number of courses per unit length;

W = Number of wales per unit length;

α_f = spirality (drop) angle due to the number of feeders (YÔB);

α_y = spirality angle due to the yarn twist liveliness (BÔA);

α_{fy} = "total" spirality angle (YÔA or A'ÔY').

From the triangle DXX':

$$\tan \alpha_f = \frac{F/C}{N/W} = \frac{F}{N} \times \frac{W}{C} \qquad (1.1)$$

Considering that [34] $W = \frac{K_w}{l}$, $C = \frac{K_c}{l}$ (1.2)

and loop shape factor $K_{c/w} = \frac{K_c}{K_w}$ (1.3)

where K_w, K_c are non dimensional parameters whose values depend on the state of relaxation and l is the loop (stitch) length (mm), then,

$$\tan \alpha_f = \frac{F}{N} \times \frac{1}{K_{c/w}} \Rightarrow \alpha_f = \tan^{-1} \frac{F}{N \times K_{c/w}} \qquad (1.4)$$

"This last equation shows that the angle of the course skew (drop) depends not only on the number of feeders but also on the shape of the loop in the particular state of relaxation and on the number of the active needles in the knitting machine, which in turn depends on the machine cut and diameter" [11].

If the direction of the rotating cylinder reverses (i.e., clockwise) then Figure 1.6 will change to the form shown in Figure 1.7, indicating that the overall spirality angle will be reduced.

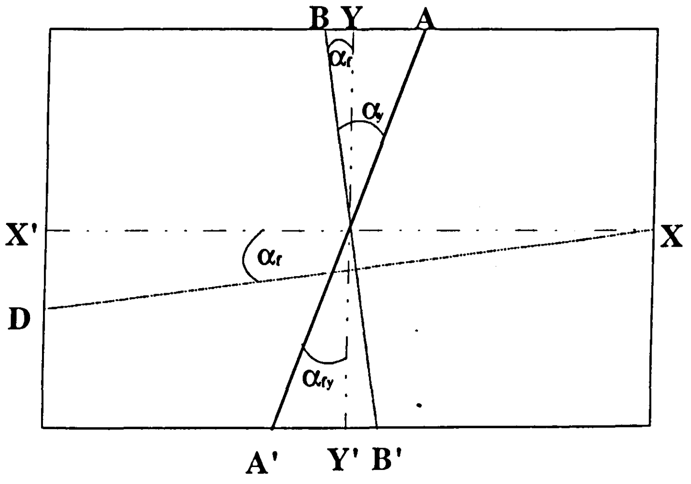


Fig. 1.7 Development of Spirality in a Single Jersey Fabric Knitted from a Z-Twisted Yarn on a Multifeed Circular Machine with a *Clockwise* Rotating Cylinder.

It could be concluded then that, in many cases it would be beneficial rather than detrimental, from the "total" spirality point of view, to use a large number of feeders on a machine, as the drop (due to the number of feeders) and the spirality (due to the yarn twist liveliness) "can combine together to create more skew, or they may partially offset each other and result in less skew" [11,41]. On the other hand, multiple feeders increase the chance of a stripy fabric being produced because of possible yarn linear density and/or shade variation between feeders [46].

Further to the conclusions of the above investigation, it has been suggested [44] that the number of feeders is responsible only for a distorted appearance of the fabric (in terms of drop effect), while the actual spirality is the same whether a single or multifeed machine is used (Fig. 1.8).

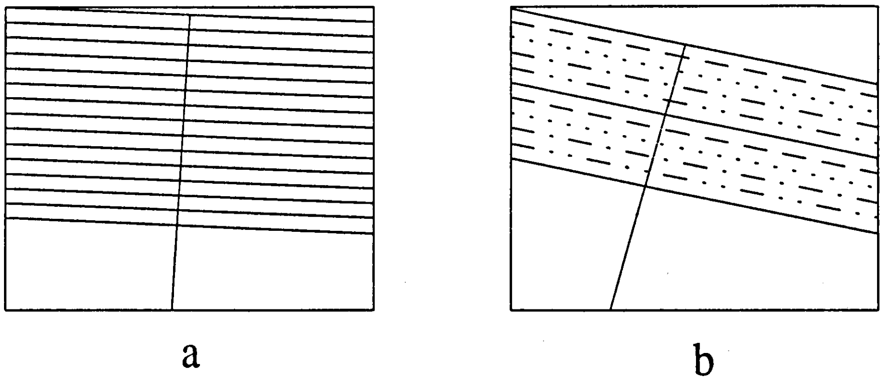


Fig. 1.8 Appearance of Distorted Fabric due to the Drop Effect (a. one feeder - b. five feeders), with 0° Spirality Angle

1.5.3 THE EFFECT OF THE ROTATION AND ITS DIRECTION OF THE CYLINDER AND CAM BOX ON SPIRALITY

In the knitting industry, two types of circular single bed machines are, in terms of their rotating parts, responsible for the knitting action; machines with revolving "cylinder cam system" (cam box) and machines with rotating "cylinder needle housing" (cylinder) [47]. These parts can be rotated clockwise or anticlockwise. Thus, when a knitting machine has a clockwise revolving cam box, the stationary cylinder is rotating relatively anticlockwise, and when a machine has a clockwise rotating cylinder, the stationary cam box is relatively revolving anticlockwise and vice versa.

It has been stated [48] that the direction of rotation of these knitting parts influences the positioning of the loops (stitches). Experiments were, therefore, carried out to determine the actual effect of the direction of rotation on the spirality of tubular single jersey knitted fabrics [17]. In these experiments, a twist-free (neutral) polyester monofilament was knitted on a machine having an anticlockwise rotating cylinder. On a close examination of the fabric produced, a slight tendency of the loops to follow the running direction of the cylinder could be detected, i.e., the individual loops were found to be inclined to the right. The loop shanks on the right were also shorter than those on the left. It has been argued that this was a result of the tension imbalance between the two "legs" of the loop during the stitch formation [11], and this skewness is especially noticeable with monofilament yarn because of its high bending rigidity [17]. "The inclination of the stitches against the direction of knitting can be traced back to the fact that the following stitch shank running in the direction of the thread-feed is subjected to higher levels of tension during interlacing process of the stitches." [49]

Disagreements concerning the actual influence of the rotation of particular mechanical parts of the knitting machine exist between various workers.

It would appear advantageous, in terms of spirality reduction, to work with Z-twisted yarns on knitting machines with clockwise rotating cylinders [11,17,49]. On the other hand, others are of the opinion that the total spirality is reduced when Z twisted yarns are knitted on a machine with an anticlockwise rotating cylinder [23,41]. There are also some workers [12] who make no stand, since their experiments showed opposing results. Still other researchers consider the effect of this factor as negligible [20,50,51]. The results are summarised and presented in Table 1.1.

Table 1.1 Effect of the Direction of the Cylinder Rotation on the Spirality

Direction of the Additional Spirality	Direction of CYLINDER	References
Z	Anticlockwise	12[†]
Z	Anticlockwise	11
Z	Anticlockwise	17
Z	Clockwise	12[††]
Z	Clockwise	23[‡]
Z	Clockwise	29
Z	Clockwise	41

[†] The authors claim that the conclusion of their results is incorrect, supporting that the opposite conclusion of the results obtained by previous workers ([††]) is correct.

[††] ITF Maille: "Le Sens de rotation des Métiers circulaires et le vrillage des tricots jersey", L'Industrie Textile, Mars 1974, p. 1032

[‡] In the case of oscillating cylinder.

This skew effect, due to the direction of the rotation of the knitting machine, is negligible when compared with the possible yarn effects on the spirality angle [12] and can be disregarded [17]. But, even if invisible, it contributes slightly, to an increase or decrease of the spirality angle. This factor related to the spirality should be taken into account when seeking the explanation of relative defects [52].

1.5.4 THE EFFECT OF THE KNITTING SPEED ON SPIRALITY

It could be said that there is no clear picture about how and whether the variation of knitting speed, when comparison is made between machines with the same settings, processing the same yarns, affects the fabric distortion (skewness-spirality). This speed is interwoven with other factors like, for example, the direction of the motion of elements (cylinder, cam box), cam setting, the yarn input tension and yarn lubrication.

From an experiment carried out to investigate the possible effect of speed, it was observed that under high speed conditions (280 revolutions per minute) the resultant fabric appeared to be slightly distorted in terms of spirality (4°). When normal speed (80 revolutions per minute) was used, no spirality could be observed. The conclusion was that "if the speed of the machine had any effect on spirality, it was not a factor of any great importance" [12].

Other workers attempted to relate the effect of the knitting speed on spirality with alterations in the loop length [53-56]. They concluded that there was no correlation. Furthermore, there is an opinion that the velocity affects the lopsideness of the loops in the case of oscillating motion of the cylinder [23] producing an "*additional spirality*" due to the high velocity. Also it has been argued that this speed causes changes in the additional spirality, that is in inverse proportion to the loop length, but not in the spirality due to the residual torque in the yarn [29]. These changes of the additional spirality were attributed to "needle fling", changes in needle direction due to the inertia force on the needle after the knitting point [57].

It was concluded that, since there is no clear evidence of the possible effect of the knitting speed itself on the spirality, it can be neglected.

1.5.5 THE EFFECT OF THE TAKE -DOWN TENSION ON SPIRALITY

One of the factors contributing to a successfully completed knitting cycle is the tension applied to the previously formed loop on the needle (or macroscopically, to the entire knitted fabric), in order to ensure reliable clearing of the knitted loops from the needles [58]. It is reported [59], that there are three main objectives for the existence of this "take-down" tension:

"1. To keep the loop hard against the needle in order to operate the latch to close or to open. Tension is necessary to overcome the flexural rigidity of the yarn that would otherwise move the yarn away from the needles.

2. To prevent the loop and the fabric from moving up and down, as the needle moves up and down. Here, tension is necessary to overcome the frictional force between the needle and the loop.

3. To draw the loops that have just been knocked over the needles."

All power-operated circular weft knitting machines are fitted with an adjustable fabric tension arrangement, allowing the take-down tension to be varied, in order to hold the fabric in position during knitting and advance it at the rate it is produced [58,60]. Usually, this mechanism consists of two to four take-down nip rollers positioned horizontally one next to the other ensuring the avoidance of any fabric slippage. The fabric as it comes out of this rollers system is wound firmly on the take-up cylinder and is termed as a "batch".

It has long been recognised that by altering the take-down tension, the dimensions of a fabric on a knitting machine can be materially affected [61]. In the case of increasing the tension, a marginal increase in loop length occurs [55] resulting in a stretcher - lengthened- fabric, with the consequent decrease in its width [61]. The fabric weight per unit length decreases [58] as the fabric has a lower value of courses per unit length. The main defect that commonly appears in the fabrics is due to the unevenly distributed take-down tension and is termed "bow" [29,62]. Although this distortion seems to be permanent, as long the fabric remains in the dry state condition, being stretched or not, wound on the take-up cylinder ("batch"), giving the impression that "a real change in fabric dimensions has been produced by this adjustment" [58], the change in take-down tension does not alter the yarn length used for the formation of a loop [63] so that no permanent alteration to the knitting quality or fabric dimensions has been made [61]. Oinuma and Takeda [29] have indicated that "input tension and take-down weight affect the loop length". It could be stated that this occurs in cases where there is excessive take-down tension applied to the fabric in the presence of a non positive yarn feeding system [64]. It has also been mentioned, without any experimental confirmation, that an excessive take-down tension influences the take-up of yarn at the feeders, in the case of flat V-bed knitting machines [60].

Some other defects associated with high take-down tension are: "a greater incidence of cuts and holes in the fabric as well wear on the knitting elements and problems when knitting weak yarns" [65].

Considering these statements, it is essential to knit with low yarn input tension and low fabric take-down tension, thereby preventing the tensile failure of the yarn [66].

A factor which has to be taken into account is the fact that there is no widely accepted method for measuring the take-down tension [58]. In practice, due to the lack of calibrated take-down mechanisms, the appropriate setting of this tension relies on experience. Therefore it is doubtful how "the distortion of the fabric on the machine due to take-down tension could be predictable" [67].

It is noticeable that after knitting and during a "dry relaxation" or a "wet relaxation" period, the fabrics, being relieved from strains (mainly due to the take-down tension) imposed on them, tend to be configured to what it is called dry or wet "relaxed physical form". This statement can be tested by comparing the numbers of courses and wales per unit length and width, measured before and after the relaxation [24,65,68].

Recent work carried out by Hepworth [69], investigating this effect by using a theoretical model, showed that there was a range wherein the angle of spirality increases with the take-down tension. In the knitted structure, the contact points between yarn loops are under considerable pressure which results in jamming. It is only when the fabric tension has reduced that pressure, that the spirality begins to decrease as the courses start to become separate. The conclusion was that the relaxed fabrics showed higher spirality than when subjected to take-down tension.

1.5.6 THE EFFECT OF THE CAM BOX SETTING (*Tightness Factor*) AND MACHINE GAUGE ON SPIRALITY

An investigation of the relationships of the course and wale spacing before and after laundering, in the case of relaxed fabrics, showed a linear relation, indicating that the changes of the loop shape are similar in both tightly and loosely knit materials [25]. On the contrary, some workers disagree with this statement, indicating that "the spirality of the loops is much greater when the fabric is slacker" [12,70] or, the tighter the knitted structure, the less distortion develops. This is attributed to the jamming that tends to occur with tighter stitches; "the tighter the stitch, the less the neighbouring yarns in the loop can move relative to each other" [71].

Another point worthy of mention concerns the stitch length and the yarn count; "A fabric produced with a shorter stitch length or relative tightness at which a fabric is knitted, for a given yarn count will develop less spirality when compared to a fabric produced from the same yarn at a longer stitch length" [22].

In terms of machine gauge, there are conflicting opinions. On the one hand it has been stated that the spirality increases with the coarseness of the gauge [70]. On the other hand, it is claimed that "the spirality of a fabric increases with the fineness of the machine gauge, for a constant angle of yarn twist. The rate of increase appears to vary with the type of machine used" [38].

1.6 EXISTING METHODS FOR THE REDUCTION OF SPIRALITY

"Spirality, although as old as the hills, is regarded as a mysterious disease, and as such requiring mysterious cures. The facts of the problem are delightfully simple, the difficulty usually arises when a practical cure is being sought" [28].

"Theoretically the effect of spirality must exist, potentially at least, with all single yarns except in the case of twistless yarns " [13].

Various methods have been adopted for overcoming this defect. These are now described.

1.6.1 MECHANICAL METHODS

1.6.1.1 *Use of Folded Yarns*

Many workers [9,11,13,15,16,18,20,22,24,29,30,36,38,41,42,49,72-74] agree that the most suitable method for producing spirality-free knitted fabrics is by using two-folded yarns. These yarns are called "dead", a term used in the industry, as they are left with a reduced or null residual torque or twist-liveliness [75]. This is because the twisting together of two ends of yarn, having the same twist direction, in the opposite direction to the spinning twist, exerts a balancing and stabilising effect [9]. The opposing torsional forces in the singles yarns and the resulted folded yarn are counterbalanced. Because of problems in dealing with the appropriate relation between the two amounts of twist, "any small amount of spirality which may develop will be in the direction of the residual twist" [22].

Replacing singles yarn by folded yarn, gives rise to an improved fabric appearance; a smoother touch [49], even light reflection [76], better stretch and more vigorous recovery in the resultant fabric [77]. Also, folded yarns are more resistant than a singles yarn to the effects of distortion and other physical effects [78], and can be made even more stable if the yarn package is dyed in this form. On the other hand, the use of two-folded yarns in knitting single jersey fabrics has the disadvantages of high yarn material and yarn production costs. Garments (e.g., T-shirts) knitted from such yarns are heavier, which is often an undesirable factor. For a given end product, the singles yarns used for the production of the two-folded yarns must be finer resulting in a dramatic increase of the production costs.

1.6.1.2 *S-Twisted and Z-Twisted Singles Yarns in the Same Feeder*

When using two ends of yarns, having equal twist amounts and in particular, equivalent twist liveliness, but opposite twist directions (S, Z), in the same feeder, the tendency to distort the formed knitted loops towards the one or the other direction (S, Z) are neutralised [15,20,29,32]. Therefore, the produced fabric appears to be straight (Plate 1.2).

In practice, it is difficult to produce yarns with exactly similar twist liveliness and fabrics produced by this method show a small degree of spirality. In fact, it has been suggested that the degree of the spirality angle, "corresponds approximately to the algebraic mean of the spiralities given by the two yarns when knitted separately" and is smaller than the any one of them used individually [17]. In addition, the spirality of this resultant fabric assumes the twist direction of the yarn with higher twist level or twist liveliness. It may be said that this method, similar to what is termed "plating" [11,49], is an effective technique for keeping the spirality of the produced fabrics to a minimum.

1.6.1.3 *S-, Z- Twisted Singles Yarns in Alternate Feeders*

As stated earlier (§ 1.2) Z-twisted yarns produce Z spirality, and S-twisted yarns produce S spirality. Therefore, knitting alternate ends of S- and Z- twisted yarns with equivalent twist levels, will produce an overall "spirality-free" fabric (Plate 1.3) [12,14,15,22,29,32,41,42,49]. Unfortunately, this method although reducing spirality, results in a fabric which has an irregular and uneven appearance, and presents a "cockling" effect on the fabric surface. The reason for this appearance can be identified by closely examining the wale loops. Loops in each course are distorted in opposite directions, following the direction of the yarn twist, producing a "herring-bone" effect [32].

Although this method is not suitable for the production of cotton or wool plain jersey knitted fabrics [29], it is commonly used in the manufacturing of stretch stockings made from fine nylon yarns [42]. The "herring-bone" effect, which is not objectionable in the latter case, gives the fabric a greater potential for lengthwise stretch.

In both methods presented in sections 1.6.1.2 and 1.6.1.3, the replacement of the yarn packages can reduce the fabric quality and lead to problems, as both these techniques are labour intensive. They include yarn package marking [20] and inspection for the avoidance of mixing the yarn types during the fabric production.

Recently, a "Z technology", introduced by Monarch [98] to knitting machines, appears to be less prone to spirality. No information regarding this technology is yet available. It is probable that a new type of sinker movement induces less torque in knitting with latch needles.

1.6.2 CHEMICAL METHODS

1.6.2.1 *Wool*

Although fabrics produced from cotton yarns are the object of this thesis (see § 2.1.1), it may be of interest to note that probably, the first attempt for chemical correction of the detrimental effect of spirality, was made on fabrics produced from crossbred worsted yarns. King [13], has reported that spirality in such cloths disappeared under a "cold crabbing" process (using cold sodium sulphide solutions). In explaining the mechanism of this process, he concluded that "it is the cross linkage (disulphide linking) which is mainly concerned in the spirality removal". However, the

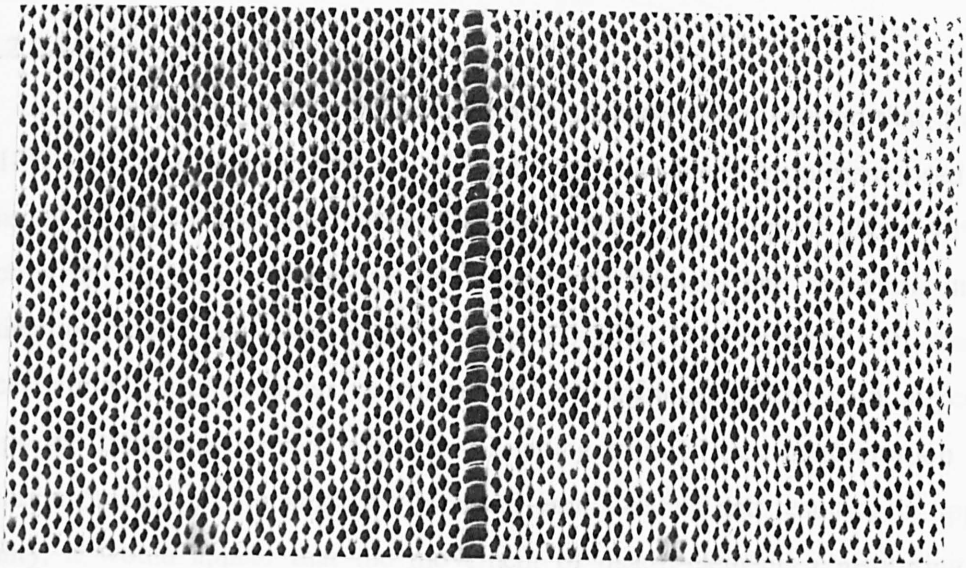


Plate 1.2 Knitted Fabric Produced from S- and Z- Twisted Yarns Feeding the Same Feeder.

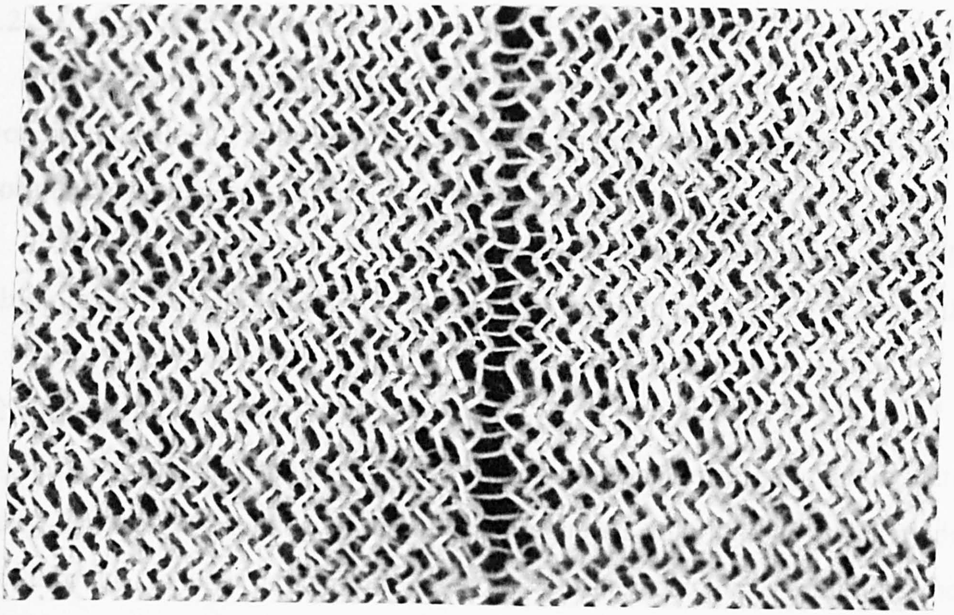


Plate 1.3 Knitted Fabric Produced from S- and Z- Twisted Yarns Feeding Alternate Feeders. (*Note the "herring-bone" effect!*)

use of sodium sulphide causes decomposition of the wool fibres resulting in the weaking of the fabric.

1.6.2.2 *Mercerisation of Cotton Yarns*

Experiments carried out by Banerjee and Alaiban [70,80] showed that, there was a 10-13% reduction in spirality in dry relaxed fabrics produced from mercerised yarns. In terms of twist-liveliness, the mercerised yarn exhibited a drop of about 45%. Yarns which were not mercerised were also made into fabrics. The reduction in spirality obtained by mercerising in the fabric state was 20-30%. They reported [70] that, "fabric mercerisation causes a larger reduction in loop asymmetry than yarn mercerisation, though the treatment remains the same. Keeping in mind that mercerisation is a wet relaxation process accompanied by fibre and yarn swelling and resulting in appreciable mobility, it would appear that the movement of macro-elements constituting a fibre, plays a decisive role in the relaxation process." Their conclusion is in agreement with that of previous workers [38] and states that although mercerisation is an efficient wet relaxation process giving the best results compared to others [16], it is not a complete solution, as the spirality of single knitted fabrics is concerned.

1.6.2.3 *Use of Small Percentage of Low Melt Polyester Fibres*

In this method a small percentage of low melt polyester fibres is blended with cotton. The resulting yarn is heat treated. This process melts the polyester preventing the cotton fibres movement and reduces spirality [11].

This method does not completely eliminate spirality, and it is possible that the resulting texture is not pleasant to the wearer as the yarn and fabric become rather stiff.

1.6.2.4 *Application of Resins* [18,41]

Resin treatments, known as cross linking are used sometimes for reduction of the spirality. The resin is applied to the fabric in aqueous solution and is set by passing the fabric through a high temperature stenter. Besides spirality reduction, the process improves dimensional stability, appearance and handle. The main drawback is the weakening of the cotton fabric.

1.6.3 FINISHING METHODS

For the minimisation of the various defects such as yarn snarliness, spirality and cockling that arise from the yarn "twist liveliness", the twist setting, i.e., "the process of relieving the stresses set up in textile fibres by twisting" [81], or relaxation process may be applied. The main requirement for this process is the action of heat in the presence of moisture on the yarn [82]. As many workers have mentioned [11,12,16,20,30,38,42, 51,81,83-89], twist setting results in an improvement of the mechanical stability of yarns. This process ensures that even highly twisted yarns become "dead" whilst retaining their twist level.

1.6.3.1 *Yarn Setting*

A number of yarn setting methods has appeared in the Textile Industry that have as a common characteristic, the setting of atmospheric conditions of high temperature and high humidity.

A method, used in the past showing good results in terms of twist relaxation, was the "yarn storage" method [49,90-92]. Single yarn twists more easily when it has had a resting period of time, allowing any static to disperse and giving the yarn a chance to pick up some of the moisture content lost during drawing and spinning [91]. Storing the yarn packages for a proper period of time at adequately high temperature and relative humidity (70-75%) contributed to a twist relaxation. However, it is necessary to exercise care to protect the yarns from condensed water, since "water condensing on walls, ceilings or pipes must be prevented from dropping on the yarn and causing subsequent stains, spots and imperfections in the goods" [92]. This technique could not be recommended for today's industrial conditions where a speedy flow of all material throughout the mills is of paramount importance.

A more effective method of twist setting is accomplished by subjecting the yarn to a hot and humid conditions for a period of time, sufficient enough to bring out the "deadness" required - depending upon the level of yarn liveliness [83,93]. More severe setting will be required when the degree of the yarn twist is greater [20,94]. For this method, yarn in package form is placed in a perfectly enclosed chamber and regulated humid air (heated air and moisture) is forced into the chamber for a given period of time [84]. It should be clearly understood that highly twisted yarns must be set under tension in order to avoid the permanent fixation of the snarls which can occur when the yarn is in the hank form [93]. A suggested method concerning setting yarn in the hank form is described as follows [88]: "The operation of setting yarns consists in placing the hanks upon two pegs at a suitable distance apart. The yarn thus mounted is then immersed in boiling water for some minutes, after which it is taken out and the pegs moved further apart by a screw mechanism, which stretches the yarn straight. After this the yarn is again immersed in the water for a further period to complete the setting operation. The particular dangers against which it is necessary to guard in this operation are, first, the period of immersion of the yarn in the water, and second, the amount of tensile strain placed upon the yarn whilst it is in the boiling water." A similar method was to stand the yarn over a basin of water through which water vapour bubbles [95]. Also steaming at 100 °C at the normal atmospheric pressure is practically equivalent to boiling in water, without the disadvantages of the latter (e.g., the motion of boiling water gives a felting effect in the case of treating wool yarns) [96]. Good results are also obtained by subjecting the yarn to dry steam in a vacuum [95].

Today, sophisticated vacuum autoclave steamers are used. Their advantage is that an even penetration of the steam to all the parts of a yarn package is achieved by evacuating the steam space, i.e., the air is removed, which makes it possible for the steam to penetrate the yarn properly [97]. It has also been suggested that better results can be obtained by repeated periods of steaming, interrupted by conditioning periods, than by one long period of steaming [95]. It has been noted [11] that steam set yarns exhibit an improved knittability as the instability created by yarn bending during knitting is reduced.

The mechanism whereby steaming relaxes the yarn liveliness has been explained by other workers (see also Appendix I):

"The release of strain in cellulosic fibres is easily achieved by the use of swelling treatments. H-bonds between cellulose molecules and between adjacent fibrils are broken, and the required relative movement of structural units can take place. Improved orientation is also brought about in cotton because of the restrictive effect of the primary wall and winding layers. The reformation in H-bonds during de-swelling is also easily understood, but the stability that can be achieved has not been widely appreciated" [98]. Efforts to reach a fuller understanding of the twist setting process mechanism related to the steam penetration into the inner layers of the yarn, had no satisfactory results [29].

"If new bonds between structural elements can be formed in the strain-free condition while the fibre is still swollen or, better still, during the final stages of deswelling, then effective setting should be obtained." [98]

"Moisture absorption acts in much the same way as the secondary thermal transition in fibres by making a dry, rigid, hydrogen-bonded structure become unbonded and mobile. The setting of cotton fabrics upon drying is an example of this." [99]

"The action of water on the loop structure from a hydrophilic yarn is more than one of simple lubrication; there is a chemical effect on the fibre molecules. On immersion in water, breakage of cross-links between adjacent long-chain fibre molecules occurs as the water molecules penetrate between them. These cross-linkages, formed when the yarn was straight, are strained when the fibres in the yarn are bent into the configuration of the knitted loop; it is this strain in the cross-linkages which causes the yarn to straighten again when unravelled from the fabric. Many of these strained cross-links are broken when the fabric is first wetted out, and on drying these linkages reform, not as before, but to give a condition of minimum strain in the loop form, so that the yarn is permanently moulded into the configuration of the knitted loop. Prior to wetting, therefore, the yarn in the fabric is essentially straight, and the stable loop shape is that of minimum energy or minimum bending for a straight yarn." [100]

The steam setting process of yarns is a temporary remedy because it does not entirely eliminate the untwisting torque of the set yarns. Furthermore, the effectiveness of this process lasts up to the time that the yarns and the knitted fabrics they produce, are processed with a wet treatment [7,9,13,17,29,30,42,49,60,98,100-103].

Although the steaming process seems simple, great care must be exercised so as to avoid much damage to the yarn.

Commonly appearing faults due to excessive steaming are [83,89]:

1. The yellowing of the white and white mixture yarns. Once this defect is developed it cannot be rectified.

2. Colour bleeding and staining in dyed yarns.

In the past, it has been suggested [16,20] that water-setting, a process involving placing the yarn packages in a vessel where water was boiling, plunging them into cold water and drying, was rather more effective than steam setting because it caused less discoloration of the dyed yarns. Although this is an advantage, it has been proved that water-setting is not a suitable modern method for the treatment of cotton yarns [98]. It was more effective on wool yarns [38]. The recommended process for cotton yarns was the mercerisation, or the use of two-folded yarns having special balanced twists [16].

1.6.3.2 *Knitted Fabric Setting* [9,11,13,16,20,29,30,44,51,60,71,104,105]

In knitted structures such as single-jersey tubular fabrics, the spirality may be temporarily corrected when it is not too severe. This can be achieved by low levels of fabric strain, achieved by using a former during steam processing or steam pressing. For worsted fabrics, high temperature steaming of the fabric reduces spirality often after scouring but not after dyeing [106]. It should be emphasised here that boarding or calendering of the fabric under ordinary finishing conditions are only transient methods because as soon as the fabric is wet again, during subsequent washing or scouring, it regains its spirality resulting in a consequent loss in appearance and discomfort in wear. In many cases [42] the fabric returns to the distorted shape it might have had, if it was produced from the same but unset yarns: "As the fabric dries out, the configuration of the yarn in loops tends to remain unchanged from that assumed in the wet state. Thus, the fabric is in a "set" condition, retaining very little of the internal stresses which previously existed. This phenomenon is best observed by comparing two yarns from fabrics taken before and after washing. If this is done, it will be found that the dry, unwashed sample tends to return to its original straight configuration. But the sample of yarn from a washed sample, which has been allowed to dry in the knitted state, will, upon unravelling, tend to remain in the configuration of the loop. Thus it is not surprising that the washed and shrunk fabric will not return to its original shape after drying, but retains the new dimensions resulted from wetting." [107]

One drawback of both steam and water setting processes is the drying stage which is time and energy consuming. Nowadays, the use of expensive radio-frequency dryers has reduced the actual time of drying but little work has been done concerning the effect of the use of such equipments on the yarns and fabrics.

However it should be pointed out that neither steam nor water set processes prevent the spirality of the knitted structure entirely. They merely reduce its level [7].

1.7 FALSE-TWIST TEXTURED YARNS

The literature review so far concerns the short-staple real twisted singles yarns and the effect of their twist liveliness on spirality of weft-knitted fabrics. However, spirality appears also in single jersey fabrics knitted from false-twist textured (FTT) yarns. It was, therefore, decided to refer to this special case of spirality, providing a brief description of the false-twist-textured yarn structure and the methods used for the reduction of spirality on knitted fabrics produced from such yarns.

1.7.1 STAGES OF FTT PROCESS - YARN STRUCTURE

1.7.1.1 *Twisting*

The twisting of a continuous-filament yarn takes place in the upstream yarn part, that is the yarn part between the false-twisting device and the twist-determination point.

When a continuous-filament yarn is twisted, two types of deformation are imposed on the filaments: a twist along the length of the filaments, and bending of some filaments so that they follow a helical path about the yarn axis [108].

1.7.1.2 *Heat Setting*

In the production of false-twist bulked yarns, the effect of heat setting is to set the above mentioned deformations into the filaments resulting in torque-free twisted yarns. In practice, it is not possible to achieve 100% setting efficiency. Some technologists have considered the yarn after setting and before untwisting to consist entirely of helically set filaments. These helices are of constant radius with a number of helical turns equal to the yarn twist [109].

According to Denton [109], the filaments, in most false twist textured yarns, are set neither in a completely straight form nor in helices of constant radius, but they migrate between the yarn centre and surface. Thus, a helically set filament when left free to relax, will not take up exactly the same shape as it held in the twisted and set yarn. The filament will tend to untwist and straighten somewhat, resulting in an increase of its helix diameter while, the number of helical turns will decrease [110].

1.7.1.3 *Untwisting*

In the third stage of the texturing process, the yarn is untwisted by the number of turns originally put in, as the yarn passes through the false-twisting device. However, the number of turns set in will be less than this: "As the yarn is untwisted, a stage will be reached at which the turns remaining will equal the set turns" [110]. Hence, when a continuously migrating helical filament within the twisted and set yarn is untwisted by the number of helical turns it contains, half the coils become reversed and half remain unreversed. The reversed coils are those lying on the outer surface of the yarn, set at a larger helix radius, whereas those coils of small helix radius remain twisted in the direction in which they were set (Fig. 1.9a). This is because "the parts of filaments with greater set curvature will tend to crimp more rapidly when the whole filament is relaxed, since their latent bending stress is greater than that of those of a smaller curvature"[109].

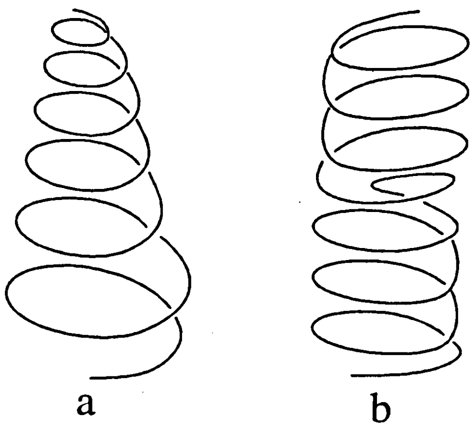


Fig. 1.9 Filament Coils

The untwisted migrating helix can be approximated to by two helices, each of constant radius and angle (Fig. 1.9b). The reversed and unreversed parts of the migrating helix are each represented by a uniform helix whose completely relaxed and completely extended length are the same as those of the section of migrating helix they represent [110].

If a twisted and set continuous filament yarn is back-twisted by twice the number of turns it contains, "the direction of rotation of the helix is reversed (two revolutions being needed to reverse each turn of the helix), but a force F is now required to hold the length constant" [108] (Fig. 1.10a). When the helix is allowed to relax, the coils contract upon each other until a very closed condition is reached. However, considerable torsional stress is stored in the coiled filament acting in that direction to compress the coil still further. To release this stress it is essential the end of coil B moves still further upwards by passing through the centre of the coil. Therefore, the untwisting of a helix by twice the number of turns it contains, results in the reverse of its equilibrium condition (Fig. 1.10b).

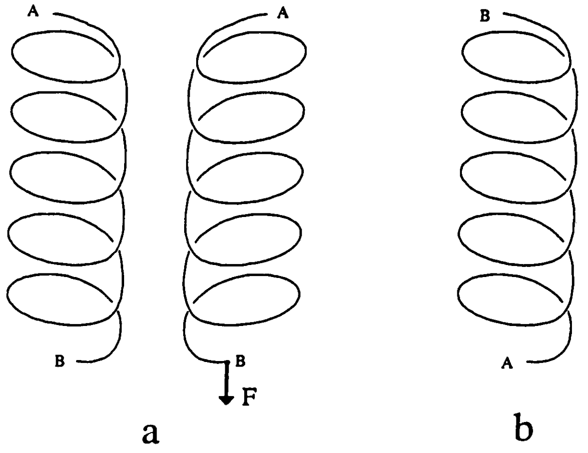


Fig. 1.10 Effect of Back-Twisting on False-Twisted Filaments

1.7.2 MECHANICAL PROPERTIES OF FTT YARNS

As mentioned previously, a false-twist textured yarn could be considered as a system of two helices with equal number of coils having different diameters, where the helix of the smaller diameter is in the reversed state.

Under normal conditions, when these yarns are fully or partly extended, torsional forces are developed in the filaments mainly because of the straightening of the helical structure. The magnitude of torsion depends on the filament geometry and on the degree of relaxation from the fully extended condition.

In fact, three conditions apply as the helical system is extended [110]:

" i. The tensions in the two parts of the helical system are the same;

ii. The torques in the two parts of the helical system are the same;

iii. Although the reversal point at which the two helical join rotates about the axis of the system and thus reduces the total number of helical turns, the number of turns in the larger-radius part of the system remains the same as that in the part of smaller radius."

Expressions for the tension (1.5) and torque (1.6) in a stretched helical spring have been derived by Love [111]. For the helix AB (Fig. 1.11), these may be written as [109]:

$$F_1 = T\left\{\frac{\sin\alpha_1}{r_1}\left(\frac{\sin\alpha_1\cos\alpha_1}{r_1}-\frac{\sin\alpha_{01}\cos\alpha_{01}}{r_{01}}\right)-\frac{E}{2\upsilon}\frac{\cos\alpha_1}{r_1}\left(\frac{\sin^2\alpha_1}{r_1}-\frac{\sin^2\alpha_{01}}{r_{01}}\right)\right\} \quad (1.5)$$

$$K_1 = T\left\{\cos\alpha_1\left(\frac{\sin\alpha_1\cos\alpha_1}{r_1}-\frac{\sin\alpha_{01}\cos\alpha_{01}}{r_{01}}\right)+\frac{E}{2\upsilon}\sin\alpha_1\left(\frac{\sin^2\alpha_1}{r_1}-\frac{\sin^2\alpha_{01}}{r_{01}}\right)\right\} \quad (1.6)$$

where T is the torsional rigidity of the filament and E/υ is the ratio of Young's modulus in bending to the shear modulus, α_1 is the helix angle and r_1 the helix radius whereas α_{01} and r_{01} are the helix angle and the helix radius in the theoretical equilibrium. In each case, the first half of the expression represents the contribution to tension or torque of the torsional stress in the filament and the second half the contribution of bending stress.

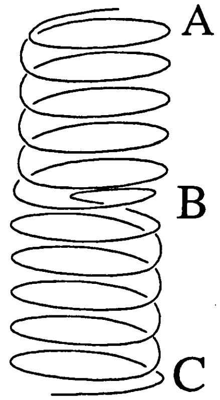


Fig. 1.11 Stretched Helical Spring

1.7.3 EFFECTS DUE TO TWIST LIVELINESS OF FTT YARNS

1.7.3.1 *Yarn Snarls*

When a piece of twist-lively FTT yarn is held by its ends providing a slackness in it, snarl formation takes place. It has also been shown [112] that a false Z-twisted yarn forms Z-twisted snarls in contrast to what happens with twist-lively ring-spun staple yarns, where a Z-twisted yarn forms S-twisted snarls. In the FTT yarns, as the twist increases, the retractive force is observed to increase. Denton [109] has reported that, above a certain surface-helix angle of $\alpha \cong 40°$ and for relaxation of more than 20% from the full extended condition, an increase of twist gives a reduction in torque with an increase in the retractive force. Above this level, the torsional forces in the reversed helix make the most significant contribution. This occurs because the bending component of the helical distortion increases as the helical coils in the twisted and set yarns become flatter, whereas the torsional forces become less important. A great deal of theoretical work on snarl formation in continuous filament yarns has been carried out by Hearle [113].

1.7.3.2 *Spirality*

When a twist-lively yarn is knitted into single jersey fabric, the fabric becomes spiral. It has been shown [114] that the combination of reduced torque and increased retractive force results in a decrease of spirality of fabrics knitted from singles false-twist textured yarns as the bulking twist increases through a practical range of twists. Fabrics knitted from false Z-twisted yarns show an S spirality as viewed from the technical face [112].

According to Denton [115], spirality in knitted fabrics is caused by couples with a component that has a vector direction at right angles to the fabric surface. In Figure 1.12, the couples in sections AB of the yarn (entering the plane of the paper in the diagram) and sections CD of the yarn (leaving this plane), satisfy this condition. If the points A and D are fixed, couples due to yarn with Z spirality, will set on the sections BC of the loop in a clockwise direction and cause S spirality as the technical face of the fabric is observed.

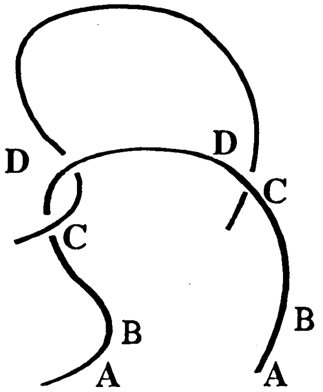


Fig. 1.12 Intermeshed Loops

1.7.4 METHODS USED FOR THE REDUCTION OF SPIRALITY

It is possible to reduce spirality by combining yarns of opposite twist liveliness and by knitting alternate courses with yarns of opposite twist liveliness as described in the previous sections (§1.6.1.2, 1.6.1.3). A method to obtain a torque-free FTT yarn and consequently a spirality-free knitted fabric, includes a post-set stage of false twisting in a direction opposite to that used in the first setting [115]. Recently, an air jet device, called DetorqueJet [116], has been developed that assists the filaments to come to a torque-free configuration in a second heater, called "set" heater, and get set at that state. Such filaments do not show any apparent torque and hence twist-liveliness, and retain most of the texture as imparted in the first stage of the texturing operation.

1.8 THEORETICAL INVESTIGATIONS OF PLAIN KNITTED FABRIC STRUCTURE

From an extended survey of the Textile literature, it is evident that much research has been carried out investigating the dimensional stability of knitted fabrics. A significant amount of this work includes the development of theoretical models of the knitted structures as well as practical methods that have been used for the stabilisation of the knitted structures. Most of the theoretical models were derived in order to explain fundamentally the experimental findings of other workers. In the following paragraphs, a brief description of the various theoretical models that attempt to relate the structure of a plain knitted fabric with the properties of the constituent yarn is presented.

1.8.1 RELAXATION OF KNITTED FABRICS

The application of forces and the generation of couples on a straight unstrained rod may result in the formation of a two dimensional loop. During straining, if only bending takes place, the loop formed is perfectly symmetrical about the central axis. If torque is applied to the rod prior to bending, the loop shape is no longer two-dimensional [34]. In practice, after knitting, the loop shaped yarn, desires to return to its straight state but this is prevented by an equal and opposite reaction from the interlocking yarns. It was Doyle [1] who first suggested that, in the absence of external forces on the fabric, or internal factors such as friction between yarns, each loop in a course would attempt to come to rest in the shape in which the strain energy is a minimum. Furthermore Doyle [117] put forward the hypothesis that the number of stitches per fabric area depends only on the stitch length l.

1.8.1.1 Relaxed Fabric Dimensions

Munden [34] reported that the fabric dimensions are completely determined by the knitted loop length and introduced the following relations that were found to apply to relaxed knitted fabrics: $c = \frac{K_c}{l}$, $w = \frac{K_w}{l}$, $s = c \times w = \frac{K_s}{l^2}$

where c is the number of courses per unit length
w is the number of wales per unit length
s is the stitch density (number of loops per unit area)
l is the loop length
K_c, K_w, K_{cw} are constants such that $K_s = K_c \times K_w$

He also defined two states of relaxation: the dry relaxed state to which unset fabrics would tend on being left to lie on a flat horizontal surface under no tensions, and the wet-relaxed state reached by fabrics that had been wetted in some prescribed way, allowed to dry flat under no tensions and then conditioned in a controlled atmosphere.

A practical approach to the investigation of the relaxed configuration made by many workers [118,119] raises many problems. The treatments necessary to bring a fabric to a relaxed state are lengthy and there is also the difficulty of recognising when such a state has been reached. It has been generally concluded that, "the knitted fabrics should be allowed to relax as freely as possible during finishing in order that they should approach as closely as possible their stable shapes and dimensions which are governed by the normal physical principles of minimum energy stored within the fabric structure" [120]. Nutting and Leaf [121] have shown that most probably, the dimensions of the relaxed loop also depend upon the ratio of the bending rigidity to the shear rigidity of the yarn. This fact highlights the basic inaccuracy of the Munden's model [122] where the three-dimensional nature of the loop has been neglected. For the same reason, Postle and Munden's [123] attempt to produce a force-determined model resulted in inconsistencies.

1.8.2 GEOMETRICAL MODELS OF THE PLAIN-KNITTED STRUCTURE

Chamberlain [124], Peirce [125], Shinn [126], Leaf and Glaskin [35] and Leaf [127] have made attempts to define geometrically the configuration of the unit cell, the loop, of a plain knitted fabric.

The earliest models [124,125] were based on the assumption that the basic structure was such, in which the shape of the loops was a simple arrangement of parts of circles and arcs, joined by straight lines. Peirce [125] also assumed that these loops, in which the maximum packing of the yarns had taken place, lay on a cylinder to allow for the three-dimensional properties of the knitted loop.

Leaf [127] in his model assumed that the loops consisted of two elasticas joined as mirror images and that these loops lay on a surface whose cross section was a sine function. "Unfortunately, this model of the loop cannot be regarded as indicating the mechanism by which the loops are actually produced. The form of the elastica assumed requires that the cloth has a tension on it and also ignores the pressures that must exist at the crossover points" [120].

1.8.3 FORCE DETERMINED MODELS

The attempts for a purely geometrical approach to the structural behaviour of plain-knitted fabrics were not entirely satisfactory. Force determined models analyse the system of inter-yarn forces acting on a loop and by assuming that the yarn behaves like an elastic rod attempt to calculate the loop shape and from that the fabric dimensions. Because the loop is a 3-dimensional structure, the calculation is very complex. The earlier force determined models resorted to simplification in the system of inter-yarn forces which made the solutions invalid. These models include those of Munden's [128], Postle's [129] and Postle and Shanahan's [130]. The only two self-consistent models are those of Hepworth's [131] and Postle and de Jong's [132]. This was because the first problem of interest was focused on the problem of predicting fabric dimensions and also because the difficulty of solution restricted interest to the simplest fabric structure, plain knitting, in which the loops were assumed to be symmetrical. Later, when computers became more powerful and numerical methods more efficient, Hepworth [69] was able to solve more complex structures, e.g., 1×1 rib [133] and plain knitting with asymmetrical loop.

1.8.4 THE THEORY OF BENDING AND TWISTING OF THE RODS APPLIED TO THE IDEALISED YARN

Love [111] has established a general theory of bending and twisting of thin rods. Hepworth [131] summarised this theory as it applied to the "idealised" yarn and derived convenient equations of equilibrium.

An initially straight rod of circular cross-section is considered which is bent and twisted by the action of forces and couples at the ends.

"Let OX, OY, OZ be a system of fixed axes with OZ parallel to the central axis of the rod in its unstressed state. At a section of the rod through a point, P, on the central axis, moving axes P_x, P_y, P_z can be set up so that P_z is along the tangent to the central axis at P, in the direction in which the length S, measured along the central axis is increasing; P_x and P_y are along linear elements of the rod which, in its unstrained state were parallel to fixed axes OX, OY. (Fig. 1.13)

If the point P and the system of moving axes P_x, P_y, P_z were allowed to move along the strained central axis with unit velocity, the angular velocity with which the moving axes rotated would have components κ_1, κ_2, τ, about the instantaneous positions of the axes, where κ_1 and κ_2 are components of curvature of the central axis and τ is the twist of the rod about its central axis."

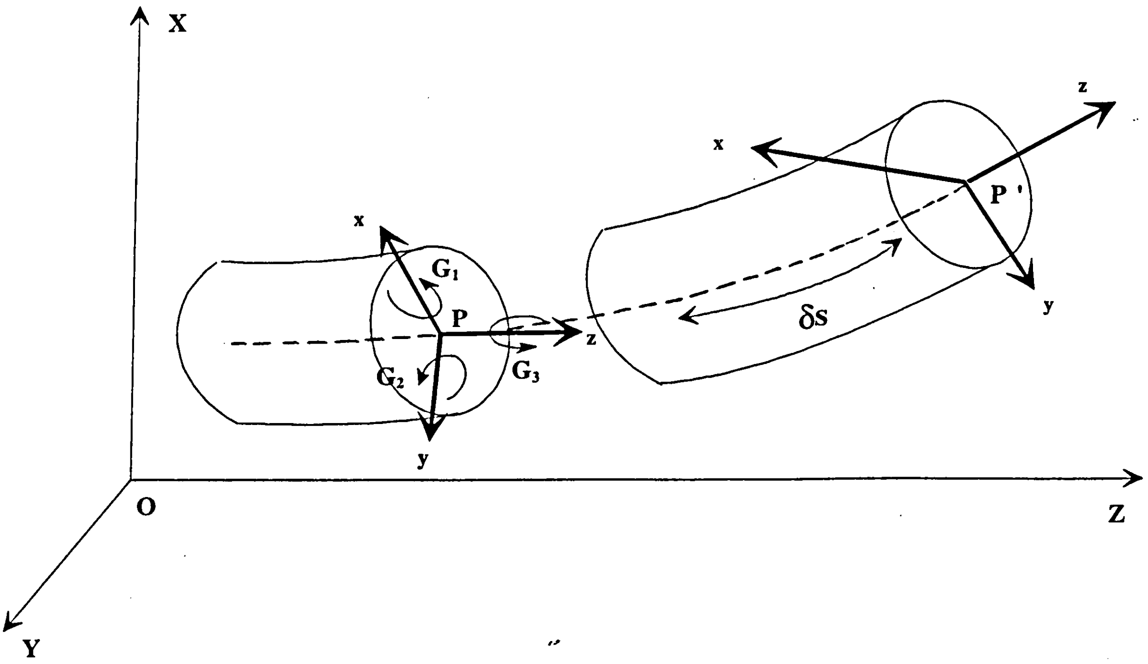


Fig. 1.13 Bent and Twisted Rod by the Action of Forces and Couples at the Ends

The "ordinary approximate theory" of bending used by Love [111] states that, if the stress couples at P have components G_1, G_2 and G_3 about the moving axes then,

$$G_1=B\kappa_1,\quad G_2=B\kappa_2,\quad G_3=C\tau$$

where B and C are the flexural torsional rigidities of the rod [131].

Basically, these are the equations that link the external forces acting on the rod with its resulting shape, since the couples on one side of the equations can be expressed in terms of the forces and couples at the end of the rod, while the curvatures and twist on the other side of the equations can be expressed in terms of co-ordinates of the central axis [134]. These co-ordinates are the rectangular co-ordinates (X,Y,Z) of the point P, together with the Euler angles (θ,φ,ψ) which define the inclination of the moving axes P_x, P_y, P_z relative to the fixed axes as shown in Fig. 1.14

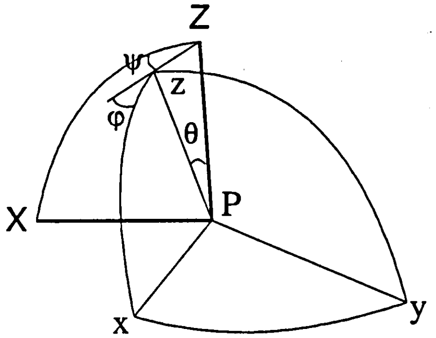


Fig. 1.14 Euler Angles

The curvature and twist can be related to the Euler angles by the expressions:

$$\kappa_1=\frac{d\theta}{ds}\sin\psi-\frac{d\psi}{ds}\sin\theta\cos\psi \tag{1.7}$$

$$\kappa_2=\frac{d\theta}{ds}\cos\psi+\frac{d\psi}{ds}\sin\theta\sin\psi \tag{1.8}$$

$$\tau=\frac{d\varphi}{ds}+\frac{d\psi}{ds}\cos\theta \tag{1.9}$$

where s is the length measured along the central axis of the rod.

The relationship between κ_1, κ_2, τ, and the stress couples G_1, G_2, G_3 and also the relationships:

$$\frac{dX}{ds} = \sin\theta\cos\psi \tag{1.10}$$

$$\frac{dY}{ds} = \sin\theta\sin\psi \tag{1.11}$$

$$\frac{dZ}{ds} = \cos\theta \tag{1.12}$$

provide six simultaneous differential equations which can be integrated numerically to give the co-ordinates and the Euler angles at any point of the central axis.

Furthermore, it was shown [131] that the loop shape is completely determined by the ratio of yarn diameter (*d*) to loop length (*l*). In order to calculate the shape of the knitted loop, it was divided into sections, each bounded by a point of application of a reaction force, and equations of equilibrium were written for each section. The only information supplied to the computer before the calculation was the value of fabric tightness expressed as d/l. The results of the calculations gave values, not only for loop shape and fabric dimensions, but also for the magnitudes and directions of inter-yarn forces.

It was also shown [131] that loop shape varies with the ratio d/l. This is in disagreement with Munden's assertion [122] that fabric dimensions are determined by loop length but it must be pointed out that his fabrics covered a small range of tightness usually found in commercial fabrics. The theoretical calculations also showed that jamming conditions in the relaxed fabric vary with tightness with no jamming for slack fabrics (d/l <0.0313) jamming between courses only for 0.0313<d/l <0.06 and jamming between both courses and wales for d/l >0.06.

1.8.5 NEW APPROACH TO A LOOP MODEL

The models developed described in the previous paragraphs were based on the assumption that the knitted loop was symmetrical. Hepworth [69] modified the previous model (§ I.1.5) by taking into account a twisting couple present in the yarn. This twisting couple represented the yarn twist liveliness. It was pointed out that on introducing this couple the loop shape became asymmetrical and that inevitably led to fabric spirality. Calculations of loop shapes for different values of tightness were made and, in agreement with the experimental observations of previous workers it was shown that spirality increased with yarn twist level and decreased with increasing fabric tightness.

1.9 CONCLUSIONS

The loop formed in the knitting process is essentially a three dimensional structure, interlacing with adjacent similar loops at points whose locations along the loop can easily change. These changes are inevitable due to the presence of forces and couples in the loop shaped yarn, as well as stresses applied to the entire knitted fabric. The knowledge of the magnitudes of the internal forces and couples is essential if the calculation of the loop shape and the relative positions of loops in the fabric is to be made.

For many years, extensive work has been carried out on the relaxation of the fabrics and the effects on their dimensional stability. Furthermore, attempts were made to develop models from a theoretical examination of fabric instability and its causes (§ 1.8.1). These models closely agree with data obtained by measuring and examining actual fabrics. Geometrical models were set up to express relationships between fabric dimensions (§ 1.8.2), followed by force-determined models that included some information about the *physics* of knitting (§ 1.8.3). To solve equations of equilibrium set up by the force-determined models, the use of energy methods was considered as necessary (§ 1.8.4). A recent development in the modelling of the knitted structure (§ 1.8.5) was based on the assumption of the asymmetrical loop shape, where the yarn torque (twist liveliness) was taken into consideration. It could be said that this approach was the first attempt to examine the spirality effect using modelling techniques.

To investigate the problem of spirality a starting point could be to use the recently developed model of knitted fabric which has been discussed earlier (§ 1.8.5), in order to examine theoretically, the behaviour of the yarn twist liveliness and its effect on spirality. A model of short staple yarns, that could include the twist liveliness as one of the parameters would be essential for such a theoretical investigation. However, this would require the modelling of yarn behaviour taking into consideration fibre disposition within the yarn and their interactions under various conditions. Since no such model of yarn exists it was clear that it would be extremely difficult for theoretical examination of the problem to lead to any solution of the problem of spirality. A more practical approach was therefore considered appropriate in an attempt to study ways of overcoming spirality. Such an investigation therefore requires the production and the detailed study of yarn and fabric samples. The results of such work are presented in the following chapters and may be helpful for other workers to develop models that could minimise the existing gap between data obtained from the theoretical and practical investigations.

1.10 PURPOSE OF THIS PROJECT

It is evident that any improvement in the dimensional stability of plain-knitted fabrics could be a boost to the single jersey industry. It was therefore decided to re-examine the existing methods for the reduction/elimination of the spirality effect. In parallel, this project was concerned with research leading to the development of a mechanical method by which a permanent solution, resulting in spirality-free knitwear, could be achieved, free from the disadvantages of the already commercially used methods. The focus was therefore, research into preventing the formation of spirality rather than methods for its removal.

CHAPTER 2

PRELIMINARY EXPERIMENTAL WORK

2.1 INVESTIGATION OF THE EFFECT OF YARN FACTORS ON SPIRALITY

The general conclusion of the literature survey presented in the first chapter, concerning the reason for the appearance of spirality on the knitted fabrics, is that the main factor responsible for this defect is yarn twist liveliness. Twist liveliness is a yarn characteristic that describes the active torsional energy present in the yarn. Its magnitude depends primarily on the amount of twist inserted in the yarn, i.e., the twist factor. Because spirality appears commonly in fabrics produced from singles yarns, it was decided to produce a range of singles yarn samples having different twist factors in order to investigate the effect of the twist and the twist liveliness on spirality. Furthermore, it was considered necessary to examine the alteration in the yarn twist due to the method of unwinding the yarn from its package as well as the shape of the yarn package, and its effect on spirality.

2.1.1 PRODUCTION OF YARN SAMPLES

It was decided to produce a range of cotton yarn samples suitable to be knitted as singles, rather than the more common use of two-folded yarns. The reason for choosing cotton as the material for the experimental work was its almost exclusive use in the knitting industry for the production of T-shirts and underwear garments, products where the spirality effect is severe. The *gauge* (number of needles per unit of circumferencial length) of the circular knitting machine available for the experimental work of the fabric production, determined the yarn linear density (namely 30 tex and 40 tex). Three twist factors (TF 29.0, 32.0, and 36.0 turns.cm^{-1}.tex^{½}) twist direction Z for both the yarn linear densities were used, giving a total of six samples. These yarn samples were wound onto cops and cone packages.

2.1.1.1 *Yarn Spinning*

The yarn samples were spun from Greek cotton, using a carded roving of 0.65 ktex on a Rieter G4 ring spinning frame, with the following specifications:

Table 2.1 Specifications of the Ring Spinning Frame

	30 tex	40 tex
Drafting gears (A)	70/33	78/49
Draft 11.024 ×(A)	23.38	17.55
Speed of delivery roller ($m.min^{-1}$)	12	14

Table 2.2 Twist Calculation

Nominal Linear Density	Nominal Twist Factor (N.T.F.) ($turns.cm^{-1}.tex^{1/2}$)	Calculated Twist ($turns.m^{-1}$)
30 tex	29.0 32.0 36.0	548.82 607.87 681.89
40 tex	29.0 32.0 36.0	467.32 506.30 566.54

2.1.1.2 *Yarn Packages*

After spinning, the yarn was wound onto a *cone.* Yarn winding is a very important stage due to several factors involved, such as: yarn fault removal, yarn conditioning, waxing [107], all of which affect the efficiency of subsequent processes.

From experience it is known that, yarn from the *cone* exhibits lower snarling tendency (i.e., the effect of twist liveliness on yarns), when compared to the same yarn taken from the *cop* even when the yarn has not been steamed. This is probably due to the tension applied to the yarn resulting from the winding speed and tensioning devices on the winding machine. This tension probably slightly extends the yarn, resulting in a rearrangement of the structure of the yarn cross-section, and may be responsible for the significant reduction of torque produced by the twist insertion during the spinning process.

2.1.2 YARN TESTING

The six yarns were tested for linear density, twist and snarliness (twist liveliness) (see Appendix II for description of the testing equipments and methods used).

2.1.2.1 *Yarn Linear Density*

The Uster Autosorter III (v4.1) was used for the determination of the yarn linear density by carrying out seven tests for each of the yarn samples. The results obtained are reported in Table 2.3.

Table 2.3 Yarn Samples Linear Density

N.L.D.‡ (tex)	N. T. F.*	Min (tex)	Max (tex)	MEAN ACTUAL LINEAR DENSITY (tex)
30	29.0	28.4	30.1	**29.3**
30	32.0	28.5	30.0	**29.3**
30	36.0	28.9	29.8	**29.4**
40	29.0	38.8	39.9	**39.4**
40	32.0	37.9	40.2	**38.9**
40	36.0	38.3	40.7	**39.5**

‡ Nominal Linear Density * Nominal Twist Factor (turns.cm^{-1}.$tex^{½}$)

2.1.2.2 *Twist Amount*

For the examination of the amount of twist inserted in each of the yarn samples, the "*single untwist-twist*" or *contraction* method was selected and tested on the fully automatic Zweigle D 301 twist testing device. The average of thirty readings was taken for each sample. The pretension system of the device were set at 0.147 N for the 29 tex, and 0.196 N for the 39 tex yarns - according to the BS:2085:1954.

The results are reported in Table 2.4 and Fig. 2.1.

Table 2.4 Measured Yarn Twist

LINEAR DENSITY (tex)	N.T.F.[*]	TWIST (turns.m^{-1}) COP[‡]	TWIST (turns.m^{-1}) CONE[‡]	MEAN TWIST[†] (turns.m^{-1})	MEAN TWIST[†] C.V.%	ACTUAL TWIST FACTOR (turns.cm^{-1}.tex$^{\frac{1}{2}}$)
29.3	29.0	603.9	592.7	**598.3**	1.85	**32.4**
29.3	32.0	656.5	631.2	**643.9**	3.85	**34.9**
29.4	36.0	711.2	711.5	**711.3**	0.04	**38.6**
39.4	29.0	522.3	505.5	**513.9**	3.22	**32.3**
38.9	32.0	545.6	526.8	**536.2**	3.45	**33.4**
39.5	36.0	632.0	625.6	**628.8**	1.00	**39.5**

[*] Nominal Twist Factor (turns.cm^{-1}.tex$^{\frac{1}{2}}$)
[†] Mean of cop and cone readings
[‡] Mean of 30 readings

2.1.2.3 *Yarn Snarliness*

The testing apparatus "PRIANIC" [135] (experimental apparatus used for the determination of the tendency of the yarn to form snarls) was used for the measurement of the yarn snarliness. The apparatus indicates the distance in centimetres between the two ends of a 1 metre length of yarn when the first snarl is formed. For each yarn sample, thirty tests were carried out and as in the twist determination procedure, the pretension weights were set at 0.147 N and 0.196 N for the yarns with linear densities of 30 tex and 40 tex respectively.

The results are given in Table 2.5 and Figure 2.2. Table 2.6 is a summary of Tables 2.3, 2.4 and 2.5.

Table 2.5 Yarn Snarliness

LINEAR DENSITY (tex)	A.T.F.[*]	SNARLINESS (cm) COP[‡]	SNARLINESS (cm) CONE[‡]	DIFFERENCE	DIFFERENCE C.V. %	MEAN[†]
29.3	**32.4**	72.7	47.4	25.3	34.9	**60.05**
29.3	**34.9**	77.0	59.7	17.3	22.4	**68.35**
29.4	**38.6**	87.9	67.9	20.0	22.7	**77.90**
39.4	**32.3**	76.1	45.5	30.6	40.3	**60.80**
38.9	**33.4**	76.2	54.0	22.2	29.1	**65.10**
39.5	**39.5**	89.6	71.3	18.3	20.4	**80.45**

[*] Actual Twist Factor (turns.cm^{-1}.tex$^{\frac{1}{2}}$)
[‡] Mean of 30 readings
[†] Mean of cop and cone readings

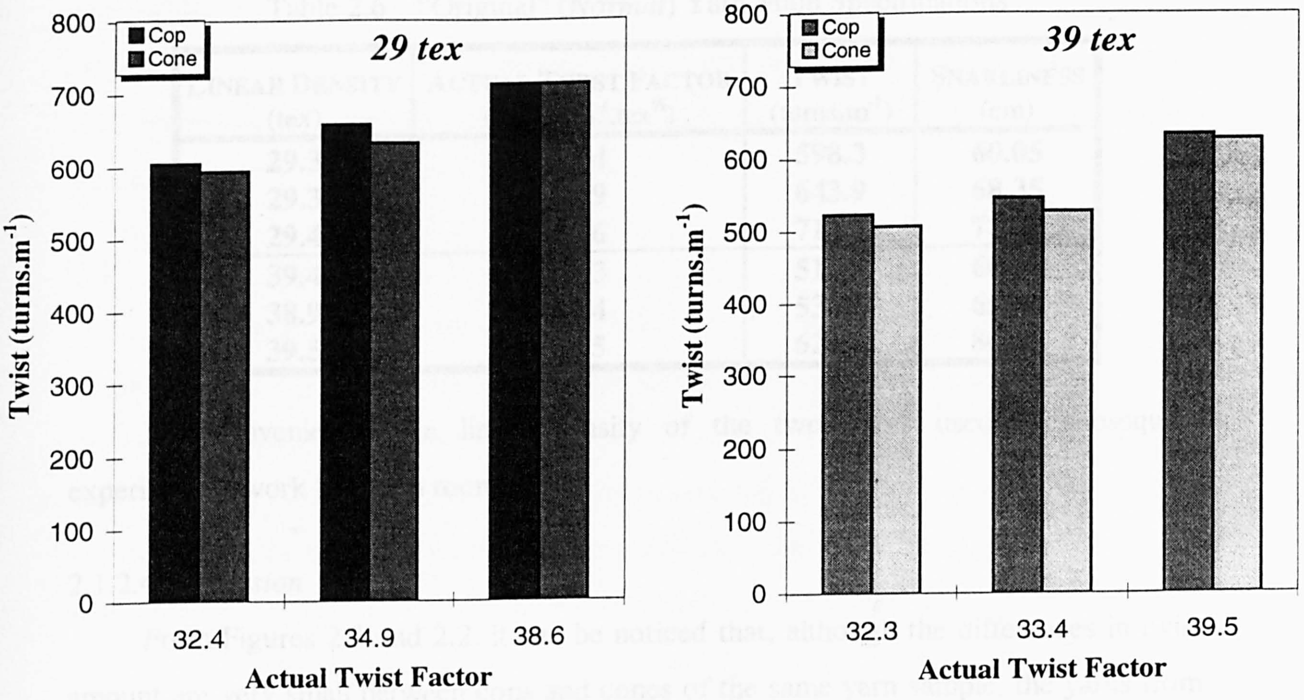


Fig. 2.1 Variation in **Twist** between Cops and Cones

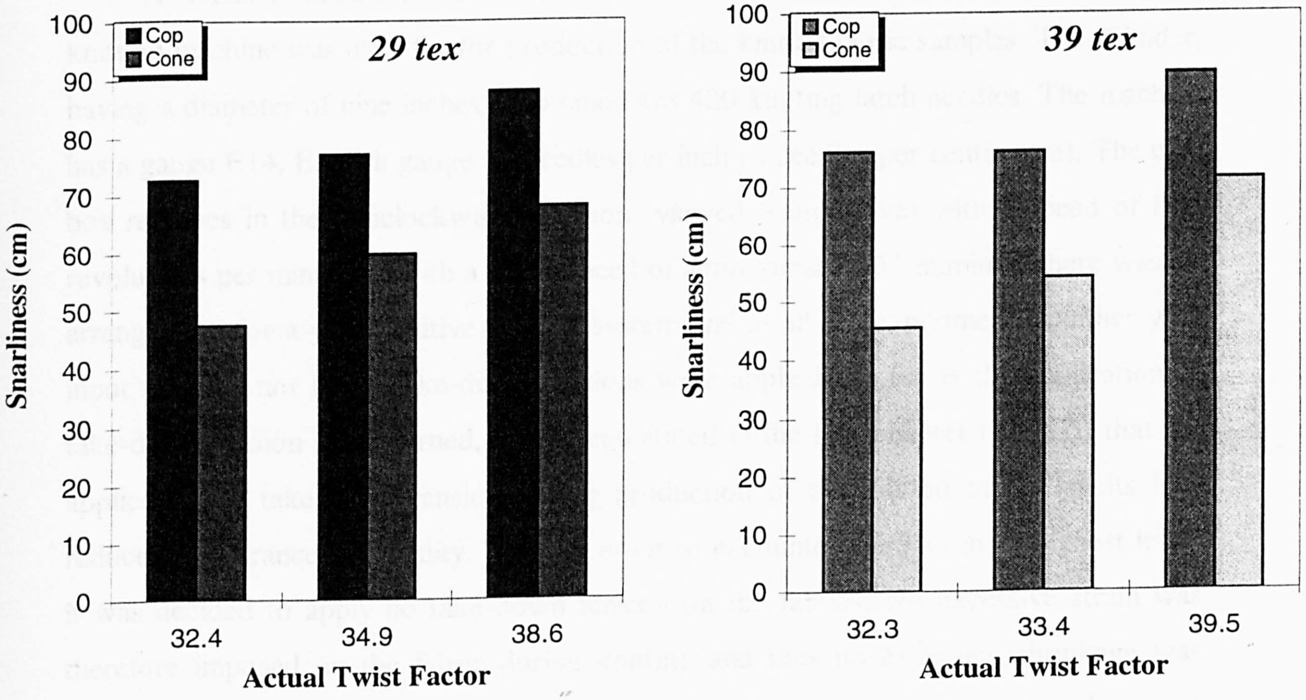


Fig. 2.2 Variation in **Yarn Snarliness** between Cops and Cones

Table 2.6 "Original" (*Normal*) Yarn Main Specifications

LINEAR DENSITY (tex)	ACTUAL TWIST FACTOR (turns.cm^{-1}.tex^{½})	TWIST (turns.m^{-1})	SNARLINESS (cm)
29.3	**32.4**	**598.3**	**60.05**
29.3	**34.9**	**643.9**	**68.35**
29.4	**38.6**	**711.3**	**77.90**
39.4	**32.3**	**513.9**	**60.80**
38.9	**33.4**	**536.2**	**65.10**
39.5	**39.5**	**628.8**	**80.45**

For convenience, the linear density of the two yarns used in subsequent experimental work has been rounded off.

2.1.2.4 *Discussion*

From Figures 2.1 and 2.2. it can be noticed that, although the differences in twist amount are very small between cops and cones of the same yarn sample, the yarns from the cones exhibit a relatively high reduction (20-40%) in snarliness. This is in agreement with the arguments advanced in section 2.1.1.2.

2.1.3 KNITTING PROCESS

2.1.3.1 *Knitting Machine Specifications/Characteristics*

A WILDT Model 5 power operated, circular one feeder (single jersey) weft knitting machine was used for the production of the knitted fabric samples. The cylinder, having a diameter of nine inches accommodates 420 knitting latch needles. The machine has a gauge E14, English gauge 14 needles per inch (6 needles per centimetre). The cam box revolves in the anticlockwise direction (viewed from above) with a speed of fifty revolutions per minute or with a linear speed of approximately 37 m.min^{-1}. There was no arrangement for a yarn positive feeding system and in all the experiments, neither yarn input tensions nor fabric take-down tensions were applied. As far as the application of take-down tension is concerned, it has been stated in the first chapter (§ 1.5.5) that the application of take-down tension during production of the knitted fabric results in a reduced appearance of spirality. Thus, in order to encounter spirality in its highest level, it was decided to apply no take-down tension on the fabrics. No excessive strain was therefore imposed on the fabric during knitting and thus no excessive shrinkage was expected after washing and drying. Furthermore, it must be remembered at this point that, all the yarn samples were **unwaxed** (i.e., more yarn friction occurred in the yarn-metal contacts), so the only tension on the yarn was due to yarn friction from the over-end unwinding process and from passage through the pig tail guides and the cam box guide.

2.1.3.2 *Fabric Production*

The yarn from the cone to the knitting zone, passes through two pig tail yarn guides, placed some distance apart from each other, and the cam box guide. The distances between the first pig tail guide and the cone, the second pig tail guide and the cam box guide, and the distance between the two pig tail guides, as well the frictional characteristics of the guides (which might influence the "twist blockage" effect) were considered as negligibly affecting the spirality of the produced fabrics.

In order to minimise the number of factors that might influence the forthcoming experiments, it was decided to keep some of the factors constant. Among them was also the tightness factor (cam box setting).

The loop length l of the produced fabric samples was calculated form the machine parameters to be:

i. for the preliminary experimental work: 5.26 mm
ii. for the main experimental work: 4.83 mm

The *tightness factor* was calculated using the formula $K = tex^{1/2} \times l^{-1}$ and found to be:

i. Preliminary experiments:	Yarns 29 tex	$K_1 = 1.023$ tex$^{1/2}$.mm^{-1}
	Yarns 39 tex	$K_2 = 1.187$ tex$^{1/2}$.mm^{-1}
ii. Main experimental work:	Yarns 29 tex	$K_3 = 1.115$ tex$^{1/2}$.mm^{-1}
	Yarns 39 tex	$K_4 = 1.293$ tex$^{1/2}$.mm^{-1}

In the knitting industry, the tightness factors commonly used, are in the range between 1.45 and 1.5 and the mean of 1.47 is normally used. It is known that the tighter the knitted fabric the less it exhibits spirality due to the restriction of the yarn movement in the knitted structure. Thus, any attempts to minimise the spirality in very loose fabrics could have the same and probably better results in tighter fabrics. This is the reason for choosing these low tightness factors for the experiments.

In most of the knitting experiments, the yarn samples were knitted sequentially in one fabric length. To avoid any possible distortions, in terms of spirality, every fabric sample was separated from adjacent samples by knitting a stripe of fabric produced from a coloured "dead" yarn. The length of this fabric stripe was approximately fifty courses.

For easier assessment of the spirality angle of the produced fabrics, a latch needle was removed from the cylinder. This produced an apparent "needle line" (along the wale) in the fabric.

2.1.4 EXPERIMENTAL WORK

2.1.4.1 *Aim*

The scope of this experiment was the investigation of the possible effect of the following four factors on the spirality of knitted fabrics:

i. the shape of the *yarn package* (cop, cone);
ii. the *twist factor* which was different in each of the six originally produced yarn samples;
iii. the *time* elapsed from the yarn production up to the fabric production and,
iv. the *atmospheric conditions* in which the yarn samples were stored.

2.1.4.2 *Tests*

Quantities of the six yarn samples, with twist factors as before (see § 2.1.2.2 and Table 2.6), were made up into two "*lots*". One of these lots was kept in a standard testing laboratory environment having 20±2 °C and 65% R.H., and is referred to as "*conditioned*" yarn. The other was kept in plastic bags so as to retain the normal room conditions and was termed as "*unconditioned*" yarn.

Fifty courses of knitted fabric were produced from each of the six yarn samples from both packages (cops, cones). The yarn in all the cases was unwound over-end from the package. The fabric was then tested for spirality after being stored in normal testing atmospheric conditions for 24 hours. The angle of spirality was measured using a transparent sheet and a protractor.

2.1.4.2.1 <u>Tests on Yarn Twist and Yarn Snarliness</u>

The yarn samples were tested for twist and the results are given in Table 2.7. Test results for yarn snarliness are given in Table 2.8.

Table 2.7 Yarn Twist Results (turns.m^{-1})

LINEAR DENSITY	A.T.F.*		1st LOT Unconditioned			2nd LOT Conditioned		
			1 Day	100 Days	*DIF.*	1 Day	100 Days	*DIF.*
29 tex	**32.4**	COP	608.2	627.0	-18.8	605.3	611.5	-6.2
		CONE	592.1	611.1	-19.0	596.4	619.0	-22.6
		DIF.	*16.1*	*15.9*		*8.9*	*-7.5*	
	34.9	COP	656.3	611.6	44.7	655.6	668.7	-13.1
		CONE	631.1	641.1	-10.0	630.4	657.2	-26.8
		DIF.	*25.2*	*-29.5*		*25.2*	*11.5*	
	38.6	COP	710.2	721.7	-11.5	699.5	713.3	-13.8
		CONE	705.2	714.7	-9.5	715.4	720.7	-5.3
		DIF.	*5.0*	*7.0*		*-15.9*	*-7.4*	
39 tex	**32.3**	COP	524.4	531.9	*-7.5*	527.5	538.2	*-10.7*
		CONE	503.4	498.8	*4.6*	506.8	511.3	*-4.5*
		DIF.	*21.0*	*33.1*		*20.7*	*26.9*	
	33.4	COP	542.2	547.8	*-5.6*	542.5	543.5	*-1.0*
		CONE	523.0	535.6	*-12.6*	529.4	550.5	*-21.1*
		DIF.	*19.2*	*12.2*		*13.1*	*-7.0*	
	39.5	COP	638.9	639.4	*-0.5*	636.1	642.9	*-6.8*
		CONE	637.7	616.0	*21.7*	618.0	630.4	*-12.4*
		DIF.	*1.2*	*23.4*		*18.1*	*12.5*	

Table 2.8 Yarn Snarliness (cm)

LINEAR DENSITY	A.T.F.*		1st LOT Unconditioned			2nd LOT Conditioned		
			1 Day	100 Days	*DIF.*	1 Day	100 Days	*DIF.*
29 tex	**32.4**	COP	78.18	72.33	*5.85*	67.02	52.60	*14.42*
		CONE	43.79	45.86	*-2.07*	43.72	41.56	*2.16*
		DIF.	*34.39*	*26.47*		*23.30*	*11.04*	
	34.9	COP	74.03	80.73	*-6.70*	78.25	72.97	*5.28*
		CONE	55.66	49.29	*6.37*	59.85	52.14	*7.71*
		DIF.	*18.37*	*31.44*		*18.40*	*20.83*	
	38.6	COP	88.06	86.82	*1.24*	89.92	80.37	*9.55*
		CONE	66.99	64.41	*2.58*	61.85	59.54	*2.31*
		DIF.	*21.07*	*22.41*		*28.07*	*20.83*	
39 tex	**32.3**	COP	76.13	74.99	*1.14*	78.59	69.12	*9.47*
		CONE	39.40	37.66	*1.74*	56.41	37.29	*19.12*
		DIF.	*36.73*	*37.33*		*22.18*	*31.83*	
	33.4	COP	79.93	74.87	*5.06*	73.54	67.63	*5.91*
		CONE	58.79	49.26	*9.53*	45.07	41.18	*3.89*
		DIF.	*21.14*	*25.61*		*28.47*	*26.45*	
	39.5	COP	89.64	88.07	*1.57*	90.47	82.41	*8.06*
		CONE	77.23	76.12	*1.11*	65.14	52.46	*12.68*
		DIF.	*12.41*	*11.95*		*25.33*	*29.95*	

*Actual Twist Factor (turns.cm^{-1}.tex^{½})

2.1.4.2.2 *Spirality Angle Tests*

a. Time: 50 days

In this series of tests, the time between yarn and fabric production was fifty days. This interval of time was the minimum possible simply because the yarn samples were produced abroad. The results obtained from the tests are presented in the Table 2.9:

Table 2.9 Spirality Angle (°) of Fabrics Produced from Yarns 29 tex and 39 tex, after 50 Days Yarn Storage

LINEAR DENSITY		**29 tex**			**39 tex**		
TWIST FACTOR		**32.4**	**34.9**	**38.6**	**32.3**	**33.4**	**39.5**
Unconditioned	COP	20.5	23.5	33.0	20.0	23.0	26.5
	CONE	17.0	20.5	31.0	18.0	21.5	25.0
	Difference	*3.5*	*3.0*	*2.0*	*2.0*	*1.5*	*1.5*
	%	*17.1*	*12.8*	*6.1*	*10.0*	*6.5*	*5.7*
Conditioned	COP	19.5	23.0	30.5	20.5	20.0	28.5
	CONE	17.5	20.5	28.5	17.5	16.5	24.5
	Difference	*2.0*	*2.5*	*2.0*	*3.0*	*3.5*	*4.0*
	%	*10.3*	*10.9*	*6.6*	*14.6*	*17.5*	*14.0*
Difference Between	COPS	*1.0*	*0.5*	*2.5*	*-0.5*	*3.0*	*-2.0*
	%	*4.9*	*2.1*	*7.6*	*2.5*	*13.0*	*7.5*
	CONES	*-0.5*	*0.0*	*2.5*	*0.5*	*5.0*	*0.5*
	%	*2.9*	*0.0*	*8.1*	*2.8*	*23.3*	*2.0*

b. Time: 100 days

The test was repeated for a time between yarn and fabric production of 100 days. The results are shown in Table 2.10. The differences in spirality angle between the two sets of the experiments due to the storage time are presented in the Tables 2.11 and 2.12 as well as in Figures 2.3 and 2.4.

Table 2.10 Effect of Yarn Package and Storing Atmospheric Conditions on Spirality Angle(°) (After 100 Days)

LINEAR DENSITY		29 tex			39 tex		
TWIST FACTOR		**32.4**	**34.9**	**38.6**	**32.3**	**33.4**	**39.5**
Uncondi-tioned	COP	33.5	34.0	45.0	24.0	26.5	40.0
	CONE	25.5	29.5	40.0	22.5	27.5	41.5
	Difference	*8.0*	*4.5*	*5.0*	*1.5*	*-1.0*	*-1.5*
	%	*23.9*	*13.2*	*11.1*	*6.3*	*3.8*	*3.8*
Condi-tioned	COP	25.0	27.5	35.0	24.0	19.0	30.5
	CONE	18.0	22.5	28.0	17.0	19.0	28.5
	Difference	*7.0*	*5.0*	*7.0*	*7.0*	*0.0*	*2.5*
	%	*28.0*	*18.2*	*20.0*	*29.2*	*0.0*	*8.2*
Difference Between	COPS	*8.5*	*6.5*	*10.0*	*0.0*	*7.5*	*9.5*
	%	*25.4*	*19.1*	*22.2*	*0.0*	*28.3*	*23.8*
	CONES	*7.5*	*7.0*	*12.0*	*5.5*	*8.5*	*13.0*
	%	*29.4*	*23.7*	*30.0*	*24.4*	*28.3*	*31.3*

Table 2.11 Effect of Time on Spirality Angle (°) : **Cops**

LINEAR DENSITY		29 tex			39 tex		
TWIST FACTOR		**32.4**	**34.9**	**38.6**	**32.3**	**33.4**	**39.5**
Uncondi-tioned	50 Days	20.5	23.5	33.0	20.0	23.0	26.5
	100 Days	33.5	34.0	45.0	24.0	26.5	40.0
	Difference	*13.0*	*10.5*	*12.0*	*4.0*	*3.5*	*13.5*
	%	*38.8*	*30.9*	*26.7*	*16.7*	*13.2*	*33.8*
Condi-tioned	50 Days	19.5	23.0	30.5	20.5	20.0	28.5
	100 Days	25.0	27.5	35.0	24.0	19.0	30.5
	Difference	*5.5*	*4.5*	*4.5*	*3.5*	*-1.0*	*2.0*
	%	*22.0*	*16.4*	*12.9*	*14.6*	*-5.3*	*6.6*

Table 2.12 Effect of Time on Spirality Angle (°) : **Cones**

LINEAR DENSITY		29 tex			39 tex		
TWIST FACTOR		**32.4**	**34.9**	**38.6**	**32.3**	**33.4**	**39.5**
Uncondi-tioned	50 Days	17.0	20.5	31.0	18.0	21.5	25.0
	100 Days	25.5	29.5	40.0	22.5	27.5	41.5
	Difference	*8.5*	*9.0*	*9.0*	*4.5*	*6.0*	*16.5*
	%	*33.3*	*30.5*	*22.5*	*20.0*	*21.8*	*39.8*
Condi-tioned	50 Days	17.5	20.5	28.5	17.5	16.5	24.5
	100 Days	18.0	22.5	28.0	17.0	19.0	28.5
	Difference	*0.5*	*2.0*	*-0.5*	*-0.5*	*2.5*	*4.0*
	%	*2.8*	*8.9*	*-1.8*	*-2.9*	*13.2*	*14.0*

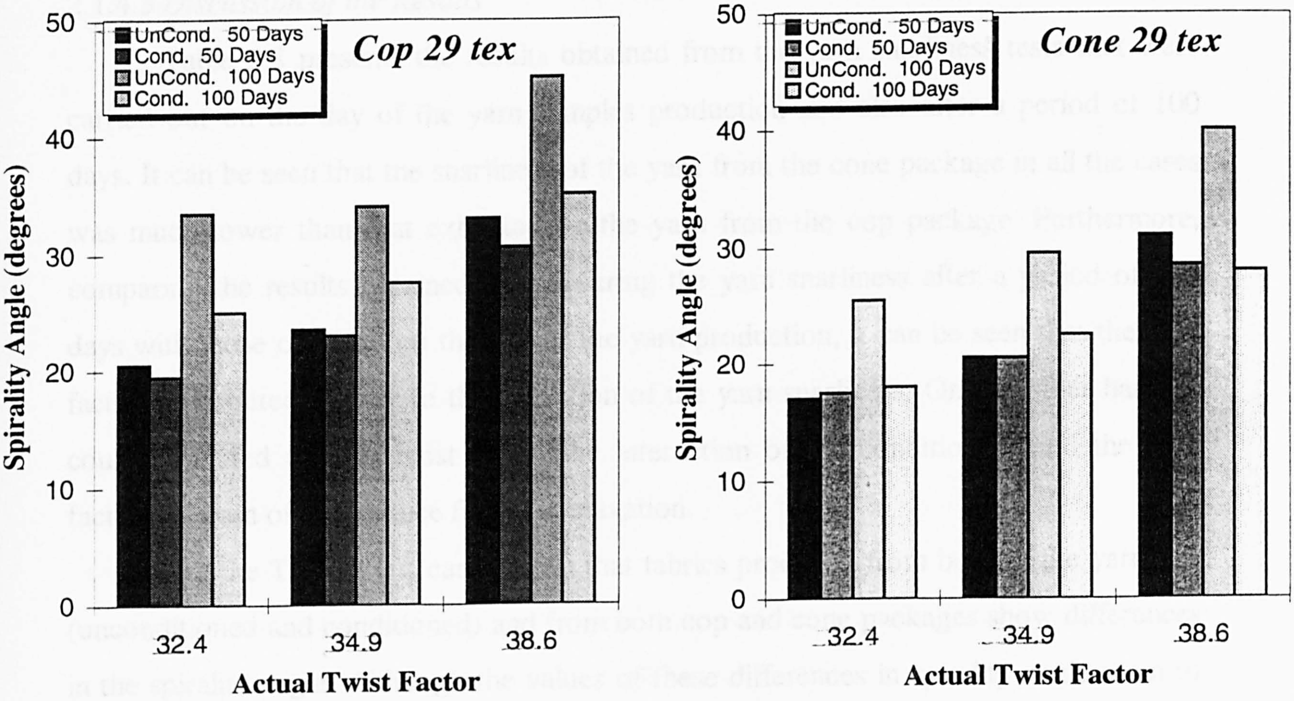


Fig. 2.3 Variation in **Spirality Angle** Shown by Knitted Fabrics (29 tex) (Effect of Yarn Package and Storing Atmospheric Conditions)

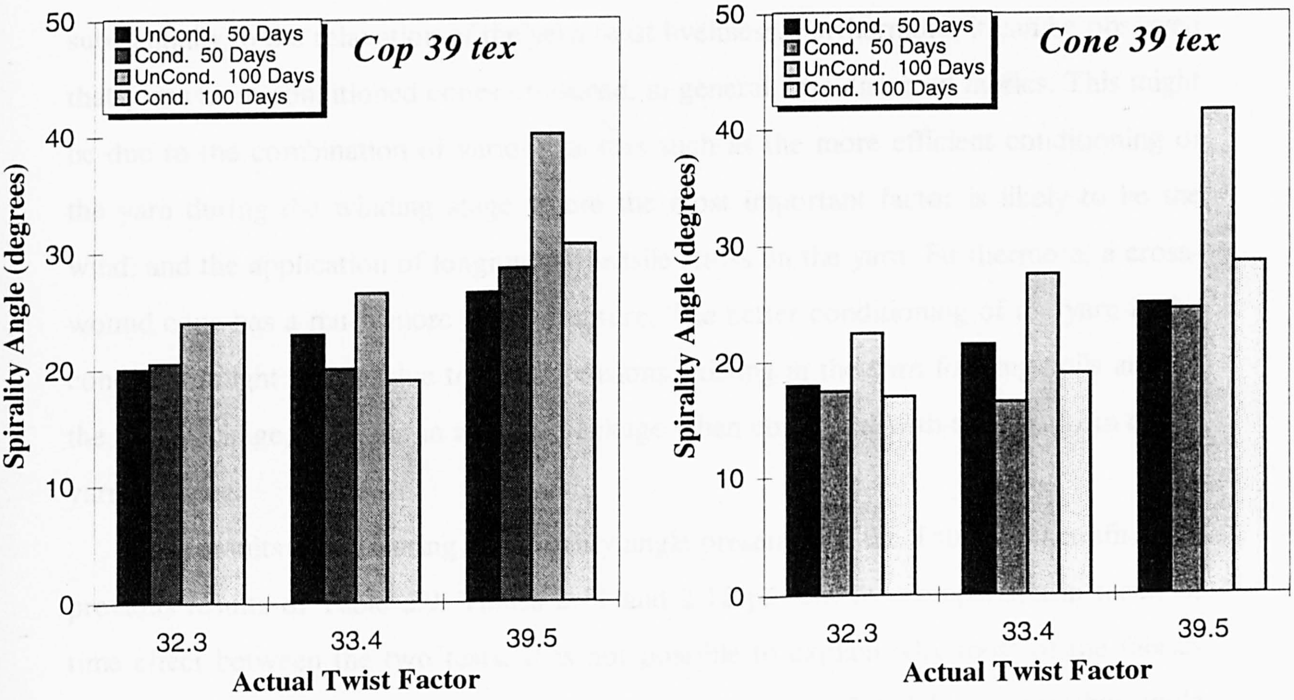


Fig. 2.4 Variation in **Spirality Angle** Shown by Knitted Fabrics (39 tex) (Effect of Yarn Package and Storing Atmospheric Conditions)

2.1.4.3 *Discussion of the Results*

Table 2.8 presents the results obtained from the yarn snarliness tests that were carried out on the day of the yarn samples production and also after a period of 100 days. It can be seen that the snarliness of the yarn from the cone package in all the cases was much lower than that exhibited by the yarn from the cop package. Furthermore, comparing the results obtained by measuring the yarn snarliness after a period of 100 days with those obtained on the day of the yarn production, it can be seen that the time factor contributed slightly to the reduction of the yarn snarliness. On the other hand, it could be stated that, in most cases, the interaction of the conditioning and the time factors is again of importance for yarn relaxation.

From the Table 2.9 it can be seen that fabrics produced from both of the yarn lots (unconditioned and conditioned) and from both cop and cone packages show differences in the spirality angle. Although the values of these differences in spirality angle seem to be rather small, the percentage differences would appear to be significant. In particular, the percentage reduction in spirality angle of those fabrics produced from the conditioned yarn samples of both linear densities (29 tex, 39 tex) indicates that the combination of the time of the yarn storage and the atmospheric conditions contributes substantially to the relaxation of the yarn twist liveliness. Furthermore, it can be observed that yarns from conditioned cones produced, in general, less distorted fabrics. This might be due to the combination of various factors such as the more efficient conditioning of the yarn during the winding stage where the most important factor is likely to be the wind, and the application of longitudinal tensile stress on the yarn. Furthermore, a cross-wound cone has a much more open structure. The better conditioning of the yarn in the cone form might also be due to lower tensions existing in the yarn forming coils around the yarn package, resulting in a softer package when compared with the cop form of the yarn package.

The results of measuring the spirality angle presented in the Table 2.10 confirm the previous results of Table 2.9. Tables 2.11 and 2.12 present the comparison in terms of time effect between the two tests. It is not possible to explain why most of the fabrics produced from conditioned yarns over a longer period exhibited higher spirality angle values.

2.2 PRELIMINARY METHODS USED FOR THE REDUCTION OF SPIRALITY

2.2.1 YARN UNWINDING FROM ITS PACKAGE

2.2.1.1 *Tortuous Twist*

The twist present in a yarn is affected by delivery from its package. A simple example of unwinding a yarn from package is shown by Tompkins [50]. An alteration in yarn twist may occur depending on the unwinding method adopted [136]. This twist, which is added (or reduced), has been termed as *tortuous twist* by Woods [137,138] and is approximately one turn for every complete circumference of the yarn on the package [139]. It is independent of the original twist, varies with the diameter of the package [140]. A simple experiment was carried out to examine the effect of the yarn unwinding methods in the alteration of the yarn twist. It was confirmed that when a length of yarn is unwound over-end from a cop or cone, a very small increase of twist amount in that yarn length occurs [139-141] while during unwinding the yarn sideways from its package no twist alteration is detected.

2.2.1.2 *Effect of Yarn Unwinding Methods on Fabric Spirality*

Adopting the view that a plain knitted fabric is frequently used for testing qualitative characteristics of some yarns [139], it was decided to examine this twist alteration, due to the *tortuosity*, in terms of spirality angle changes of single jersey tubular knitted fabrics. Tests carried out using commercially produced cops showed that the percentage differences in yarn twist amount, following over-end and sideways unwinding methods, did not seriously affect the spirality (difference $\leq 1°$). This is in full agreement with the statement that "this twist variation is negligible and cannot be detected either in the yarn or cloth" [142], when highly twisted yarns are concerned.

2.2.2 YARN STEAM-SETTING PROCESS

The purpose of this experiment was to investigate the effect of the yarn steaming process on the yarn properties and to confirm the effect of the steaming process on the temporary reduction of the spirality angle of fabrics produced from steamed yarns.

Quantities, of the six yarn samples with twist factors as before (see § 2.1.2.2 and Table 2.6), were made up into two "*lots*"; the first lot was given the name *normal*, whereas the samples of the second lot (*steamed*) were wound on perforated conical supports on a Gilbos winding machine with a speed of 600 $m.min^{-1}$. The perforated supports provided a means for easier penetration of the steam in the yarn package. These cones were placed in a Sanderson steam vacuum autoclave for the setting process. The yarns were steamed for 50 minutes at 105 °C under a pressure of approximately 69 $kN.m^{-2}$ (kPa). After this stage, the yarn samples were left to dry in room conditions. Finally, both the normal and steamed yarn samples were stored in standard atmospheric conditions (20±2 °C, 65±2 % R.H.) for one to four days.

Both the yarn sample lots were tested for linear density, twist, tenacity, hairiness, evenness, thickness and friction. The description of the testing devices and settings can be found in Appendix II. The results obtained from testing *normal* and *steamed* original yarns, are summarised in Table 2.13 and presented in Figures 2.5 to 2.8.

2.2.2.1 *Discussion of the Results*

From Table 2.13, it is clear, that the steaming process did not affect the linear density of the 39 tex yarn samples. In the case of yarns 29 tex, it is seen that the linear density of the yarn samples with low twist factor (i.e., TF 32.3 and TF 33.4), was marginally higher when the yarns were steamed. These differences were insignificant.

Similarly, steaming did not affect the yarn twist. This can be seen from the Figures 2.5 and 2.7.

Considering the significant differences in yarn tenacity, it could be said that the steaming process weakened the yarn. This reduction in strength is probably due to the water absorption that occurs during steaming. It is known that cotton fibres are hollow fibres of circular cross-section that have collapsed. When fibres absorb water they

Table 2.13 Effect of the Steam on Various Yarn Properties

Yarn Property	**29 tex**						**39 tex**					
	TF 32.4		**TF 34.9**		**TF 38.6**		**TF 32.3**		**TF 33.4**		**TF 39.5**	
	Normal	Steamed	Normal	Steamed	Normal	Steamed	Normal	Steamed	Normal	Steamed	Normal	Steamed
Linear Density (tex)	29.1	30.52	29.68	30.8	30.1	30.3	40.12	39.54	40.6	40	40.54	40.82
Twist (turns.m^{-1})	617.6	599.8	660.8	656.4	720.1	738	524.6	520.5	549.7	544	625.7	631.7
Tenacity (cN.tex^{-1})	12.55	12.4	15.11	12.66	16.43	14.13	14.19	12.17	14.77	13.17	16.51	14.44
Hairiness (Hairs.m^{-1})	64.77	58.11	60.88	51.5	43.7	48.21	125.27	79.67	76.64	66.25	64.67	53.92
Evenness (CV%)	14.37	13.66	13.92	14.63	13.99	13.06	13.01	13.55	11.97	12.57	12.56	12.58
Thickness (mm)	0.338	0.351	0.333	0.341	0.329	0.323	0.41	0.417	0.391	0.406	0.384	0.387
Coefficient of Friction (μ)	0.241	0.252	0.239	0.289	0.242	0.26	0.249	0.268	0.246	0.264	0.25	0.262

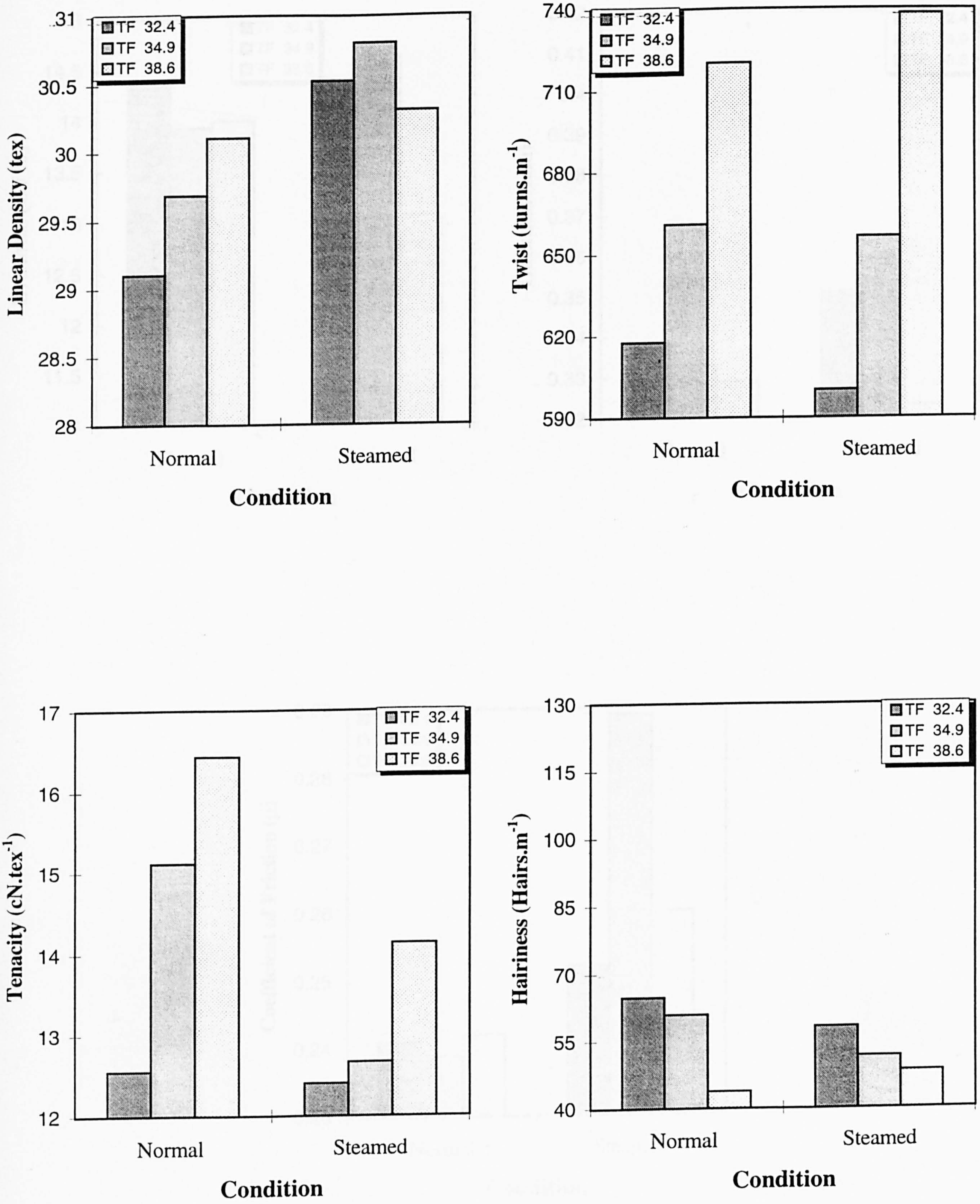


Fig. 2.5 Effect of the Steam on Properties of the Yarn **29 tex**

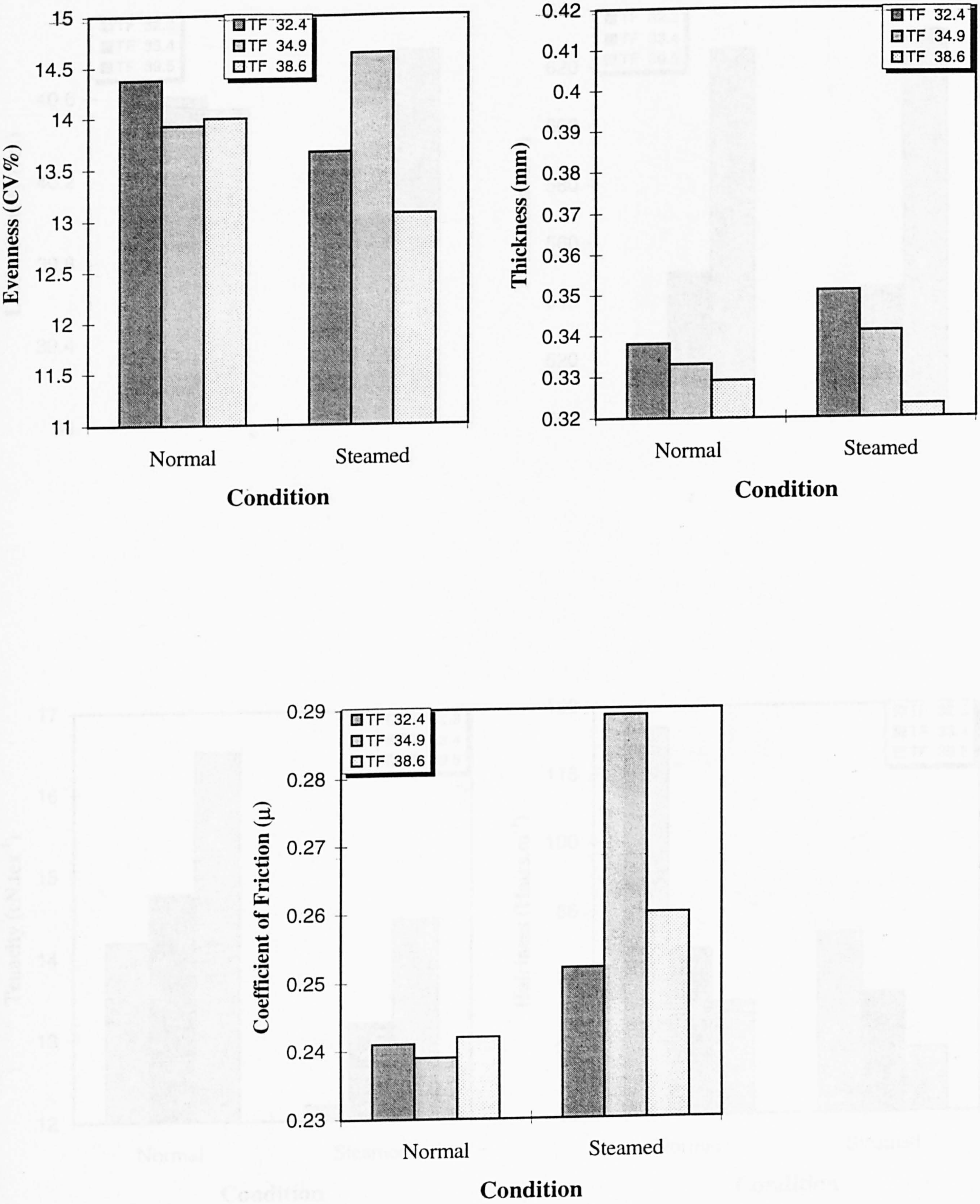


Fig. 2.6 Effect of the Steam on Properties of the Yarn **29 tex** (cont.)

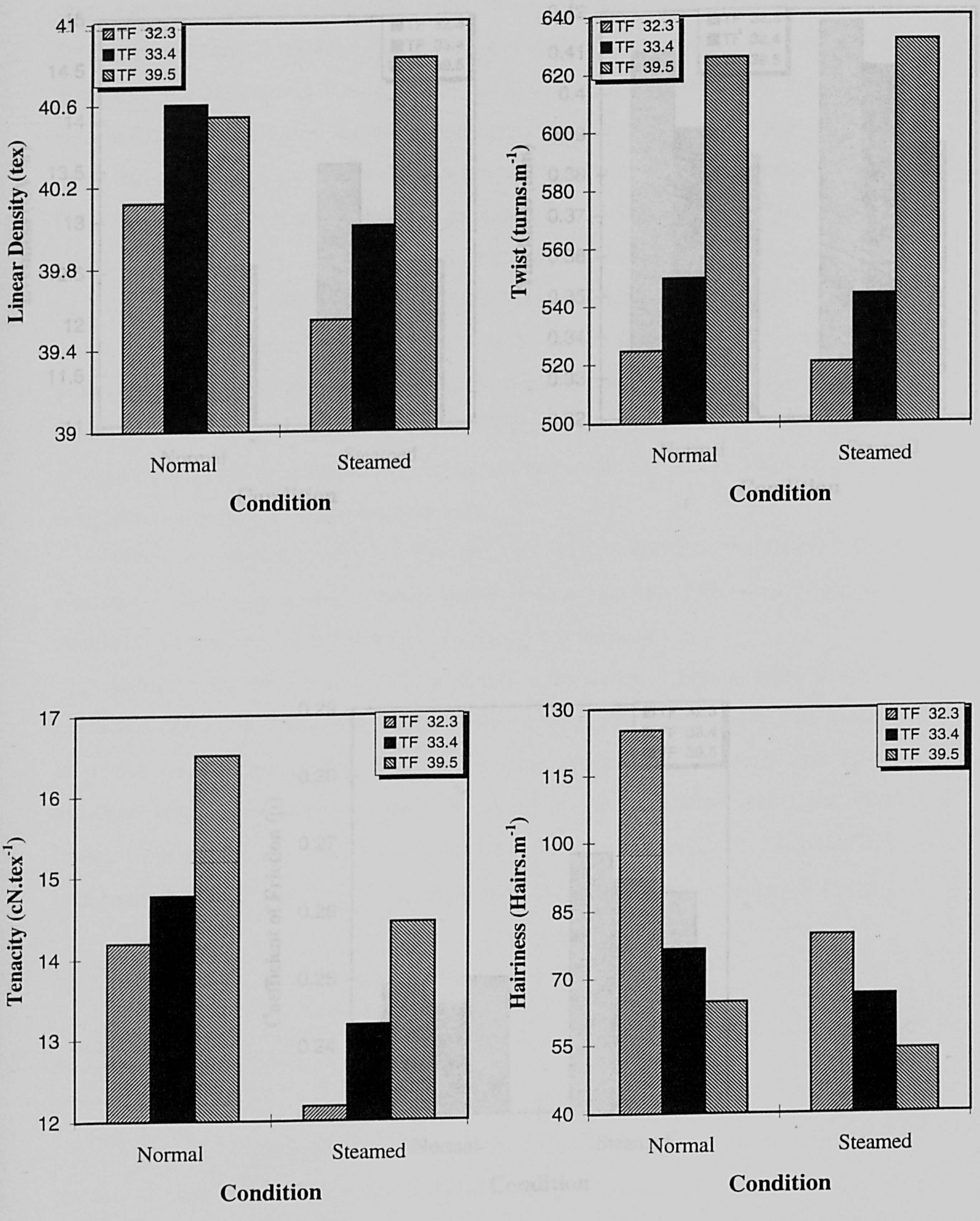


Fig. 2.7 Effect of the Steam on Properties of the Yarn **39 tex**

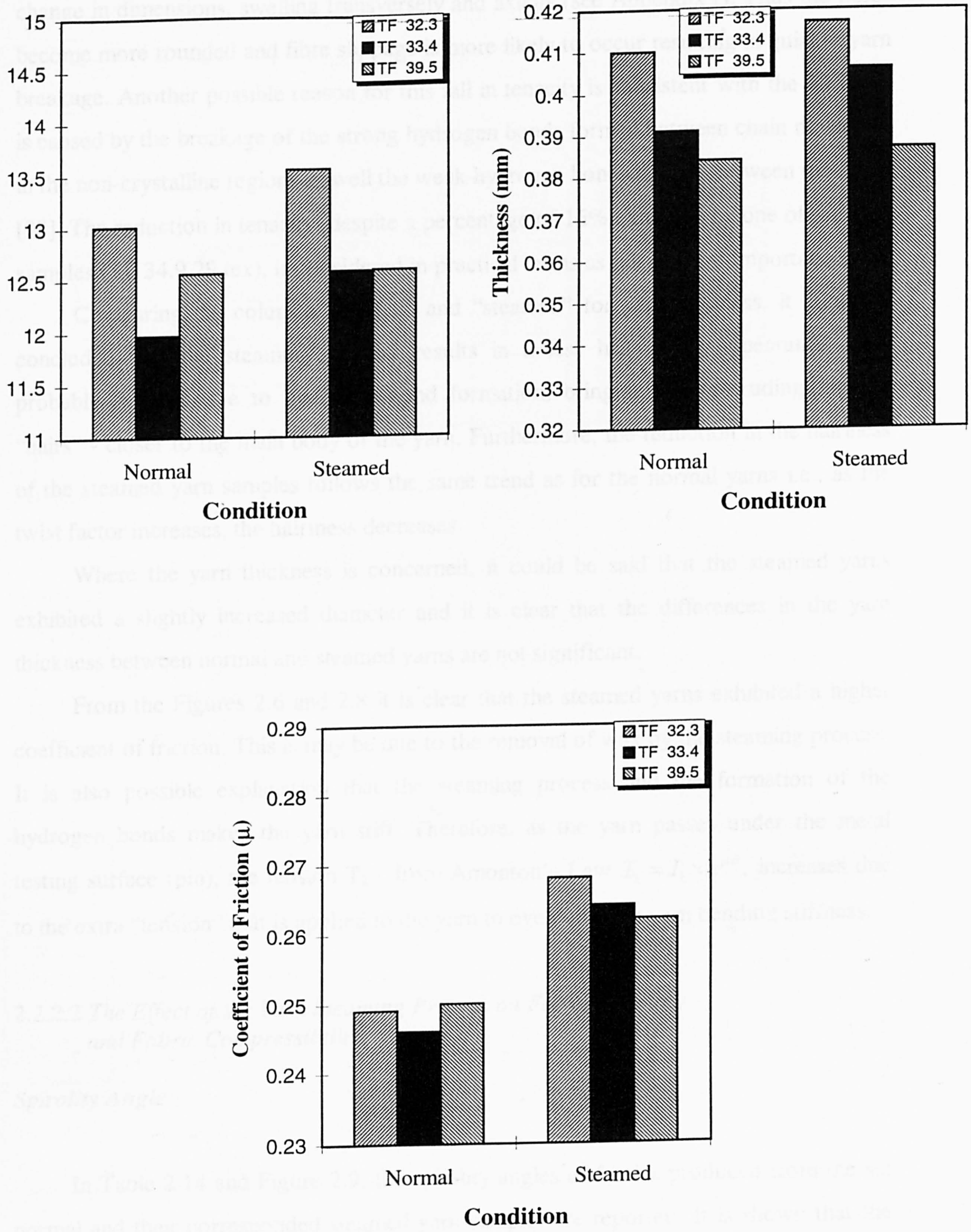


Fig. 2.8 Effect of the Steam on Properties of the Yarn **39 tex** (cont.)

change in dimensions, swelling transversely and axially (see Appendix I). Thus the fibres become more rounded and fibre slippage is more likely to occur resulting in quicker yarn breakage. Another possible reason for this fall in tenacity is consistent with the idea that is caused by the breakage of the strong hydrogen bonds formed between chain molecules in the non-crystalline regions as well the weak hydrogen bonds formed between the fibres [98]. The reduction in tenacity, despite a percentage of 16% exhibited by one of the yarn samples (TF 34.9 29 tex), is considered in practical terms as not of great importance.

Comparing the columns "normal" and "steamed" for yarn hairiness, it could be concluded that the steaming process results in a less hairy yarn appearance. This probably is again due to hydrogen bond formation, bringing the protruding fibres - "hairs" - closer to the main body of the yarn. Furthermore, the reduction in the hairiness of the steamed yarn samples follows the same trend as for the normal yarns i.e., as the twist factor increases, the hairiness decreases.

Where the yarn thickness is concerned, it could be said that the steamed yarns exhibited a slightly increased diameter and it is clear that the differences in the yarn thickness between normal and steamed yarns are not significant.

From the Figures 2.6 and 2.8 it is clear that the steamed yarns exhibited a higher coefficient of friction. This is may be due to the removal of wax by the steaming process. It is also possible explanation that the steaming process and the formation of the hydrogen bonds makes the yarn stiff. Therefore, as the yarn passes under the metal testing surface (pin), the tension T_2 - from Amonton's Law $T_2 = T_1 \times e^{\mu\vartheta}$, increases due to the extra "tension" that is applied to the yarn to overcome the yarn bending stiffness.

2.2.2.2 *The Effect of the Yarn Steaming Process on Fabric Spirality and Fabric Compressibility*

Spirality Angle

In Table 2.14 and Figure 2.9, the spirality angles of fabrics produced from the six normal and their corresponded steamed yarn samples are reported. It is shown that the yarn steaming results in less spiral fabrics. The spirality reduction is very significant for the fabrics produced from the steamed yarns prior to washing, and less significant after washing, when comparison has to be made between fabrics knitted from the normal and the steamed yarns. It must be pointed out that more significant reduction can only be achieved by optimum yarn steaming conditions.

Table 2.14 Effect of the Steaming Process on the Spirality Angle (**degrees** °)

	Yarn Samples	Before Washing		After Washing	
		Normal	Steamed	Normal	Steamed
29 tex	TF 32.4	16.0	9.5	20.0	12.0
	TF 34.9	20.0	10.0	18.5	15.5
	TF 38.6	27.0	15.5	27.5	24.0
39 tex	TF 32.3	13.0	10.0	15.0	14.5
	TF 33.4	16.5	10.0	16.5	13.0
	TF 39.5	28.0	14.5	22.0	19.0

Compressibility

Table 2.15 and Figure 2.10 present the effect of the yarn steaming process on the compressibility of the knitted fabrics. It seems that in most cases, there is a slight reduction in the surface thickness of the fabrics produced from the steamed yarns. It could be said that the yarn stiffness, perhaps due to the strong hydrogen bonds formed between the fibre molecule chains, is a factor that influences the compressibility of the steamed yarns.

Table 2.15 Effect of Steam on Compressibility of Knitted Fabrics

Samples	Thickness (mm)				Surface Thickness (mm)		Compressibility	
	Normal		Steamed		Normal	Steamed	Normal	Steamed
	196 Pa	9.81 kPa	196 Pa	9.81 kPa	T_2-T_{100}	T_2-T_{100}	%	%
29 tex								
TF 32.4	1.245	0.674	1.160	0.591	0.571	0.569	45.9	49.1
TF 34.9	1.360	0.746	1.153	0.639	0.614	0.514	45.1	44.6
TF 38.6	1.416	0.782	1.325	0.725	0.634	0.600	44.8	45.3
39 tex								
TF 32.3	1.429	0.826	1.295	0.753	0.603	0.542	42.2	41.9
TF 33.4	1.399	0.828	1.286	0.713	0.571	0.573	40.8	44.6
TF 39.5	1.401	0.879	1.292	0.765	0.522	0.527	37.3	40.8

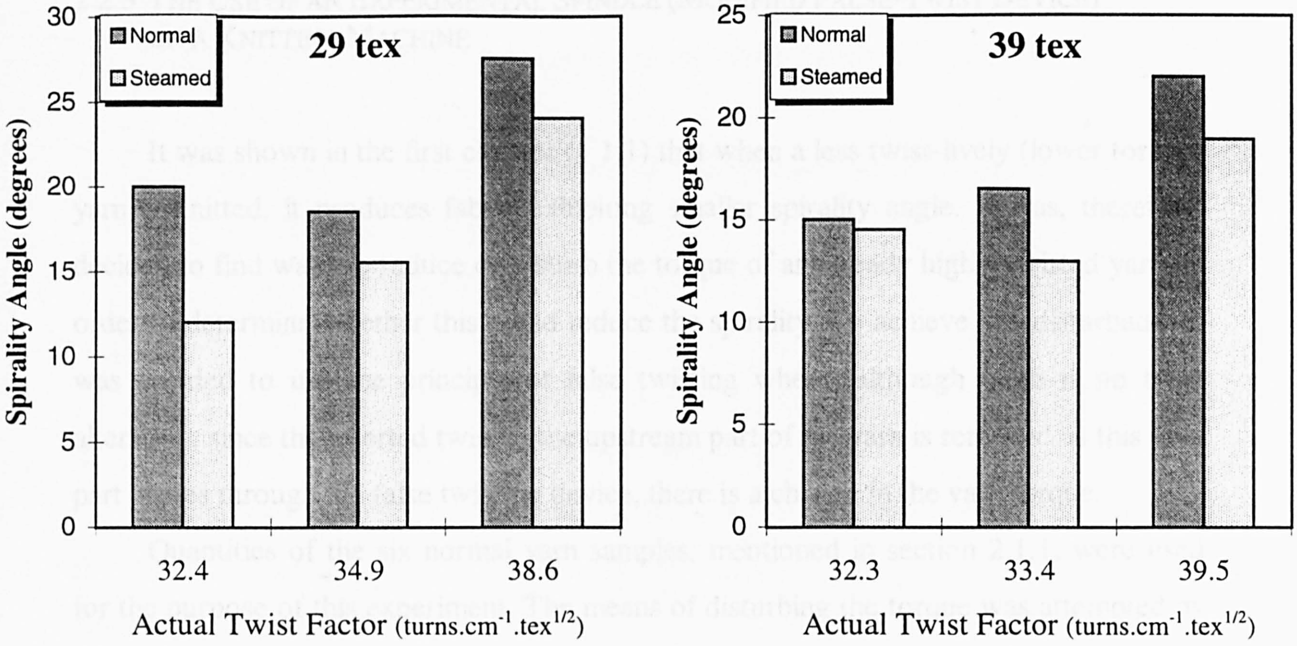


Fig. 2.9 Effect of the Steam on Spirality of Fabrics Knitted from the Yarn **29 tex**

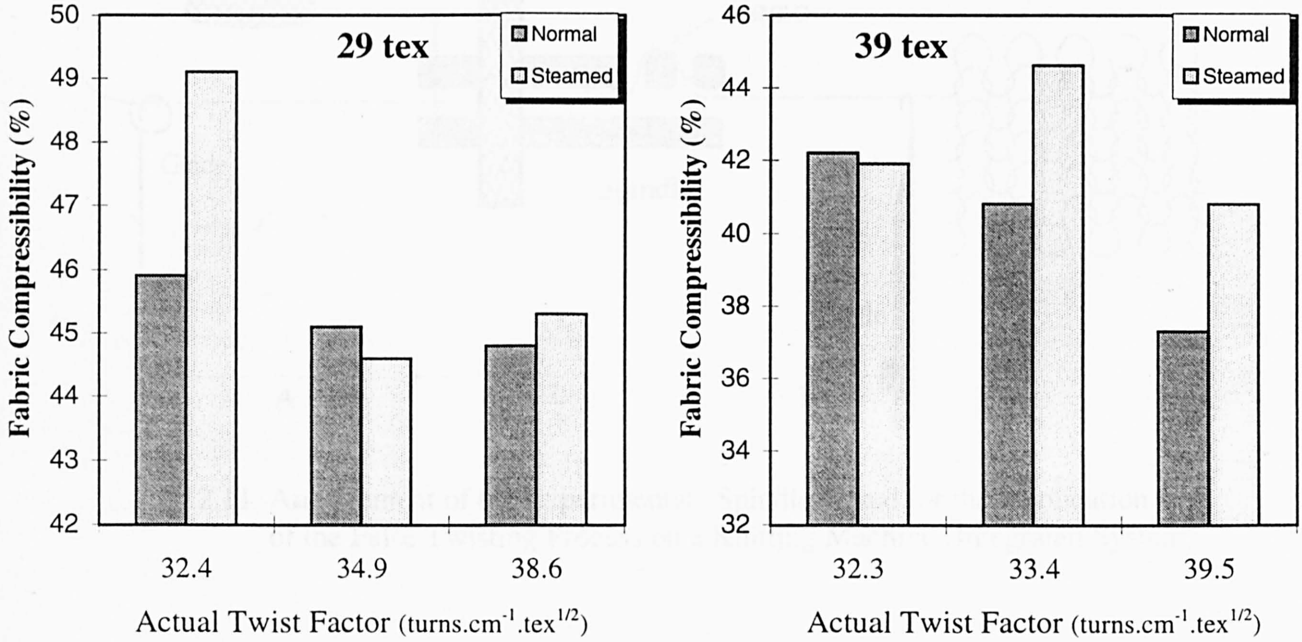


Fig. 2.10 Effect of the Steam on Compressibility of Fabrics Knitted from the Yarn **39 tex**

2.2.3 The Use of an Experimental Spindle (Modified False-Twist Device) on a Knitting Machine

It was shown in the first chapter (§ 1.1) that when a less twist-lively (lower torque) yarn is knitted, it produces fabric exhibiting smaller spirality angle. It was, therefore, decided to find ways to reduce or disturb the torque of an already highly twisted yarn, in order to determine whether this could reduce the spirality. To achieve this disturbance it was decided to use the principle of false twisting where, although there is no twist alteration, since the inserted twist in the upstream part of the yarn is removed as this yarn part passes through the false twisting device, there is a change in the yarn torque.

Quantities of the six normal yarn samples, mentioned in section 2.1.1, were used for the purpose of this experiment. The means of disturbing the torque was attempted by the use of a specially designed hollow spindle having two apertures (Fig. 2.11):

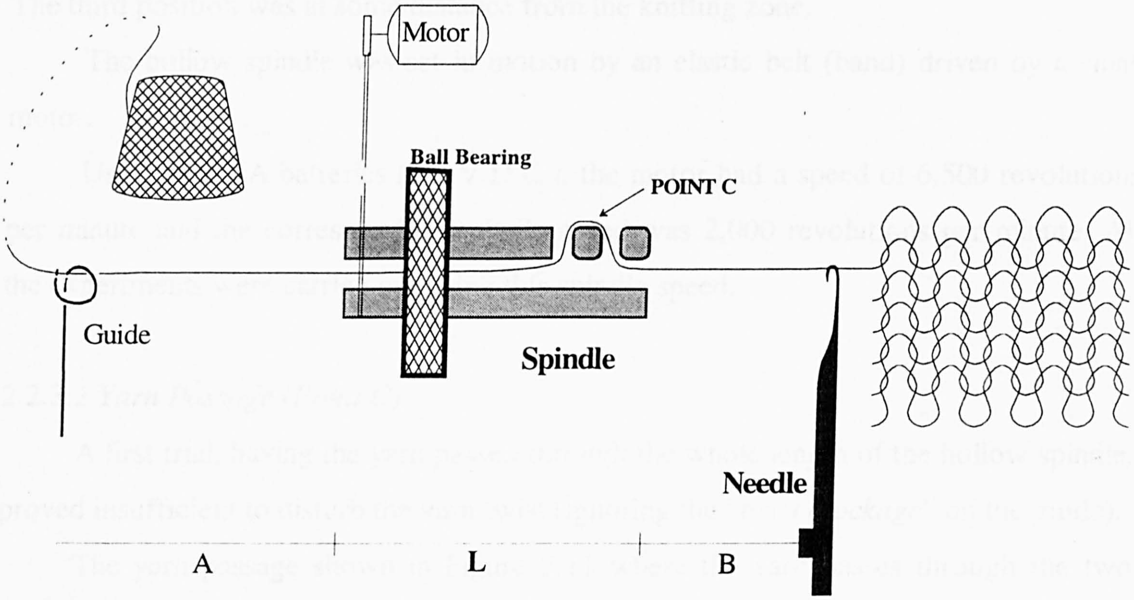


Fig. 2.11 Arrangement of the Experimental "Spindle" Used for the Application of the False Twisting Process on a Knitting Machine (Integrated System)

where: A: distance between yarn guide and back end of the spindle;

B: distance between the feeding end of the spindle and the knitting zone;

L: length of the spindle;

D: outer diameter of the spindle where a driven belt comes in contact with it;

T_0: normal twist of the yarn;

T_1: twist in the zone A+L;

T_2: twist in the zone B;

2.2.3.1 *Mounting the Spindle on the Knitting Machine*

The device was mounted on the WILDT circular knitting machine that was used for the experimental work (§ 2.1.3.1). Three locations of the spindle on the knitting machine were examined.

The first position of the spindle feeding end was in the knitting zone, the second was twenty five millimetres from that zone, with the guide of the cam box in between. The third position was at some distance from the knitting zone.

The hollow spindle was set in motion by an elastic belt (band) driven by a small motor.

Using two AA batteries (2.5 V D.C.), the motor had a speed of 6,500 revolutions per minute and the corresponding spindle speed was 2,000 revolutions per minute. All the experiments were carried out using this spindle speed.

2.2.3.2 *Yarn Passage (Point C)*

A first trial, having the yarn passed through the whole length of the hollow spindle, proved insufficient to disturb the yarn twist (ignoring the "*twist blockage*" on the guide).

The yarn passage shown in Figure 2.11 where the yarn passes through the two apertures as well as the passage shown in the Figure 2.12a, where the yarn passed through a single aperture, proved also insufficient to disturb the twist.

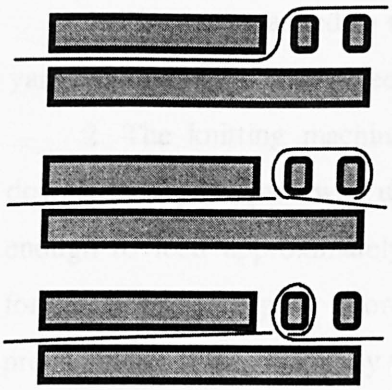


Fig. 2.12 Yarn Passages

These results indicated the necessity of blocking the twist in the spindle. This was achieved by passing the yarn through the two apertures in the manner shown in Figures 2.12b, and 2.12c so as to provide sufficient "*friction*" between the yarn and the surface of the spindle, as well as on the yarn itself. Because of the excessive hairiness of the yarn following the passage in the Figure 2.12b, the passage as shown in Figure 2.12c was chosen as the best for the purpose of the present experiments.

2.2.3.3 *Knitted Fabric Samples Production*

With the arrangement selected, a false twist is inserted. When a false-twist spindle is inserting twist continuously in a yarn under dynamic conditions, the twist in the upstream yarn part (after passing through the spindle) will cancel the twist in the downstream yarn part, because of the equal and opposite nature of the twist. It was decided to locate the feeding end of the spindle very close to the knitting zone so that the chance of yarn breakage was reduced.

In most of the experiments that were carried out on the knitting machine, using many possible combinations, it was found that the arrangement with the spindle had no effect on the spirality angle. A possible reason for the ineffectiveness of the system was the speed ratio between motor-spindle and the knitting machine. The speed of the yarn passing through the spindle, equal to the unwinding yarn speed from its cone (110 m.min^{1}) could be considered too high so that the spindle did not provide a sufficient yarn untwisting action. It was, therefore, decided to increase that ratio, by operating the knitting machine manually, but keeping a constant rotating speed as far as possible.

By reducing the machine speed, there was sufficient time for the spindle to untwist the part of the yarn being in between the feeding end of the spindle and the knitting zone. However, this was accompanied by the formation of numerous snarls in the upstream part of the yarn, end breaks [143], and an irregular loop distortion in the fabric.

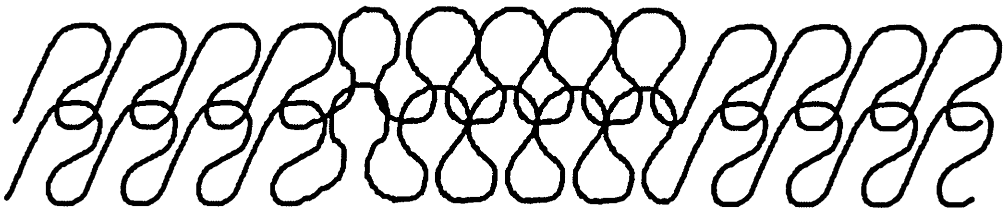
The next attempt used intermittent operation of the spindle with a parallel intermittent operation of the machine. Locating the spindle at a distance approximately 50 cm from the knitting zone, a sufficient yarn length could be untwisted, and the following experiment was carried out:

1. The yarn was fed to the knitting zone without the spindle operational, so that a yarn length long enough to feed approximately 180 needles was processed.

2. The knitting machine was stopped. The spindle was then rotated until the downstream yarn part was untwisted enough. This yarn part had a length sufficient enough to feed approximately thirty needles. Holding firmly between the thumb and forefinger this yarn part, in order to prevent yarn breakage and twist gain (due to twist propagation), it was manually fed to the knitting zone.

This procedure was repeated keeping the operation time constant for all the courses (i.e., stages 1, 2). It was found that the fabric produced, appeared with two stripes of thirty almost vertical wales each, formed by regular shaped loops, separated by fabric which showed a greater angle of spirality than that which usually occurred. This was due to alternate length of yarn having twist gain and twist loss, as the spindle was rotated.

The shape of these stripes is shown in the following figure:



Various other combination of spindle rotations and changing in parallel the distances between guides, spindle and knitting zone, were examined with no success (in terms of spirality reduction).

2.2.3.4 *Summary and Conclusion*

An attempt to use the false twisting method for yarn torque disturbance or reduction, in order to minimise the spirality effect of the single jersey tubular knitted fabrics proved unsuccessful. A similar experiment that was also carried out by using yarn quantities from the same yarn samples that were slightly steamed did not present any promising effectiveness of the method, in spite the fact that the false twisting that was used in a previous research [143] had an effect on blend cotton/polyester 67/33 where there was a balance of torque in the yarn and the fabric showed zero spirality. The latter could be explained simply because the polyester, as thermoplastic material could be affected by the heat of the heater on a FTT machine. The results of the experiments indicated that a possible method for the reduction of the spirality effect should include a real reduction of the twist or torque existing in the yarn.

CHAPTER 3

A NEW METHOD FOR THE REDUCTION OF SPIRALITY

3.1 THE ACTION OF TORSIONAL FORCES IN THE YARN

It is well known that when a strand of fibres is twisted, torsional forces are introduced in the fibres. The law of action-reaction applies to this case. The inserted mechanical couple of the torsional forces generates another couple in the opposite direction. This "*generated*" couple tends to untwist (detwist [21]) the yarn.

When two ends of a length of yarn are clamped, and provided the yarn has a degree of slackness, the above mentioned reaction finds an outlet in the formation of ***snarls***. If the twist direction in the single yarn is Z, the twist direction in the snarl is S, as it occurs in the case of folding Z-twisted singles yarns [135].

If one of the yarn ends is left free of any external forces, it can be observed that it rotates in the opposite direction to the twist direction (untwisting action). This action continues until a substantial percentage of the potential energy of the torsional forces, existing in the yarn, has been "removed" (relaxed). Thereafter, the untwisting action decelerates significantly.

At this point it is necessary to note that although the torque has been removed from the yarn, accompanied by a significant reduction in terms of the twist level, the yarn does not return to its original (stable) condition, that of a strand of fibres. When a twisted yarn is knitted, the resultant single jersey fabric exhibits a spirality effect which follows the direction of the yarn twist direction (Z-twisted yarn produces Z-spirality, as the technical face of the fabric is being observed).

3.2 YARN STEAMING PROCESS

It is generally acknowledged that the advantage of steaming yarns is the temporary suspension of their untwisting tendency (§ 1.6.3.1). Thus, depending on the efficiency of the steaming process, when a piece of steamed yarn is held from one end, having the other free of any external distorted forces, either a small untwisting action may be observed or no action can be detected due to the null residual torque in the yarn. By knitting such a steamed yarn, the resultant single jersey fabric exhibits very small, if any, spirality. However, on subjecting a single jersey fabric produced from steamed yarn to a wetting or washing process, the fabric becomes spirality-distorted. This indicates that the water was responsible for the latent torque in the yarn regaining its energy and, because the yarn was in the fabric form, the tendency for yarn untwisting to occur causes spirality in the fabric. In other words, the steaming process renders the forces generated by the fibres inactive, as long as the yarn-fabric does not come in contact with water molecules. The steamed yarn can now be considered as the "original" stable-state of the yarn.

3.3 PARTIALLY UNTWISTING THE STEAMED YARN

Taking into account the effect of steam on the relaxation of the torsional forces in a yarn, it was considered that the partial untwisting of such a steamed yarn, free of any torsional energy, would result in new torsional forces being introduced in the opposite direction.

Experiments confirm this, because when such a yarn is allowed to slacken whilst having the two ends clamped, snarls are formed which seem to disobey the twist direction "rule". *The net Z-twisted yarn forms Z-twisted snarls.* From this result it can be concluded that **in certain cases, the direction of the singles yarn twist does not indicate the direction of the active torsional forces (twist liveliness)** and consequently, **the direction of the singles yarn twist does not necessarily represent the direction of the spirality effect of the single jersey fabrics.**

3.4 WASHING THE FABRIC PRODUCED FROM THE PARTIALLY UNTWISTED STEAMED YARN

As mentioned above (§ 3.2), during the fabric washing process, the factor, that was responsible rendering the torsional forces inactive in the steamed Z-twisted yarn structure, is removed, leaving the originally generated torque to act. The result of this action is the appearance of Z spirality. It would appear reasonable to assume that when such a yarn is steamed and then subjected to an untwisting process, new torsional forces are generated resulting in S spirality. During a washing process, the torsional forces counterbalance each other. When this balance is exact, ideal conditions are established and the washed knitted fabric is free of any spirality distortion. However, it will appreciated that the effect is influenced by fibre, yarn and fabric structure and properties.

This qualitative explanation can only be advanced at this stage, since the magnitude of the phenomenon is difficult to estimate quantitatively. In chapter seven an attempt is made to investigate this phenomenon.

3.5 STAGES OF THE METHOD

Summarising the above paragraphs it can be concluded that, a method for the reduction or elimination of the spirality effect should comprise the following ***principal*** stages (Appendix III):

a. Production of Highly Twisted Yarns (higher twist factor than is commonly accepted in the knitting industry);
b. Yarn Steaming Process (yarn twist setting-fixation);
c. Partial Yarn Untwisting Process (15-30%);
d. Production of Knitted Fabric using the partially untwisted steamed yarn;
e. Washing and Drying the Knitted Fabric.

The first three stages of this method seem to be similar to false-twist-texturing method (FTT) of continuous filaments (§ 1.7.1), but there are important differences.

In FTT method, the original yarn consists of a number of *continuous filaments* in a parallel arrangement. The false-twisting device inserts twist to the upstream part of the yarn. This section of the twisted yarn is heat set as it comes in contact with the plate of a heater. The effect of heat setting is *permanent* as the filaments are made from a *thermoplastic* material. Next, this section of the twist-set yarn is untwisted by the *same number of turns* inserted in the first place, as it passes through the false-twisting device.

The new method is applied to yarns made from *non-thermoplastic short staple fibres* (cotton). The original yarn is *twisted* and the yarn steam setting process provides a *temporary* setting of the twist. After the steam setting stage of the new method, the *partial* yarn untwisting process takes place.

Table 3.1 summarises the differences between the two methods as well as yarn and knitted fabric characteristics.

3.6 PRELIMINARY EXPERIMENTS

In order to assess the effect of using the new method, a series of tests were carried out. For these tests, quantities of the Z-twisted yarns, that were produced as described in the section 2.1.1, were used. For convenience, these yarns are termed as "*normal*".

Quantities of the same yarns were steamed, using a simple steam generator and these yarns are termed as "*steamed*" yarns. The drying of the steamed yarns was carried out in a vacuum oven set at 80 °C for a period of 15 minutes. The efficiency of the steaming, in terms of reducing or nullifying the active torsional energy in the yarn, was subjectively judged.

In the following experiments, two lots of yarns were used. One of the lots was characterised by a low twist factor and used as reference. The other lot was composed of yarns with a higher twist factor. In the latter steamed yarn samples, various levels of S twist were inserted resulting in yarn samples, termed as "*processed*" yarns, with the yarn having a Z net twist level close to the level of the first yarn lot. Thus, a comparison of the spirality angles exhibited by fabrics produced from yarns with similar twist levels could be achieved.

Table 3.1 Differences between False Twist Textured Process and Partial Yarn Untwisting Method

FALSE TWIST TEXTURING PROCESS	PARTIAL UNTWISTING
Thermoplastic continuous filaments.	Non-thermoplastic short staple fibres.
Twistless bundle of filaments is subjected to this process.	Highly twisted yarn produced from the spinning stage is used in this method.
Permanent setting of the inserted twist in the upstream part of the yarn is achieved, as the yarn comes in contact with the plate of a heater.	Temporary setting of the originally spun yarn is achieved by steaming the yarn in autoclave vacuum steaming machines. This setting effect lasts up to the first wet processing of the yarn.
Total removal of the twist inserted in the first place, as the downstream part of the yarn is untwisted after passing through the false twisting device.	Partial (15-30% of the origin twist) yarn untwisting. The total untwisting of the yarn results in the loss of the yarn status as it has been converted to a strand of fibres having negligible strength.
One active torque appears to exist in the yarn as the FTT yarn is stretched. This torque that originates from the bending of the coils is inactive as the yarn is free to contract. The yarn forms repeated groups of two sets of coils having different direction.	It is assumed that the processed yarn has two levels of torque: the torque existent in the highly twisted yarn that has been temporary set, and the torque that introduced during the partial yarn untwisting.
Permanent appearance of spirality in the knitted fabrics mainly due to the inserted torque in the downstream part of the yarn. This spirality is not affected by any wetting process since the material used is hydrophobic.	Appearance of spirality in one direction and change of this direction during wet processing, resulting in a permanent reduction/elimination of spirality.

3.6.1 APPLICATION OF THIS METHOD ON Z-TWISTED YARNS **(39 tex)**

3.6.1.1 *Yarn Samples*

From the yarns of linear density 39 tex, samples with twist factors of 32.3 and 39.5 (turns.cm^{-1}.tex$^{1/2}$) were used for this experiment. The first yarn sample (TF 32.3, 514 turns.m^{-1}) was used as a reference. Nominal S twist (111 turns.m^{-1}) was inserted in the second yarn sample (TF 39.5, 629 turns.m^{-1}), resulting in a net twist level of nominal 518 turns.m^{-1} in the Z direction. Thus, this yarn had an almost equivalent twist level to the yarn with the low twist factor. Therefore, the fabrics produced from these yarns could be compared in terms of spirality angle. The untwisting process took place on a Volkmann Two-for-One twisting frame where the unwinding guide was not in use and the spindle was adjusted for the minimum yarn input tension.

3.6.1.2 *Knitted Fabric Production*

Applying the settings mentioned in the section 2.1.3.2, seventy courses were knitted of the following yarn samples:

			Nominal Remaining Z Twist (turns.m^{-1})
1. TF 32.3	(N)	Normal	(518);
2. TF 32.3	(S)	Steamed	(518);
3. TF 39.5	(N)	Normal	(629);
4. TF 39.5	(S)	Steamed	(629);
5. TF 39.5	(P)	Processed with (S) 111 turns.m^{-1}	(518);

3.6.1.3 *Measurement of Spirality Angle*

After the washing (one cycle) and drying procedures, the spirality angle of the fabrics were measured. The results obtained are presented in the Table 3.2 and Figure 3.1:

Table 3.2 **Spirality Angle** (°) of Fabrics Knitted from Yarns **39** tex

Sample No	T.F.	Condition	Before Washing	After Washing	Difference (**B**-**A**)
1	**32.3**	Normal	28.5	28.5	*0.0*
2	**32.3**	Steamed	11.0	13.0	*- 2.0*
Difference (1-2)			*17.5*	*14.5*	
3	**39.5**	Normal	35.5	30.0	*5.5*
4	**39.5**	Steamed	16.5	17.0	*- 0.5*
Difference (3-4)			*19.0*	*13.0*	
5	**39.5**	Processed	2.5	4.0	*- 1.5*
Difference (2-5)			*8.5*	*9.0*	

Note: The negative sign in the column of differences represents an increase of the spirality angle after the washing treatment. Also **B** stands for Before Washing and **A** stands for After Washing.

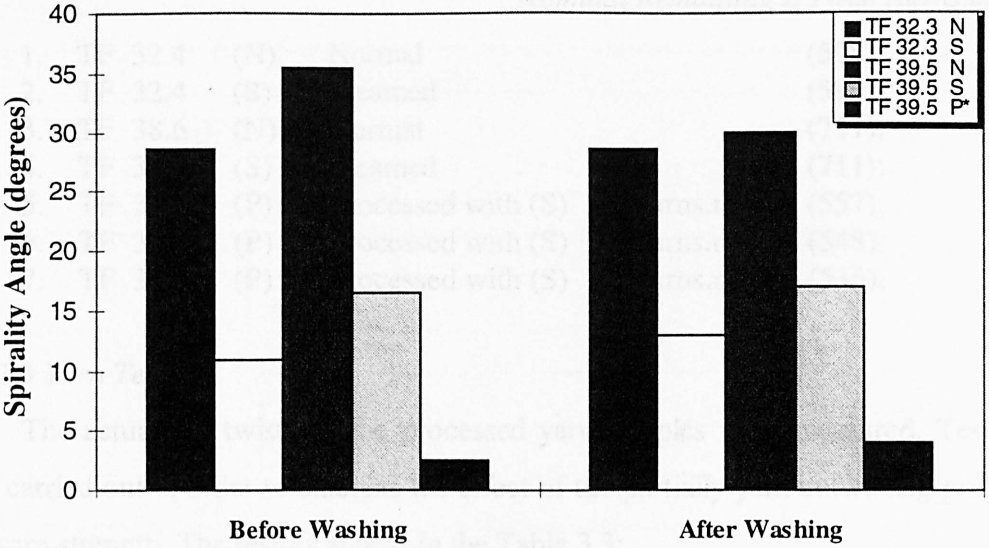


Fig. 3.1 Effect of the New Method on the Spirality Angle
*N - Normal, S - Steamed, P - Processed (i.e., Nominal 111 turns.m^{-1} S untwist in the steamed yarn 39 tex, T.F. 39.5)

3.6.2 APPLICATION OF THIS METHOD ON Z-TWISTED YARNS **29 TEX**

3.6.2.1 *Aim of the Experiment*

In the previous test, a comparison of spirality angles, exhibited on fabrics produced from yarn samples of 39 tex with *equivalent* twist level, was attempted. For the present experiment, using yarn samples of 29 tex, it was decided to examine the cases where various levels of S twist were inserted in the yarns (i.e., less net twist in the *processed* than the *normal* yarn), and their effect on the spirality angle of the fabrics produced.

3.6.2.2 *Yarn Samples*

The yarns with the lowest and highest twist factors (TF 32.4 and TF 38.6) were selected for this test. The yarn with TF 32.4 was used as a reference. The untwisting process of the steamed yarn with TF 38.6 (711 turns.m^{-1}) was carried out on the same Volkmann Two-for-One twisting frame. The twist adjustment had been set in such a way as to result in twist levels of 154, 163 and 175 turns.m^{-1} (S direction). Therefore, assuming ideal conditions, the three processed yarn samples should have net nominal twist levels of 557, 548 and 536 turns.m^{-1} (Z), respectively.

				Nominal Remaining Z Twist (turns.m^{-1})
1.	TF 32.4	(N)	Normal	(598);
2.	TF 32.4	(S)	Steamed	(598);
3.	TF 38.6	(N)	Normal	(711);
4.	TF 38.6	(S)	Steamed	(711);
5.	TF 38.6	(P)	Processed with (S) 154 turns.m^{-1}	(557);
6.	TF 38.6	(P)	Processed with (S) 163 turns.m^{-1}	(548);
7.	TF 38.6	(P)	Processed with (S) 175 turns.m^{-1}	(536);

3.6.2.3 *Yarn Tests*

The actual net twists of the processed yarn samples were measured. Tests were also carried out in order to examine the effect of the partially yarn untwisting process on the yarn strength. The results appear in the Table 3.3:

Table 3.3 Twist and Strength Testing Results of Yarns **29** tex

No	T.F.‡	CONDITION	ACTUAL TWIST	ELONGATION at break	FORCE at break	TENACITY	WORK OF RUPTURE
			(turns.m^{-1})	%	cN	cN.tex^{-1}	cN.cm
1	32.4	Normal	601.6	6.98	440.33	14.68	721.32
2	32.4	Steamed	**590.9**	**6.79**	**404.11**	**13.47**	**655.08**
3	38.6	Normal	719.4	7.25	483.69	16.12	803.82
4	38.6	Steamed	**719.2**	**6.80**	**466.53**	**15.55**	**742.46**
5	38.6	Proc. 154†	**570.4**	**6.16**	**389.62**	**12.99** (16.5 %)	**579.44**
6	38.6	Proc. 163	576.0	6.52	385.53	12.85 (17.4 %)	599.22
7	38.6	Proc. 175	562.0	6.77	410.81	13.69 (12.0 %)	664.58

† Nominal S untwist (turns.m^{-1}) in the steamed yarn.

‡ Twist Factor (turns.cm^{-1}.tex^{½})

3.6.2.4 *Knitted Fabric Production*

Applying the settings mentioned in section 2.1.3.2, sixty courses of fabric were produced from each of the following yarn samples, being separated by sixty courses of fabric made of coloured "dead" yarn. Two sets of fabric samples were examined, in terms of spirality angle, and the results are shown in the Tables 3.4 and 3.5 as well as in Figures 3.2 and 3.3.

Table 3.4 **Spirality Angle** (°) of Fabrics Produced from Yarns **29 tex** (1st set)

Sample No	T.F.	Condition	**Before Wetting**	**After Wetting**	Difference (**B-A**)
1	**32.4**	Normal	31.0	26.0	*5.0*
2	**32.4**	Steamed	13.5	13.5	*0.0*
Difference (1-2)			*17.5*	*12.5*	
3	**38.6**	Normal	38.5	23.5	*15.0*
4	**38.6**	Steamed	19.0	11.0	*8.0*
Difference (3-4)			*19.5*	*12.5*	
5	**38.6**	Proc.154*	1.5	3.5	*-2.0*
6	**38.6**	Proc.163	-2.0	3.0	*-5.0*
7	**38.6**	Proc.175	1.5	6.5	*-5.0*

* Nominal S untwist (turns.m^{-1}) in the steamed yarn

Note: The negative sign in the column of the spirality angle values indicates that the fabric showed spirality of S direction. Also **B** stands for Before Wetting and **A** stands for After Wetting.

Table 3.5 **Spirality Angle** (°) of Fabrics Produced from Yarns **29 tex** (2nd set)

Sample No	T.F.	Condition	**Before Wetting**	**After Wetting**	Difference (**B-A**)
1	**32.4**	Normal	34.5	29.0	*5.5*
2	**32.4**	Steamed	11.5	13.5	*-2.0*
Difference (1-2)			*23.0*	*15.5*	
3	**38.6**	Normal	33.0	25.5	*7.5*
4	**38.6**	Steamed	19.5	15.5	*4.0*
Difference (3-4)			*13.5*	*10.0*	
5	**38.6**	Proc.154	2.5	2.5	*0.0*
6	**38.6**	Proc.163	1.0	1.0	*0.0*
7	**38.6**	Proc.175	3.0	6.0	*-3.0*

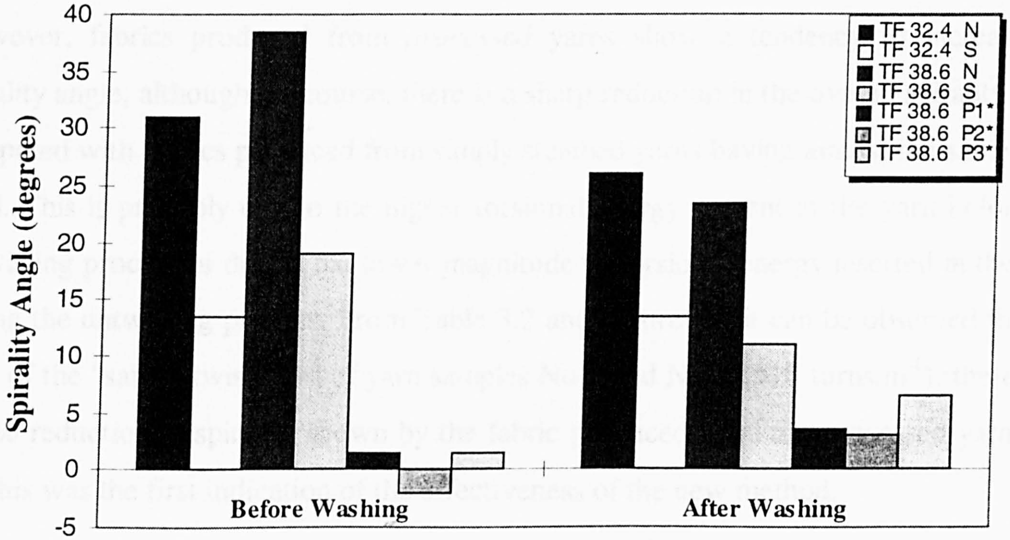


Fig. 3.2 Effect of the New Method on the Spirality Angle (1st Set)

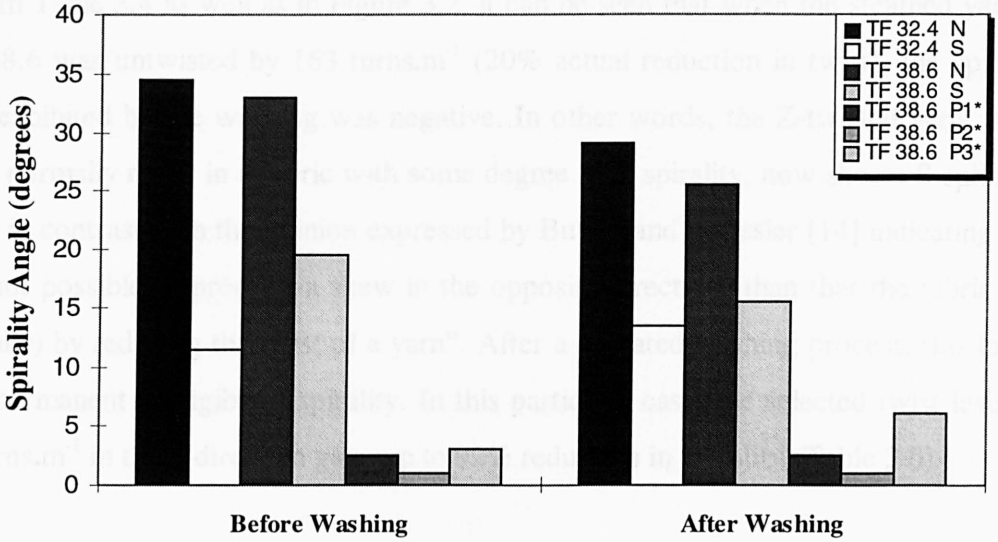


Fig. 3.3 Effect of the New Method on the Spirality Angle (2nd Set)

*N - Normal, S - Steamed, P - Processed (i.e., P_1, P_2, P_3 : Nominal 154, 163, 175 turns.m^{-1} S twist in the steamed yarn 29 tex, T.F. 38.6, respectively)

3.6.3 RESULTS - DISCUSSION

Spirality Effect

From the Figures 3.1, 3.2 and 3.3 the significant effect of the setting process on the reduction of the spirality effect of the fabrics is obvious. It is evident for the knitted fabrics produced from normal yarn samples that, in this case, there appears to be some reduction in spirality. For some of the knitted fabrics produced from steamed yarn samples, washing appears to increase spirality, while in other instances spirality reduces. However, fabrics produced from *processed* yarns show a tendency to increase the spirality angle, although, of course, there is a sharp reduction in the overall spirality when compared with fabrics produced from simply steamed yarns having almost the same twist level. This is probably due to the higher torsional energy present in the yarn before the untwisting process or due to the lower magnitude of torsional energy inserted in the yarn during the untwisting process. From Table 3.2 and Figure 3.1 it can be observed that, in spite of the "same" twist level of yarn samples No 2 and No 5 (518 turns.m^{-1}), there was a 69% reduction in spirality shown by the fabric produced from the processed yarn (No 5). This was the first indication of the effectiveness of the new method.

In Table 3.4 as well as in Figure 3.2, it can be seen that when the steamed yarn of T.F. 38.6 was untwisted by 163 turns.m^{-1} (20% actual reduction in twist), the spirality angle exhibited before washing was negative. In other words, the Z-twisted yarn, while would normally result in a fabric with some degree of Z spirality, now shows S spirality. This is in contrast with the opinion expressed by Buhler and Haussler [14] indicating that "it is not possible to produce a skew in the opposite direction (than that the fabric had originally) by reducing the twist of a yarn". After a repeated washing process, this fabric had a permanent negligible Z spirality. In this particular case, the selected twist level of 163 turns.m^{-1} in the S direction gave up to 92% reduction in spirality (Table 3.6).

Table 3.6 Percentage Differences in Spirality Angle

(All the comparisons were made with the steamed yarn sample (corresponding No 2))

Nominal S Untwist (turns.m^{-1})	Table 3.4	Table 3.5
154	74%	81%
163	78%	92%
175	52%	55%

Yarn Tenacity

From Table 3.3, it is concluded that an insignificant reduction in terms of yarn strength is observed when comparison is made between the processed yarn samples and the steamed yarn from which they were produced. When these processed samples are compared with the yarn that has an "equivalent" twist level, the reduction in strength is considered as negligible (16.5% reduction for the yarn processed with 154 turns.m^{-1}, 17.4% for the yarn processed with 163 turns.m^{-1} and 12% reduction for the yarn processed with 175 turns.m^{-1}).

3.6.4 APPLICATION OF THIS METHOD ON COMMERCIALLY USED Z-TWISTED YARNS **20 tex**

After the application of the new method to laboratory spun yarn samples, it was decided to carry out another experiment in order to investigate the effect of the new method on a commercially-used Z-twisted knitting yarn.

3.6.4.1 *Yarn Sampling*

A commercially available combed cotton single yarn with 770 turns.m^{-1} (Z) was obtained. For the experimental work, six processed yarn samples were prepared from a quantity of steamed yarn and are listed below:

	Nominal Remaining Z Twist (turns.m^{-1})
1. Original-normal yarn	(770);
2. Steamed yarn	(750);
3. Processed with (S) 111 turns.m^{-1}	(639);
4. Processed with (S) 133 turns.m^{-1}	(617);
5. Processed with (S) 157 turns.m^{-1}	(593);
6. Processed with (S) 182 turns.m^{-1}	(568);
7. Processed with (S) 206 turns.m^{-1}	(544);

The two-for-one twisting frame that was used for this stage of the method had a lower limit of 111 turns.m^{-1} twist level. Removal of lower levels of twist, although desirable was not possible.

The yarn samples were knitted on the same knitting machine as earlier (§ 2.1.3.2) without using the take-down tension. Fifty courses of each of the samples were produced. The loop length was calculated and was found to be 5.05 mm (tightness factor 0.885 tex$^{1/2}$.mm^{-1}). The very low value of the tightness factor was suitable for the appearance of a great spirality distortion on the knitted fabric samples. The fabric samples were separated by fifty courses of coloured yarn between each sample, in order to avoid any possible disturbance of the spirality effect by the neighbouring samples.

The fabric samples were allowed to relax for a period of thirty six hours before the spirality angle was measured after wetting. The spirality angles of the dried fabric samples are presented in Table 3.7. Figure 3.4 shows the relation between the actual and calculated twist. In Table 3.8 as well as in Figures 3.5 and 3.6, the relations between percentage reductions in the actual twist, tenacity and spirality angle are presented.

Table 3.7 Experimental Results of Tests Carried out on a Commercially Used Knitting Yarn **20 tex** and Fabrics

SAMPLES		Actual Net Z TWIST		ELONG. [*]		FORCE [*]		TENACITY		Work of RUPTURE		SPIRALITY	
No	Condition	turns.m^{-1}	CV%	%	CV%	cN	CV%	cN.tex^{-1}	CV%	cN.cm	CV%	BW	AW
1	Normal (Z-twisted)	789.3	3.91	6.46	5.67	315.79	6.31	15.79	6.31	502.01	10.98	32°	28°
2	Steamed (Z-twisted)	739.1	4.11	5.91	6.25	293.05	8.25	14.65	8.25	406.66	14.71	9°	14°
3	N[†] S Untwist **111** turns.m^{-1}	648.3	3.96	5.30	4.11	275.77	4.61	13.79	4.61	366.75	9.67	0°	6°
4	N[†] S Untwist **133** turns.m^{-1}	645.9	4.46	5.13	5.54	253.07	6.84	12.65	6.84	326.72	12.14	2°	6°
5	N[†] S Untwist **157** turns.m^{-1}	645.6	2.40	5.32	5.36	243.16	7.28	12.16	7.28	326.51	11.33	-1°	2°
6	N[†] S Untwist **182** turns.m^{-1}	646.5	3.90	4.71	7.07	184.06	11.82	9.20	11.82	228.47	17.02	-2°	-1°
7	N[†] S Untwist **206** turns.m^{-1}	623.9	4.12	4.96	7.05	192.71	11.30	9.64	11.30	252.96	16.61	1°	2°

[*] Elongation at break; Force at break; BW : Before Washing AW: After Washing

[†] Nominal S Untwist in the steamed Z-twisted yarn

Table 3.8 Effect of the Yarn Untwisting Process on **the Percentage Reduction (%)** of ***Twist*** and ***Tenacity*** of Yarns and Fabric ***Spirality***
(in comparison with the Normal Yarn No 1, i.e., 770 turns.m^{-1} (Table 3.7))

Sample	Nominal S Untwist		**Actual Twist**	**Tenacity**	**Spirality**
No	turns.m^{-1}	%	%	%	%
3	111	14.0	17.9	12.7	78.6
4	133	16.8	18.2	19.9	78.6
5	157	19.9	18.2	23.0	92.9
6	182	23.0	18.1	41.7	103.6
7	206	26.1	21.0	38.9	92.9

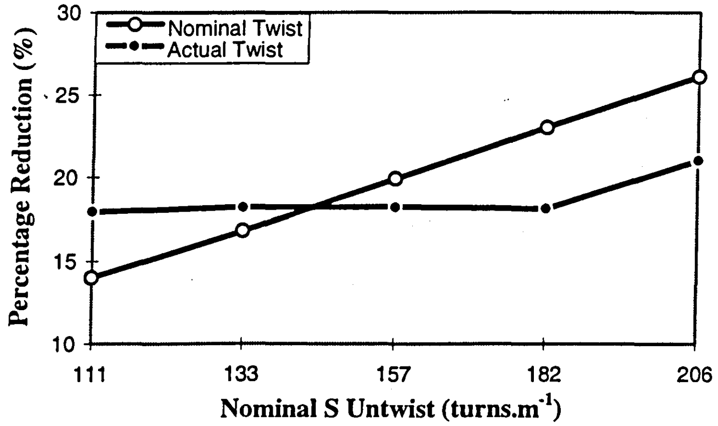


Fig. 3.4 Relation between Actual and Calculated Twist

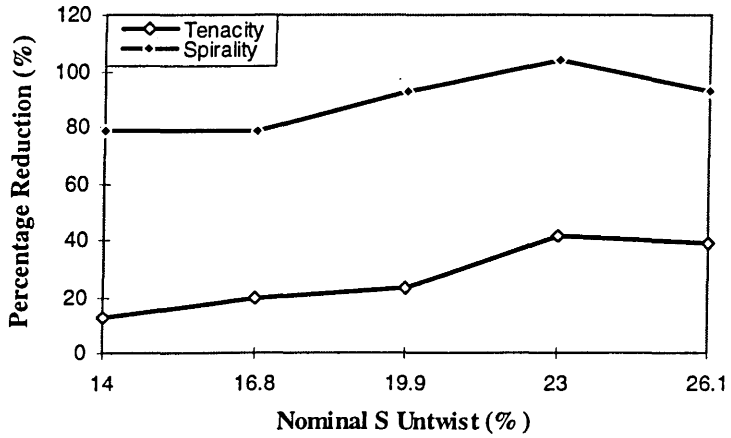


Fig. 3.5 Effect of the Calculated (Nominal) Reduced Twist on the Percentage (%) Reduction of Yarn Tenacity and Fabric Spirality

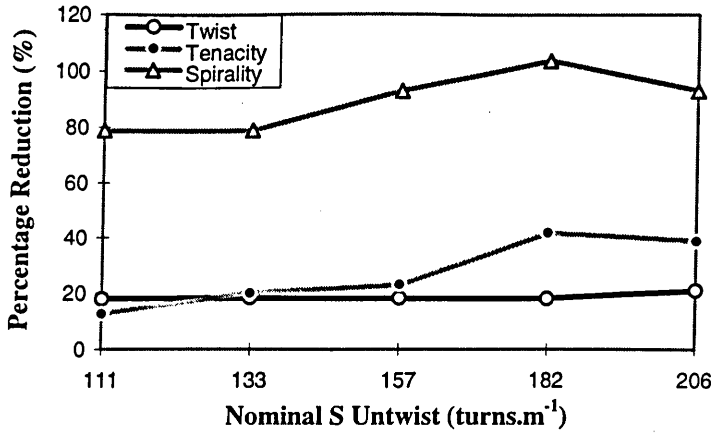


Fig. 3.6 Relation between Twist, Tenacity and Spirality Angle Percentage Reduction (%)

3.6.4.2 *Discussion*

It is clear from the results, that the new method was very effective in reducing the spirality angle and in many cases knitted fabrics show no spirality at all. In particular, from the Tables 3.7 and 3.8 and Figure 3.6, the following conclusions can be drawn:

Although different twist levels were subtracted, the actual measured twist level remaining in the yarns was in all the cases almost the same. This can easily be seen in Figure 3.4 where the relation between the percentage reduction in calculated (nominal) and actual twist is presented. It is observed that the measured twist in samples 3 to 6 does not show any marked difference despite various levels of twist removal, having a step of approximately 24 turns.m^{-1} between successive pairs, whereas sample 7 does show clearly the twist reduction. This difference between the calculated and the actual twist could not be explained.

Furthermore, the reduction of the yarn twist in different levels resulted in a clear reduction of the yarn tenacity. But the most interesting observation of this experiment was that, although the percentage reduction in the yarn twist was small (approximately 18%), the percentage reduction in spirality exhibited by the knitted fabrics after washing reached and exceeded a level of 100%.

If the reductions in both the strength and the spirality are taken into consideration, the optimum reduction in twist for this particular commercial yarn could be of the order of 157 turns.m^{-1}.

CHAPTER 4

APPLICATION OF THE NEW METHOD FOR THE REDUCTION OF SPIRALITY OF KNITTED FABRICS

4.1 DESCRIPTION OF THE EXPERIMENT

Numerous studies on the effect of twist on yarn and fabric properties have shown that twist is a significant factor that determines the nature and the properties of a yarn.

It was found from preliminary experiments that the application of the method of partially untwisting the steam-set ring-spun yarns, affected the spirality angle of the single jersey knitted fabrics. Furthermore, this angle could be reduced to a minimum level, by optimising the amount of twist inserted in the opposite direction to the original twist direction.

This yarn partial untwisting process contributes significantly to the reduction of the spirality effect, but a careful survey of the available literature offered no information regarding the exact mechanism. It was decided, therefore, to carry out an experimental investigation into the effect of the untwisting process on some yarn properties as well as knitted fabric properties.

This chapter will describe experimental work in which the untwisting process is applied both to the "*normal*" and the "*steamed*" yarns.

4.1.1 YARN SAMPLES

The yarn samples that were initially produced for the preliminary experiments (§ 2.1.1.1), were also used for this experimental work. The samples were from two different yarn linear densities (namely 29 tex and 39 tex) with three different twist factors (Table 2.6) for each yarn (i.e., six "*normal*" yarn samples). These samples were unwaxed, single, Z-twisted, ring-spun cotton yarns.

4.1.2 YARN STEAM-SETTING PROCESS

Quantities of each of the six yarn samples were wound on perforated conical supports on a Gilbos winding machine with a speed of 600 $m.min^{-1}$. The perforated supports provided a means for easier penetration of the steam in the yarn package.

All the cones were placed in a Sanderson steam vacuum autoclave for the setting process. The yarns were steamed for 50 minutes at 105 °C under a pressure of approximately 69 kN.m^{-2} (kPa). After this stage, the yarn samples were left to dry in room conditions. Finally, they were stored in standard atmospheric conditions (20±2 °C, 65±2 % R.H.) for four days.

4.1.3 YARN PARTIAL UNTWISTING PROCESS

A Volkmann two-for-one twisting frame was used for the insertion of various S direction twists (subtracted twist). All the yarn samples were processed on the same spindle to avoid any possible variation due to machine factors. The tension applied to the yarn in its passage through the hollow spindle was 9.81 mN (tensioning capsule inside the spindle). Thirty five "*processed*" yarn samples were produced as shown in the following table. The differences in twist levels inserted were approximately 18 turns.m^{-1} for yarn linear density of 29 tex and 10 turns.m^{-1} for yarn linear density of 39 tex. For both yarn linear densities, the tests were stopped when the yarns proved to be too weak.

Linear Density	**29 tex**			**39 tex**		
Nominal S Untwist (turns.m^{-1})	**Twist Factor (TF)** (turns.cm^{-1}.tex^{½})					
	32.4	**34.9**	**38.6**	**32.3**	**33.4**	**39.5**
111	✓	✓	✓	✓	✓	✓
121				✓	✓	✓
129	✓	✓	✓			
133				✓	✓	✓
142				✓	✓	✓
147	✓	✓	✓			
154					✓	✓
163	✓	✓	✓		✓	✓
182	✓	✓	✓			
200		✓	✓			
220		✓	✓			

A further 35 samples this time without steam setting were also untwisted to the same levels.

4.1.4 FABRIC PRODUCTION

A total number of seventy yarn samples, including both the normal and the steamed lots, were thus produced. These yarns were knitted on a WILDT model 5 knitting machine (§ 2.1.3.1) producing fabric samples of 130 courses each. Seventy courses of fabric were produced from dead coloured yarn, after every fabric sample, to avoid possible disturbance in spirality from the adjacent samples. The loop length was calculated and found to be 4.83 mm and the tightness factor was: for yarns 29 tex $K_1 = 1.023\ \text{tex}^{1/2}.\text{mm}^{-1}$ and for yarns 39 tex $K_2 = 1.187\ \text{tex}^{1/2}.\text{mm}^{-1}$. In order to minimise the number of factors that might influence these experiments, it was decided to keep the tightness factor constant. It is well known that the tighter the knitted fabrics the less spirality is exhibited due to the restriction of the yarn movement in the knitted structure. Thus, any attempts to minimise the spirality in very loose fabrics could have the same and probably better results in tighter fabrics. This is the reason for choosing these low tightness factors. No take-down tension was applied to the fabrics and no arrangement was made for yarn positive feed because a positive feeding device was not available. As the application of take-down tension is concerned, it has been stated in the first chapter (§ 1.5.5) that the application of take-down tension of the produced knitted fabric results in the appearance of less spirality. Thus, in order to encounter spirality in its highest level, it was decided to apply no take-down tension on the fabrics. No excessive strain was therefore imposed on the fabric during knitting and thus no excessive shrinkage was expected after washing and drying.

4.1.5 WASHING PROCESS

The fabric samples were washed without any washing powder in a domestic washing machine for a normal cycle of 25 minutes. The drying stage took place in a domestic dryer.

4.2 YARN AND FABRIC SAMPLES TESTING (see also Appendices II, IV)

4.2.1 YARN TESTING

The yarn samples, both normal and steamed, were tested for twist, linear density, evenness, strength, hairiness and thickness.

4.2.1.1 *Twist*

The Zweigle D 301 twist tester was used for the measurement of the twist of all the yarn samples. The results are given in Tables 4.1 and 4.2. Each reading is the average of 10 tests. For all the tests, the twist direction of the rotating clamp of the tester had been set to the Z position (i.e., Z-twisted yarns). The Tables 4.3 and 4.4 present the percentage reduction in terms of actual twist measurements whereas the percentage reductions of the calculated twist are reported in the Tables 4.5 and 4.6. Furthermore the relation between the percentage reduction of actual and calculated twist is presented in Figures 4.1 and 4.2.

Table 4.1 **Twist** Test Results of the Z-twisted Yarn **39 tex** (turns.m^{-1})

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.3	TF 33.4	TF 39.5	TF 32.3	TF 33.4	TF 39.5
0	531.7	554.7	642.1	520.9	553.3	630.1
111	447.6	475.4	539.6	437.5	466.0	531.6
121	460.8	465.1	531.8	446.1	457.4	531.9
133	449.7	454.9	518.1	436.2	453.8	511.1
142	-	449.0	514.5	436.9	454.4	513.6
154	-	449.8	492.6	-	438.7	486.6
163	-	447.7	500.2	-	444.1	481.0

Table 4.2 **Twist** Test Results of the Z-twisted Yarn **29 tex** (turns.m^{-1})

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.4	TF 34.9	TF 38.6	TF 32.4	TF 34.9	TF 38.6
0	616.9	665.7	742.3	619.5	660.4	731.2
111	537.2	575.8	632.9	537.3	566.7	635.4
129	523.7	573.8	608.3	537.9	568.9	621.5
147	528.5	556.0	593.2	529.5	551.5	611.6
163	522.0	544.2	603.5	502.1	543.8	596.5
182	511.0	536.4	584.7	499.9	530.7	587.5
200	-	513.8	575.6	-	521.9	552.9
220	-	521.7	558.0	-	511.7	559.0

Table 4.3 Percentage (%) Reduction of Actual Twist of the Yarn **39 tex**

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.3	TF 33.4	TF 39.5	TF 32.3	TF 33.4	TF 39.5
111	15.8	14.3	16.0	16.0	15.8	15.6
121	13.3	16.2	17.2	14.4	17.3	15.6
133	15.4	18.0	19.3	16.3	18.0	18.9
142	-	19.1	19.9	16.1	17.9	18.5
154	-	18.9	23.3	-	20.7	22.8
163	-	19.3	22.1	-	19.7	23.7

Table 4.4 Percentage (%) Reduction of Actual Twist of the Yarn **29 tex**

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.4	TF 34.9	TF 38.6	TF 32.4	TF 34.9	TF 38.6
111	12.9	13.5	14.7	13.3	14.2	13.1
129	15.1	13.8	18.1	13.2	13.9	15.0
147	14.3	16.5	20.1	14.5	16.5	16.4
163	15.4	18.3	18.7	19.0	17.7	18.4
182	17.2	19.4	21.2	19.3	19.6	19.7
200	-	22.8	22.5	-	21.0	24.4
220	-	21.6	24.8	-	22.5	23.6

Table 4.5 Percentage (%) Reduction of Calculated Twist of the Yarn **39 tex**

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.3	TF 33.4	TF 39.5	TF 32.3	TF 33.4	TF 39.5
111	20.9	20.0	17.3	21.3	20.1	17.6
121	22.8	21.8	18.8	23.2	21.9	19.2
133	25.0	24.0	20.7	25.5	24.0	21.1
142	-	25.6	22.1	27.3	25.7	22.5
154	-	27.8	24.9	-	27.8	24.4
163	-	29.4	25.4	-	29.5	25.9

Table 4.6 Percentage (%) Reduction of Calculated Twist of the Yarn **29 tex**

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.4	TF 34.9	TF 38.6	TF 32.4	TF 34.9	TF 38.6
111	18.0	16.7	15.0	17.9	16.8	15.2
129	20.9	19.4	17.4	20.8	19.5	17.6
147	23.8	22.1	19.8	23.7	22.3	20.1
163	26.4	24.5	22.0	26.3	24.7	22.3
182	29.5	27.3	24.5	29.4	27.6	24.9
200	-	30.0	26.9	-	30.3	27.4
220	-	33.0	29.6	-	33.3	30.1

Discussion: From Tables 4.3 to 4.6 it can be seen that the percentage reduction of the actual twist of each processed yarn sample is lower than the percentage reduction of the correspondent calculated twist (i.e., *(original - nominal inserted)/original*). This is probably because of the yarn irregularity (affecting the normal twist distribution), a fact

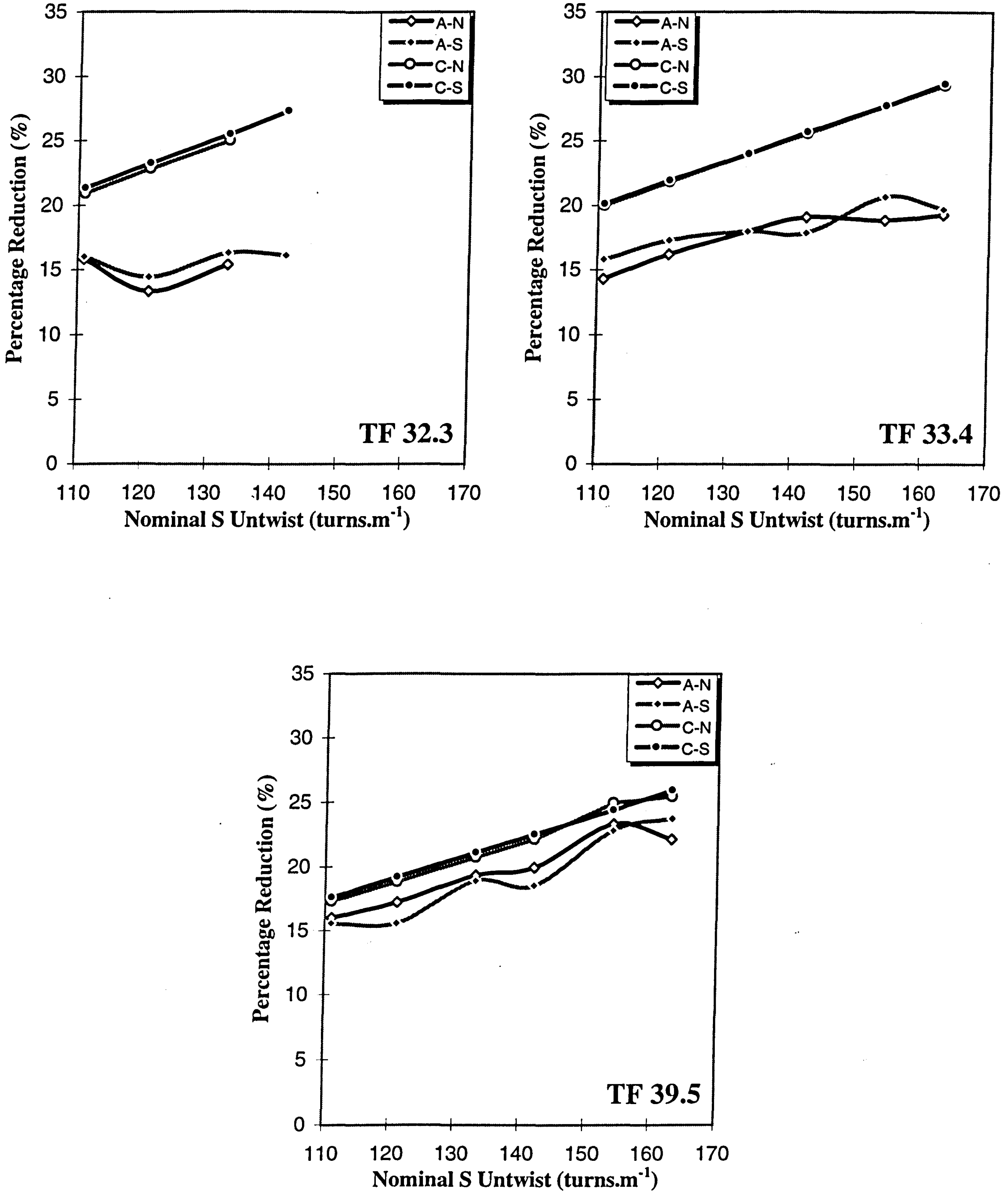


Fig. 4.1 Relation between Nominal and Calculated **S Untwist** (Yarn 39 tex)

* A-N Actual / Normal, A-S Actual / Steamed, C-N Calculated / Normal, C-S Calculated / Steamed

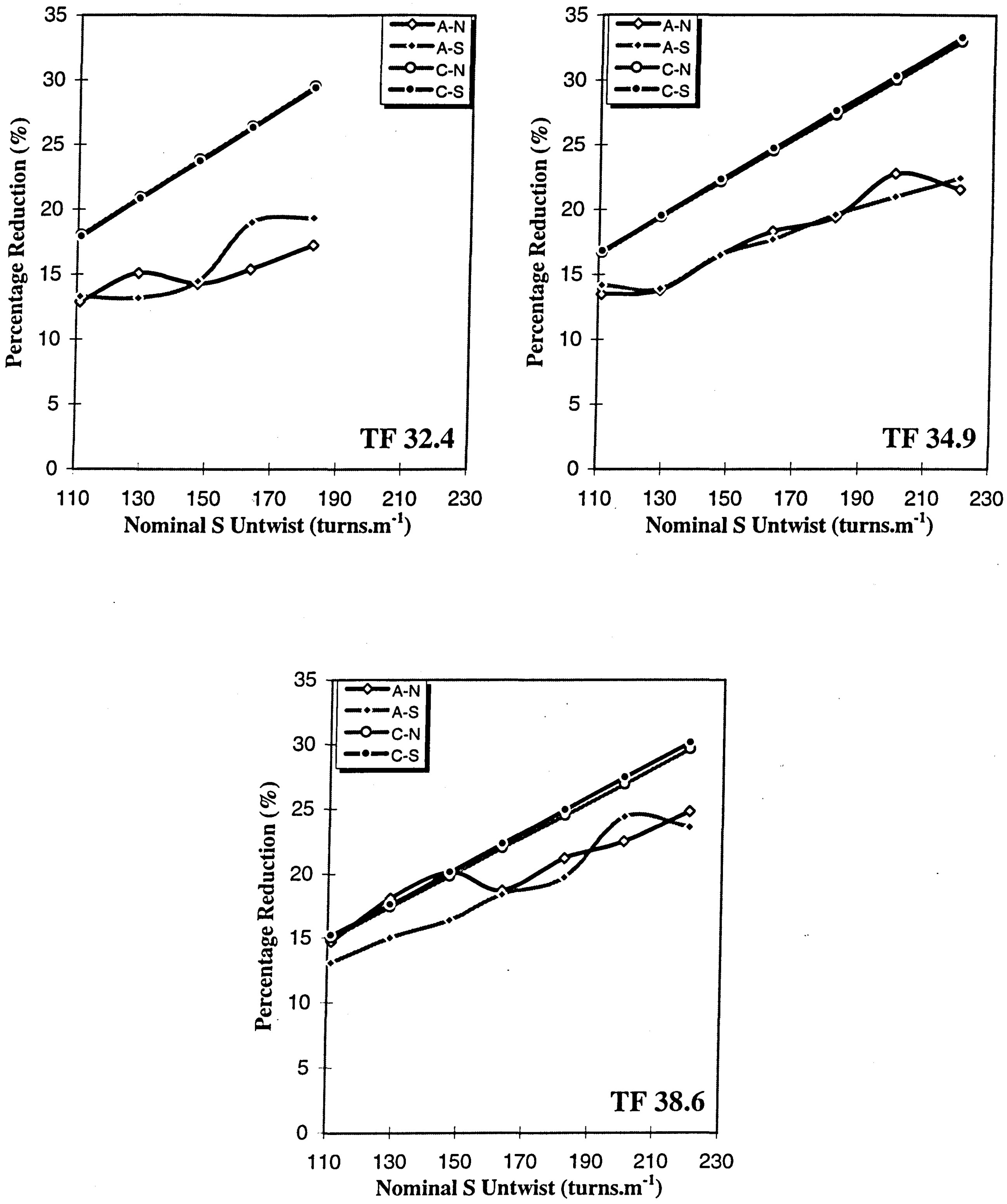


Fig. 4.2 Relation between Nominal and Calculated **S Untwist** (Yarn 29 tex)

* A-N Actual / Normal, A-S Actual / Steamed, C-N Calculated / Normal, C-S Calculated / Steamed

that becomes more evident if the variance (CV%) of the twist measurements is taken into account (see Appendix IV). Another factor could be small deviation in twist from that set at the two-for-one twisting frame.

For both the yarn linear densities (29 tex and 39 tex), the measured actual twist in the samples produced from the "normal" (unset) yarns is, in most of cases, higher than that of the "steam-set" processed yarns. These differences are not significant.

4.2.1.2 *Linear Density*

The linear density of the various produced yarn samples was calculated by weighing 50 m hanks on an electronic micro balance. The results for linear density (tex) are presented in Tables 4.7 and 4.8.

Table 4.7 **Linear Density (tex)** Test Results of the Z-twisted Yarn **39 tex**

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.3	TF 33.4	TF 39.5	TF 32.3	TF 33.4	TF 39.5
0	40.48	40.00	39.20	39.82	39.50	40.32
111	39.40	38.96	38.98	38.64	39.28	39.50
121	39.04	38.68	40.04	38.22	39.52	40.44
133	37.74	39.18	38.60	37.10	38.66	38.72
142	-	38.56	40.44	37.52	39.40	40.68
154	-	39.20	38.84	-	38.62	38.80
163	-	39.20	39.48	-	38.52	39.08

Table 4.8 **Linear Density (tex)** Test Results of the Z-twisted Yarn **29 tex**

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.4	TF 34.9	TF 38.6	TF 32.4	TF 34.9	TF 38.6
0	29.90	28.66	29.38	29.60	29.88	29.68
111	29.56	29.88	29.50	28.74	29.16	29.56
129	29.38	28.40	29.40	28.80	29.60	29.14
147	30.28	28.94	28.76	28.82	28.98	30.00
163	30.52	28.64	29.76	29.00	28.70	28.90
182	28.82	28.60	28.92	29.16	29.56	29.48
200	-	28.60	30.18	-	28.90	29.76
220	-	28.30	30.24	-	28.02	29.66

Discussion: There is an insignificant reduction in the linear density within most of the groups (both the normal and steamed lots) of the various yarn samples as the inserted amount of S twist increases. It is possible that this effect is the result of a combination of the two factors acting within the two-for-one twister during the yarn processing; firstly the *untwisting* process renders the structure more open, this then results in an easier fibre slippage during the *winding* operation, which can be considered as a form of yarn drafting process.

4.2.1.3 *Evenness*

The mass irregularity of the samples was examined by the Uster Tester 3 apparatus, and the results are reported in Tables 4.9 and 4.10.

Table 4.9 **Evenness** Test Results of the Z-twisted Yarn **39 tex** (CVm %)

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.3	TF 33.4	TF 39.5	TF 32.3	TF 33.4	TF 39.5
0	13.28	12.14	12.07	13.06	13.01	12.46
111	13.03	12.96	12.45	12.19	12.57	13.80
121	12.33	12.43	11.99	12.74	12.74	13.18
133	12.91	13.25	12.43	13.14	13.97	12.83
142	-	13.15	12.41	13.08	13.65	12.45
154	-	12.61	12.46	-	13.19	13.00
163	-	12.47	12.68	-	12.89	13.08

Table 4.10 **Evenness** Test Results of the Z-twisted Yarn **29 tex** (CVm %)

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.4	TF 34.9	TF 38.6	TF 32.4	TF 34.9	TF 38.6
0	14.10	14.92	14.17	14.56	13.48	13.53
111	13.64	14.30	13.58	14.53	13.99	14.04
129	14.84	14.72	14.19	13.61	14.05	14.33
147	12.85	14.77	14.53	13.89	14.39	14.36
163	12.92	15.06	14.72	13.64	14.04	14.85
182	13.54	14.01	14.83	13.02	14.82	13.84
200	-	13.81	14.42	-	14.74	13.57
220	-	13.35	15.01	-	14.45	14.15

Discussion: Although it was thought that the untwisting process could possibly result in a less irregular yarn, the results shown in the Tables 4.9 and 4.10 do not indicate any particular pattern and it would appear that the untwisting process has little effect on the regularity of the yarn.

4.2.1.4 *Strength*

Considering that the most essential factor in the new method is the insertion of a small amount of twist in the opposite direction than that present in the yarn originally, it was decided to investigate the effect of this twist reduction on the yarn strength.

Yarn lengths of 50 cm were tested for tenacity on a Textechno Statimat M Tensile Tester. The mean tenacity values of twenty five readings are presented in Tables 4.11, 4.12 and in Figures 4.3 and 4.4. Tables 4.13 and 4.14. Figures 4.5 and 4.6 present the percentage differences between original yarns (both the normal and steamed) and the untwisted yarn samples.

Table 4.11 **Tenacity** Test Results of the Z-twisted Yarn **39 tex** (cN.tex^{-1})

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.3	TF 33.4	TF 39.5	TF 32.3	TF 33.4	TF 39.5
0	12.92	14.33	15.78	11.80	13.13	13.20
111	8.97	11.93	13.33	7.53	9.91	11.08
121	9.04	10.35	13.47	7.47	9.67	12.29
133	8.19	9.55	14.13	5.99	8.60	10.85
142	-	9.11	12.07	6.40	7.78	12.79
154	-	8.29	11.37	-	7.47	10.89
163	-	8.91	12.13	-	6.94	10.10

Table 4.12 **Tenacity** Test Results of the Z-twisted Yarn **29 tex** (cN.tex^{-1})

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.4	TF 34.9	TF 38.6	TF 32.4	TF 34.9	TF 38.6
0	14.06	13.33	14.63	11.13	12.03	14.31
111	11.40	12.11	13.65	8.21	9.45	11.88
129	9.24	12.38	12.72	8.32	10.02	11.46
147	7.75	9.80	13.03	7.82	8.30	11.15
163	6.91	9.62	12.82	5.81	8.69	10.62
182	6.60	9.28	13.03	5.89	8.80	10.65
200	-	8.95	11.51	-	7.42	9.63
220	-	7.23	11.70	-	9.08	9.83

Table 4.13 Percentage (%) Reduction of Tenacity of the Yarn **39 tex**

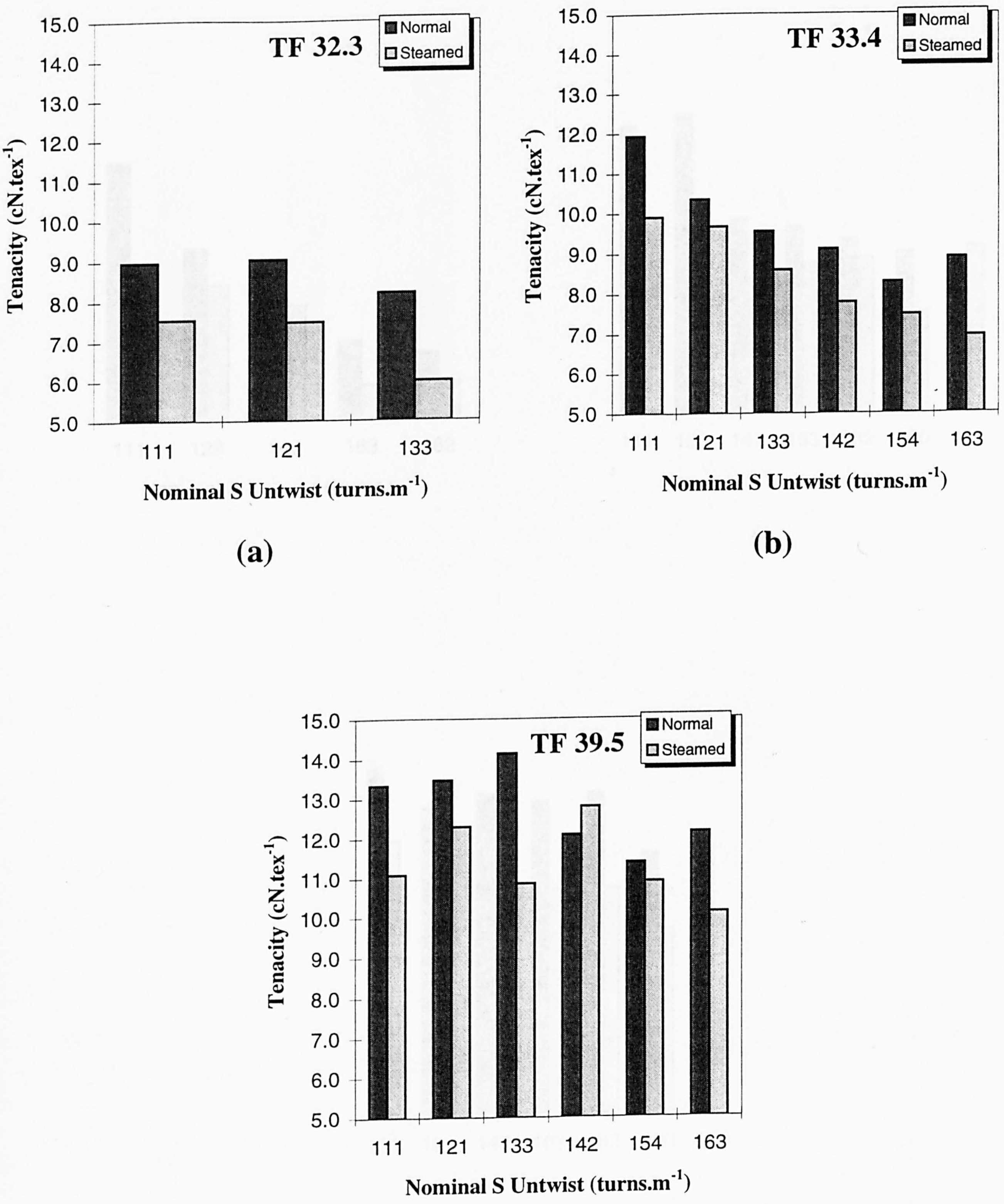
Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.3	TF 33.4	TF 39.5	TF 32.3	TF 33.4	TF 39.5
111	30.57	16.75	15.53	36.19	24.52	16.06
121	30.03	27.77	14.64	36.69	26.35	6.89
133	36.61	33.35	10.46	49.23	34.50	17.80
142	-	36.42	23.51	45.76	40.75	3.11
154	-	42.15	27.95	-	43.11	17.50
163	-	37.82	23.13	-	47.14	23.48

Table 4.14 Percentage (%) Reduction of Tenacity of the Yarn **29 tex**

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.4	TF 34.9	TF 38.6	TF 32.4	TF 34.9	TF 38.6
111	18.92	9.15	6.70	26.02	21.45	16.98
129	34.28	7.13	13.06	25.25	16.71	19.92
147	44.88	26.48	10.94	29.74	31.00	22.08
163	50.85	27.83	12.37	47.80	27.76	25.79
182	53.06	30.38	10.94	47.08	26.85	25.58
200	-	32.86	21.33	-	38.32	32.70
220	-	45.76	20.03	-	24.52	31.31

Discussion: It is generally recognised that as twist is introduced into a strand of short staple fibres, there is an increase in cohesion between fibres. The superficial friction generated between the fibres which are packed in the yarn structure, provides strength to the yarn. Thus the yarn becomes able to withstand any longitudinal stresses applied to it. It is also well known that *as the twist increases, the yarn strength increases up to a point and then reduces.*

From Tables 4.11 and 4.12 and Figures 4.3 and 4.4, it is evident, as expected, that the twist reduction causes a reduction in the tenacity of all the examined processed yarn samples. This is probably due to the opening of the yarn structure that reduces the contact surface between the fibres and thus fibre slippage is more likely to occur resulting in quicker yarn breakage. Tables 4.13 and 4.14 as well as Figures 4.5 and 4.6 compare the percentage reduction in tenacity, for the *normal* and *steamed* original yarn samples. Comparing the normal and steamed yarn lots it is seen that in most cases, the steamed yarns appear weaker after the untwisting process. This may be explained if the

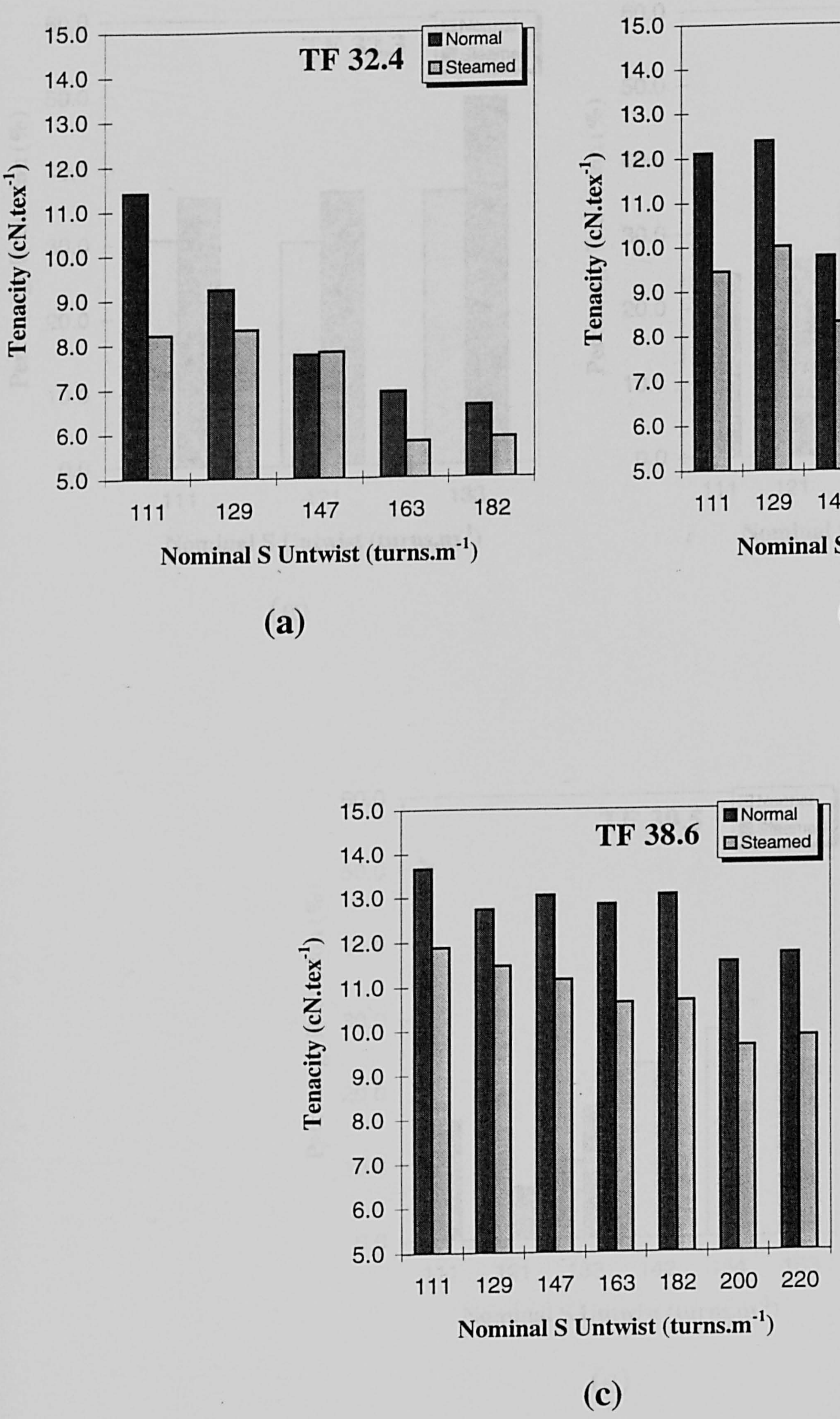


(a)

(b)

(c)

Fig. 4.3 Effect of the Untwisting Process on the **Tenacity** of both Normal and Steamed Yarn Samples **39 tex**

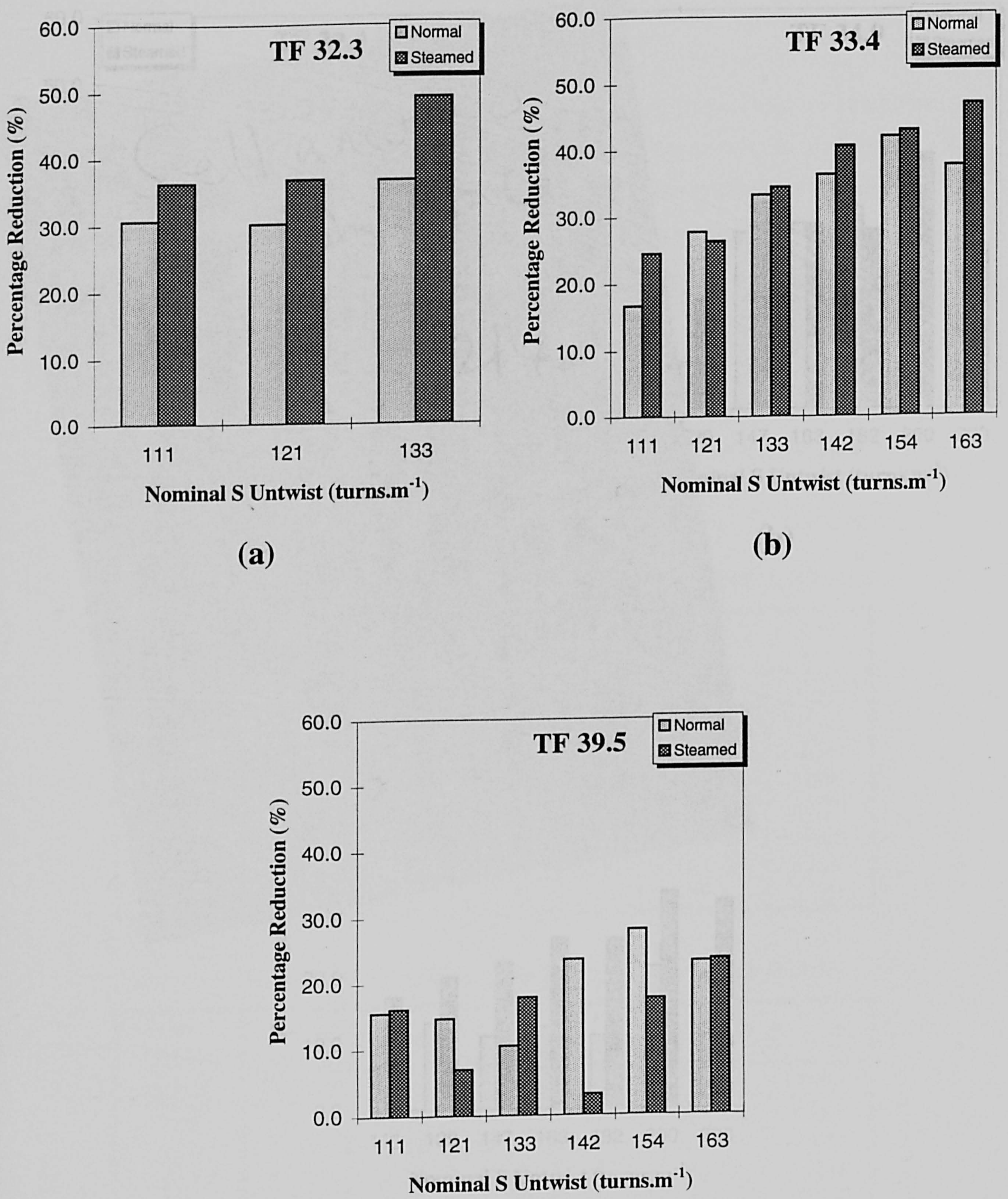


(a)

(b)

(c)

Fig. 4.4 Effect of the Untwisting Process on the **Tenacity** of both Normal and Steamed Yarn Samples **29 tex**

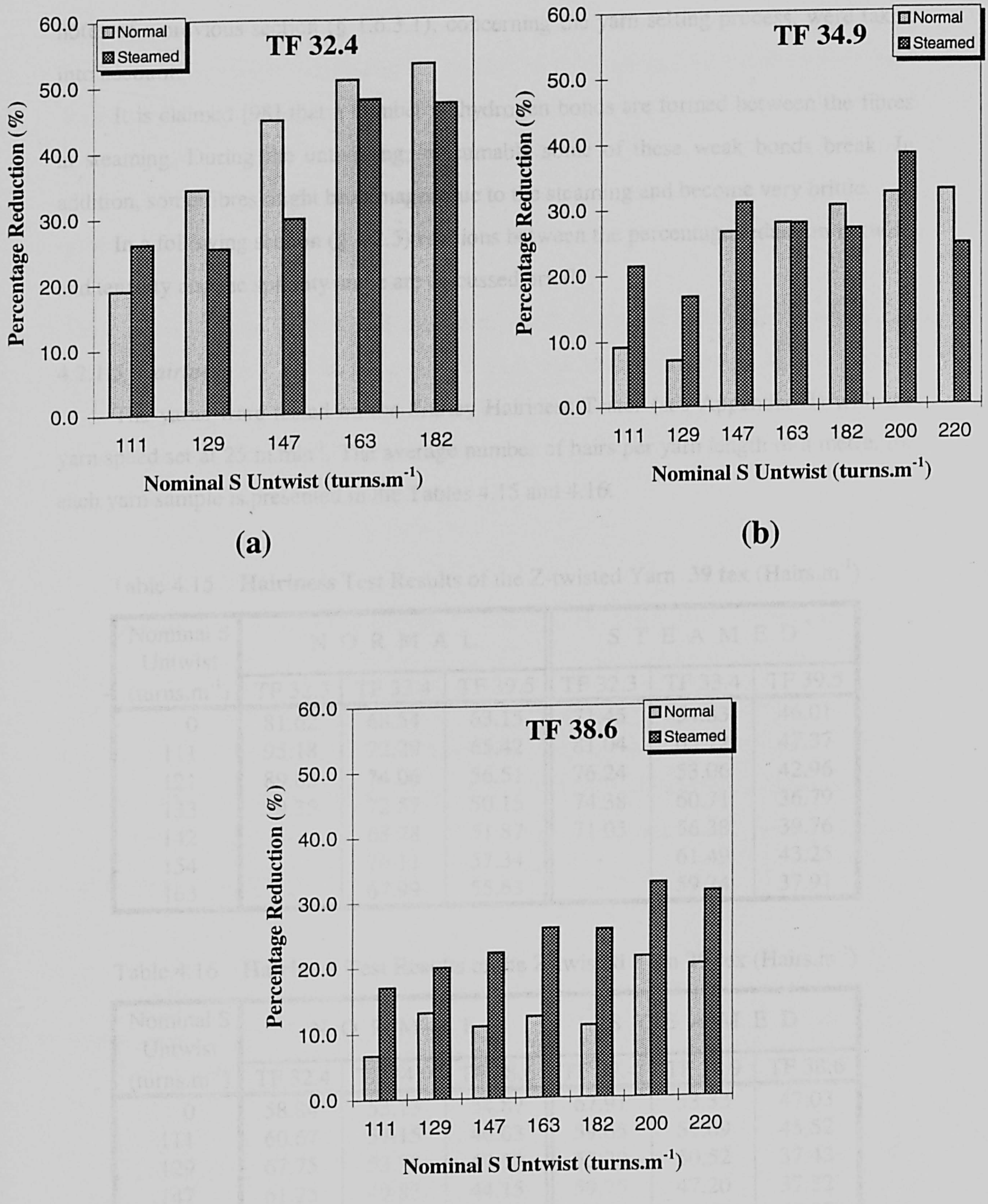


(a)

(b)

(c)

Fig. 4.5 Percentage Reduction of **Tenacity** of both Processed Normal and Steamed Yarn Samples **39 tex**



(a)

(b)

(c)

Fig. 4.6 Percentage Reduction of **Tenacity** of both Processed Normal and Steamed Yarn Samples **29 tex** notes of a previous section (§ 1.6.3.1), concerning the yarn setting process, were taken into account.

It is claimed [98] that a number of hydrogen bonds are formed between the fibres in steaming. During the untwisting, presumably some of these weak bonds break. In addition, some fibres might be damaged due to the steaming and become very brittle.

In a following section (§ 4.2.5) relations between the percentage reduction in twist, and tenacity and the spirality angle are discussed briefly.

4.2.1.5 *Hairiness*

The yarns were tested on the Shirley Hairiness Tester (see Appendix II) with the yarn speed set at 25 m.min^{-1}. The average number of hairs per yarn length of a metre, for each yarn sample is presented in the Tables 4.15 and 4.16.

Table 4.15 **Hairiness** Test Results of the Z-twisted Yarn **39 tex** (Hairs.m^{-1})

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.3	TF 33.4	TF 39.5	TF 32.3	TF 33.4	TF 39.5
0	81.62	68.54	63.15	71.45	54.83	46.01
111	95.18	72.29	65.42	81.04	63.72	47.37
121	89.83	74.06	56.51	76.24	53.06	42.96
133	79.35	72.57	50.15	74.38	60.71	36.79
142	-	68.78	51.87	71.05	56.38	39.76
154	-	76.11	57.34	-	61.49	43.25
163	-	67.99	55.63	-	59.74	37.91

Table 4.16 **Hairiness** Test Results of the Z-twisted Yarn **29 tex** (Hairs.m^{-1})

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.4	TF 34.9	TF 38.6	TF 32.4	TF 34.9	TF 38.6
0	58.84	53.13	54.87	67.91	53.33	47.03
111	60.67	57.15	46.03	59.65	51.09	45.52
129	67.75	53.34	47.53	55.20	50.52	37.43
147	61.25	49.83	44.15	59.75	47.20	37.32
163	63.88	50.92	40.99	58.45	45.41	36.87
182	68.61	51.67	44.93	60.92	48.29	40.57
200	-	48.95	32.75	-	46.80	34.86
220	-	49.74	36.40	-	50.12	36.83

Discussion: Although there is a great variation of hairiness within each of the yarn sample groups, a slight increase in the number of hairs appears for the *processed* yarns for most of the yarn samples (normal and steamed lots), when compared with the original yarns. Exceptions to this are the cases of the highly Z-twisted yarns (39 tex TF 39.5 and 29 tex TF 38.6) where a decrease becomes apparent. It is also clear that steamed yarns in general have a less hairy appearance than normal yarns. In an attempt to explain this observation, the following point has been considered:

The process of untwisting would appear to result in a more open yarn structure and consequently there is an increase in the yarn diameter (bulkiness). As the partially untwisted yarn passes over a fixed point through the slot of the hairiness tester, more hairs are probably detected resulting in an increase of the hairiness index (i.e., hairs per metre), because of the apparent increase in yarn diameter.

4.2.1.6 *Thickness*

A specially designed accessory (Appendix II, Plate II.9), developed in the department's workshop, was used for an indirect yarn thickness measurement. The yarn was wound on the accessory with the help of a manual experimental winding device. The accessory with the yarn was then placed on the Fast-01 Fabric Compression Tester. The average number of yarns in the examination area (10 cm^2) was sixteen. A pressure of 196 N.m^{-2} (Pa) was applied on the yarns to be examined. The means of 5 readings for each yarn sample are presented in Tables 4.17 and 4.18.

Table 4.17 **Thickness** Results of the Z-twisted Yarn **39 tex** (mm)

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.3	TF 33.4	TF 39.5	TF 32.3	TF 33.4	TF 39.5
0	0.410	0.391	0.384	0.417	0.406	0.387
111	0.403	0.402	0.371	0.435	0.423	0.421
121	0.433	0.420	0.393	0.461	0.435	0.413
133	0.432	0.436	0.396	0.436	0.437	0.410
142	-	0.419	0.392	0.452	0.430	0.409
154	-	0.411	0.392	-	0.428	0.411
163	-	0.401	0.380	-	0.421	0.403

Table 4.18 **Thickness** Results of the Z-twisted Yarn **29 tex** (mm)

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.4	TF 34.9	TF 38.6	TF 32.4	TF 34.9	TF 38.6
0	0.338	0.333	0.329	0.351	0.341	0.323
111	0.356	0.327	0.327	0.358	0.356	0.331
129	0.361	0.343	0.349	0.373	0.359	0.356
147	0.363	0.346	0.327	0.396	0.365	0.352
163	0.375	0.351	0.343	0.371	0.381	0.367
182	0.352	0.341	0.336	0.369	0.388	0.362
200	-	0.347	0.323	-	0.377	0.340
220	-	0.359	0.354	-	0.378	0.368

Discussion: The overall conclusion that could be reached by considering the data in these tables is that the untwisting process results in an increase of the yarn thickness. Comparing the normal and steamed yarn lots it can be seen that the steamed yarn samples exhibit higher values of thickness. It is possible that the process of untwisting produces an opening of the yarn structure. It is also possible, that in the case of steamed yarns, the formed weak hydrogen bonds between the fibres [98] enable the "open" yarn structure to keep its shape, whereas in the case of the normal yarns it seems that the open structure under the same testing pressure (196 N.m^{-2}) collapses. The increase in thickness or bulkiness is probably responsible for the softer handle of fabrics, knitted from such processed yarns.

It is also seen that, in most of the yarn samples, as the Nominal S Untwist level is increased, the thickness increases up to a maximum point and then reduces. In fact, considering also the other major yarn and fabric properties such as tenacity and spirality angle (Tables 4.11, 4.12, 4.19, 4.20), it would appear that there is an optimum level of S untwist to be inserted in the yarn to obtain the least spirality.

4.2.2 FABRIC TESTING

4.2.2.1 *Spirality Angle*

A transparency and a protractor were used for the direct measurement of the spirality angle of the fabric samples produced from the selected yarn samples (see § 4.1.1, 4.1.3). Two sets of fabric samples were produced: the first was knitted from the yarn immediately after the untwisting process (i.e., preventing any relaxation) while the second was produced after an interval of thirteen days. The purpose of this was to investigate the effect of *time* on the new method of reducing spirality. Both sets of samples were washed before spirality was measured. The results of spirality, obtained from the fabrics produced immediately after the yarn untwisting process, are presented in Tables 4.19 and 4.20. The corresponding percentage reduction in spirality angle of these fabrics is presented in Tables 4.21 and 4.22. Tables 4.23 and 4.24 report the results obtained by measuring the spirality angle of the washed fabrics knitted after a period of 13 days from yarn partial untwisting process. The corresponding percentage reduction in spirality angle of the latter fabric samples is presented in Tables 4.25 and 4.26. The effects on the reduction in spirality of the time interval between the yarn untwisting process and fabric production, as well as the effect of the yarn steaming process in interaction with both the time and the untwisting process, are presented in the Figures 4.7 to 4.12. The same results expressed as percentage reductions are shown in the Figures 4.13 to 4.18.

Table 4.19 **Spirality Angle** (°) Test Results of the **Washed** Fabrics Produced from Yarn **39 tex Immediately after Untwisting**

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.3	TF 33.4	TF 39.5	TF 32.3	TF 33.4	TF 39.5
0	15.0	16.5	22.0	14.5	13.0	19.0
111	5.5	11.0	18.5	8.0	7.5	10.0
121	17.0	10.0	13.0	9.0	7.0	7.5
133	7.0	8.0	15.0	2.5	4.5	9.5
142	-	7.5	12.0	2.0	1.0	8.0
154	-	8.0	9.0	-	2.5	7.5
163	-	4.5	10.0	-	2.5	6.0

Table 4.20 **Spirality Angle** (°) Test Results of the **Washed** Fabrics Produced from Yarn **29 tex Immediately after Untwisting**

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.4	TF 34.9	TF 38.6	TF 32.4	TF 34.9	TF 38.6
0	20.0	18.5	27.5	12.0	15.5	24.0
111	11.5	14.5	24.5	7.0	8.0	17.0
129	11.0	15.0	19.0	4.0	8.5	15.5
147	12.0	15.5	17.0	3.5	7.0	13.5
163	9.5	10.0	14.0	3.0	5.5	8.0
182	9.5	8.0	11.5	3.0	6.5	5.5
200	-	9.5	12.0	-	2.0	3.5
220	-	8.5	8.5	-	2.0	2.5

Table 4.21 Percentage (%) Reduction of **Spirality*** (Yarn **39 tex** Immediately After Untwisting)

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.3	TF 33.4	TF 39.5	TF 32.3	TF 33.4	TF 39.5
111	63.3	33.3	15.9	44.8	42.3	47.4
121	-13.3	39.4	40.9	37.9	46.2	60.5
133	53.3	51.5	31.8	82.8	65.4	50.0
142	-	54.5	45.5	86.2	92.3	57.9
154	-	51.5	59.1	-	80.8	60.5
163	-	72.7	54.5	-	80.8	68.4

Table 4.22 Percentage (%) Reduction of **Spirality*** (Yarn **29 tex** Immediately After Untwisting)

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.4	TF 34.9	TF 38.6	TF 32.4	TF 34.9	TF 38.6
111	42.5	21.6	10.9	41.7	48.4	29.2
129	45.0	18.9	30.9	66.7	45.2	35.4
147	40.0	16.2	38.2	70.8	54.8	43.8
163	52.5	45.9	49.1	75.0	64.5	66.7
182	52.5	56.8	58.2	75.0	58.1	77.1
200	-	48.6	56.4	-	87.1	85.4
220	-	54.1	69.1	-	87.1	89.6

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* The percentage results shown in Tables 4.21 and 4.22 were obtained from Tables 4.19 and 4.20 respectively. The spirality angle of each fabric produced from untwisted yarns was compared with the non-untwisted yarn, (i.e., 0 turns.m^{-1} in S direction).

Table 4.23 **Spirality Angle** Test Results of the **Washed** Fabrics Produced from Yarn **39 tex after 13 Days from the Untwisting Process** (°)

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.3	TF 33.4	TF 39.5	TF 32.3	TF 33.4	TF 39.5
111	10.5	12.5	14.0	6.5	5.0	10.0
121	9.5	11.0	14.0	4.0	3.5	9.0
133	9.5	10.0	13.5	4.5	5.0	8.5
142	-	10.0	13.5	5.0	5.0	9.0
154	-	12.5	14.0	-	3.5	10.0
163	-	9.0	9.5	-	5.5	9.0

Table 4.24 **Spirality Angle** Test Results Of the **Washed** Fabrics Produced from Yarn **29 tex after 13 Days from the Untwisting Process** (°)

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.4	TF 34.9	TF 38.6	TF 32.4	TF 34.9	TF 38.6
111	14.5	13.0	18.5	9.5	11.0	14.5
129	14.0	15.5	14.5	9.5	10.0	13.5
147	12.5	15.5	20.0	9.0	9.0	14.5
163	11.0	15.5	19.0	7.5	7.0	13.5
182	11.0	13.5	15.0	4.5	6.5	9.0
200	-	9.0	14.0	-	5.0	4.0
220	-	10.0	11.5	-	6.5	3.5

Table 4.25 Percentage (%) Reduction of **Spirality**
(Yarn **39 tex** after 13 Days from the Untwisting Process)

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.3	TF 33.4	TF 39.5	TF 32.3	TF 33.4	TF 39.5
111	30.0	24.2	36.4	55.2	61.5	47.4
121	36.7	33.3	36.4	72.4	73.1	52.6
133	36.7	39.4	38.6	69.0	61.5	55.3
142	-	39.4	38.6	65.5	61.5	52.6
154	-	24.2	36.4	-	73.1	47.4
163	-	45.5	56.8	-	57.7	52.6

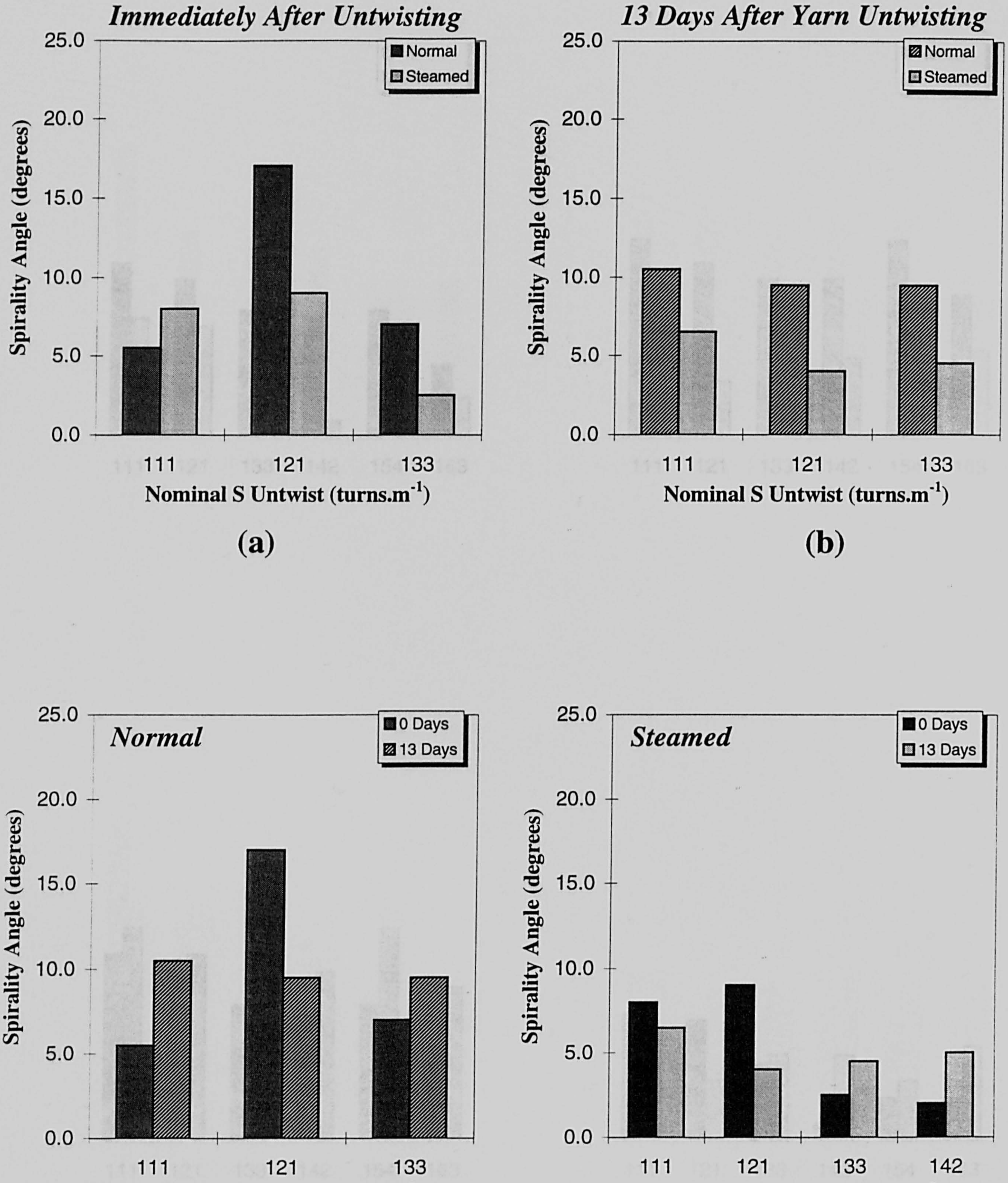
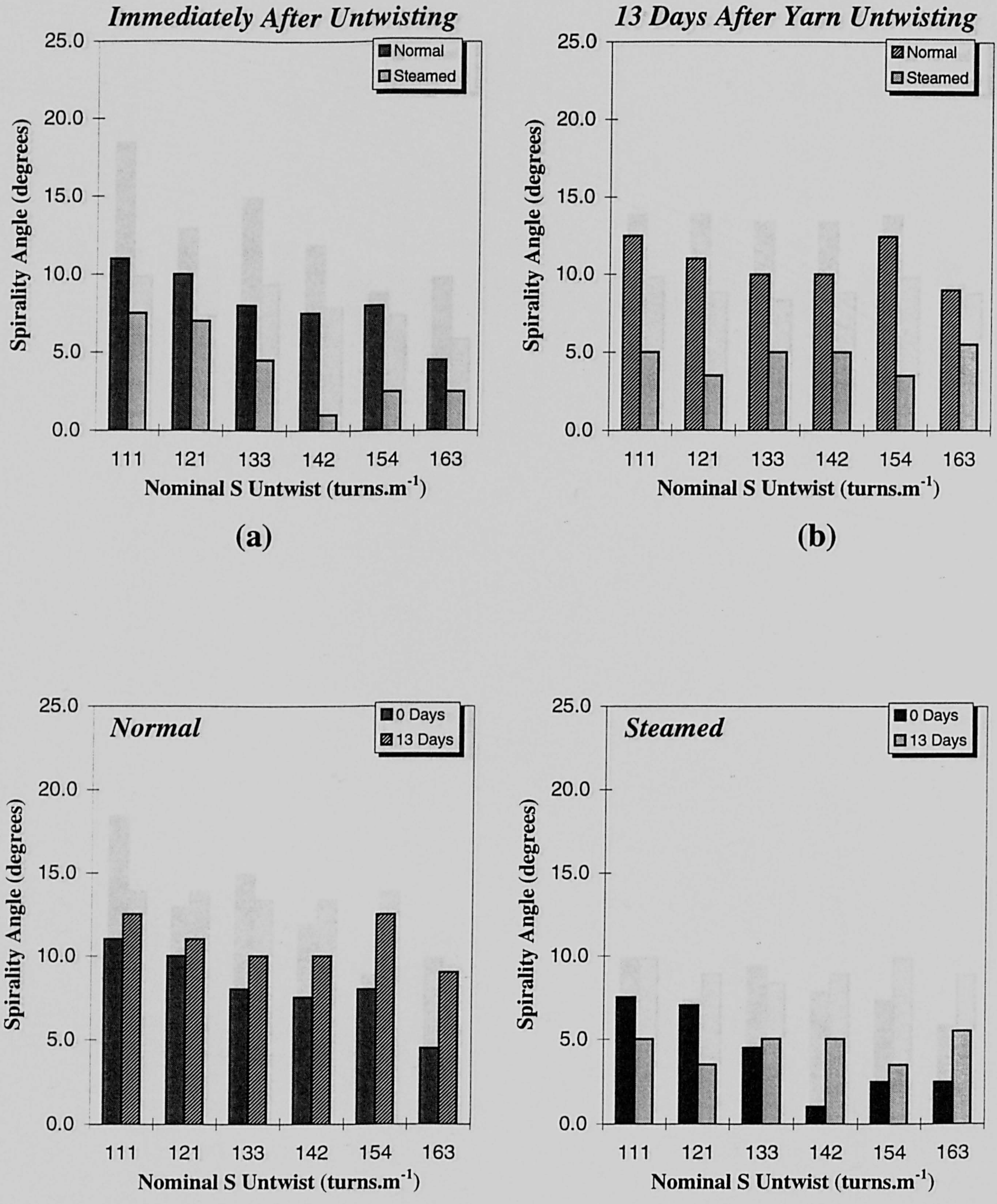


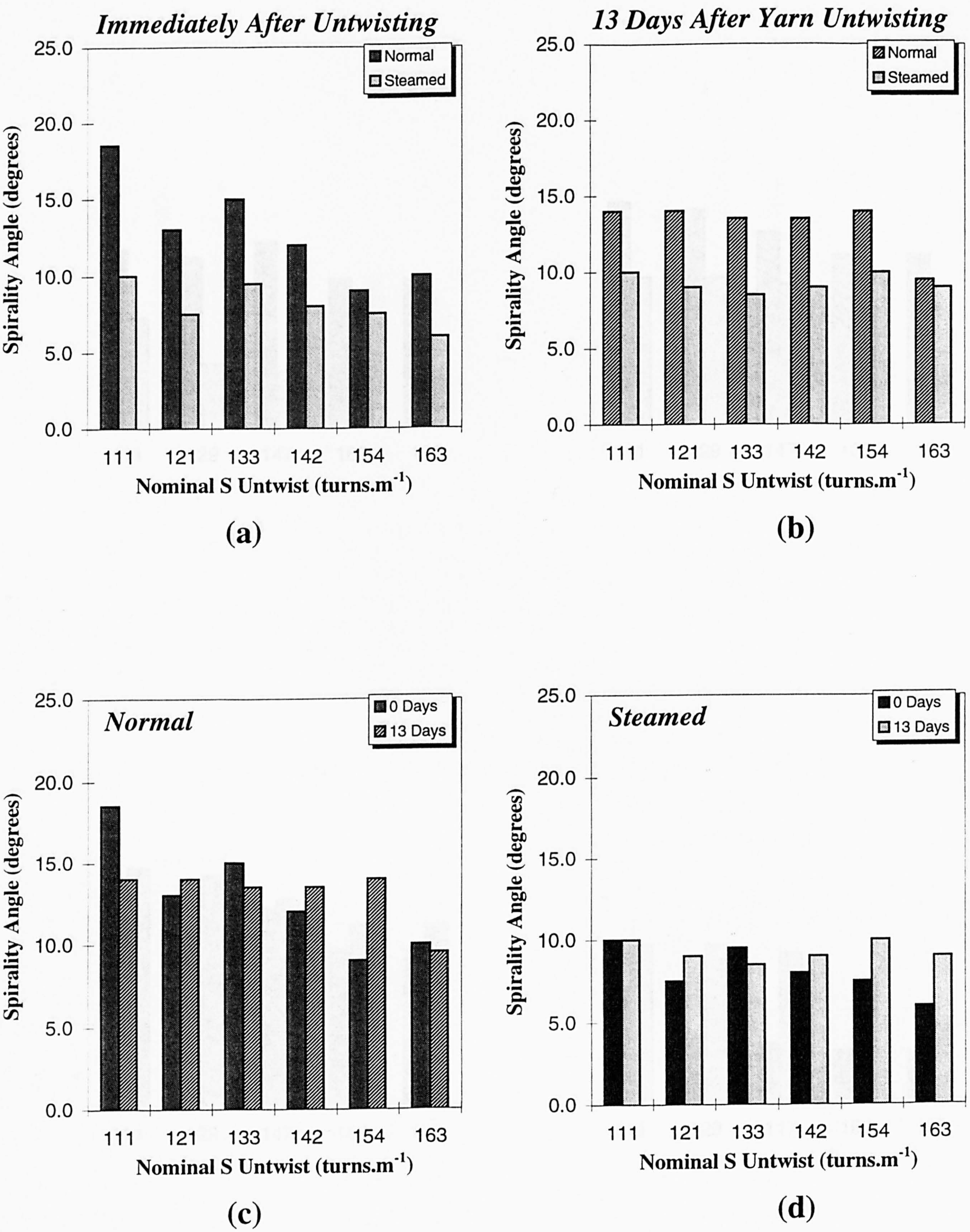
Fig. 4.7 Effect of **Steam** and "**Time**" on Spirality Angle
(Processed Yarn Samples **39 tex TF 32.3**)



(a) (b)

(c) (d)

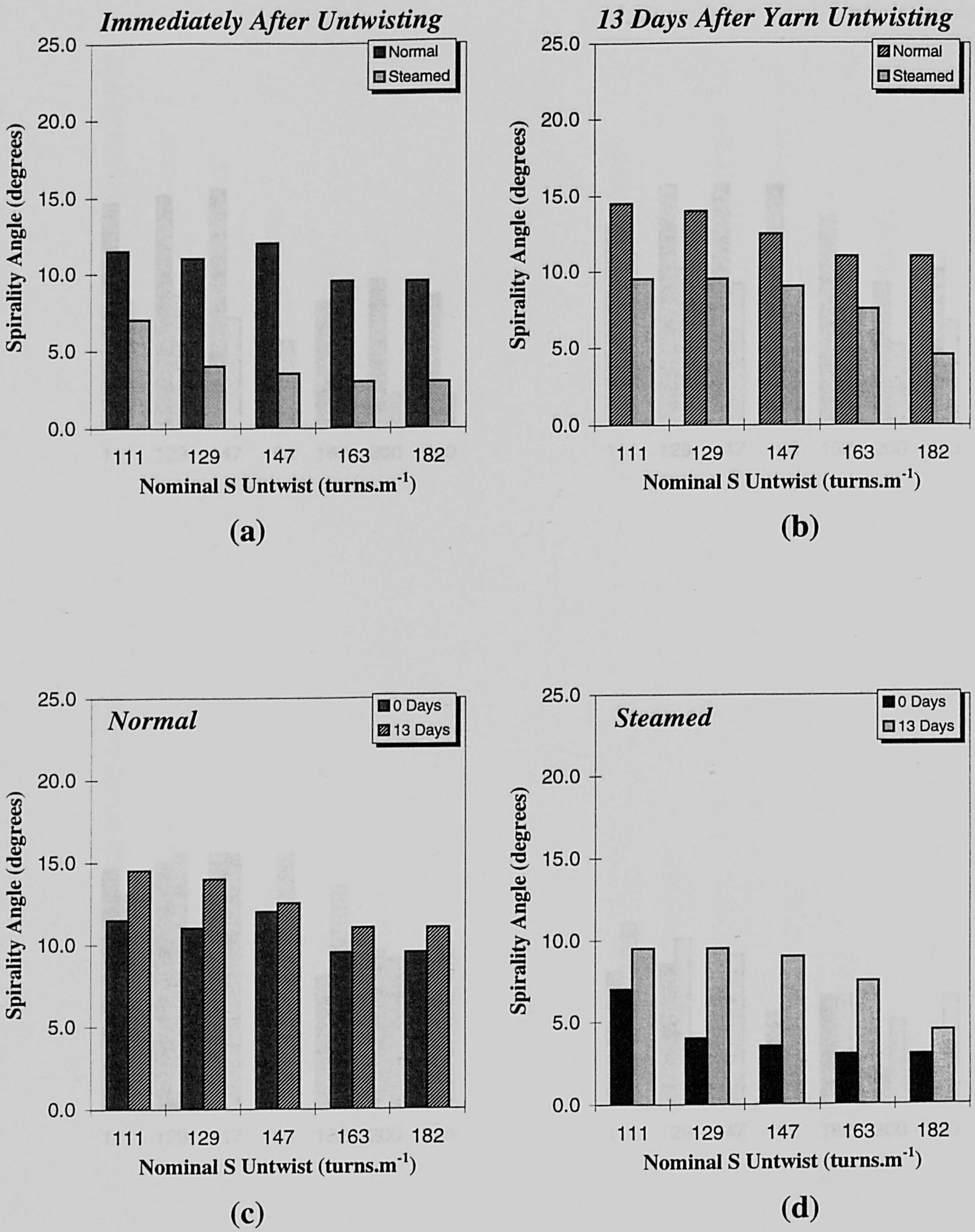
Fig. 4.8 Effect of **Steam** and "**Time**" on Spirality Angle
(Processed Yarn Samples **39 tex TF 33.4**)



(a) (b)

(c) (d)

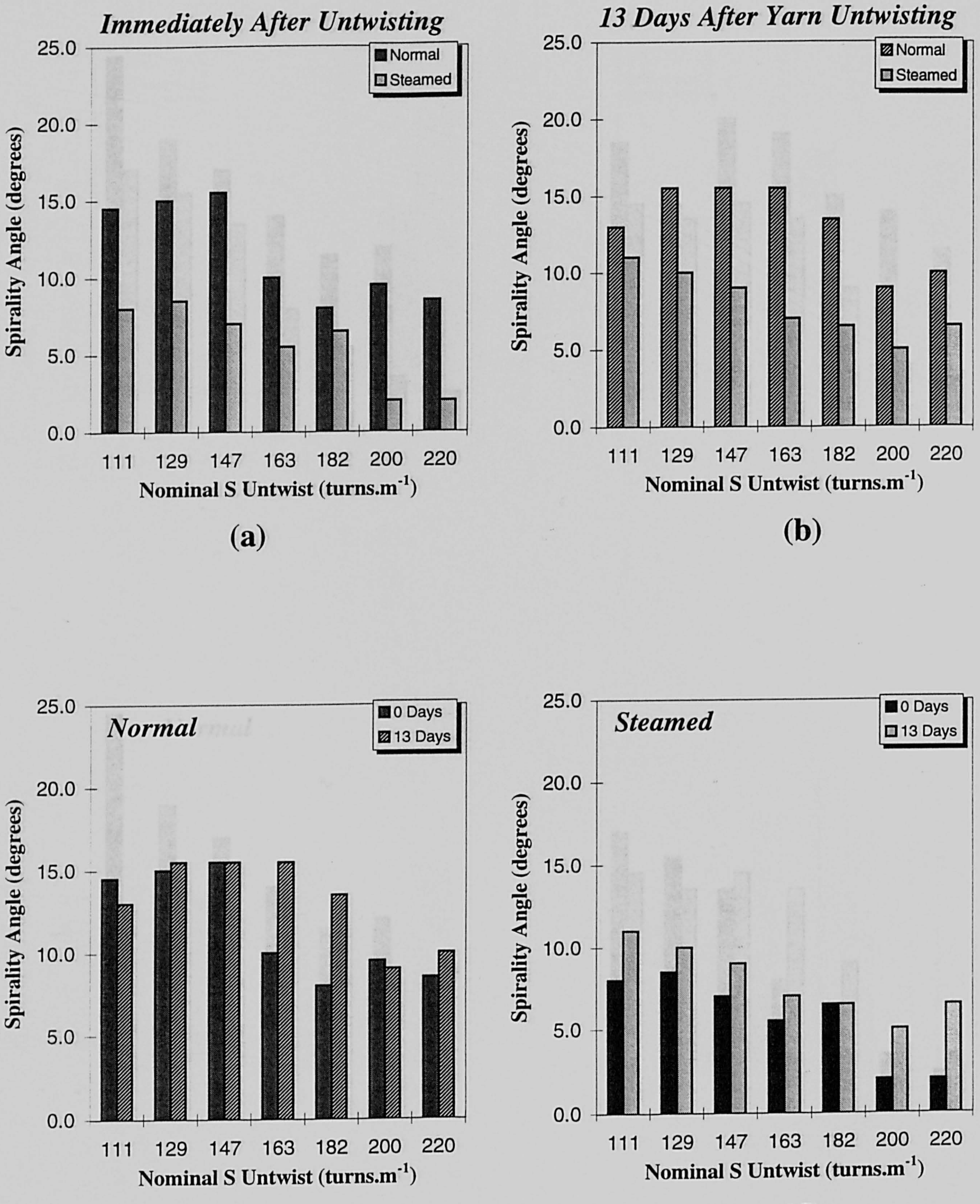
Fig. 4.9 Effect of **Steam** and "**Time**" on Spirality Angle
(Processed Yarn Samples **39 tex TF 39.5**)



(a) (b)

(c) (d)

Fig. 4.10 Effect of **Steam** and "**Time**" on Spirality Angle
(Processed Yarn Samples **29 tex TF 32.4**)



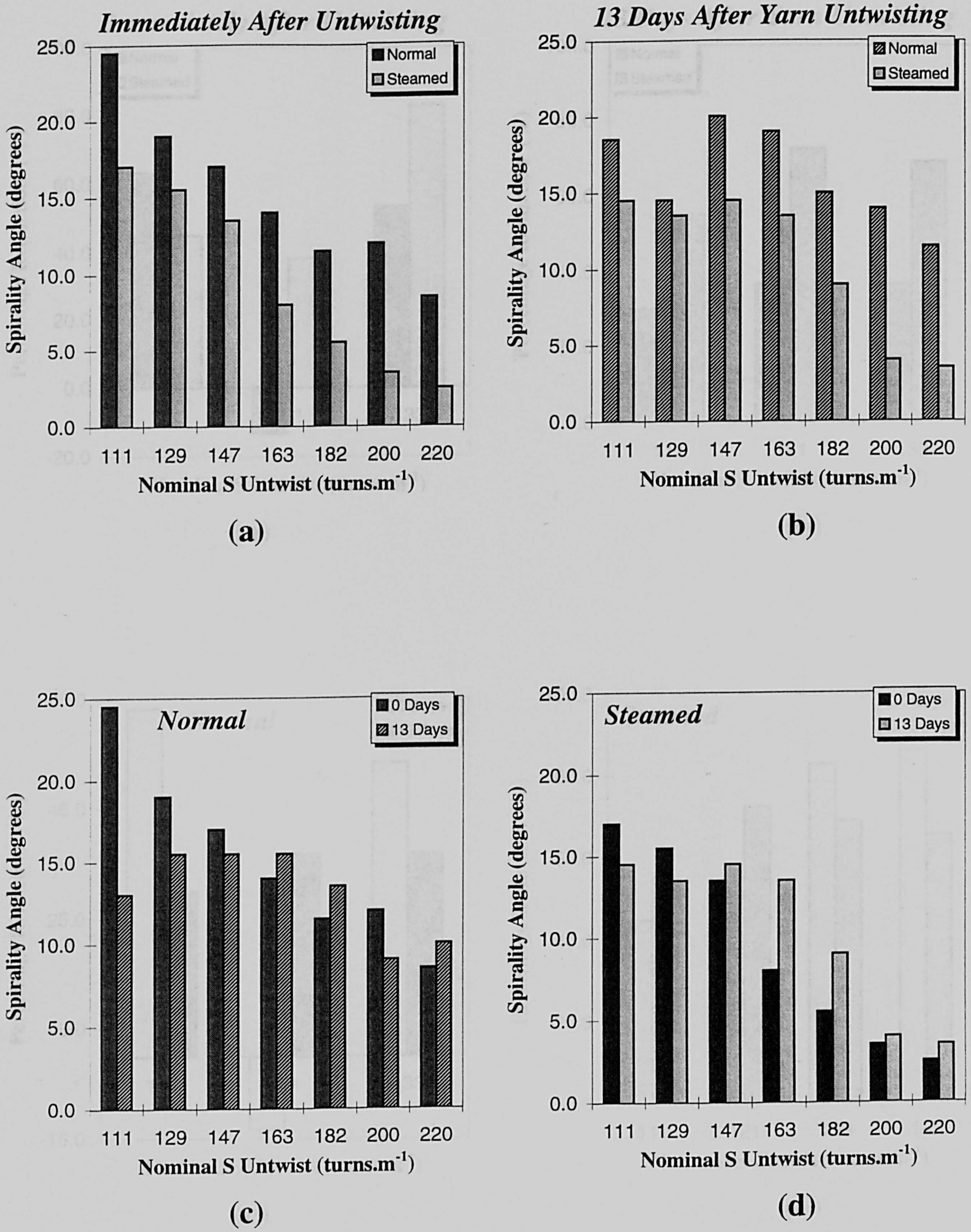
(a)

(b)

(c)

(d)

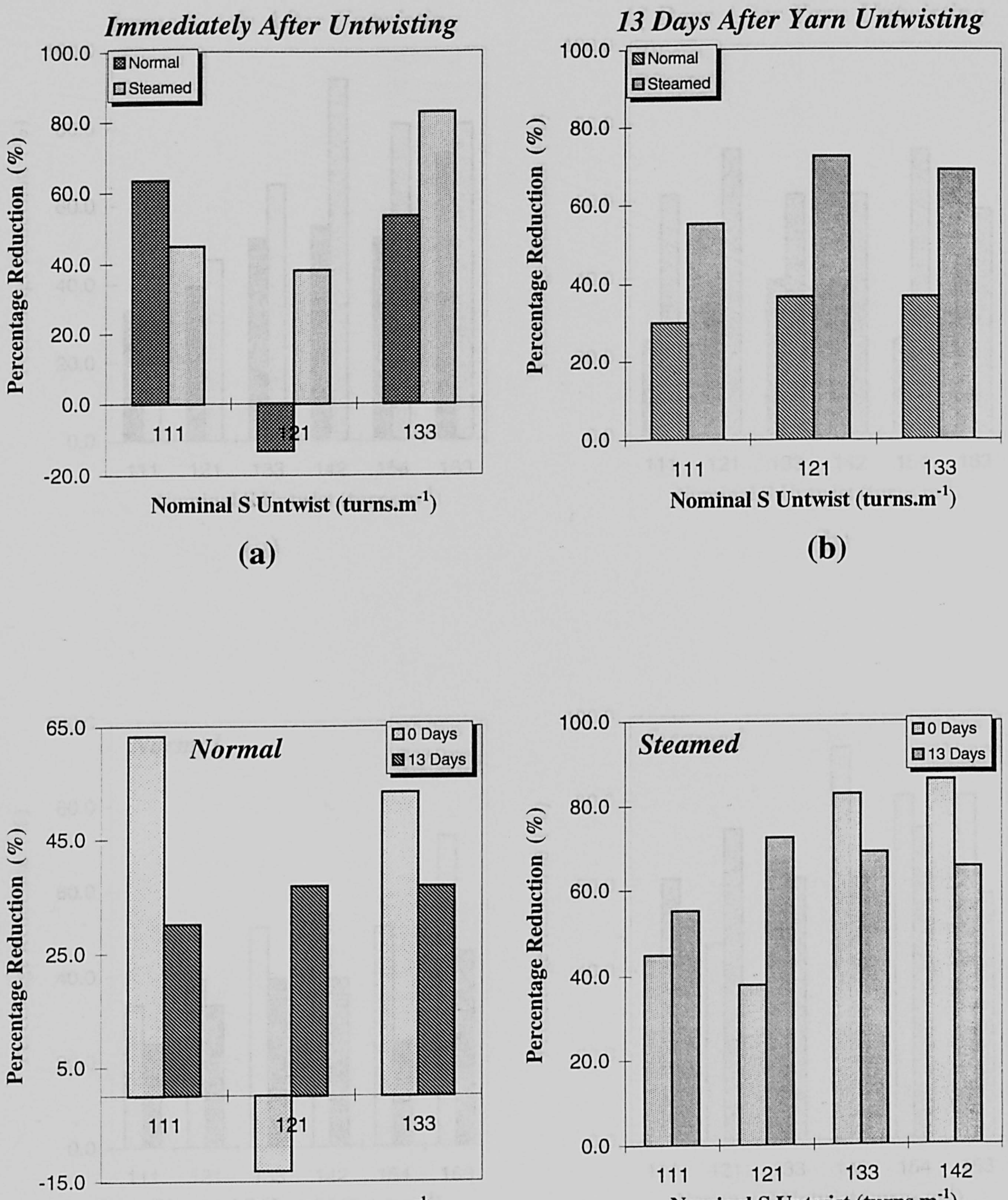
Fig. 4.11 Effect of **Steam** and "**Time**" on Spirality Angle
(Processed Yarn Samples **29 tex TF 34.9**)



(a) (b)

(c) (d)

Fig. 4.12 Effect of **Steam** and "**Time**" on Spirality Angle
(Processed Yarn Samples **29 tex TF 38.6**)



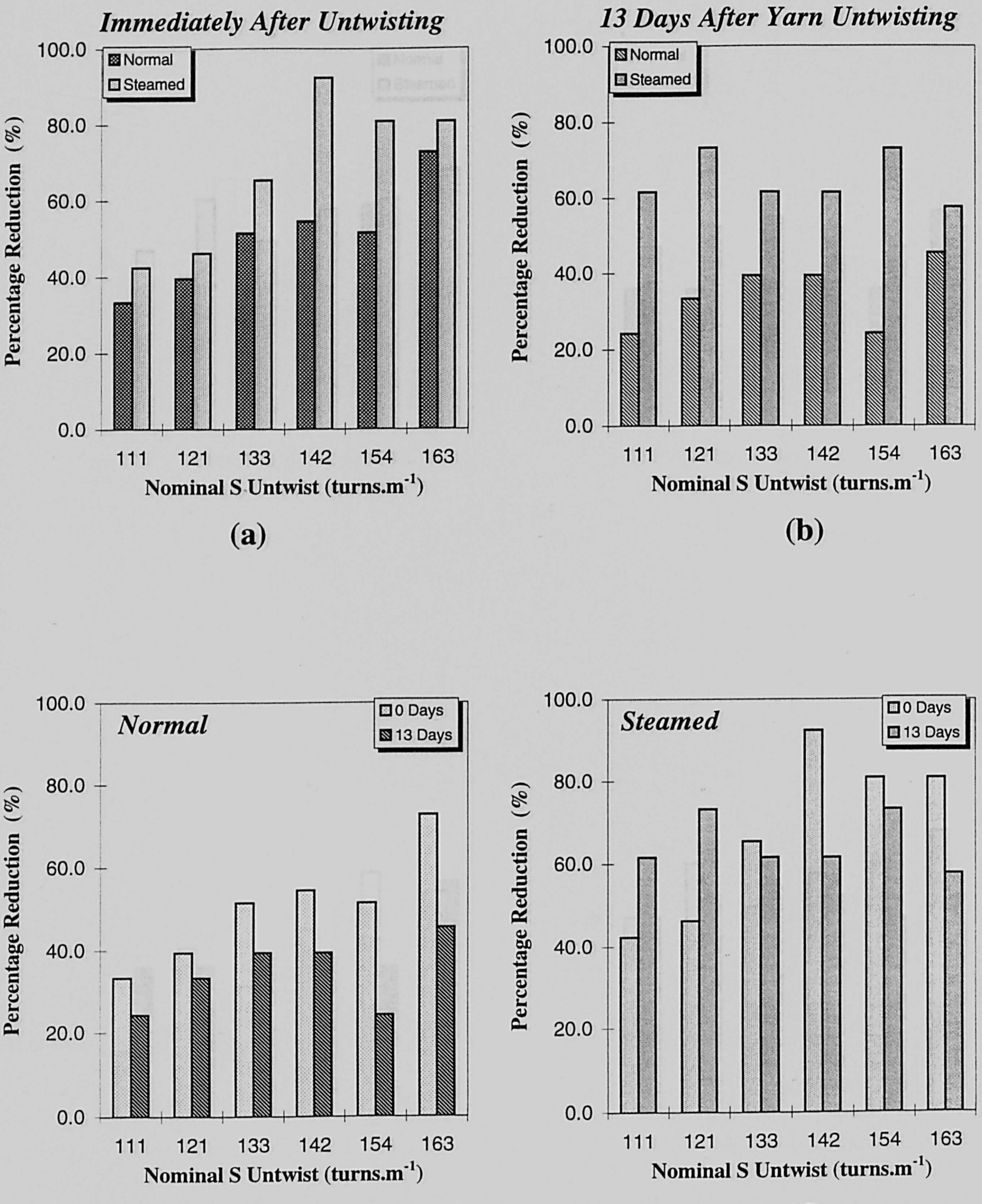
(a)

(b)

(c)

(d)

Fig. 4.13 Effect of **Steam** and "**Time**" on Spirality Angle (% Reduction)
(Processed Yarn Samples **39 tex TF 32.3**)



(a) (b)

(c) (d)

Fig. 4.14 Effect of **Steam** and "**Time**" on Spirality Angle (% Reduction)
(Processed Yarn Samples **39 tex TF 33.4**)

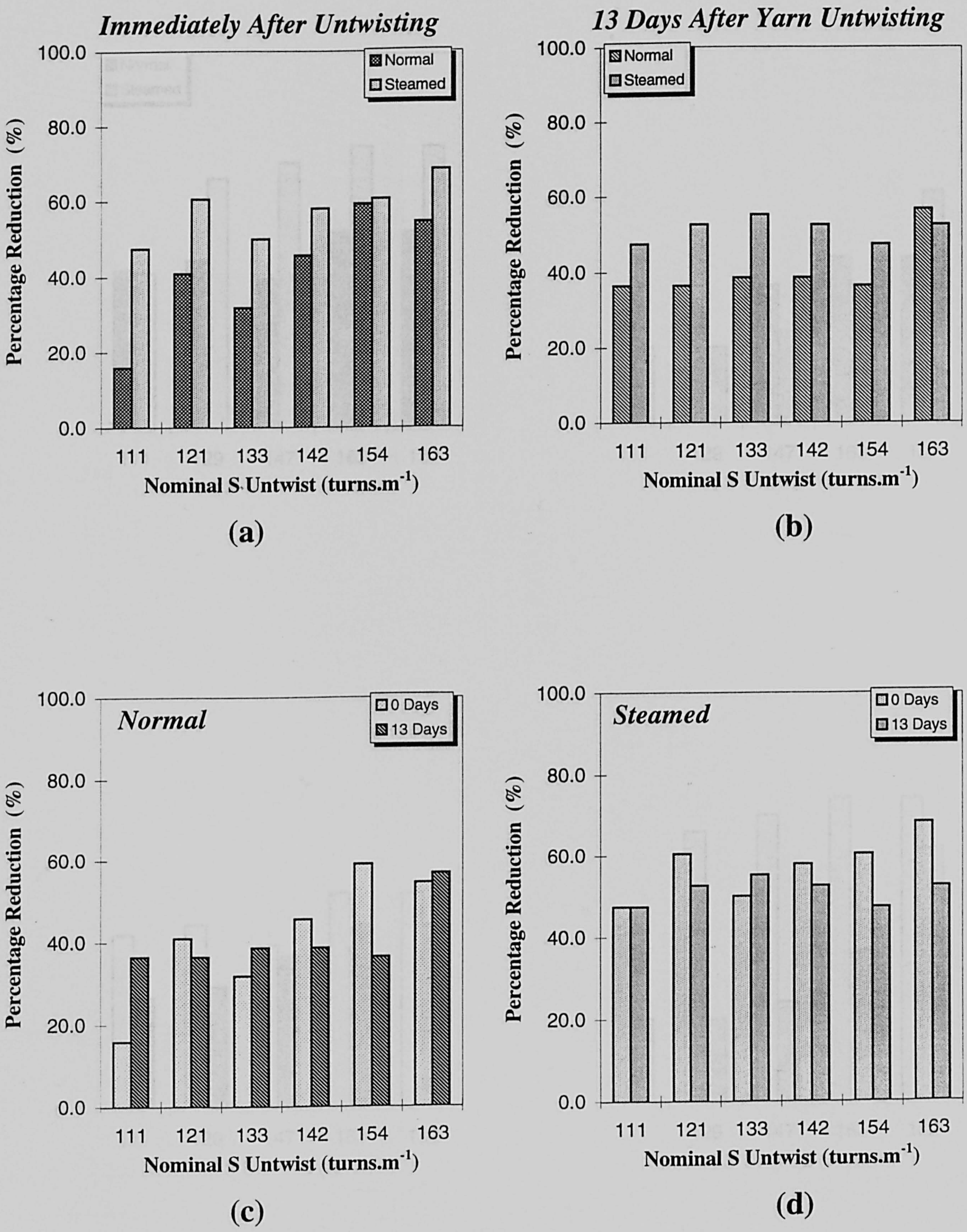
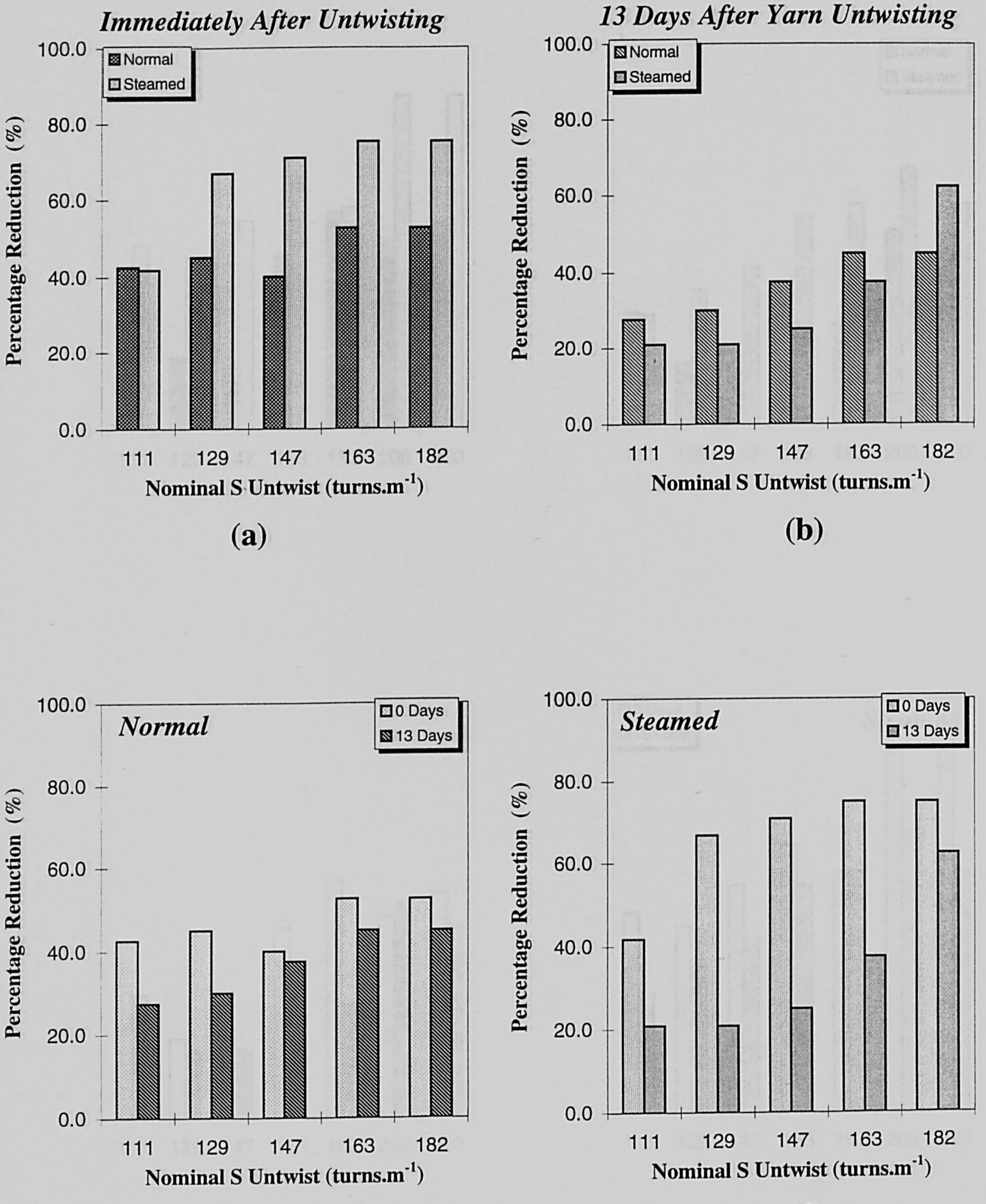


Fig. 4.15 Effect of **Steam** and "**Time**" on Spirality Angle (% Reduction)
(Processed Yarn Samples **39 tex TF 39.5**)



(a) **(b)**

(c) **(d)**

Fig. 4.16 Effect of **Steam** and "**Time**" on Spirality Angle (% Reduction) (Processed Yarn Samples **29 tex TF 32.4**)

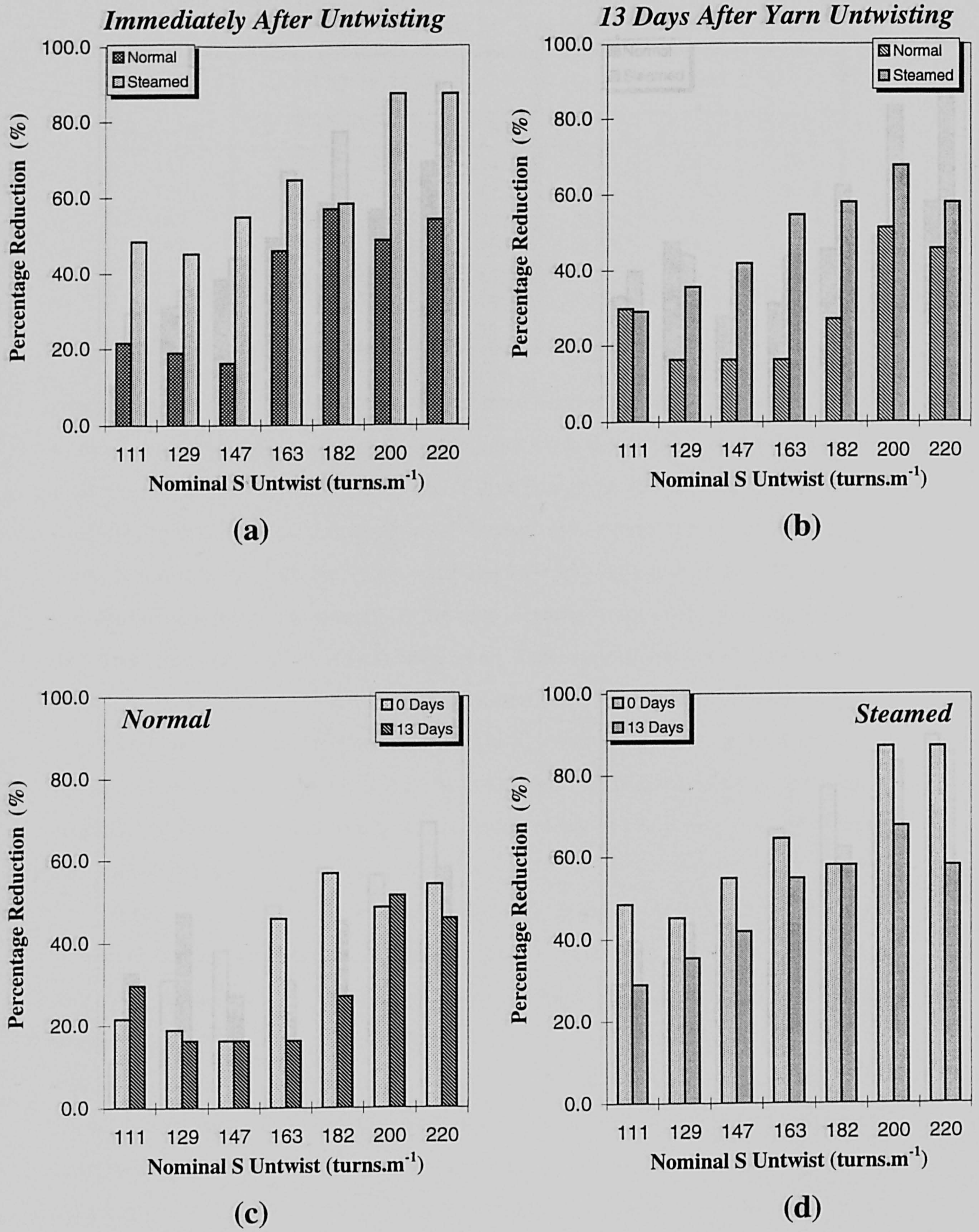


Fig. 4.17 Effect of **Steam** and "**Time**" on Spirality Angle (% Reduction)
(Processed Yarn Samples **29 tex TF 34.9**)

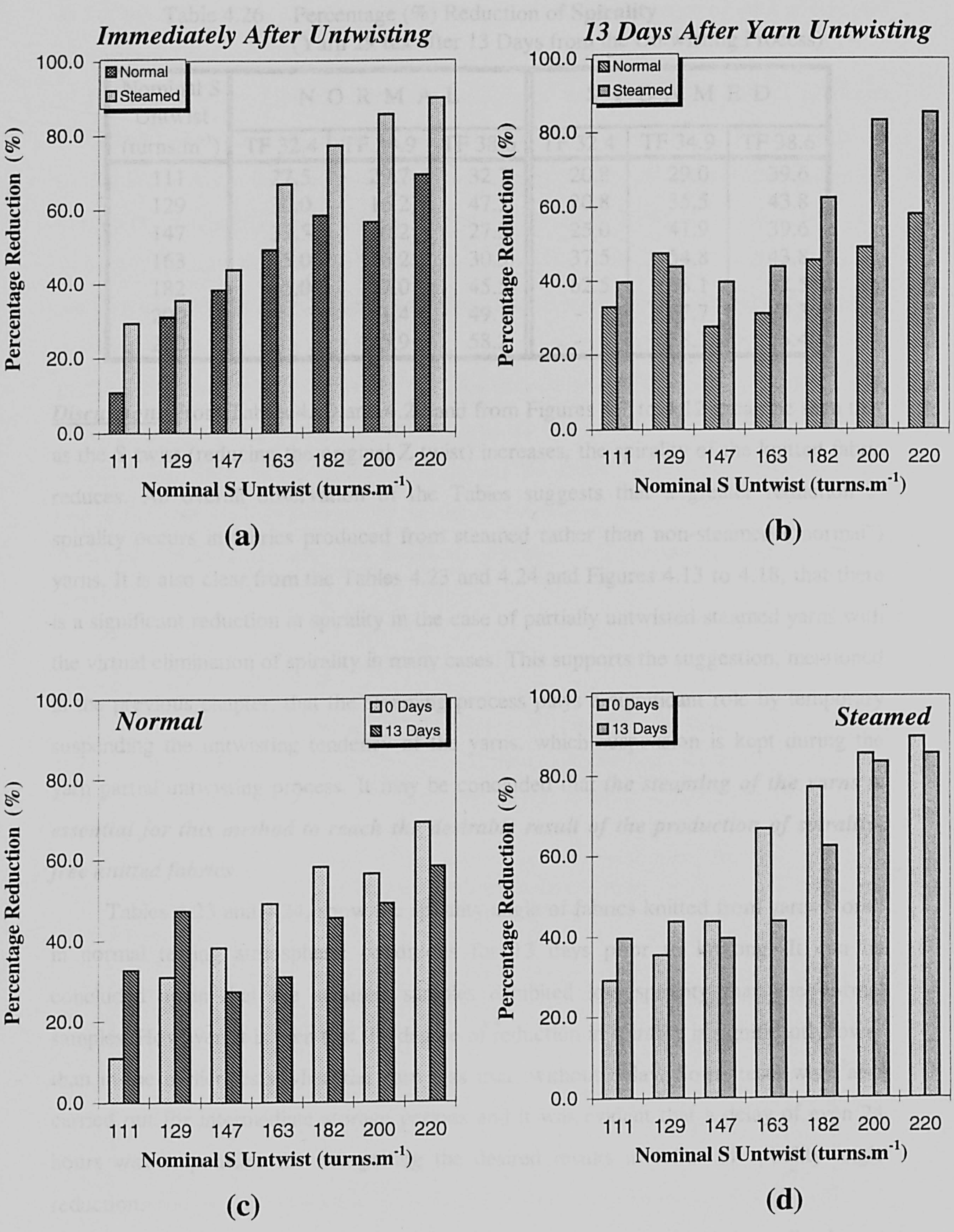


Fig. 4.18 Effect of **Steam** and **"Time"** on Spirality Angle (% Reduction)
(Processed Yarn Samples **29 tex TF 38.6**)

Table 4.26 Percentage (%) Reduction of **Spirality**
(Yarn **29 tex** after 13 Days from the Untwisting Process)

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.4	TF 34.9	TF 38.6	TF 32.4	TF 34.9	TF 38.6
111	27.5	29.7	32.7	20.8	29.0	39.6
129	30.0	16.2	47.3	20.8	35.5	43.8
147	37.5	16.2	27.3	25.0	41.9	39.6
163	45.0	16.2	30.9	37.5	54.8	43.8
182	45.0	27.0	45.5	62.5	58.1	62.5
200	-	51.4	49.1	-	67.7	83.3
220	-	45.9	58.2	-	58.1	85.4

Discussion: From Tables 4.19 and 4.20 and from Figures 4.7 to 4.12 it can be seen that as the S twist (reducing the original Z twist) increases, the spirality of the knitted fabric reduces. An overall observation of the Tables suggests that a greater reduction in spirality occurs in fabrics produced from steamed rather than non-steamed ("normal") yarns. It is also clear from the Tables 4.23 and 4.24 and Figures 4.13 to 4.18, that there is a significant reduction in spirality in the case of partially untwisted steamed yarns with the virtual elimination of spirality in many cases. This supports the suggestion, mentioned in the previous chapter, that the steaming process plays a significant role by temporary suspending the untwisting tendency of the yarns, which suspension is kept during the yarn partial untwisting process. It may be concluded that ***the steaming of the yarns is essential for this method to reach the desirable result of the production of spirality-free knitted fabrics***.

Tables 4.23 and 4.24, show the spirality angle of fabrics knitted from yarns stored in normal testing atmospheric conditions for 13 days prior to knitting. It can be concluded again that the steamed samples exhibited less spirality than the normal samples. However, it is seen that the degree of reduction in spirality is significantly lower than in the earlier tests when the yarn was used without delay. Some tests were also carried out for intermediate storage periods and it was evident that a delay of even 24 hours was responsible for not getting the desired results in terms of spirality angle reduction.

Comparing the two sets of fabrics produced from yarn samples (i) immediately and (ii) after a period of time following the untwisting process (Tables 4.19, 4.20, 4.23 and 4.24), it could be concluded that:

a) For the normal yarn samples of linear density 39 tex, the storage of yarn in standard atmospheric conditions did not affect the spirality of the fabrics.

b) For the steamed yarns of linear density 29 tex and 39 tex, the fabrics produced immediately after yarn untwisting showed very low values of remaining spirality angle.

c) For low levels of introduced S untwist in steamed yarns of 29 tex, the storing time did not affect the spirality much. On the contrary, with higher levels of S-twist (above 147 turns.m^{-1}) the time delay seems to assist the relaxation of the various torsional forces in the yarn and, when such processed and relaxed yarns were knitted, the fabrics, although showing smaller values of spirality angle, were not spirality free, as is the objective of this project. It is suggested therefore that, for the best results, the processed yarn should be knitted as soon as possible in order to entrap the energy of the various torsional forces active in the yarn, in the structure of the knitted fabric. This would give them the opportunity to act advantageously in the fabric where many other forces (mainly frictional and bending) are also involved, resulting in a maximum reduction of the spirality.

4.2.2.2 *Fabric Thickness*

The Fast-01 Fabric compression meter was used for the determination of the thickness of the produced fabric samples, and the results are reported in the Tables 4.27 to 4.30, and in Figures 4.19 to 4.22. The pressure on the fabric samples was 196 N.m^{-2}.

Table 4.27 **Thickness** Test Results for the Fabrics Produced from Yarn **39 tex Immediately after Untwisting** (mm)

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.3	TF 33.4	TF 39.5	TF 32.3	TF 33.4	TF 39.5
0	2.648	2.764	2.642	2.471	2.531	2.466
111	2.430	2.390	2.365	2.124	2.230	1.963
121	2.555	2.660	2.584	2.474	2.517	2.523
133	2.649	2.468	2.652	2.505	2.534	2.466
142	-	2.550	2.488	2.363	2.394	2.412
154	-	2.521	2.363	-	2.285	2.350
163	-	2.498	2.617	-	2.443	2.474

Table 4.28 **Thickness** Test Results for the Fabrics Produced from Yarn **29 tex Immediately after Untwisting** (mm)

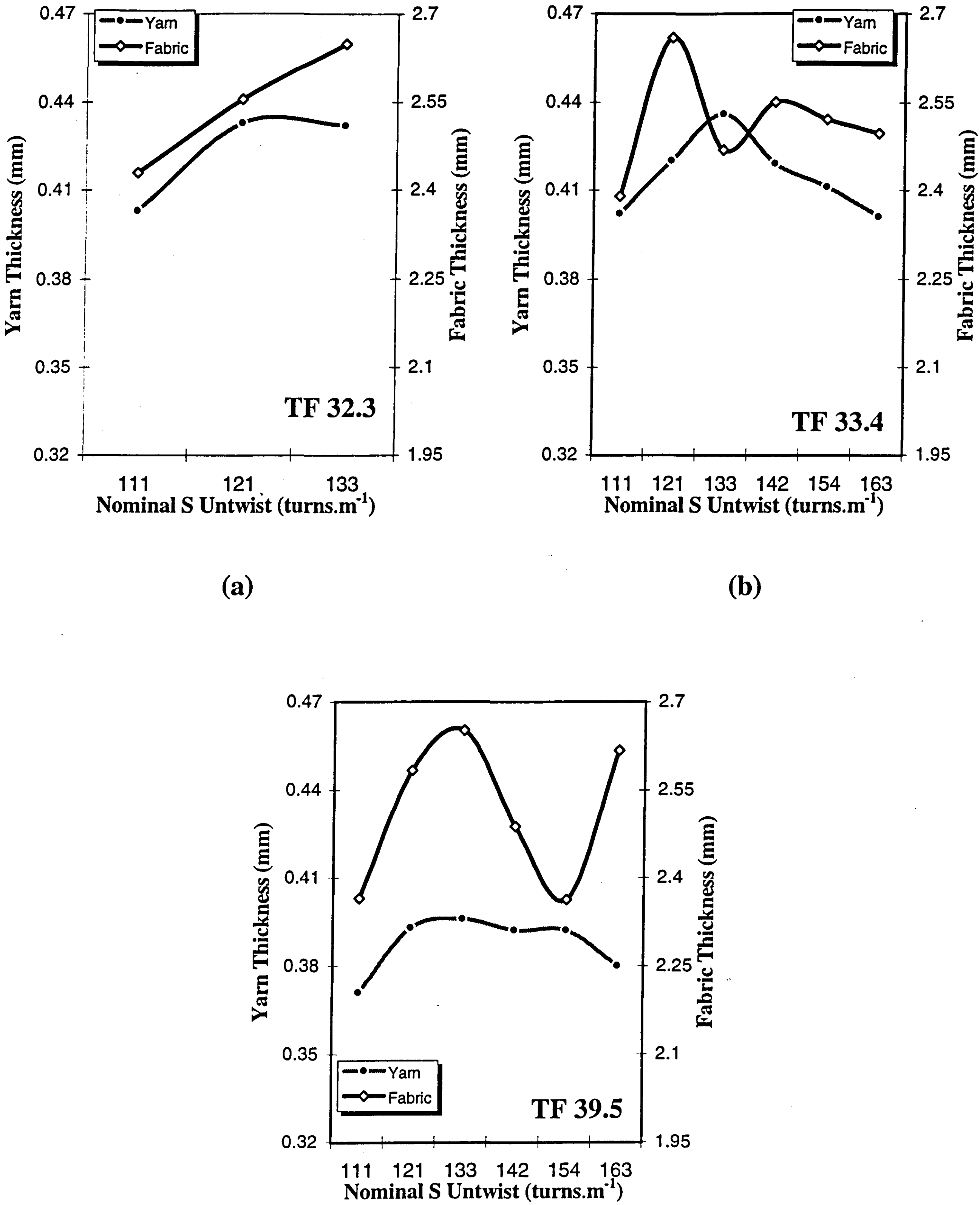
Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.4	TF 34.9	TF 38.6	TF 32.4	TF 34.9	TF 38.6
0	2.278	2.400	2.466	2.057	2.255	2.430
111	2.187	2.206	2.404	2.298	2.405	2.411
129	2.547	2.577	2.620	2.329	2.310	2.517
147	2.452	2.416	2.405	2.127	2.160	2.300
163	2.203	2.267	2.262	2.077	2.170	2.108
182	2.278	2.375	2.216	2.185	2.195	2.170
200	-	2.281	2.176	-	1.972	2.143
220	-	2.292	2.255	-	2.102	2.129

Table 4.29 **Thickness** Test Results for the Fabric Produced from Yarn **39 tex after 13 Days from the Untwisting Process** (mm)

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.3	TF 33.4	TF 39.5	TF 32.3	TF 33.4	TF 39.5
111	2.434	2.525	2.590	2.520	2.423	2.502
121	2.680	2.675	2.641	2.518	2.455	2.400
133	2.538	2.586	2.387	2.458	2.428	2.469
142	-	2.575	2.567	2.424	2.500	2.410
154	-	2.855	2.850	-	2.778	2.777
163	-	2.865	2.861	-	2.680	2.644

Table 4.30 **Thickness** Test Results for the Fabrics Produced from Yarn **29 tex after 13 Days from the Untwisting Process** (mm)

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.4	TF 34.9	TF 38.6	TF 32.4	TF 34.9	TF 38.6
111	2.390	2.478	2.543	2.291	2.214	2.502
129	2.290	2.224	2.410	2.327	2.210	2.316
147	2.334	2.484	2.357	2.209	2.387	2.297
163	2.523	2.440	2.582	2.240	2.268	2.410
182	2.558	2.496	2.644	2.285	2.380	2.382
200	-	2.807	2.797	-	2.526	2.466
220	-	2.707	2.717	-	2.508	2.465

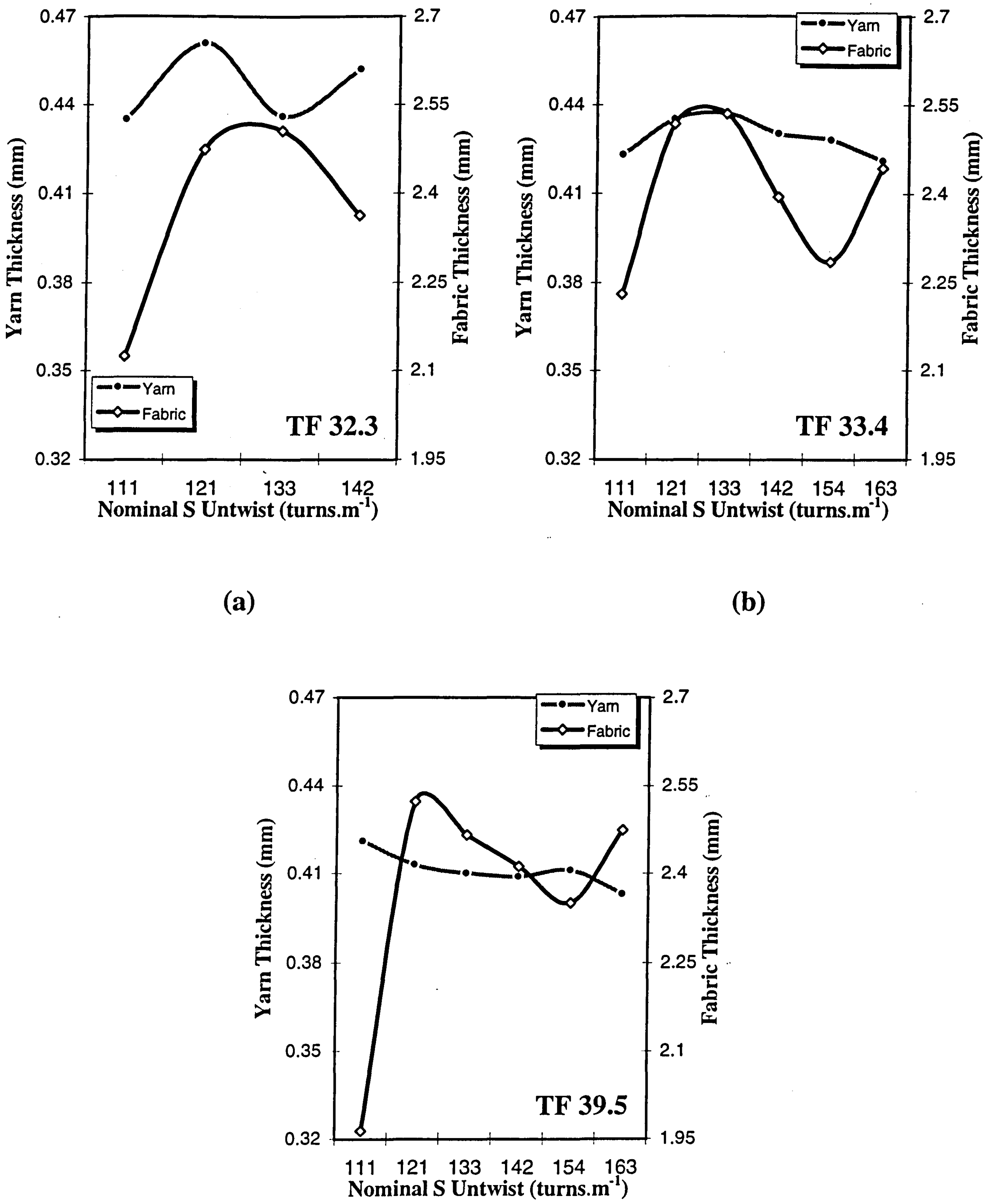


(a)

(b)

(c)

Fig. 4.19 Relation between **Yarn** and **Fabric Thicknesses (Normal** Yarn **39 tex)**



(a)

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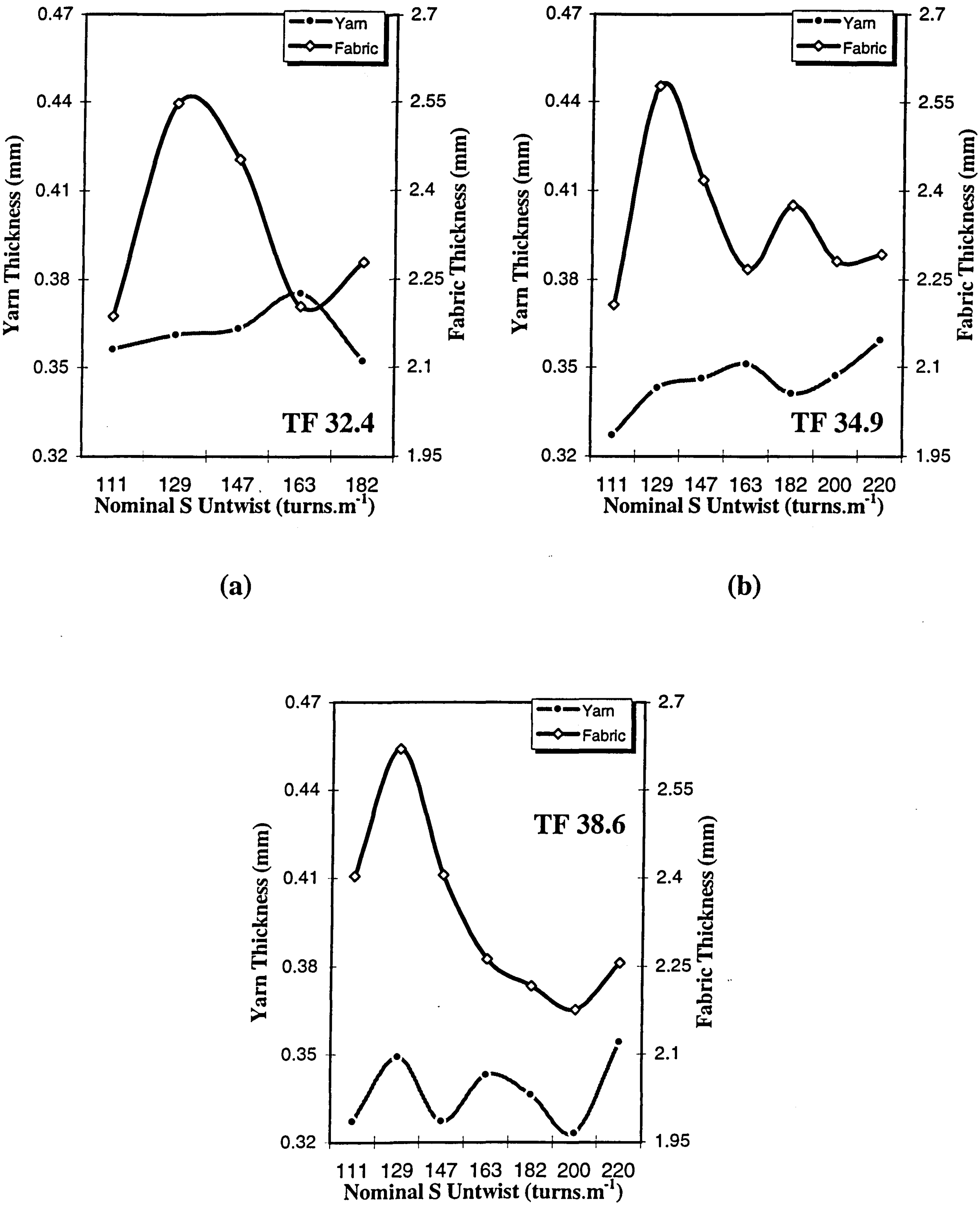
Fig. 4.20 Relation between **Yarn** and **Fabric Thicknesses (Steamed** Yarn **39 tex)**

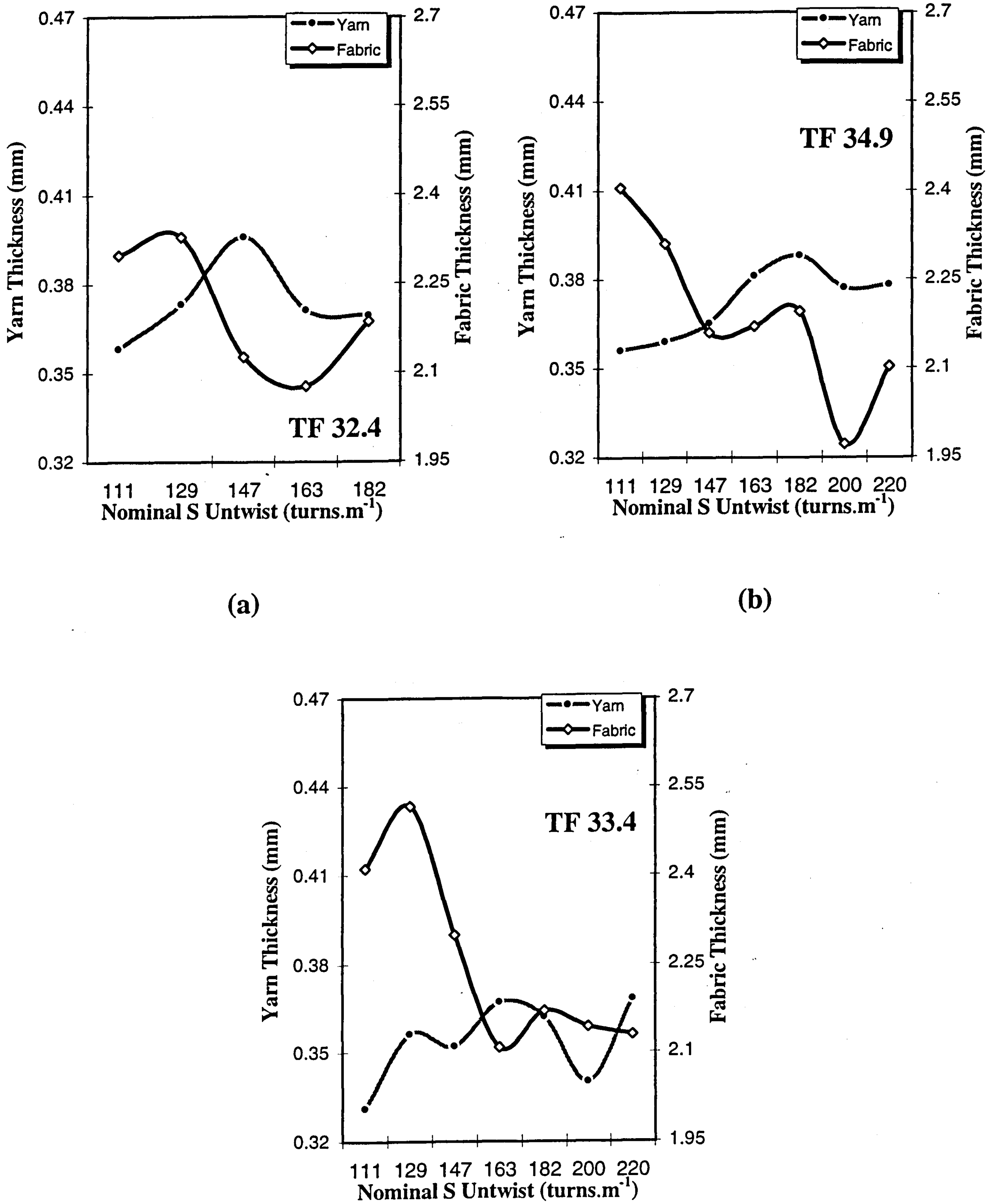


(a)

(b)

(c)

Fig. 4.21 Relation between **Yarn** and **Fabric Thicknesses** (**Normal** Yarn **29 tex**)



(a)

(b)

(c)

Fig. 4.22 Relation between **Yarn** and **Fabric Thicknesses (Steamed** Yarn **29 tex)**

Discussion: From the data of the Tables 4.27 to 4.30, and Figures 4.19 to 4.22, no clear relation between the reduction of yarn twist and the thickness of the fabrics produced from such processed yarns is evident.

When comparison is made between normal and steamed yarns, the general conclusion is that fabrics from steamed yarn samples show lower values of thickness than that of non-steamed (normal) yarns.

The period of the 13 days between the yarn untwisting process and knitting seems to affect the thickness of the fabric samples as, in most of the cases, an increase was recorded, especially where the yarn was untwisted to a higher degree. It is possible that the magnitudes of the various forces that keep the fibres packed and make the yarn stiff, were reduced during that time, resulting in a slight increase of diameter.

4.2.2.3 *Fabric Compressibility*

During the measurement of the thicknesses of the various fabric samples described in the previous section (§ 4.2.2~~3~~.2), readings of thickness were also taken with a testing pressure of 9.81 kN.m^{-2} (kPa). The formula $\frac{T_2 - T_{100}}{T_2} \times 100\%$ was used for the calculation of the percentage compressibility of the fabrics, where T_2 and T_{100} were the readings of the fabric thickness when the applied pressure onto the fabric was 196 N.m^{-2} (Pa) and 9.81 kN.m^{-2} (kPa) respectively. The results are reported in Tables 4.31 and 4.32 for the fabrics produced immediately after the yarn untwisting process. Tables 4.33 and 4.34 present the percentage compressibility of the fabrics that were produced with a delay of 13 days. The time effect on the compressibility of the produced fabrics is shown in Figures 4.23 to 4.26.

Table 4.31 Percentage **Compressibility** of Fabrics Produced from Yarn **39 tex Immediately after Untwisting** (%)

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.3	TF 33.4	TF 39.5	TF 32.3	TF 33.4	TF 39.5
0	34.4	36.0	30.2	40.3	40.7	37.9
111	38.6	38.7	37.4	41.6	44.9	42.7
121	31.9	37.4	37.5	38.1	39.7	40.0
133	38.4	35.4	36.5	39.8	40.3	37.6
142	-	38.1	35.2	37.7	39.3	37.0
154	-	38.8	36.5	-	37.9	37.7
163	-	38.2	38.6	-	40.8	39.5

Table 4.32 Percentage **Compressibility** of Fabrics Produced from Yarn **29 tex Immediately after Untwisting** (%)

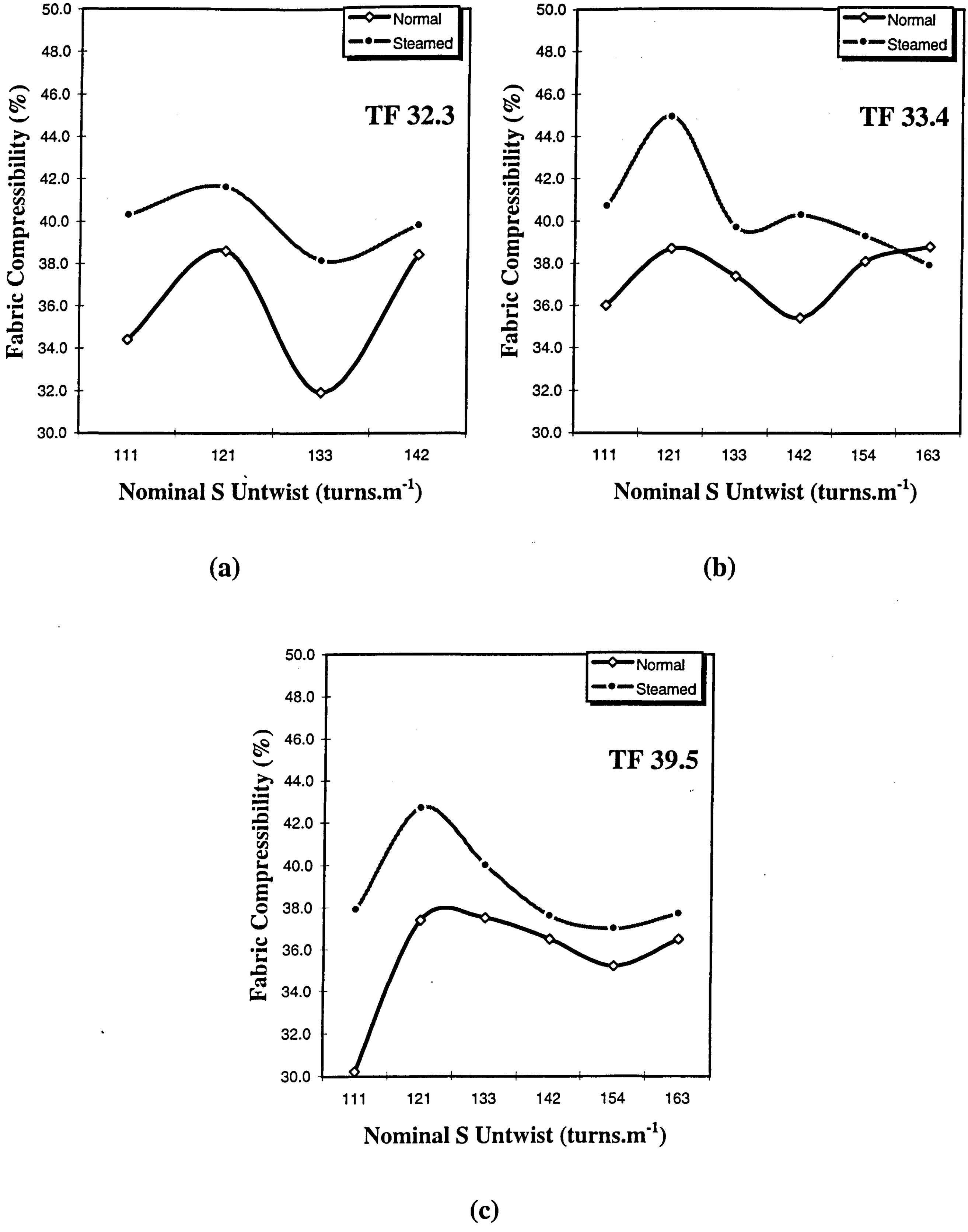
Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.4	TF 34.9	TF 38.6	TF 32.4	TF 34.9	TF 38.6
0	40.3	39.6	37.7	43.5	46.2	43.6
111	45.3	45.6	46.2	36.2	38.8	39.7
129	44.7	44.3	45.0	47.1	45.3	45.6
147	46.3	46.0	44.0	44.4	45.0	43.0
163	44.0	45.4	44.3	44.6	47.0	45.0
182	46.1	45.2	45.6	46.9	47.0	43.5
200	-	48.3	43.1	-	44.1	44.8
220	-	44.5	42.4	-	44.3	44.8

Table 4.33 Percentage **Compressibility** of Fabrics Produced from Yarn **39 tex after 13 Days from the Untwisting Process** (%)

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.3	TF 33.4	TF 39.5	TF 32.3	TF 33.4	TF 39.5
111	37.1	37.5	38.2	42.3	40.1	39.7
121	43.1	41.6	38.7	43.1	42.1	37.9
133	37.5	38.5	35.0	40.2	38.9	38.4
142	-	37.5	35.3	39.2	39.2	36.4
154	-	41.0	38.5	-	42.4	40.2
163	-	39.1	40.2	-	39.3	39.5

Table 4.34 Percentage **Compressibility** of Fabrics Produced from Yarn **29 tex after 13 Days from the Untwisting Process** (%)

Nominal S Untwist (turns.m^{-1})	NORMAL			STEAMED		
	TF 32.4	TF 34.9	TF 38.6	TF 32.4	TF 34.9	TF 38.6
111	46.3	44.6	43.1	47.1	44.8	48.6
129	45.4	44.2	46.8	49.9	46.1	45.0
147	45.1	43.8	44.8	45.4	47.6	43.2
163	47.3	45.3	43.3	47.1	45.9	46.3
182	46.6	44.8	42.8	44.5	46.3	44.8
200	-	47.3	46.6	-	47.9	46.4
220	-	46.6	45.8	-	48.3	45.5

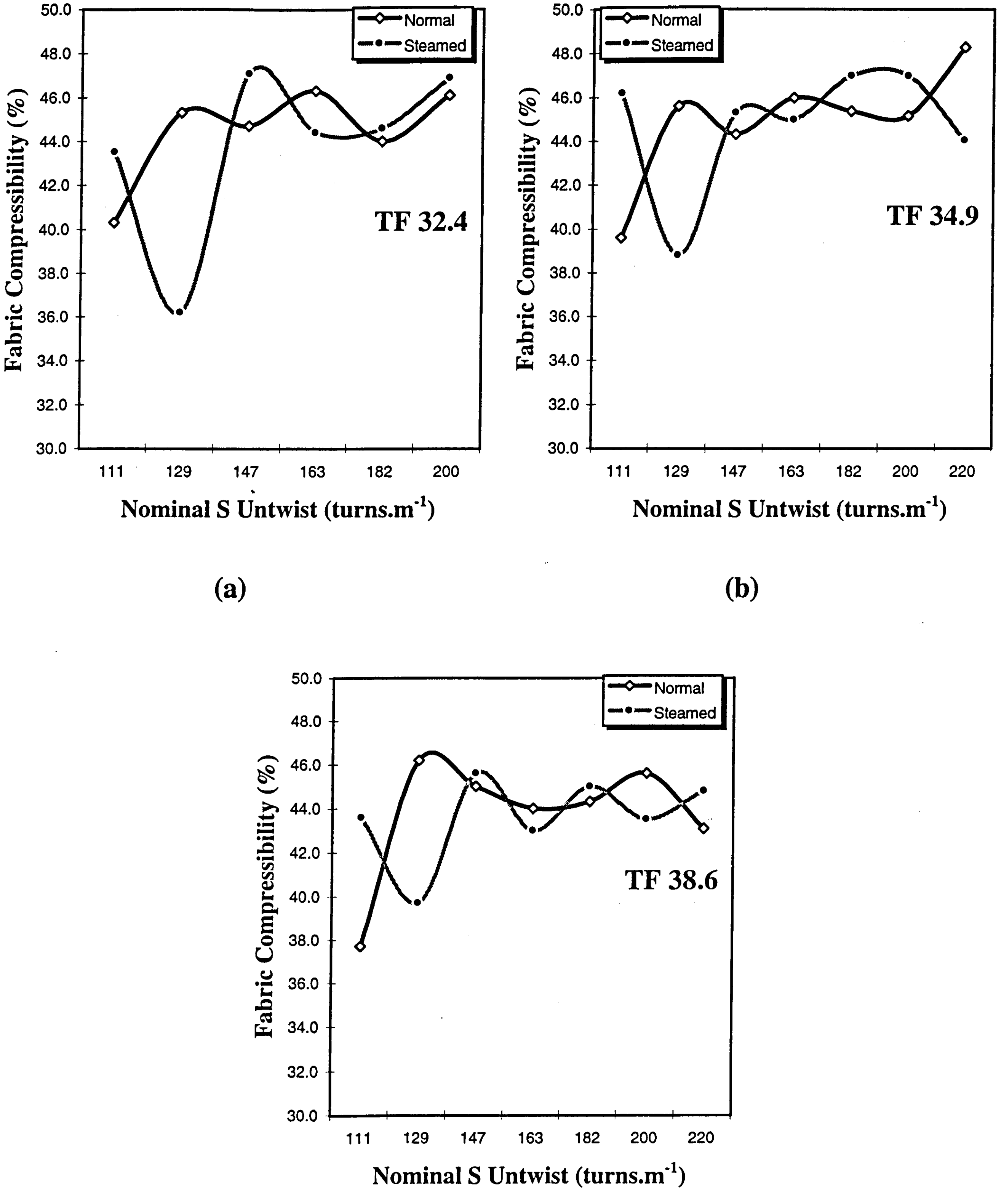


(a)

(b)

(c)

Figure 4.23 **Compressibility** (%) of Fabrics Knitted from Yarn **39 tex** Immediately after Untwisting



(a)

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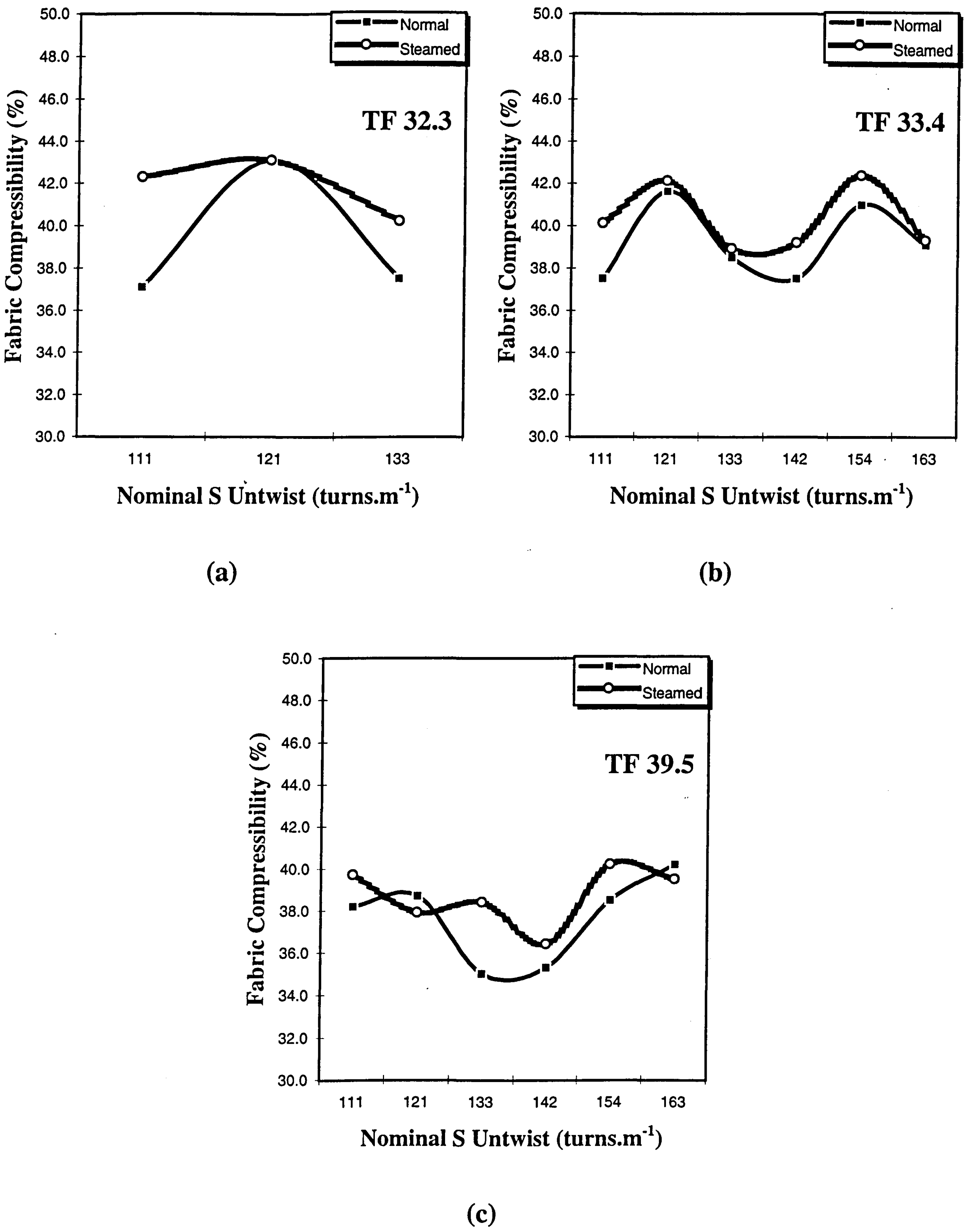
Figure 4.24 **Compressibility** (%) of Fabrics Knitted from Yarn **29 tex** Immediately after Untwisting



(a)

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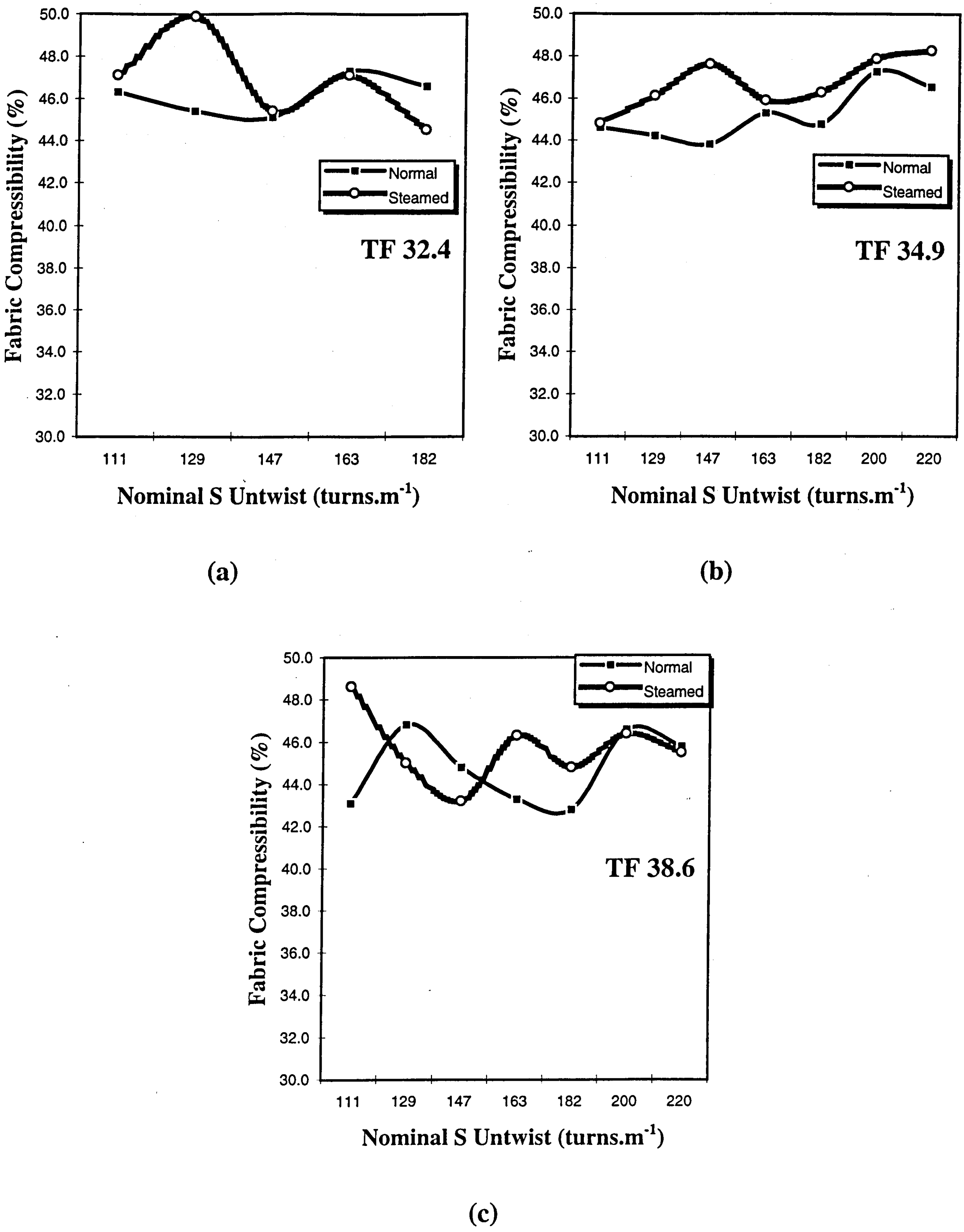
Figure 4.25 **Compressibility** (%) of Fabrics Knitted from Yarn **39 tex** after 13 days from Untwisting



(a)

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Figure 4.26 **Compressibility** (%) of Fabrics Knitted from Yarn **29 tex** after 13 days from Untwisting

Discussion: From Tables 4.31 to 4.34 and from Figures 4.23 to 4.26 it can be concluded that although there are some differences in the percentage compressibility of the fabrics, there are no special trends.

In most cases, the fabrics knitted from partially untwisted steamed yarns exhibit higher compressibility than the fabrics knitted from partially untwisted unsteamed (normal) yarns. The intervened time of 13 days seems that does not affect seriously the compressibility of the fabrics knitted from both normal and steamed yarns.

4.2.3 TWIST - TENACITY - SPIRALITY

The results reported in Tables 4.3 & 4.4, 4.13 & 4.14, 4.21 & 4.22 and 4.25 & 4.26, are summarised in Tables 4.35 and 4.36, Figures 4.27 and 4.28 show the corresponding graphic presentation of data.

From Figures 4.27 and 4.28 it is obvious that, although the percentage reduction in terms of twist and tenacity is small enough, the percentage reduction in spirality angle of the knitted fabrics it is substantially large for all the tested yarn samples. It could be suggested therefore, that partially untwisting the ring spun yarns is very effective in reducing the spirality angle without much loss of the yarn strength.

Table 4.35 Percentage Reduction (%) of Twist, Tenacity and Spirality **(Yarn 39 tex)**

Nominal	**TF 32.3**								**TF 33.4**								**TF 39.5**							
S Untwist	Normal				Steamed				Normal				Steamed				Normal				Steamed			
turns.m^{-1}	Tw	Te	S_0	S_{13}	Tw	Te	S_0	S_{13}	Tw	Te	S_0	S_{13}	Tw	Te	S_0	S_{13}	Tw	Te	S_0	S_{13}	Tw	Te	S_0	S_{13}
111	15.8	30.6	63.3	30.0	16.0	36.2	44.8	55.2	14.3	16.8	33.3	24.2	15.8	24.5	42.3	61.5	16.0	15.5	15.9	36.4	15.6	16.1	47.4	47.4
121	13.3	30.0	-13.3	36.7	14.4	36.7	37.9	72.4	16.2	27.8	39.4	33.3	17.3	26.4	46.2	73.1	17.2	14.6	40.9	36.4	15.6	6.9	60.5	52.6
133	15.4	36.6	53.3	36.7	16.3	49.2	82.8	69.0	18.0	33.4	51.5	39.4	18.0	34.5	65.4	61.5	19.3	10.5	31.8	38.6	18.9	17.8	50.0	55.3
142	-	-	-	-	16.1	45.8	86.2	65.5	19.1	36.4	54.5	39.4	17.9	40.8	92.3	61.5	19.9	23.5	45.5	38.6	18.5	3.1	57.9	52.6
154	-	-	-	-	-	-	-	-	18.9	42.2	51.5	24.2	20.7	43.1	80.8	73.1	23.3	28.0	59.1	36.4	22.8	17.5	60.5	47.4
163	-	-	-	-	-	-	-	-	19.3	37.8	72.7	45.5	19.7	47.1	80.8	57.7	22.1	23.1	54.5	56.8	23.7	23.5	68.4	52.6

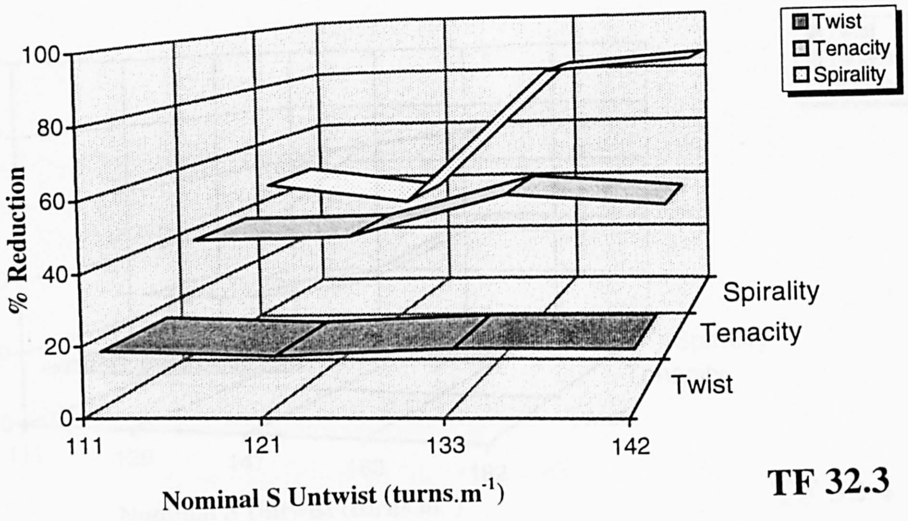
Table 4.36 Percentage Reduction (%) of Twist, Tenacity and Spirality **(Yarn 29 tex)**

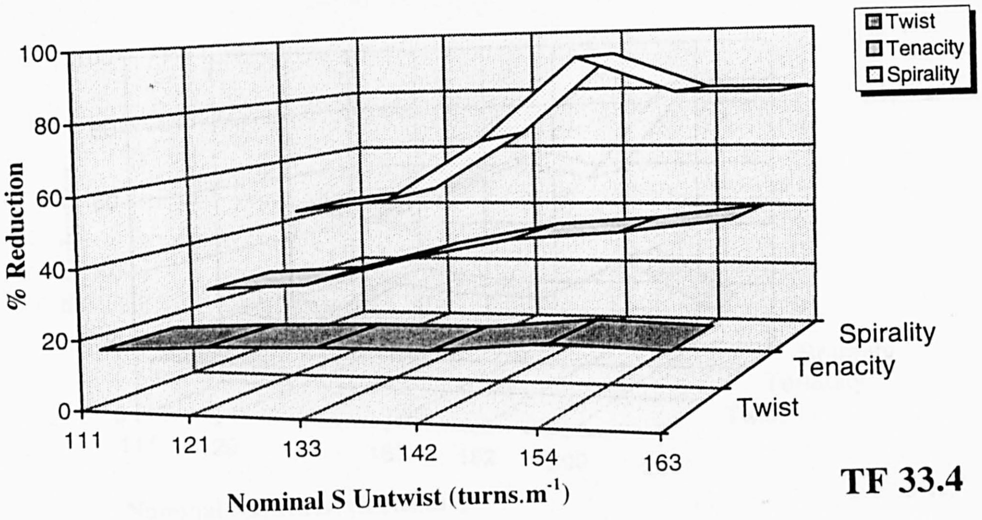
Nominal	**TF 32.4**								**TF 34.9**								**TF 38.6**							
S Untwist	Normal				Steamed				Normal				Steamed				Normal				Steamed			
turns.m^{-1}	Tw	Te	S_0	S_{13}	Tw	Te	S_0	S_{13}	Tw	Te	S_0	S_{13}	Tw	Te	S_0	S_{13}	Tw	Te	S_0	S_{13}	Tw	Te	S_0	S_{13}
111	12.9	18.9	42.5	27.5	13.3	26.2	41.7	20.8	13.5	9.2	21.6	29.7	14.2	21.5	48.4	29.0	14.7	6.7	10.9	32.7	13.1	17.0	29.2	39.6
129	15.1	34.3	45.0	30.0	13.2	25.3	66.7	20.8	13.8	7.1	18.9	16.2	13.9	16.7	45.2	35.5	18.1	13.1	30.9	47.3	15.0	19.9	35.4	43.8
147	14.3	44.9	40.0	37.5	14.5	29.7	70.8	25.0	16.5	26.5	16.2	16.2	16.5	31.0	54.8	41.9	20.1	10.9	38.2	27.3	16.4	22.1	43.8	39.6
163	15.4	50.8	52.5	45.0	19.0	47.8	75.0	37.5	18.3	27.8	45.9	16.2	17.7	27.8	64.5	54.8	18.7	12.4	49.1	30.9	18.4	25.8	66.7	43.8
182	17.2	53.1	52.5	45.0	19.3	47.1	75.0	62.5	19.4	30.4	56.8	27.0	19.6	26.9	58.1	58.1	21.2	10.9	58.2	45.5	19.7	25.6	77.1	62.5
200	-	-	-	-	-	-	-	-	22.8	32.9	48.6	51.4	21.0	38.3	87.1	67.7	22.5	21.3	56.4	49.1	24.4	32.7	85.4	83.3
220	-	-	-	-	-	-	-	-	21.6	45.8	54.1	45.9	22.5	24.5	87.1	58.1	24.8	20.0	69.1	58.2	23.6	31.3	89.6	85.4

Tw: Twist, Te: Tenacity

S_0: Spirality of fabrics knitted immediately after the yarn partial untwisting process.

S_{13}: Spirality of fabrics knitted after 13 days from the yarn partial untwisting process.





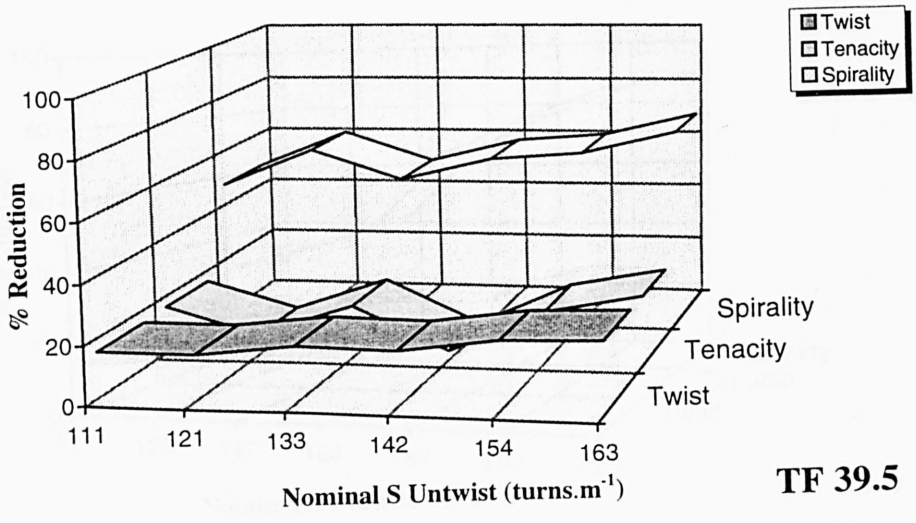
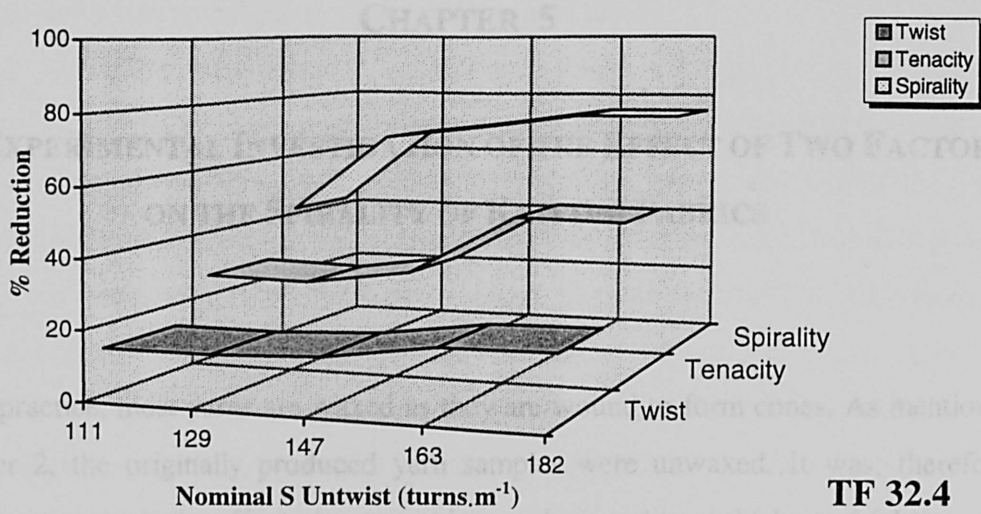
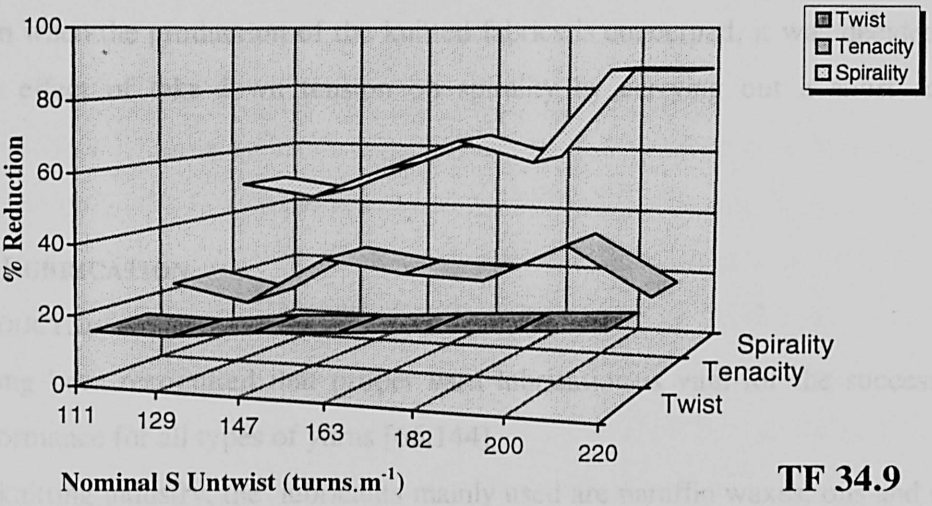


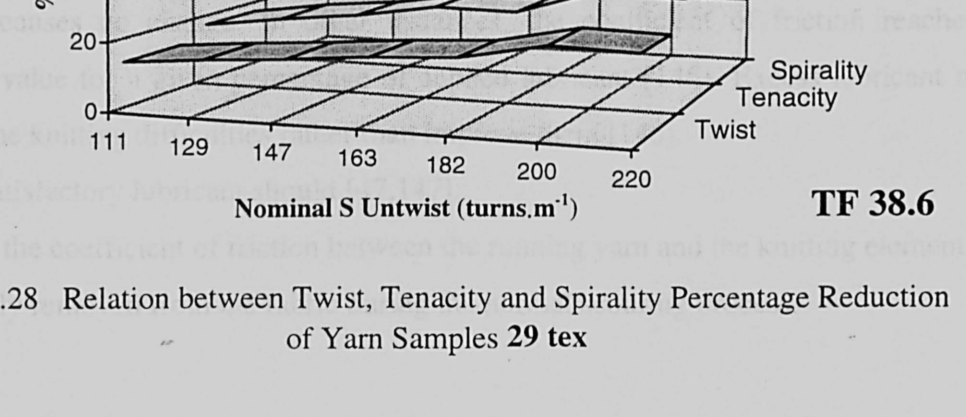
Fig. 4.27 Relation between Twist, Tenacity and Spirality Percentage Reduction of Yarn Samples **39 tex**



TF 32.4



TF 34.9



TF 38.6

Fig. 4.28 Relation between Twist, Tenacity and Spirality Percentage Reduction of Yarn Samples **29 tex**

CHAPTER 5

EXPERIMENTAL INVESTIGATION OF THE EFFECT OF TWO FACTORS ON THE SPIRALITY OF KNITTED FABRICS

In practice, most yarns are waxed as they are wound to form cones. As mentioned in chapter 2, the originally produced yarn samples were unwaxed. It was, therefore, decided to investigate the effect of yarn waxing on the spirality of the knitted fabrics.

Since, the take-down tension is a factor that is generally to be taken into consideration when the production of the knitted fabrics is concerned, it was decided to examine the effect of take-down tension on spirality by carrying out a short scale experiment.

5.1 YARN LUBRICATION

5.1.1 INTRODUCTION

It is long been recognised that proper yarn lubrication is vital for the successful knitting performance for all types of yarns [66,144].

In the knitting industry, the lubricants mainly used are paraffin waxes, oils and oil-water emulsions [78,145]. In applying these lubricants, three points should be noted:

1. The assumption that a lubricant having high efficiency on one fibre type will be equally efficient on others can lead to severe problems in processing.
2. The percentage of lubricant applied to produce optimum conditions will probably vary from yarn to yarn.
3. In some instances, the coefficient of friction is reduced until the addition of further lubricant causes no change. In other instances, the coefficient of friction reaches a minimum value for a given percentage of applied lubricant [145]. Excess lubricant may increase the knitting difficulties rather than improve them [146].

A satisfactory lubricant should [47,147]:

i. reduce the coefficient of friction between the running yarn and the knitting elements.
ii. be easily removed from the fabric during the normal scouring process.

iii. have no deleterious effect on the yarn and machine parts.
iv. be non-volatile at normal temperatures and unaffected by storage.

The application of lubricants to knitting yarns, which is invariably carried out during the yarn winding stage [24,146], affects the frictional properties of the yarns [148]. It is known [147] that friction is purely a surface effect, so that "lubrication on the surface of the yarn is all that is necessary to change the yarn friction. The wax treatment forms a thin film of wax on the surface of the yarn so that, by waxing, two yarns initially having different frictional values, may be given similar frictional properties and hence knit similarly, since their surfaces after waxing will be similar" [146]. Lubrication reduces the coefficient of friction of the yarn as well its rigidity [78,145]; "wax treatment allows the torque in the yarn to release itself earlier in the process" [7]. This contrasts with the statement that "waxing does not significantly affect the flexural and torsional rigidities of the fabric" [149].

It was believed that poor fabric appearance, caused by distortion of individual loops, might be remedied by lubrication [149]. In one study, knitted fabric, produced from mercerised yarn treated with three consecutive waxing operations, exhibited a reduction in spirality, confirming the hypothesis that the friction properties have an effect on the spirality [12]. However, it is also reported [7,17,39] that the yarn waxing treatment resulted in a very little or no improvement in the final product as far as spirality was concerned. In one case [17], "the waxed yarn in an unwashed fabric exhibited a slightly flatter pattern, whereas waxed and unwaxed yarns exhibited an almost identical pattern in the washed fabric".

Although it would appear that lubrication (i.e., waxing) has a negligible effect on spirality, it must be said that "a great degree of difficulty is faced during knitting unwaxed yarns" [39], demonstrating the necessity for effective yarn lubrication [150]. By applying wax to the yarn, a low yarn friction may be obtained [148], which results in easier yarn sliding over the various guides and knitting elements during the process of knitting, avoiding by this means yarn breakage or at least the production of faulty fabric [24,144]. In addition, a lubrication treatment facilitates an even distribution of the yarn round the needles, resulting in better regularity of the knitting process [78].

5.1.2 EXPERIMENTS

Having no clear picture whether the spirality angle is affected by yarn waxing, it was decided to carry out an experiment to investigate the effect of wax (as a lubricant) and the method of its application onto the yarns. This experiment was carried out on fabrics knitted from yarn samples processed with the new method (yarn partial untwisting process) of spirality reduction described in chapter 3.

5.1.2.1 *Yarn Sampling*

The Z-twisted yarn 29 tex of TF 34.9 was used for these experiments. The yarn was steamed for 40 minutes in conditions described in section 4.1.2 and left for over a month in normal atmospheric conditions. Eight different samples of yarn were produced from the parent yarn as follows:

5.1.2.1.1 Samples

[The abbreviations, S for Steamed Yarn, D for Double Winding Process, W for Wax Application, P for Processed Yarn (Untwisting Process), which appear inside the brackets of the yarn samples declares the sequence of the indicated processes. For example, Sample 5 SDWP means that at first the yarn was steamed (S), then was wound twice on a cone (D), during the second winding process a waxing process (W) took place and at last the yarn was partially untwisted (P).]

Sample 1: Steamed yarn (S).

Sample 2: Steamed yarn wound twice on a cone (SD).

Sample 3: Double waxed steamed yarn. The waxing process took place during the double winding process (SDW).

Sample 4: Steamed yarn waxed by passing through two paraffin tubes positioned before the knitting zone of the knitting machine (SW).

Sample 5: Yarn, as in sample 3, processed with the new method by inserting 175 turns.m^{-1} (random choice) in the S direction (SDWP).

Sample 6: Steamed yarn (as sample 1) processed with the new method by inserting 175 turns.m^{-1} in the S direction (SP).

Sample 7: As sample 6, the yarn passing twice from the winding process before the untwisting process (SDP).

Sample 8: As sample 6, the yarn being double waxed (SDPW).
The first waxing treatment took place during a winding process on the Gilbos winding machine. The second waxing treatment took place, on-line, on the two-for-one twisting frame with the paraffin tube being placed between the guide and the pretension disc.

Sample 9: As sample 6, the yarn being waxed just before its entrance to the knitting zone (as in the case of sample 4) (SPW).

As mentioned earlier, yarn lubrication usually takes place during the yarn winding process. In chapter 2 it was indicated that the transfer of the yarn from one package (cop) to the other (cone) results in reduction of the yarn torque. Since the yarns were already on cone packages, and they should be rewound for the double application of wax, it was thought necessary to rewind twice the yarn sample No 2 onto a cone. This process is termed the ***double winding process*** (**D**). This enabled the effect of the ***waxing*** (**W**) to be isolated by comparing yarn sample No 2 with sample No 3. Yarn samples Nos 7 and 8 were produced for the same reason. The examination of the effect of the interaction between waxing treatment and ***untwisting process*** (**P**) on the spirality effect led to the preparation of the yarn samples Nos 5 and 8. This could be achieved by comparing yarn samples Nos 5 and 8 with those samples that were not untwisted, i.e., yarn samples Nos 1 to 4. Samples No 2 and No 7, were prepared in order to make clearer the effect of the wax itself, and isolate yarn factors arising from the winding procedure (tension, friction). These factors could also be examined by comparing some other pairs of samples (e.g., No 1 & No 2, No 6 & No 7).

5.1.2.1.2 *Winding*

The winding of the above list of the yarn samples took place on a Gilbos winding machine, using the same "head" in order to minimise the possible variation in the results. The winding speed was maintained at 440 m.min^{-1}.

5.1.2.1.3 <u>Waxing During Winding</u>

A cylindrical paraffin tube, was placed in the yarn passage between the supply and the delivery package to provide the waxing treatment. The yarn was in contact with the cylindrical surface of the tube.

Problems of yarn breakage, were faced during the untwisting of sample No. 8. The yarn breaks were found to take place in the region of the pretension disc placed just before the winding zone on the Volkmann two-for-one twisting machine. A possible explanation was the accumulation of paraffin flakes between the tension discs, which was observed to take place in this particular experiment. Therefore, it was decided to exclude the testing results of this sample from further statistical data processing.

5.1.2.2 *Coefficient of Yarn Friction*

The yarn samples were tested for friction on metal. The Shirley Yarn Friction Tester with the settings described in Appendix II were used, and the results are reported in Table 5.1.

Table 5.1 Effect of Lubrication on the Yarn Coefficient of Friction (μ)

Yarn /Fabric Sample Nos	Type	μ
1	S	0.238
2	SD	0.161
3	SDW	0.180
6	SP	0.218
7	SDP	0.176
8	SDPW	0.118

It can be seen that yarn sample No 3, being double waxed, showed a higher coefficient of friction than the unwaxed sample No 2. Furthermore, the combination of the untwisting process and the waxing treatment (sample No 8) gave a very small coefficient of friction, almost half of that of the steamed yarn sample No 1.

5.1.2.3 *Knitting Stage*

The same settings of the knitting machine used in the main experimental work (section 4.1.4) were maintained in these experiments. Neither take-down tension nor input yarn tension were applied to the fabric, yarn. From each yarn sample, fabric of 100 courses was produced, being separated from its adjacent samples by a stripe of sixty courses produced from coloured "dead" yarn, so as to avoid any disturbance to the spirality from the adjacent fabric samples. The calculated, from the machine parameters, loop length and the tightness factor were 4.83 mm and $K_l=1.134$ tex^{½}.mm^{-1} respectively.

5.1.2.4 *Spirality Measurement*

The spirality angles of the produced fabrics were measured before and after a washing process. The results are presented in Table 5.2.

Table 5.2 Spirality Angle (°)

Yarn /Fabric Sample Nos	Type	Before Washing	After Washing
1	S	9.0	12.0
2	SD	16.0	13.0
3	SDW	11.5	9.0
4	SW	14.0	7.0
5	SDWP	-7.0	-2.0
6	SP	-8.0	-0.5
7	SDP	-8.5	-5.0
8	SDPW	-7.0	-4.0
9	SPW	-2.5	3.0

5.1.3 RESULTS - DISCUSSION

For the interpretation of the results obtained by measuring the spirality angle of the fabric samples, a statistical analysis of variance was carried out using the Yates's Algorithm.

5.1.3.1 *Statistical Analysis of Variance*

The results of Table 5.2 (except the result of sample No 8) were arranged in a convenient order to form Table 5.3. The letter **A** stands for the Waxing treatment, **B** for the Untwisting process, **C** for double winding process and **D** stands for the Washing treatment. The positive sign (+) indicates that the process applied to the yarn/fabric, whereas the negative sign (-) indicates that the particular treatment or process was not carried out. The results of the application of Yates's Algorithm are reported in Tables 5.4 and 5.5.

Table 5.3 Rearrangement of the Spirality Angle (°) of Table 5.2

		A-		A+	
		B-	B+	B-	B+
C-	D-	9.0	-8.0	14.0	-2.5
	D+	12.0	-0.5	7.0	3.0
C+	D-	16.0	-8.5	11.5	-7.0
	D+	13.0	-5.0	9.0	-2.0

Table 5.4 Application of Yates's Algorithm

	A	B	C	D	x	1	2	3	4	Factor Ef.	Factor $\sum x^2$	
1	-	-	-	-	9.0	23.0	12.5	24.5	61	3.8125	-	-
2	+	-	-	-	14.0	-10.5	12.0	36.5	5	0.6250	1.5625	A
3	-	+	-	-	-8.0	27.5	21.5	7.5	-122	-15.2500	930.2500	B
4	+	+	-	-	-2.5	-15.5	15.0	-2.5	22	2.7500	30.2500	AB
5	-	-	+	-	16.0	19.0	10.5	-76.5	-7	-0.8750	3.0625	C
6	+	-	+	-	11.5	2.5	-3.0	-45.5	-13	-1.6250	10.5625	AC
7	-	+	+	-	-8.5	22.0	-1.5	6.5	22	2.7500	30.2500	BC
8	+	+	+	-	-7.0	-7.0	-1.0	15.5	4	0.5000	1.0000	ABC
9	-	-	-	+	12.0	5.0	-33.5	-0.5	12	1.5000	9.0000	D
10	+	-	-	+	7.0	5.5	-43.0	-6.5	-10	-1.2500	6.2500	AD
11	-	+	-	+	-0.5	-4.5	-16.5	-13.5	21	2.6250	27.5625	BD
12	+	+	-	+	3.0	1.5	-29.0	0.5	9	1.1250	5.0625	ABD
13	-	-	+	+	13.0	-5.0	0.5	-9.5	-6	-0.7500	2.250	CD
14	+	-	+	+	9.0	3.5	6.0	-12.5	14	1.7500	12.250	ACD
15	-	+	+	+	-5.0	-4.0	8.5	5.5	-3	-0.3750	0.5625	BCD
16	+	+	+	+	-2.0	3.0	7.0	-1.5	-7	-0.8750	3.0625	ABCD

Table 5.5 Analysis of Significance

Source	Factor $\sum x^2$	Freedom	Mean	F
A	1.6	1	1.6	0.4
B	930.3	1	930.3	212.0
C	3.1	1	3.1	0.7
D	9.0	1	9.0	2.1
AB	30.3	1	30.3	69
AC	10.6	1	10.6	2.4
AD	6.3	1	6.3	1.4
BC	30.3	1	30.3	6.9
BD	27.6	1	27.6	6.3
CD	2.3	1	2.3	0.5
ABC	1.0	1		
ABD	5.1	1		
ACD	12.3	1	} 4.4	
BCD	0.6	1		
ABCD	3.1	1		

From the statistical tables it can be found that : $F_{1,5\ 0.05} = 6.6$ and $F_{1,5\ 0.01} = 16.3$

It could be concluded that the B factor, i.e., the untwisting process, is significant at the 1% level, and the AB (Waxing-Untwisting) & BC (Double Winding - Untwisting) interactions are significant at the 5% level. The BD (Untwisting-Washing) interaction is approaching significance at the 5% level. None of the other sources of variation is significant. Since the B factor is very significant, it could be concluded that the significance of the combined treatments are mainly due to the untwisting process.

Examination of the AB interaction (significant at 5% level).

Table 5.6 AB Interaction Analysis of Spirality Angle (°)

	A-	A+	B means
B-	12.50	10.3750	11.4375
B+	-22.00	-8.5000	-15.2500
A means	-4.75	0.9375	-1.9062

Note: Each of the values is the mean of the four experimental results at each combination of levels of A and B.

Referring to Table 5.6, it can be seen that, when the yarn is only steamed (B-) the spirality is reduced from 12.5° to 10.375°, - a decrease of magnitude 2.125° - due to the waxing treatment. On the other hand, when the yarn is untwisted or processed (B+), the spirality although negative, is increased from -22° to -8.5°, an increase of magnitude 13.5°.

The difference in size of these changes is responsible for the significance of the interaction AB. It could be concluded then that the effect of the waxing treatment, although significant when interacting with the untwisting process, does not substantially affect the spirality of the knitted fabrics. This is also supported by the fact that the statistical analysis shows that waxing (A) as factor by itself is not significant.

5.2 THE EFFECT OF TAKE-DOWN TENSION ON SPIRALITY

It has been mentioned in the first chapter, that there is some confusion as to whether take-down tension affects the appearance of knitted fabric. Before carrying out a large scale experiment for the examination of the effect of the take-down tension on the fabrics produced from untwisted yarns using the new process, it was decided to run a short scale experiment.

5.2.1 EXPERIMENTS

5.2.1.1 *Yarn Samples*

From the range of yarn samples described in section 4.1.3, ten samples were chosen randomly.

Group A:	Yarn with linear density **39 tex**, Z-twisted.	
Sample 1:	TF 33.4	Normal;
Sample 2:	TF 39.5	Steamed;
Sample 3:	TF 32.3	with Nominal S Untwist of 133 turns.m^{-1};
Sample 4:	TF 33.4	with Nominal S Untwist of 142 turns.m^{-1};
Sample 5:	TF 39.5	with Nominal S Untwist of 154 turns.m^{-1};

Group B:	Yarn with linear density **29 tex**, Z-twisted.	
Sample 6:	TF 32.4	Normal;
Sample 7:	TF 34.9	Steamed;
Sample 8:	TF 32.4	with Nominal S Untwist of 154 turns.m^{-1};
Sample 9:	TF 34.9	with Nominal S Untwist of 163 turns.m^{-1};
Sample 10:	TF 38.6	with Nominal S Untwist of 175 turns.m^{-1};

5.2.1.1.1 _Yarn Twist_

The prepared yarn samples listed above were tested for twist. The results are reported in Table 5.7.

Table 5.7 Twist of the Various Yarn Samples (turns.m^{-1})

Yarn Samples	Original Z Twist	Nominal S Untwist	Net Z Twist Nominal	Net Z Twist Actual
1	536.2	-	-	568.0
2	628.8	-	-	635.6
3	513.9	133	380.9	436.2
4	536.2	142	394.2	461.6
5	628.8	154	474.8	492.2
6	598.3	-	-	604.4
7	643.9	-	-	675.4
8	598.3	154	444.3	520.8
9	643.9	163	480.9	551.2
10	711.3	175	536.3	591.4

5.2.1.2 *Fabric Samples*

Two sets of fabric samples were produced on the knitting machine with the same specifications as described in section 4.1.4. The samples of the first set were produced without any take-down tension, while for the second set, the take-down tension mechanism provided by the knitting machine was used.

5.2.1.2.1 Fabric Testing

The fabric samples were left to relax for 24 hours in normal conditions. The spirality angle of each of the fabric samples was measured. Then, the fabrics were washed and after drying in normal atmospheric conditions, the measurement of the spirality angle was repeated. The results are presented in the Table 5.8 and in Figures 5.1 to 5.4.

Table 5.8 Spirality Angle of Fabric Samples (see also Appendix V)

Yarn Samples	Actual Z Twist (turns.m^{-1})	Spirality Angle (°) Take-Down (-) B.W.	Spirality Angle (°) Take-Down (-) A.W.	Spirality Angle (°) Take-Down (+) B.W.	Spirality Angle (°) Take-Down (+) A.W.
1	568.0	17.0	11.0	6.5	7.0
2	635.6	15.0	10.0	10.0	9.0
3	436.2	-4.0	1.0	-0.5	6.0
4	461.6	-4.0	0.0	0.0	-0.5
5	492.2	-4.0	2.5	0.0	2.0
6	604.4	18.0	12.5	10.0	3.5
7	675.4	15.0	12.0	9.0	6.5
8	520.8	-8.5	1.0	0.0	-3.0
9	551.2	-6.0	3.0	-2.0	2.0
10	591.4	-9.0	5.0	-0.5	-1.0

Note: B.W. : Before Washing A.W. : After Washing
The positive sign (+) in the column of Take-Down tension indicates the application of this tension to the fabric.
The negative sign (-) in the data of the spirality angle means that the spirality angle was in the opposite direction.

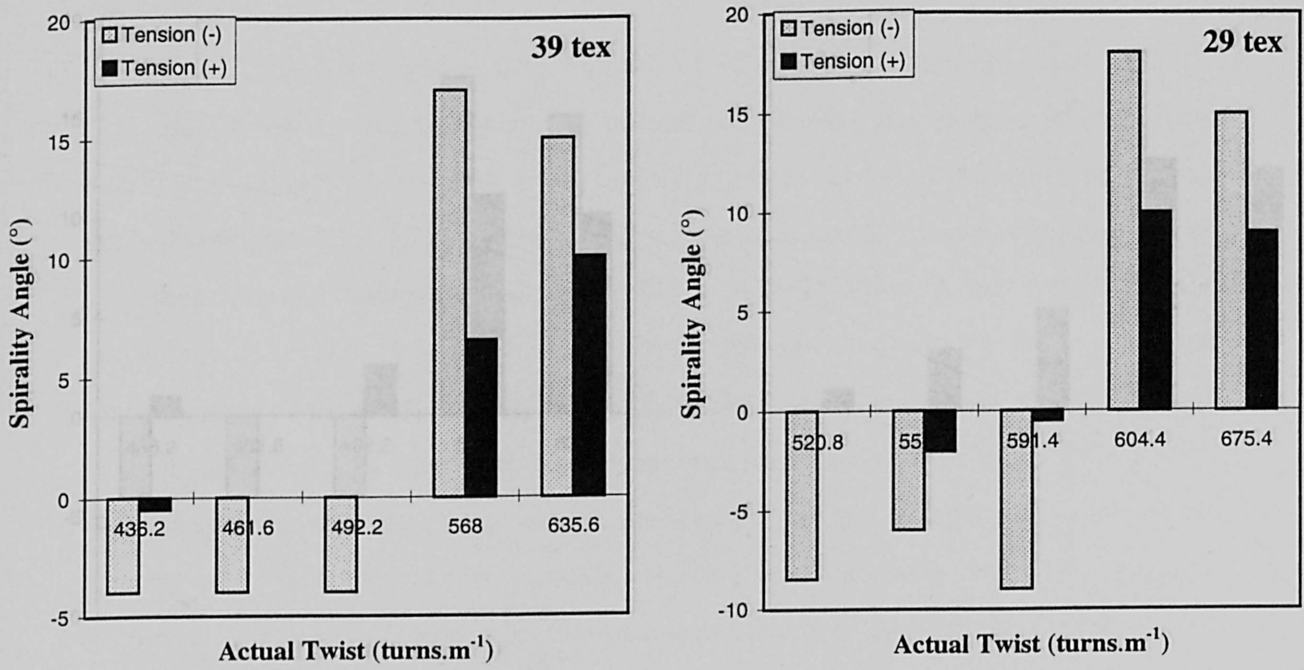


Fig. 5.1 The Effect of **Take-Down Tension** on the Spirality of Various Knitted Fabrics **Before** Washing

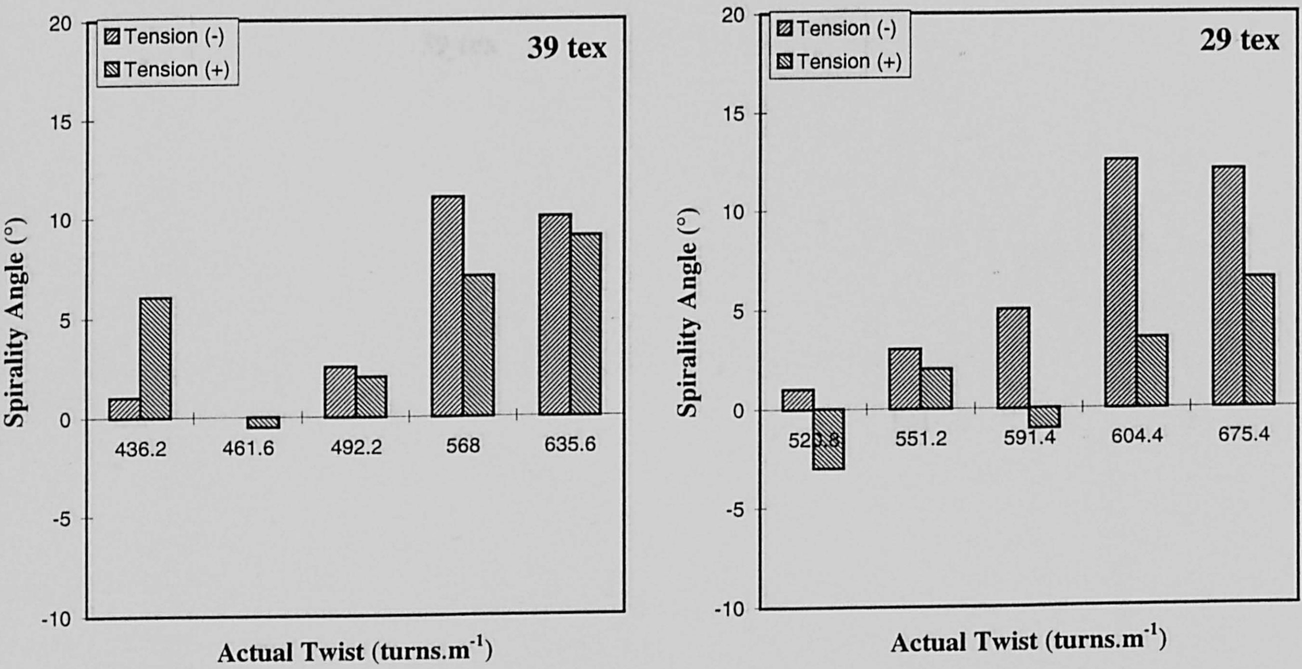


Fig. 5.2 The Effect of **Take-Down Tension** on the Spirality of Various Knitted Fabrics **After** Washing

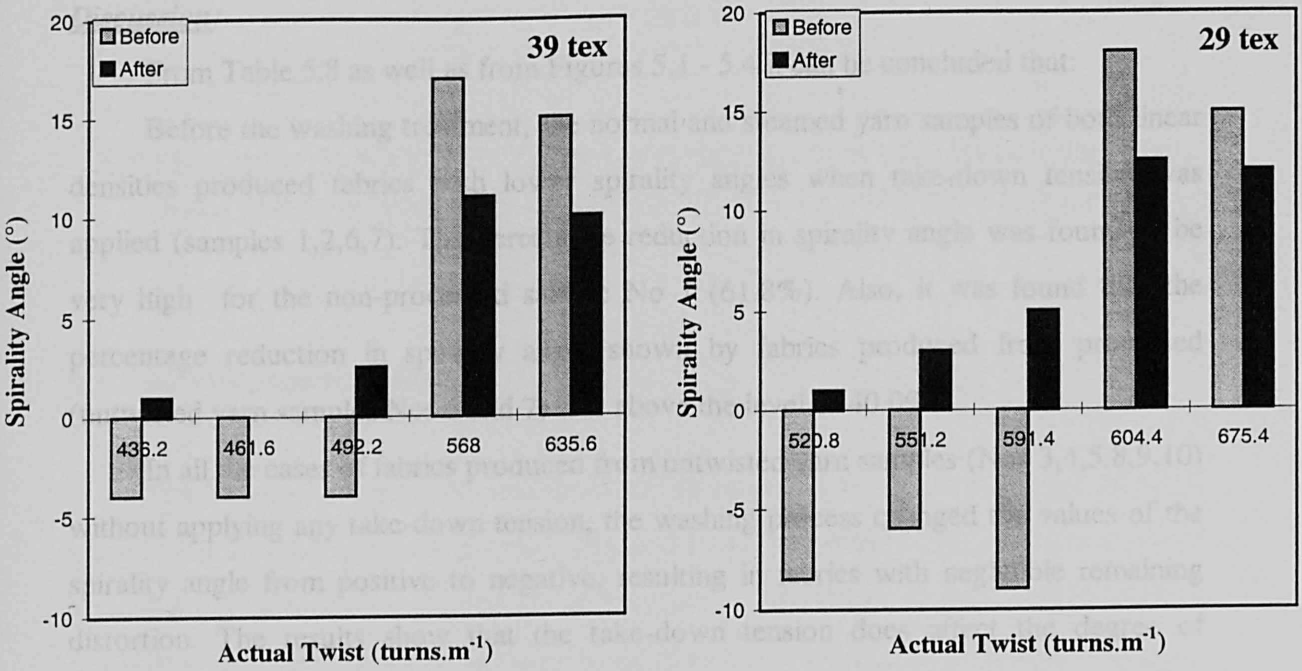


Fig. 5.3 The Effect of **Washing** on the Spirality of Various Fabrics Knitted **without** Take-Down Tension

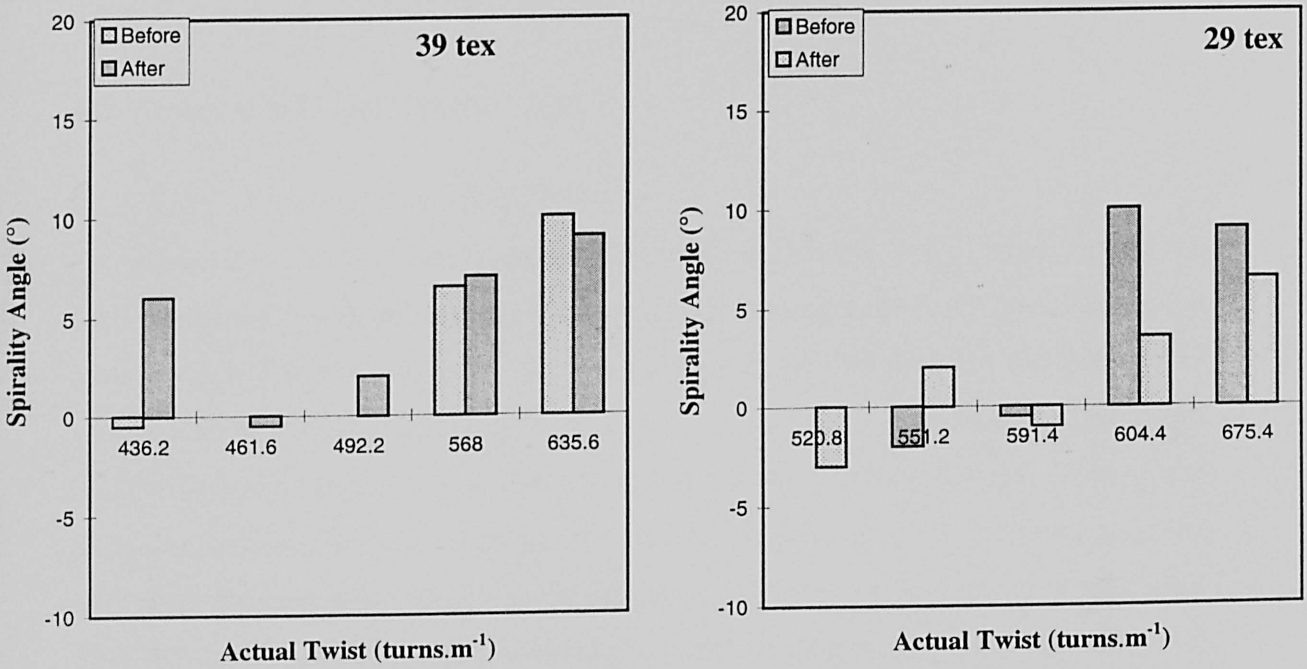


Fig. 5.4 The Effect of **Washing** on the Spirality of Various Fabrics Knitted **with** Take-Down Tension

Discussion:

From Table 5.8 as well as from Figures 5.1 - 5.4 it can be concluded that:

Before the washing treatment, the normal and steamed yarn samples of both linear densities produced fabrics with lower spirality angles when take-down tension was applied (samples 1,2,6,7). The percentage reduction in spirality angle was found to be very high for the non-processed sample No 1 (61.8%). Also, it was found that the percentage reduction in spirality angle shown by fabrics produced from processed (untwisted yarn samples Nos 6 and 7) was above the level of 40.0%.

In all the cases of fabrics produced from untwisted yarn samples (Nos 3,4,5,8,9,10) without applying any take-down tension, the washing process changed the values of the spirality angle from positive to negative, resulting in fabrics with negligible remaining distortion. The results show that the take-down tension does affect the degree of spirality. Considering that in some cases there is a significant effect of take-down tension on spirality, and also the fact that a procedure which partially untwists yarn could also increase yarn breakage, it was decided to carry out a more detailed investigation of take-down tension on fabric spirality.

CHAPTER 6

APPLICATION OF PARTIAL YARN UNTWISTING FOR THE REDUCTION OF SPIRALITY OF FABRICS KNITTED WITH TAKE-DOWN TENSION

6.1 AIM OF THIS EXPERIMENT

The purpose of the experiment described in chapter 4 was to examine the effect of partial yarn untwisting on the various yarn and fabric properties. The production of the various fabric samples was carried out in the research laboratory. It was decided to carry out further experimental work, in order to examine the new method, described in chapter 3, as applied to fabric production in simulated industrial conditions. A factor that was not included in the experimental work described in chapter 4, was the application of take-down tension to the knitted fabrics. This is invariably used in the industry. Although a small scale experiment has been carried out to examine the effect of the take-down tension on the spirality (§ 5.2), it was considered necessary to repeat this experiment on a larger scale.

6.2 YARN AND FABRIC PRODUCTION

6.2.1 YARN UNTWISTING PROCESS

Quantities of the yarn samples described in section 4.1.1 were wound on perforated conical supports and steamed for 20 minutes under the conditions described in section 4.1.2. The Volkmann two-for-one twisting frame was used for the insertion of various amounts of S twist. Thirty three steamed yarn samples were processed as shown in the following Table 6.1. For both of the yarn linear densities (29 tex, 39 tex), the difference between successive untwist levels was approximately 12 turns.m^{-1}, and the tests were stopped when the yarns proved to be too weak. Furthermore, it was clear from the experiments described in chapter 4 that, the insertion of small amounts of S twist in the yarns with high twist factors, had small effect on the reduction of the spirality.

Table 6.1 Processed Yarn Samples

Linear Density	**29 tex**			**39 tex**		
Nominal S Untwist (turns.m^{-1})	**Twist Factor (TF)** (turns.cm^{-1}.tex^{½})					
	32.4	**34.9**	**38.6**	**32.3**	**33.4**	**39.5**
111				✓	✓	
121				✓	✓	
133	✓			✓	✓	✓
142	✓	✓		✓	✓	✓
154	✓	✓	✓	✓	✓	✓
163	✓	✓	✓		✓	✓
175	✓	✓	✓			✓
191		✓	✓			
206		✓	✓			
220			✓			

6.2.2 FABRIC PRODUCTION

The conditions described in section 4.1.4 were used and take-down tension was applied to the fabric samples as they were knitted, by being gripped in a pair of rollers positioned in the bottom part of the knitting machine. Because of the lack of any measuring device, it was not possible to record the take-down tension.

6.3 TESTING OF YARN AND FABRIC SAMPLES (SEE APPENDICES II, VI)

6.3.1 YARN TESTING

As the present experiment was carried out a long time after the experiment described in chapter 4, it was considered wise to re-test the yarn samples for twist, count, evenness, strength, hairiness, abrasion resistance and friction. The equipment and the settings that were used for these tests, were the same as those described in the section 4.2 and Appendix II.

6.3.1.1 *Twist Amount*

The Zweigle D 301 twist tester was used for the measurement of the yarn twist. The average of 10 tests for each yarn sample is recorded in Table 6.2, and in Table 6.3, the corresponding percentage reduction of the actual twists is presented.

Table 6.2 Actual Net **Z -Twist** Testing Results (turns.m^{-1})

Nominal S Untwist	**39 tex**			**29 tex**		
(turns.m^{-1})	TF 32.3	TF 33.4	TF 39.5	TF 32.4	TF 34.9	TF 38.6
0	520.5	544.0	631.7	599.8	656.4	738.0
111	441.2	469.6	-	-	-	-
121	435.2	461.1	-	-	-	-
133	428.6	461.9	513.9	546.3	-	-
142	435.5	443.8	504.2	524.3	555.0	-
154	417.5	434.4	491.0	525.5	548.2	581.5
163	-	433.4	491.5	506.2	538.2	584.9
175	-	-	484.9	493.6	529.3	557.6
191	-	-	-	-	518.8	558.6
206	-	-	-	-	520.0	553.2
220	-	-	-	-	-	543.9

Table 6.3 Percentage (%) Reduction of Actual **Twist**

Nominal S Untwist	**39 tex**			**29 tex**		
(turns.m^{-1})	TF 32.3	TF 33.4	TF 39.5	TF 32.4	TF 34.9	TF 38.6
111	15.2	13.7	-	-	-	-
121	16.4	15.2	-	-	-	-
133	17.7	15.1	18.6	8.9	-	-
142	16.3	18.4	20.2	12.6	15.4	-
154	19.8	20.1	22.3	12.4	16.5	21.2
163	-	20.3	22.2	15.6	18.0	20.7
175	-	-	23.2	17.7	19.4	24.4
191	-	-	-	-	21.0	24.3
206	-	-	-	-	20.8	25.0
220	-	-	-	-	-	26.3

6.3.1.2 *Linear Density*

In Table 6.4 the mean of 5 tests of yarn linear densities (tex) are presented. Each test was carried out by weighing 50 m hanks of the samples yarn on an electronic micro balance.

Table 6.4 **Yarn Linear Density** Testing Results (tex)

Nominal S Untwist	**39 tex**			**29 tex**		
(turns.m^{-1})	TF 32.3	TF 33.4	TF 39.5	TF 32.4	TF 34.9	TF 38.6
0	39.54	40.00	40.82	30.52	30.80	30.30
111	38.80	39.32	-	-	-	-
121	38.64	38.40	-	-	-	-
133	39.38	37.94	39.04	28.20	-	-
142	38.78	38.72	39.72	28.00	29.24	-
154	38.40	38.00	40.06	29.50	28.80	30.10
163	-	38.84	39.08	28.78	29.70	30.38
175	-	-	39.50	28.04	28.80	29.54
191	-	-	-	-	29.34	29.30
206	-	-	-	-	29.00	29.40
220	-	-	-	-	-	29.14

Discussion: Although the overall results of the Table 6.4 show an insignificant reduction in yarn linear density as the untwist amount in the S direction increases, they follow no particular trend.

6.3.1.3 *Evenness*

The various yarn samples were tested for diameter irregularity. The results shown in Table 6.5 provide no clear picture of the effect of untwisting on irregularity.

Table 6.5 **Evenness** Testing Results (CVm %)*

Nominal S Untwist	**39 tex**			**29 tex**		
(turns.m^{-1})	TF 32.3	TF 33.4	TF 39.5	TF 32.4	TF 34.9	TF 38.6
0	13.55	12.57	12.58	13.66	14.63	13.06
111	13.37	12.27	-	-	-	-
121	12.70	12.10	-	-	-	-
133	12.63	12.60	12.58	14.56	-	-
142	12.84	12.65	13.28	15.23	13.70	-
154	11.65	12.49	12.75	14.91	13.89	13.62
163	-	12.69	13.31	14.05	13.83	14.35
175	-	-	12.93	14.44	14.62	14.57
191	-	-	-	-	14.26	13.29
206	-	-	-	-	14.67	14.11
220	-	-	-	-	-	14.25

* Coefficient of Variation of Yarn Mass per centimetre of yarn length

6.3.1.4 *Strength*

The results of testing the yarns for elongation and tenacity are presented in the Tables 6.6 and 6.7. The percentage reduction in these two factors is shown in the Tables 6.8 and 6.9 respectively.

Table 6.6 **Elongation** at Break Testing Results (%)

Nominal S Untwist	**39 tex**			**29 tex**		
(turns.m^{-1})	TF 32.3	TF 33.4	TF 39.5	TF 32.4	TF 34.9	TF 38.6
0	7.11	7.40	8.16	7.01	6.93	7.57
111	5.53	5.94	-	-	-	-
121	5.72	6.03	-	-	-	-
133	5.19	5.57	6.76	5.54	-	-
142	4.82	5.54	6.51	5.31	6.18	-
154	5.09	4.50	6.69	5.15	6.00	6.27
163	-	5.49	6.78	5.04	6.10	6.67
175	-	-	6.47	4.86	5.98	6.50
191	-	-	-	-	5.40	5.92
206	-	-	-	-	5.33	5.74
220	-	-	-	-	-	5.73

Table 6.7 **Tenacity** at Break Testing Results (cN.tex^{-1})

Nominal S Untwist	**39 tex**			**29 tex**		
(turns.m^{-1})	TF 32.3	TF 33.4	TF 39.5	TF 32.4	TF 34.9	TF 38.6
0	12.17	13.17	14.44	12.40	12.66	14.13
111	8.30	9.71	-	-	-	-
121	8.74	9.15	-	-	-	-
133	7.08	8.41	12.65	8.73	-	-
142	5.54	7.22	12.35	7.74	9.99	-
154	6.94	5.04	12.28	8.14	9.59	12.03
163	-	6.89	11.76	6.51	9.09	12.42
175	-	-	11.27	6.02	9.57	11.85
191	-	-	-	-	8.28	11.05
206	-	-	-	-	7.96	9.67
220	-	-	-	-	-	10.33

Table 6.8 Percentage (%) Reduction of Yarn **Elongation** at Break

Nominal S Untwist	**39 tex**			**29 tex**		
(turns.m^{-1})	TF 32.3	TF 33.4	TF 39.5	TF 32.4	TF 34.9	TF 38.6
111	22.2	19.7	-	-	-	-
121	19.5	18.5	-	-	-	-
133	27.0	24.7	17.2	21.0	-	-
142	32.4	25.1	20.2	24.3	10.8	-
154	28.4	39.2	18.0	26.5	13.4	17.2
163	-	25.8	16.9	28.1	12.0	11.9
175	-	-	20.7	30.7	13.7	14.1
191	-	-	-	-	22.1	21.8
206	-	-	-	-	23.1	24.2
220	-	-	-	-	-	24.3

Table 6.9 Percentage (%) Reduction of Yarn **Tenacity** at Break

Nominal S Untwist	**39 tex**			**29 tex**		
(turns.m^{-1})	TF 32.3	TF 33.4	TF 39.5	TF 32.4	TF 34.9	TF 38.6
111	31.8	26.3	-	-	-	-
121	28.2	30.5	-	-	-	-
133	41.8	36.1	12.4	29.6	-	-
142	54.5	45.2	14.5	37.6	21.1	-
154	43.0	61.7	15.0	34.4	24.2	14.9
163	-	47.7	18.6	47.5	28.2	12.1
175	-	-	22.0	51.5	24.4	16.1
191	-	-	-	-	34.6	21.8
206	-	-	-	-	37.1	31.6
220	-	-	-	-	-	26.9

Discussion: From the Table 6.6 it is clear that, as the S untwist increases, the elongation at break of the yarn reduces. Also, from Tables 6.7 and 6.9 it is clear that, as was expected, the tenacity of the yarn samples decreases as the untwist increases. This is in agreement with the results reported in the chapter 4 (§ 4.2.1.4).

6.3.1.5 *Hairiness*

The hairiness of the various yarn samples was measured on the Shirley Hairiness Tester. The results are presented in Table 6.10.

Table 6.10 **Hairiness** Testing Results (Hairs.m^{-1})

Nominal S Untwist	**39 tex**			**29 tex**		
(turns.m^{-1})	TF 32.3	TF 33.4	TF 39.5	TF 32.4	TF 34.9	TF 38.6
0	79.67	66.25	53.92	58.11	51.50	48.21
111	92.74	75.88	-	-	-	-
121	75.96	72.89	-	-	-	-
133	84.57	82.84	49.68	68.54	-	-
142	110.02	84.48	46.28	67.36	54.01	-
154	101.46	83.48	47.61	75.17	56.94	47.37
163	-	68.96	50.24	71.73	54.48	42.48
175	-	-	44.06	67.40	59.00	43.81
191	-	-	-	-	50.81	34.48
206	-	-	-	-	57.70	38.54
220	-	-	-	-	-	47.20

Discussion: For the samples with the lower twist factors for both the yarn counts, there was an increase in hairiness as the yarn samples became more untwisted. In contrast, for samples with higher twist factors, a decrease in the number of hairs became apparent. This could mean that above a certain twist factor the untwisting action opens the yarn structure, and many protruding fibres come closer to the yarn body or slide inside the yarn. To confirm this statement, further microscope examination of these yarns was necessary.

6.3.1.6 *Abrasion Resistance*

A special apparatus designed by Johari [151] was used for assessing the abrasion resistance of the various samples of processed yarns (see also Appendix II). The test results are presented in the Table 6.11.

Table 6.11 **Abrasion Resistance** Testing Results (Cycles)

Nominal S Untwist	39 tex			29 tex		
(turns.m^{-1})	TF 32.3	TF 33.4	TF 39.5	TF 32.4	TF 34.9	TF 38.6
111	83	116	-	-	-	-
121	84	104	-	-	-	-
133	63	79	200	68	-	-
142	47	70	221	83	104	-
154	57	64	208	41	119	218
163	-	54	173	46	91	210
175	-	-	155	55	88	200
191	-	-	-	-	86	149
206	-	-	-	-	61	149
220	-	-	-	-	-	79

Discussion: The strength tests showed that, as the yarn looses its twist, it becomes weaker. The yarn abrasion tests show a similar trend and as the S untwist increases, the yarn abrasion resistance reduces. Only a few abrasion cycles were needed to damage severely and finally break a yarn that has been substantially untwisted.

6.3.1.7 *Friction (Yarn on Metal Surface)*

The SDL 96 Shirley Electronic Friction Tester was used to determine the coefficient of friction of the yarn samples. The results are shown in Table 6.12.

Table 6.12 **Friction** Testing Results (μ)

Nominal S Untwist	39 tex			29 tex		
(turns.m^{-1})	TF 32.3	TF 33.4	TF 39.5	TF 32.4	TF 34.9	TF 38.6
0	0.268	0.264	0.262	0.252	0.289	0.260
111	0.272	0.266	-	-	-	-
121	0.266	0.259	-	-	-	-
133	0.261	0.255	0.250	0.251	-	-
142	0.263	0.282	0.270	0.267	0.272	-
154	0.268	0.280	0.270	0.252	0.272	0.258
163	-	0.258	0.262	0.283	0.268	0.267
175	-	-	0.259	0.266	0.262	0.267
191	-	-	-	-	0.264	0.250
206	-	-	-	-	0.254	0.251
220	-	-	-	-	-	0.258

Discussion: Due to the lack of any discernible trend in the friction testing coefficient, it is very difficult to reach any conclusions concerning any possible effect that the untwisting process might have on this frictional property of the yarns. However, it is important to notice that all values of the coefficient of friction were lower than 0.3 which is the recommended upper limit for knitting yarns [63].

6.3.2 FABRIC TESTING

6.3.2.1 *Spirality Angle*

The fabrics, that were knitted with take-down tension were left to relax for 24 hours under normal atmospheric conditions for testing. The spirality angle was measured for each of the fabrics. These results are coded in Table 6.13 as *BW* since there spiralities were measured *before washing* the fabrics. The fabric samples were then twice washed in a domestic washing machine (normal cycle for non-colourfast cotton fabrics; water temperature 40 °C). The spirality angles, after the second washing process, are recorded in Table 6.13 under the code *AW* (*after washing*). The percentage reduction in spirality angle is shown in Table 6.14.

Table 6.13 **Spirality Angle (°)**

Nominal S Untwist (turns.m^{-1})	**39 tex**						**29 tex**					
	TF 32.3		TF 33.4		TF 39.5		TF 32.4		TF 34.9		TF 38.6	
	BW	AW	BW	AW	BW	AW	BW	AW	BW	AW	BW	AW
0	9.5	8.0	11.0	16.0	11.0	16.0	12.5	11.5	14.5	17.0	16.5	18.0
111	2.0	5.0	2.0	4.5	-	-	-	-	-	-	-	-
121	9.0	8.0	12.0	11.5	-	-	-	-	-	-	-	-
133	0.0	6.5	2.0	5.0	3.5	7.5	2.0	3.0	-	-	-	-
142	-2.0	0.5	-1.0	0.5	1.0	2.0	0.0	1.5	0.0	2.5	-	-
154	1.0	2.0	0.5	1.5	0.0	3.0	0.0	0.5	1.0	3.0	4.0	6.0
163	-	-	0.0	0.0	2.0	0.0	0.0	0.0	-1.0	0.0	4.0	9.0
175	-	-	-	-	-3.0	2.5	-4.0	-1.0	3.0	2.0	-1.0	4.0
191	-	-	-	-	-	-	-	-	1.5	4.0	0.0	4.0
206	-	-	-	-	-	-	-	-	0.0	5.5	3.5	6.5
220	-	-	-	-	-	-	-	-	-	-	1.0	11.5

Note: The negative sign in front of some readings of spirality angle indicates that the fabric exhibited S spirality in these cases.

Table 6.14 Percentage (%) Reduction in **Spirality Angle** (After Washing)

Nominal S Untwist	**39 tex**			**29 tex**		
(turns.m^{-1})	TF 32.3	TF 33.4	TF 39.5	TF 32.4	TF 34.9	TF 38.6
111	37.5	71.9	-	-	-	-
121	5.2	28.1	-	-	-	-
133	18.8	68.8	53.1	73.9	-	-
142	93.8	96.9	87.5	87.0	85.3	-
154	75.0	90.6	81.3	95.7	82.4	66.7
163	-	100.0	100.0	100.0	100.0	50.0
175	-	-	84.4	108.7	88.2	77.8
191	-	-	-	-	76.5	77.8
206	-	-	-	-	67.6	63.9
220	-	-	-	-	-	36.1

Discussion: From Table 6.13 it is clear that, in many cases, the fabric samples had zero spirality angles both before and after washing. For fabrics produced from the yarn samples of TF 33.4, TF 39.5 (39 tex) and TF 32.4, TF 34.9 (29 tex), an untwist of 163 turns.m^{-1} (percentage reduction of 20.1%, 22.3%, 15.6%, 18.0% respectively) could be considered as the optimum.

6.3.2.2 *Thickness - Compression*

The Fast-01 fabric compression meter was used to measure the thickness of the fabric samples. Also to assess the compressibility of these fabrics, each fabric was tested twice: firstly with an applied pressure of 196 N.m^{-2} (Pa) on the testing head area and secondly with a pressure of 9.81 kN.m^{-2} (kPa) (see Appendix II). The fabric thicknesses are shown in Tables 6.15 and 6.16, and the compressibility is recorded in Table 6.17.

Table 6.15 **Fabric Thickness** Testing Results (mm); Fabrics Knitted from **39 tex** Yarns

NOMINAL S UNTWIST	TF 32.3		TF 33.4		TF 39.5	
(turns.m^{-1})	**196 N.m^{-2}**	**9.81 kN.m^{-2}**	**196 N.m^{-2}**	**9.81 kN.m^{-2}**	**196 N.m^{-2}**	**9.81 kN.m^{-2}**
0	1.295	0.753	1.286	0.713	1.292	0.765
111	1.245	0.717	1.344	0.755	-	-
121	1.288	0.722	1.311	0.738	-	-
133	1.284	0.716	1.194	0.706	1.297	0.721
142	1.260	0.711	1.253	0.707	1.312	0.738
154	1.276	0.748	1.226	0.692	1.213	0.724
163	-	-	1.327	0.715	1.342	0.728
175	-	-	-	-	1.294	0.706

Table 6.16 **Fabric Thickness** Testing Results (mm); Fabrics Knitted from **29 tex** Yarns

NOMINAL S UNTWIST	TF 32.4		TF 34.9		TF 38.6	
(turns.m^{-1})	**196 N.m^{-2}**	**9.81 kN.m^{-2}**	**196 N.m^{-2}**	**9.81 kN.m^{-2}**	**196 N.m^{-2}**	**9.81 kN.m^{-2}**
0	1.160	0.591	1.153	0.639	1.325	0.725
133	1.173	0.569	-	-	-	-
142	1.128	0.581	1.119	0.570	-	-
154	1.067	0.563	1.106	0.606	1.221	0.614
163	1.085	0.550	1.123	0.563	1.179	0.593
175	1.135	0.530	1.196	0.580	1.174	0.579
191	-	-	1.178	0.583	1.173	0.573
206	-	-	1.160	0.591	1.138	0.584
220	-	-	-	-	1.221	0.611

Table 6.17 **Fabric Compressibility** Testing Results (%)

Nominal S Untwist	**39 tex**			**29 tex**		
(turns.m^{-1})	TF 32.3	TF 33.4	TF 39.5	TF 32.4	TF 34.9	TF 38.6
0	41.9	44.6	49.1	49.1	44.6	45.3
111	42.4	43.8	-	-	-	-
121	43.9	43.7	-	-	-	-
133	44.2	40.9	44.4	51.5	-	-
142	43.6	43.6	43.8	48.5	49.1	-
154	41.4	44.5	40.3	47.2	45.2	49.7
163	-	46.1	45.8	49.3	49.9	49.7
175	-	-	45.4	53.3	51.5	50.7
191	-	-	-	-	50.5	51.2
206	-	-	-	-	49.1	48.7
220	-	-	-	-	-	50.0

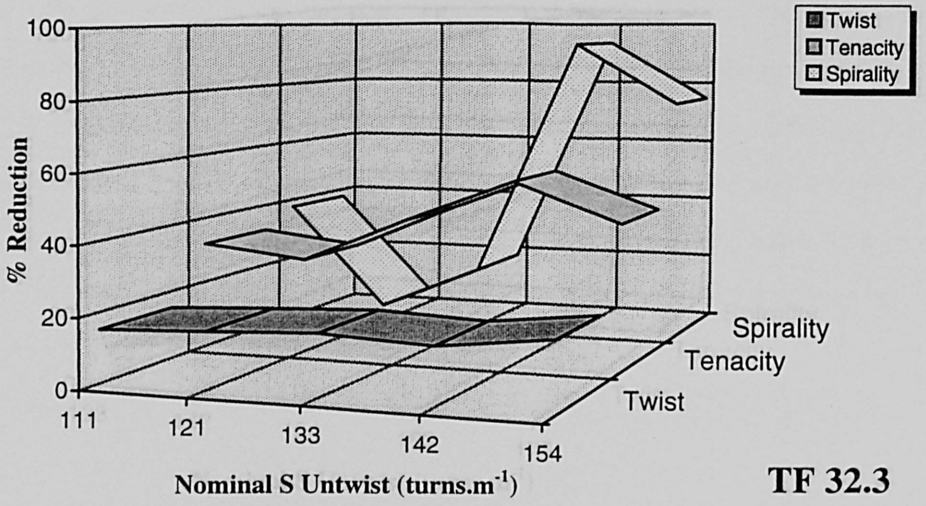
Discussion: From Tables 6.15 and 6.16, it seems that fabric thickness and fabric compressibility show no particular trend. This is in agreement with the findings of the same tests reported in chapter 4.

6.4 TWIST - TENACITY - SPIRALITY

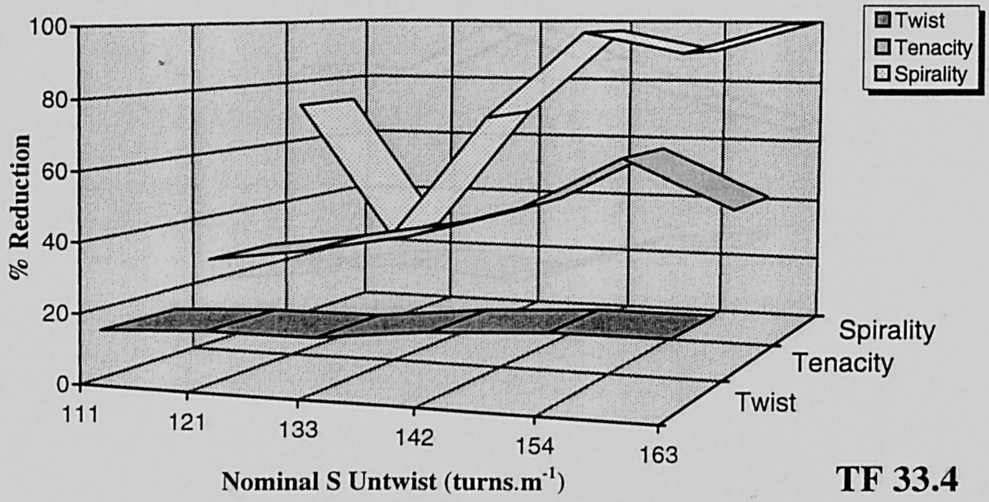
Table 6.18 summarises results obtained from testing for yarn twist and tenacity as well as fabric spirality after washing. Figures 6.1 and 6.2 are graphic presentations of the data of this table.

Table 6.18 Percentage (%) Reduction of **Twist, Tenacity** and **Spirality Angle**

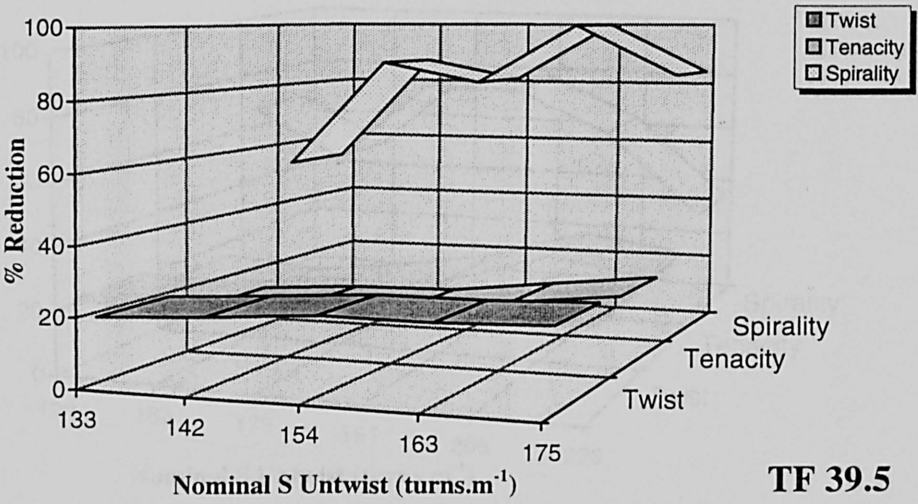
Nominal	**39 tex**									**29 tex**								
S Untwist	TF 32.3			TF 33.4			TF 39.5			TF 32.4			TF 34.9			TF 38.6		
(turns.m^{-1})	Twist	Tenac.	Spiral.	Twist	Tenac.	Spiral.	Twist	Tenac.	Spiral.	Twist	Tenac.	Spiral.	Twist	Tenac.	Spiral.	Twist	Tenac.	Spiral.
111	15.2	31.8	37.5	13.7	26.3	71.9	-	-	-	-	-	-	-	-	-	-	-	-
121	16.4	28.2	5.2	15.2	30.5	28.1	-	-	-	-	-	-	-	-	-	-	-	-
133	17.7	41.8	18.8	15.1	36.1	68.8	18.6	12.4	53.1	8.9	29.6	73.9	-	-	-	-	-	-
142	16.3	54.5	93.8	18.4	45.2	96.9	20.2	14.5	87.5	12.6	37.6	87.0	15.4	21.1	85.3	-	-	-
154	19.8	43.0	75.0	20.1	61.7	90.6	22.3	15.0	81.3	12.4	34.4	95.7	16.5	24.2	82.4	21.2	14.9	66.7
163	-	-	-	20.3	47.7	100.0	22.2	18.6	100.0	15.6	47.5	100.0	18.0	28.2	100.0	20.7	12.1	50.0
175	-	-	-	-	-	-	23.2	22.0	84.4	17.7	51.5	108.7	19.4	24.4	88.2	24.4	16.1	77.8
191	-	-	-	-	-	-	-	-	-	-	-	-	21.0	34.6	76.5	24.3	21.8	77.8
206	-	-	-	-	-	-	-	-	-	-	-	-	20.8	37.1	67.6	25.0	31.6	63.9
220	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	26.3	26.9	36.1



TF 32.3

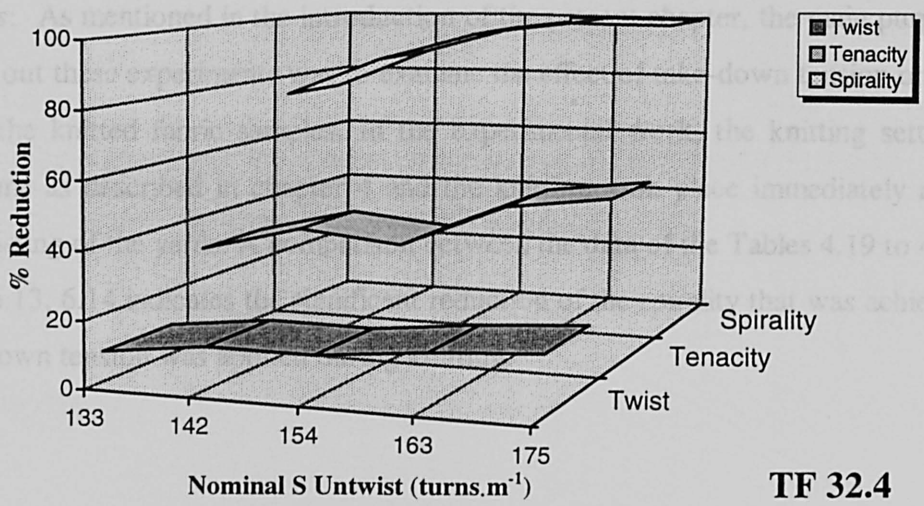


TF 33.4

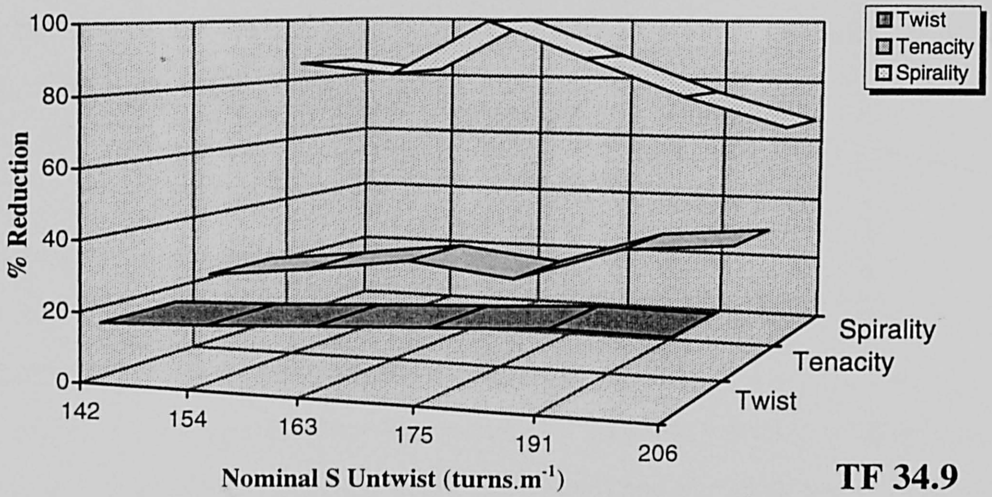


TF 39.5

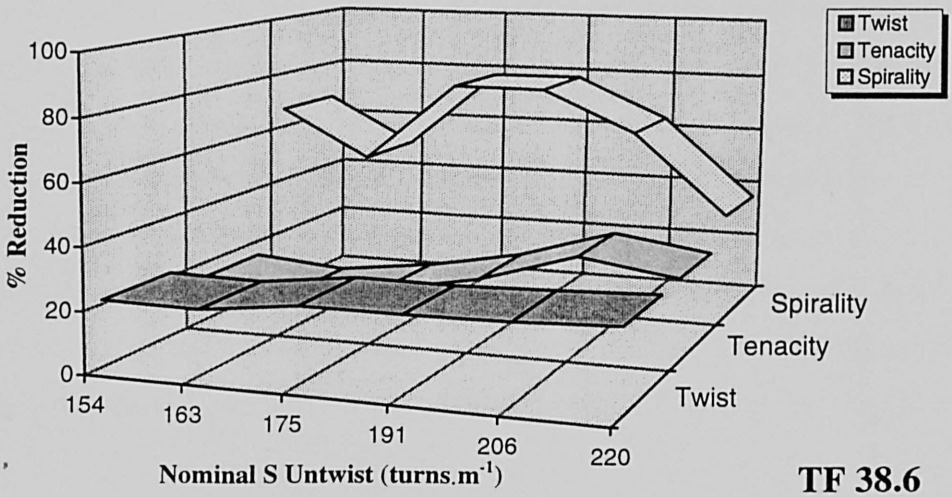
Fig. 6.1 Relation between Percentage Reduction of Twist, Tenacity and Spirality and the Nominal S Untwist (turns.m^{-1}) of Samples Knitted from **39 tex** Yarns



TF 32.4



TF 34.9



TF 38.6

Fig. 6.2 Relation between Percentage Reduction of Twist, Tenacity and Spirality and the Nominal S Untwist (turns.m^{-1}) of Samples Knitted from **29 tex** Yarns

Conclusions: As mentioned in the introduction of the present chapter, the main purpose for carrying out these experiments was to examine the effect of take-down tension on the spirality of the knitted fabric samples. In the experimental work, the knitting settings were the same as described in chapter 4 and the knitting took place immediately after partial untwisting of the yarns. A comparison between the data of the Tables 4.19 to 4.22 and Tables 6.13, 6.14 indicates the significant reduction of the spirality that was achieved when take-down tension was applied during knitting.

CHAPTER 7

EFFECT OF PARTIAL UNTWISTING ON THE YARN STRUCTURE - A THEORETICAL APPROACH

7.1 INTRODUCTION

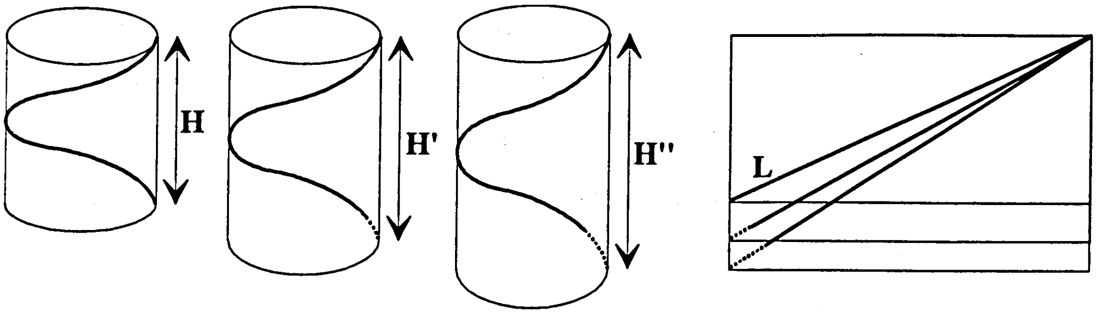
It is clear that changes in the yarn structure resulting from the partial untwisting will lead to the changes in yarn properties already described. In the present chapter, these alterations of yarn structure will be considered, theoretically, supported by a more detailed microscopic examination.

7.2 THEORY OF UNTWISTING YARNS

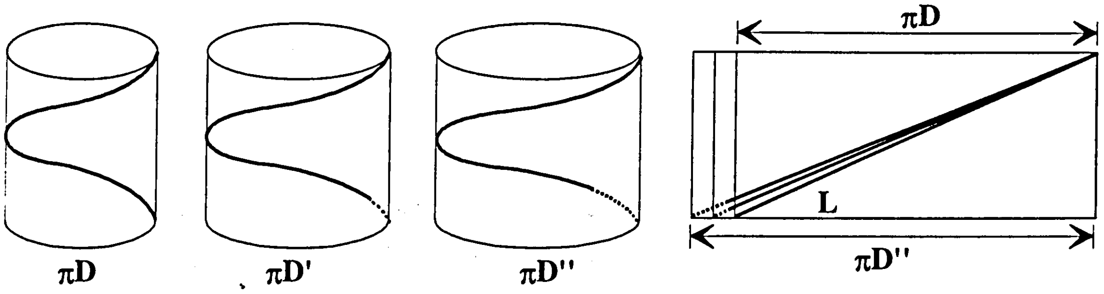
7.2.1 CONFIGURATION OF THE UNTWISTED YARN

In Figure 7.1, two possible configurations of a fibre in a yarn during untwisting are presented. It is assumed that the fibre length is constant and one fibre end is fixed on the upper end of the model yarn.

As twist is removed, the compressive and contractive forces generated during the twisting stage of yarn formation, are reduced, resulting in an increase in yarn length and diameter. Due to the tension applied in practice during the untwisting, there is an increase in length whereas the diameter is less affected. Later examination of fibre configuration shows that the core of the yarns remain more or less as compact as it was before untwisting, and it seems that it is mainly the outer yarn layers that are affected, - becoming more open. But whether the total yarn torque is affected by the torque and/or the bending of the inner-core fibres, or of the fibres laying in the outer yarn layers is still uncertain.



a. Untwisting with Longitudinal Tensile Load (Dynamic Condition)



b. Untwisting without any Tensile Load (Static Condition)

Fig. 7.1 Possible Configurations of the Fibres in the Yarn Structure According to the Condition of Untwisting (a. Constant Diameter b. Constant Yarn Length)

In Figure 7.2, possible torsional couples in an untwisted steamed yarn are illustrated. These couples are [152]:

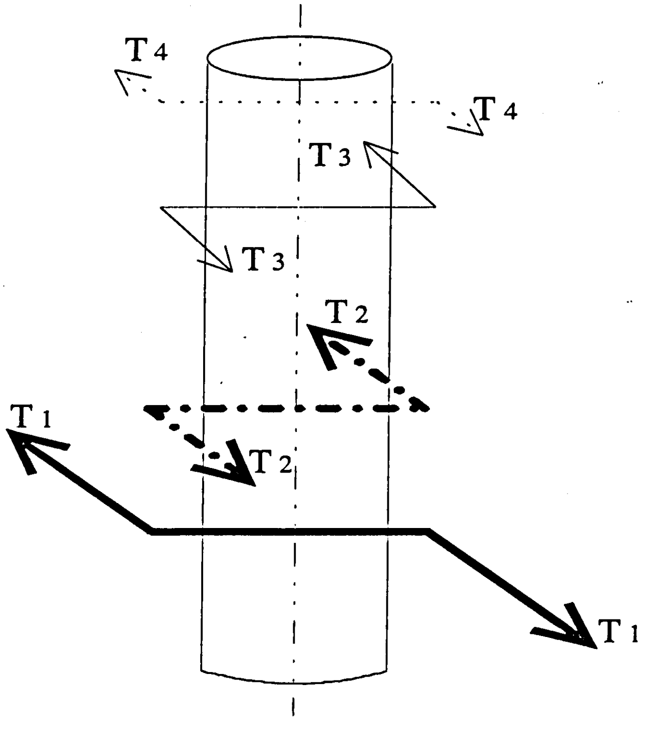


Fig. 7.2 Torsional Couples in a Processed Yarn

T_1 - The couple needed to twist the yarn. This will depend on the level of twist and the rate of twisting, but will also increase with tension.

T_2 - The internal torque in the yarn after twisting. This is due to the torsional and bending stresses in the fibres due to the twisting plus couples generated by components of the axial stresses in the fibres when the yarn is tensioned. Thus, T_2 is tension dependent. T_2 will decrease with time due to gradual relaxation of the torsional and bending stresses.

T_3 - The internal torque in the yarn after steaming. Hopefully, steaming will largely eliminate the torsional and bending stresses in the fibres. The tension - dependent torsion will remain, however.

T_4 - The couple needed to partially untwist the yarn. The direction and magnitude of this torque will depend on the twist level, rate of untwisting, tension.

T_5 - The internal torque in the yarn after partial untwisting. This will depend on all of the factors mentioned above: bending and twisting stresses in the fibres, yarn tension, level of twist, effectiveness of steam setting, relaxation time.

To measure the magnitudes of T_4 and T_5 the following experiment can be carried out:

A known length of relaxed Z-twisted yarn is mounted on Saad's torsional rigidity measuring apparatus [153]. A small amount of S-twist is inserted in the yarn, recording simultaneously the torque (T_4). Then the internal torque in the yarn after this partial untwisting (T_5) is left to reach the state of its minimum energy. The ratio T_4 / T_5 can be obtained leading to a possible correlation between initially inserted torque and final torque remaining in the yarn. Furthermore, the ratio between the initially inserted twist and the partially removed twist can be calculated.

It has been stated that the yarn torque may be redeveloped by applying a tensile stress to a twisted singles yarn which otherwise would not exhibit any residual torque or rotation tendencies [154-156]. Thus, as the yarn is partially untwisted on the two-for-one twisting frame, the tension of winding releases some previously latent torque. Also the yarn is subjected to more tension during knitting [157] as it passes from its package through guides, tensioning devices, and finally round the knitting elements (needles). It therefore requires an increased tension to pull it over these successive contact surfaces.

From the main experimental work it was found that the partially untwisted yarns showed a higher coefficient of friction also leading to higher tensions. Thus, the redevelopment of the *internal torque in the yarn after steaming* (T_3) due to these tensions, reduces the magnitude of the torsional energy of the *internal torque in the yarn after partial untwisting* (T_5).

It could, therefore, be said that when a partially untwisted short staple Z-twisted yarn is knitted in a single jersey fabric, the exhibited S spirality, before any dry or wet relaxation of the fabric, is the result of the torsional energy of *the couple needed to partially untwist the yarn* (T_4) reduced by the torsional energy of the redeveloped torque due to tensions of the winding and knitting operations. In other words,

$$E_f = E_u - (E_w + E_k)$$

where,

E_f = the net torsional energy in the yarn being in the loop configuration of the knitted structure before relaxation,

E_u = the torsional energy of the couple needed to partially untwist the yarn,

E_w = the torsional energy redeveloped due to tension of the winding process, and

E_k = the torsional energy regenerated by the yarn friction on the knitting machine.

Young [158] examining the effect of untwisting a worsted yarn - by carrying out an experiment where a Z-twisted yarn was untwisted to a nominal zero twist and then retwisted with S twist (following the untwist-twist testing principle) - reached the conclusion that "the fibres are forced into a new configuration, but because their positions have been determined by the original pattern of migration, they cannot release all their tension by migration or slippage". Steinberger [159] claims that "the torque released in a given type of yarn does not depend in a very sensitive manner upon the naturally occurring yarn variations but upon the amount of torsional energy initially put into it, diminished by the dissipation of the potential energy of internal strain as a function of the slow readjustment in the dry conditions or the rapid readjustment in the steaming and in the blow-off".

Although Pittman [160] has introduced a theory concerning the torsional energy stored in a yarn, Hearle [161] describing a set of mathematical expressions interrelating four yarn parameters, namely, tension, extension, torque and twist, concluded that these expressions could not be applied directly in cases such as untwisting "where the geometrical relations change".

7.3 FIBRE MIGRATION

7.3.1 CONCEPT OF FIBRE MIGRATION

In order to study the effect of the untwisting process on the yarn structure, it is desirable to have some knowledge of the position of the fibres in the yarn.

In theoretical studies of a simple yarn structure, the usual practice is to assume that an ideal singles yarn consists of a core fibre surrounded by coaxial cylindrical layers of other fibres, each individual fibre forming a helix of constant radius and constant pitch [162].

Realising that yarns withstand surface abrasion, Peirce [125] suggested that such an idealised short staple yarn could not exist, but that "fibres appearing on the surface of a yarn have their ends tucked inside".

Morton [162] and Morton and Yen [163] stated that, fibres twisted round the longer path at the yarn surface would be at a higher tension, forcing fibres of lower tension to be displaced and follow shorter paths closer to the yarn axis (core). They argued that "the tight fibres would attempt to ease themselves of their strain by gradually working their way into the core, while the slack *core fibres* would move towards the surface" [163]. This interchange would be continuous, leading to an indefinite cyclic migration. With short staple yarns some fibres follow one of the longer paths in the outer zones of the yarn structure, and cease to be "effective competitors" for a more comfortable "core" position. Such fibres are characterised as "projecting fibres" [163].

It has been stated [164] that any fibre migration occurring in a yarn will ultimately be reflected in the properties of the fabric. The knowledge of factors, that induce and affect a biased fibre distribution in a yarn, constitutes a large part of the information required for the prediction of the structure and properties of the yarn as well the effect on the resultant fabric in the finishing processes.

In chapter 3 it was shown that a partial untwisting of a yarn reduced the spirality in the resultant fabric sometimes even producing negative spirality. Furthermore, washing and drying the fabric produced a modification of the fabric structure which resulted in minimum spirality. It has been stated by Riding [165] that the migration intensity of the yarn is determined by the spinning twist and is not affected by any other variables or subsequent processes. It was therefore decided to examine the possible changes in fibre migration which occur during untwisting.

7.3.2 METHOD OF EXAMINING FIBRE MIGRATION

7.3.2.1 *The Tracer Fibre Technique*

Morton and Summers [166] developed the tracer fibre technique that incorporates the principle of "optical dissolution" [167] in their study of the fibre arrangement in Fibro sliver. Later on, Morton and Yen [163] used the same technique in the study of fibre migration in Fibro yarns.

7.1.2.2 *Brief Description of the Technique*

In applying this technique, a small proportion (which varies among 0.02% by weight for slivers and laps to 1.00 % by weight for yarns [168]) of black dyed tracer fibres is introduced in the carding stage, with the remaining of undyed material. The resultant end-product (sliver, roving or yarn) is then immersed in a liquid medium having the same or substantially the same refractive index (see Appendix VII) as that of the fibres concerned. When the yarn is then examined under a low power microscope, the uncoloured fibres almost disappear from view leaving the path of each tracer coloured fibre to be clearly discerned. The tracer is seen against the faint background of the yarn body as a wavy line representing the projection in one plane of a helix [162]. To show up the yarn boundaries sufficiently clearly, a small proportion of liquid of different refractive index can be added to the main liquid [163]. In the particular case where Fibro fibres were examined, the main liquid medium was methyl salicilate and a small proportion of bromobenzene was added to show up the yarn boundaries. The mixture of liquids with different refractive indices is used mainly for photographic purposes. By means of a micrometer eyepiece, the location of the tracer with respect to the upper and lower yarn boundaries can be observed as peaks and troughs of successive waves, the intervals between which are noted on the vernier scale of the traversing stage.

7.3.2.3 *Behaviour of the Fibre Migration*

The chief features of the migration behaviour are usually characterised by the following parameters [21, 169, 170]:

a) ***Mean fibre position.*** This represents the overall tendency of a fibre to be near the surface or near the centre of a yarn.

It can be calculated from the formula:

$$\bar{Y} = \frac{1}{z}\int_0^z Y dz = \frac{\sum Y}{n} \tag{7.1}$$

where $Y = \left(\frac{r}{R}\right)^2$ r = helix radius, R = yarn radius, z = length along the yarn, and n = number of observations.

b) ***Amplitude of Migration.*** The magnitude of the deviations from the mean position and is represented by the *Root Mean Square Deviation (r.m.s.)*

r.m.s. deviation:

$$D = \left[\frac{1}{z}\int_0^z (Y-\bar{Y})^2 dz\right]^{1/2} = \left[\frac{\sum(Y-\bar{Y})^2}{n}\right]^{1/2} \tag{7.2}$$

For an incomplete migration in which $(r/R)^2$ varies linearly with Z, it is shown [169] that the amplitude of migration is given by $A=D\sqrt{3}$ and the mean radial traverse is $P=2A=2D\sqrt{3}$.

c) ***Rate of Migration.*** The rate of change of radial position. For this , the *Mean Migration Intensity* is used :

$$I = \left[\frac{1}{z}\int_0^z \left(\frac{dY}{dz}\right)^2 dz\right]^{1/2} = \left[\sum\left(\frac{dY}{dz}\right)^2 \Big/ n\right]^{1/2} \tag{7.3}$$

d) ***Migration Frequency.*** It has been suggested [140] that the most interesting point in the migratory behaviour of a fibre is the frequency with which reversals in the direction of migration take place. The most satisfactory quantity to characterise the rate of reversal is considered to be the "*Mean Migration Period*". For a partial migration, the migration period is given by $z = \frac{2P}{I} = 4\sqrt{3}\,D/I$ and migration frequency $= I/4\sqrt{3}D$.

7.3.2.4 *Methods for Assessing Fibre Migration*

A typical configuration of a tracer fibre observed under microscope is shown in Figure 7.3.

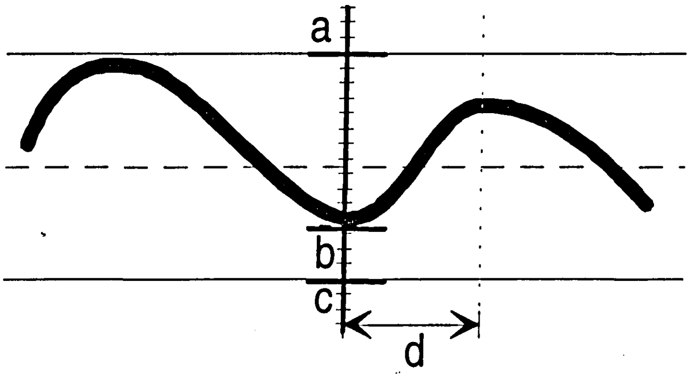


Fig. 7.3 Measured Distances in a Yarn Containing Tracer Fibre

Morton and Yen [163] made measurements at successive peaks and troughs of the tracer image. Each peak and trough was in turn brought to register with the hair line of a micrometer eyepiece and scale readings were taken at *a*, *b*, and *c*.

The diameter of the yarn in scale units was then given by *c-a*, while the offset of the trough (or peak as the case might be) from the yarn axis was given by $b - \frac{a+c}{2}$. In addition, the distance between adjacent troughs and peaks, marked as *d*, as well as the overall extent of the tracer was obtained. With this method it was possible to make drawings of the paths followed by the tracers in the horizontal plane.

In order to avoid effects due to change in the yarn diameter, Gupta [171] expressed the radial position of the fibres in terms of the ration r/R:

$$\frac{r}{R} = \frac{\left(\frac{a+c}{2}\right) - b}{\left(\frac{a-c}{2}\right)} \qquad (7.4)$$

A plot of r/R against length along the yarn shows the cylindrical envelope of varying radius around which the fibre is following a helical path.

Since the path followed by a fibre in the yarn is actually in three dimensions, it can only be fully established if observations are made in more than one direction. Riding [165] achieved this by viewing the fibre from two directions at right angles by placing a plane mirror near the yarn in the liquid with the plane of the mirror at 45° to the direction of observation (Figure 7.4). By measuring the distances of the fibre from the yarn axis by the x and y co-ordinates, which are at right angles to each other for the two images as seen from the microscope, and the corresponding diameters dx and dy, he reached the following equation for fibre radial position:

$$\frac{r}{R} = 2\left[(x/dx)^2 + (y/dy)^2\right]^{1/2} \qquad (7.5)$$

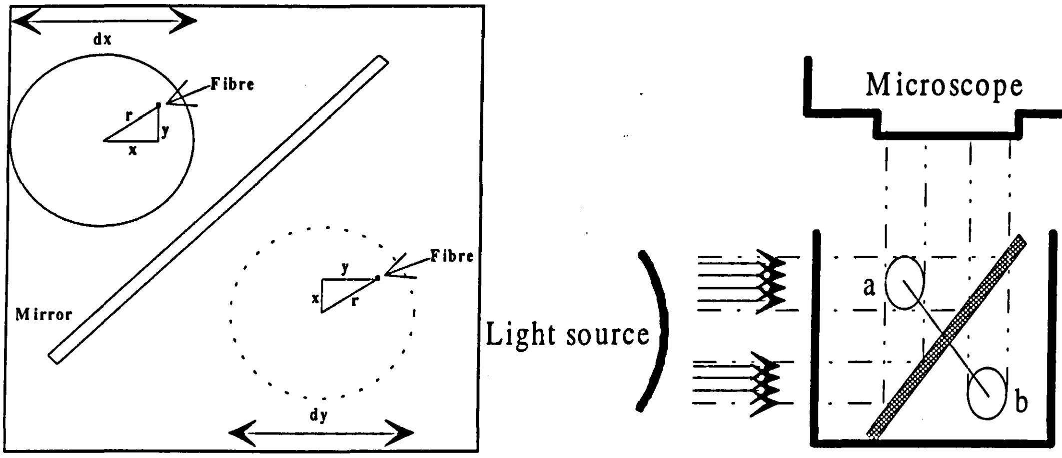


Fig. 7.4 Modified Technique for Observing Two Orthogonal Projections of a Yarn (by Riding [165]) (a = yarn, b = image)

Hearle and Gupta [170] moved a step further by taking into account the problem of asymmetry in the yarn cross section reaching the equation:

$$\frac{r}{R} = \frac{1}{2}\left(r_1/R_1 + r_2/R_2\right) \quad \text{at} \quad z = 1/2\,(z_1+z_2) \qquad (7.6)$$

where r_1,r_2 are the helix radii (crest, trough) and R_1,R_2 the yarn radii at positions z_1, z_2 along the yarn.

Hearle *et al* [172] suggested that the fibre migration in the yarns results from a combination of two mechanisms: one dependent on tension variation that results from the displacement of buckled fibres, and the other, termed "geometrical mechanism", that concerns the geometry of ribbon twisting. The former predominates to give a rapid migration while the latter, depending on the initial twist, gives rise to a slower migration. In ring spinning of staple fibres, because of the presence of roving twist, a fibre is likely to "be situated at an angle to the direction of motion before its emergence from the front roller to the twisting zone" [173]. As a consequence, part of the fibre may enter the high-tension zone, while the rest of it remains in the low-tension zone. This would allow the former part to migrate towards the core and the latter to the outer sheath resulting in the development of "long term migration" in the final yarn. It is probable that the geometric mechanism is not so important [174], although it might be caused to play a significant part as a means of controlling the yarn structure and properties.

7.3.3 EXPERIMENTAL WORK

"The combination of the high double refraction of cotton fibres and the presence of convolutions leads in any case to comparatively poor transparency but, in addition, there is great difficulty in obtaining completely effective wetting-out of the specimen by the dispersion liquid when the fibres are twisted together" [163]. Due to these problems, it was decided to carry out an experiment using rayon fibres.

The tracer fibres were from the same rayon material and dyed with a direct dyestuff. The proportion of the tracer fibres in the yarns was calculated and found to be 0.3% (see Appendix VII).

7.3.3.1 *Yarn Production*

Two Z-twisted *normal* yarn samples with linear density 34 tex were produced from rayon roving containing 0.3% black tracer fibres. The first *normal* sample was highly twisted to 917 turns.m^{-1} and was used for the production of two *processed* yarn samples, being partially untwisted by nominal twist of 220 turns.m^{-1} and 234 turns.m^{-1} in the S direction, respectively. The second *normal* yarn sample was produced with a twist level of 714 turns.m^{-1}. The nominal net twist of the *processed* samples was approximately 700 turns.m^{-1}. Thus, a comparison between yarns having similar net twist levels could be made.

A fabric sample was knitted from each of the four yarns, i.e., two normal yarns and two processed yarns and the spirality angle was measured. The yarn specifications as well as the spirality angle of the fabrics are presented in the Table 7.1.

Table 7.1 Specifications of the Rayon Yarn Samples Containing Tracer Fibres

Sample Code	Actual Twist		Linear Density	Tenacity		Spirality (°)	
turns.m^{-1}	turns.m^{-1}	CV%	tex	cN.tex^{-1}	CV%	BW	AW
917	917	2.9	34.1	13.0	7.3	20	14
917-220	684	5.2	34.7	13.9	9.1	-1	5
917-234	665	4.7	34.7	12.9	10.1	-6	0
714	714	3.6	33.9	14.4	9.3	17	18

BW : Before Washing *AW : After Washing*

7.3.3.2 *Observation of the Tracer Fibre Migration*

In order to study the structure of the processed, partially untwisted yarn, a cross-sectional view of the yarn along its length would have been appropriate. Although this was achieved by previous workers (Riding [165]), the lack of similar equipment led the present author to find another method for observing a 3-dimensional view of the tracer fibre.

7.3.3.3 *New Method for the Observation of the Tracer Fibres*

In order to observe the radial position of the fibres, each yarn specimen under test was led through a glass trough filled with ethyl salicilate having a refractive index of 1.550. The trough was mounted on the stage of a “Projectina” projection microscope (Plates 7.1 and 7.2). The yarn placed in the path of illumination, appeared bright due to its optical anisotropy with the dark tracer following a helical path. The image of a fibre

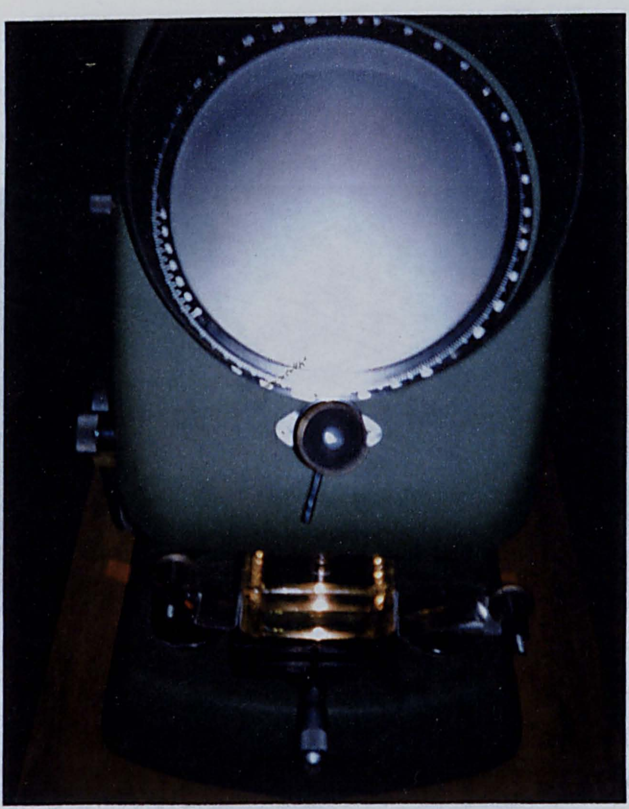


Plate 7.1 Projectina Microscope

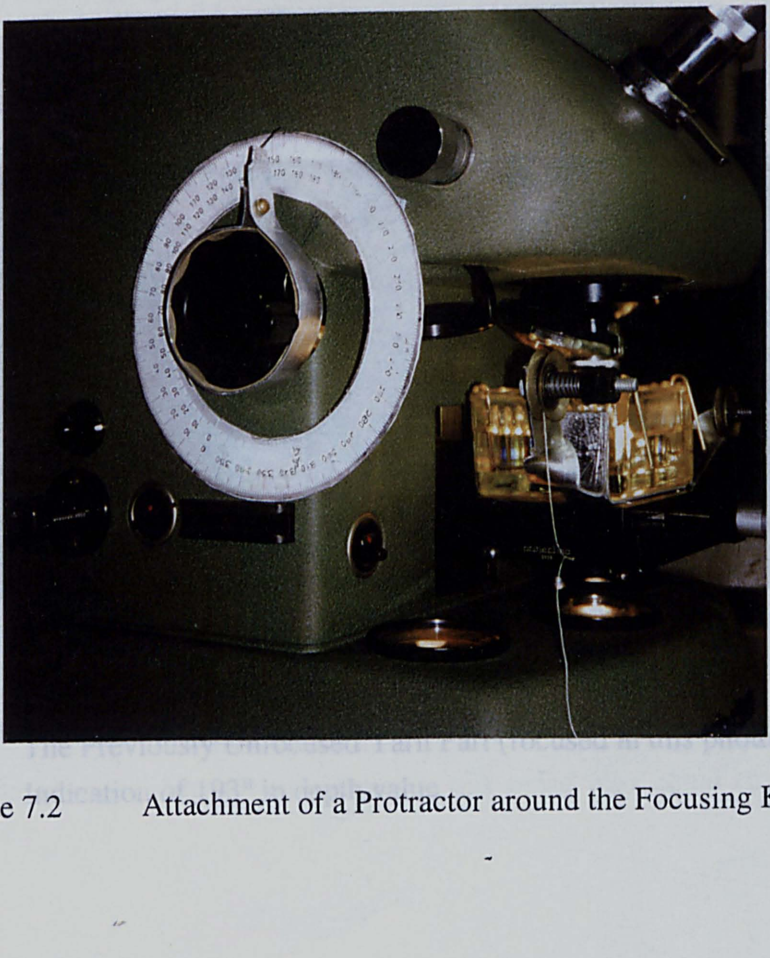


Plate 7.2 Attachment of a Protractor around the Focusing Knob

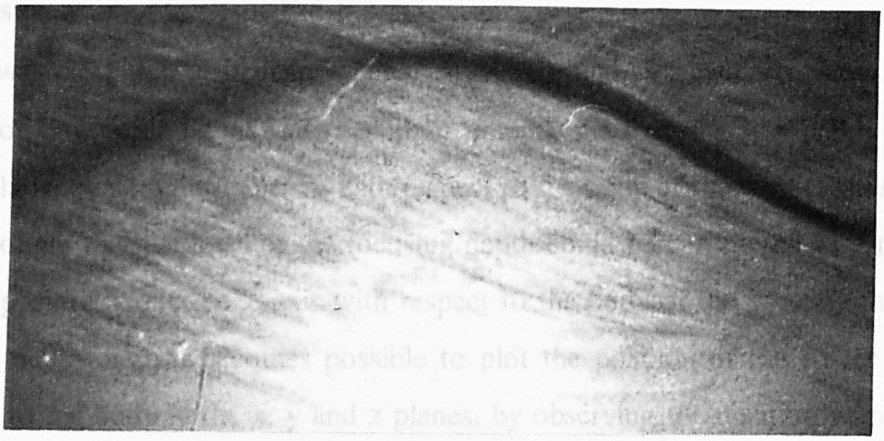


Plate 7.3 The Focused Part of the Yarn had an Indication of 149° in depth value

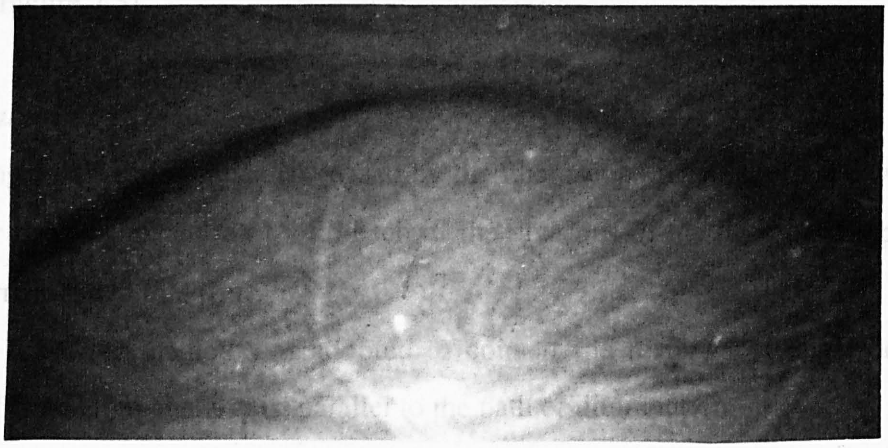


Plate 7.4 The Previously Unfocused Yarn Part (focused in this photograph) had an Indication of 193° in depth value

could be observed by the traverse movement of the stage. The "bottom line" of the yarn was always adjusted to match with reference horizontal hair line of the projection screen. A special device was designed in order to keep all the tested yarn samples under the same tension.

It was clear that at high magnification (× 40), and consequently when only small sections of yarn could be viewed (maximum 1 mm), the focusing was highly dependent on the relative position of the fibre with respect to the body of the yarn (Plates 7.3, 7.4). It was thought that the level of the focusing depth could be considered as a measure of the fibre position along the Z-axis with respect to the body of the yarn. With a suitable reference depth, it then becomes possible to plot the position of the tracer fibre with reference to the body in the x, y and z planes, by observing the position with regard to both the screen co-ordinates and the rotary position of the focusing knob. This rotary position was determined by noting the angle differences on a protractor fixed in relation to the focusing mechanism (Plate 7.4). Thus, the obtained data such as the *length of the yarn* ℓ between the chosen examined points, the *horizontal diameter* **D** *of the yarn* at each of these points, the *distance* f of the tracer fibre from one side of the yarn (viewed image) as well as the *distance* f' of the tracer fibre from one side of the yarn (along the viewing direction) obtained from angle readings of focusing depth, could provide sufficient information for plotting the 3-dimensional configuration of the tracer fibre in the yarn (Figure 7.5).

7.3.3.4 *Calibration*

Using a calibration guide (provided by the microscope manufacturer) it was found that under the magnification of ×40, each of the divisions of the lines on the projection screen corresponded to 8 μm.

The following method was adopted to convert the readings of angle degrees to position of fibre along the Z axis, parallel to the path of illumination.

It was assumed that [175], at each of the measured points along the tested yarn length, the horizontal and the vertical diameters of the yarn are equal. Also it was assumed that the difference between the minimum and maximum values in depth represented the value of the vertical diameter, this being also equal to the horizontal

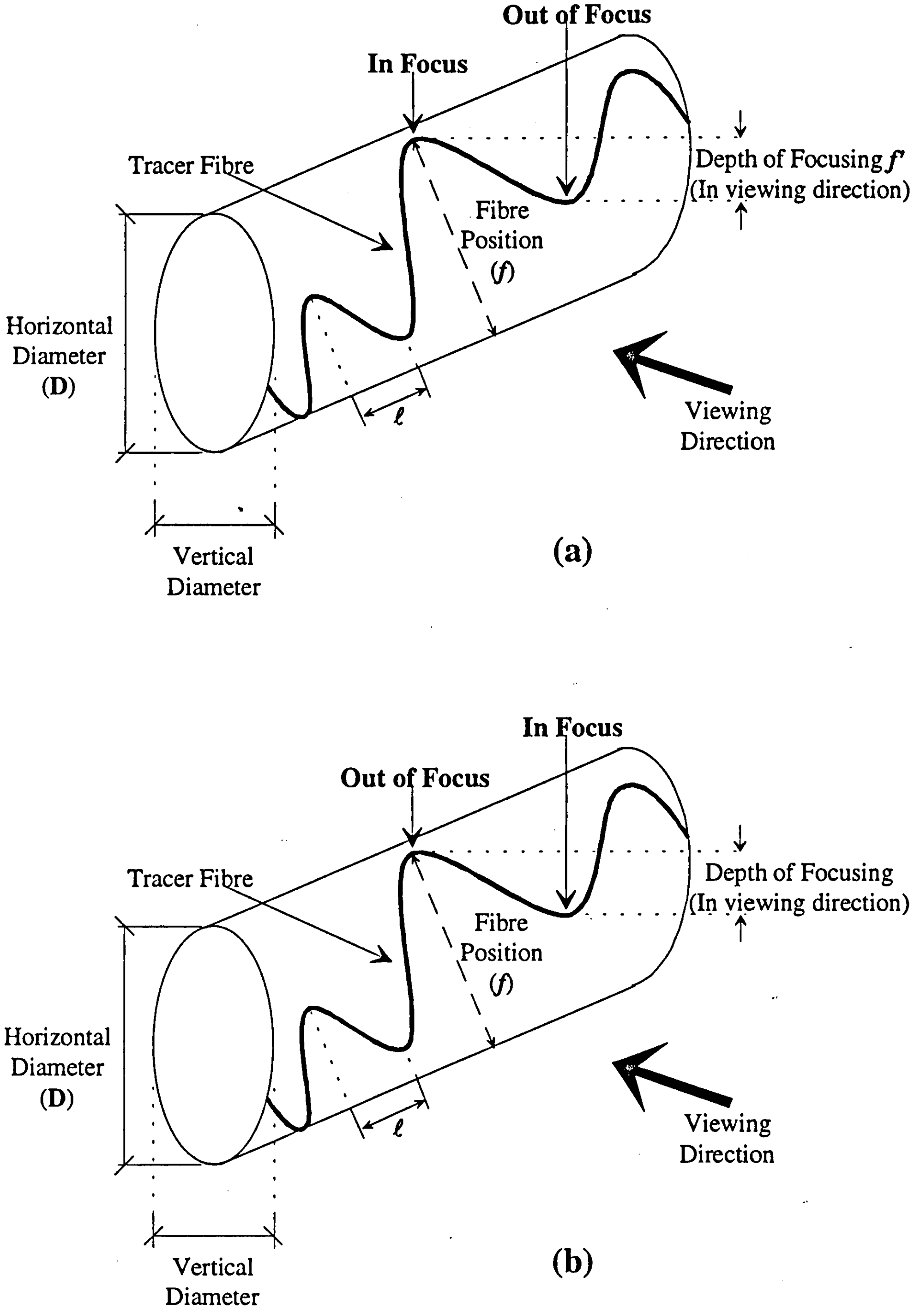


Figure 7.5 Graphic Presentation of a Yarn Containing a Tracer Fibre

diameter, which was that point of the yarn where the highest value of depth was measured. A calibration factor κ for converting the degrees (°) into millimetres (mm) could then be calculated. For example,

$$0.27\ mm = 203\kappa\ mm - 110\kappa\ mm \Rightarrow \kappa = 0.0029$$

After examining a number of 60 tracer fibres, measuring approximately 20 parts on each fibre (see appendix VII), it was found that the most suitable value for the calibration factor κ should be 0.00248 having a coefficient of variation 16.28%.

For each tracer fibre, the location of the individual fibre points and the distance from the outer yarn surface that was closer to the objective lens, were calculated at the end of the test by multiplying the absolute difference between the overall minimum recorded value of depth and the depth value of that point, with the conversion constant 0.00248.

In an experiment, the horizontal yarn diameter was 0.23 mm measured in that part of the yarn where the maximum depth value (224°) was noted. The minimum value of depth was 109°. Therefore, for the Plate 7.3, the focused part of the tracer fibre with the indication of 149° was located at $|109° - 149°| \times 0.00248 = 0.01$ mm from the front surface of the yarn (closer to the objective lens), whereas for the Plate 7.4, the focused part of the tracer fibre was located at $|109° - 193°| \times 0.00248 = 0.21$ mm from the front surface of the yarn. It must be noted that the bigger the indication in degrees of depth, the closer to the objective lens the yarn is being brought, focusing its back side.

In some individual determinations, the tracer fibre's vertical diameter was found to be greater than the corresponding horizontal diameter (see Tables 7.3-7.5). However, this was considered acceptable for two reasons: firstly the calibration factor for converting the degrees into millimetres had a great coefficient of variation (C.V.) and, secondly, the hairy regions of the yarns had not been taken into account when the horizontal diameter was determined. In such cases, part of a tracer fibre could be outside the main body of the yarn. Although in such cases it may have seemed that the calibration factor was in error, the small number of determinations for which this occurred (73 from the 1224 tested parts of the 60 individual fibres (6%)) confirmed the good estimation of this factor.

7.3.3.5 *Experimental Work*

As this measurement of tracer fibre migration was very time consuming and tedious, examination of only 5 mm lengths of yarn was considered as practicable when using the magnification of ×40.

With very hairy yarn specimens, the yarn boundaries were not distinctly defined and the value D had to be estimated roughly. Measurements were taken on the peaks, troughs and in randomly chosen places between them. The point where the measurements started was also chosen randomly. The parts close to the ends of the tracer fibres or the ends themselves were avoided.

Fifteen determinations were made examining different tracer fibres from each of the four yarn samples.

Plates 7.5 and 7.6 present the appearance of each of the four tested yarn samples on the screen of the Projectina microscope, under different magnifications.

7.3.3.6 *Calculation*

Difficulties can arise due to yarn irregularity along its length, deviations from a circular cross-section and the asymmetry of the axis of twisting found in real (spun) yarns. For the examination of the migration behaviour of such yarns, Hearle *et al* [169] derived suitable formulae to avoid these problems. The same formulae were also used for the present experimental work.

Tracer fibre measurements were expressed in terms of equation 7.4. For convenience, in each measurement, the "bottom line" of the yarn was brought to match with the horizontal hair line of the projector. In this way, $\boldsymbol{c}$ was always zero (0) and $\boldsymbol{a}$ was the actual measured horizontal diameter at this point of the yarn (see Figure 7.3). Expression 7.4 therefore became:

$$\frac{r}{R}=\frac{D/2-f}{D/2} \tag{7.7}$$

where $\boldsymbol{D}$ the horizontal yarn diameter and f the indication of the position of the tracer fibre taken on the vertical hair line of the projection screen.

For the Mean Fibre Position expression 7.1 was used, whereas the amplitude of migration (Root Mean Square Deviation r.m.s.) was calculated from expression 7.2.

The mean Migration Intensity was calculated from a modified form of formula 7.3

$$I = \left[\frac{\sum \left(\frac{Y_1 - Y_2}{l_1} \right)^2}{n} \right]^{\frac{1}{2}} \tag{7.8}$$

where l_1 was the distance between the adjacent indications Y_1, Y_2.

The expression $$\frac{I}{4D\sqrt{3}} \tag{7.9}$$

indicates the migration frequency.

7.3.3.7 *Results - Discussion*

The mean values of each of the calculated factors for every group of the tested yarn samples are summarised in Table 7.2.

Table 7.2 Results of the Tracer Fibre Migration Experiment

Sample Code turns.m^{-1}	**T.F.** turns.cm^{-1} .tex$^{1/2}$	**Diameter**		**Fib. Position**		**r.m.s. Dev.**		**Intensity (I)**		**Frequency**	
		Horiz. (mm)	Vertical (mm)	mean	CV%	mean	CV%	mean	CV%	mean	CV%
917	5.6	0.21	0.212	0.2483	19.4	0.2817	15.4	2.1187	21.0	1.0821	11.7
917-220	4.2	0.21	0.223	0.2606	22.0	0.2694	22.0	1.8096	30.9	0.9595	14.5
917-234	4.1	0.22	0.226	0.2425	29.3	0.2466	22.8	1.5934	29.6	0.9340	16.0
714	4.3	0.23	0.226	0.2448	24.6	0.2303	22.9	1.4201	26.4	0.8886	10.7

It can observed that the mean fibre position and the r.m.s. deviation are only very slightly affected by the partial untwisting. This observation agrees with experimental results presented by Hearle and Gupta [170], who pointed out that a mean fibre position which falls below the value of 0.3 indicates a uniform density of packing of fibres in the yarn. This indicates that the density is greater near the centre of the yarn. This is noticeable in all the yarn samples except the processed "917-220 turns.m^{-1}" yarn which shows a change in the packing density in the centre of the yarn. The r.m.s. deviation is less than the value of 0.29, which would result from complete ideal migration. It is evident therefore that in the yarn "917 turns.m^{-1}" the migration appeared to be near to ideal.

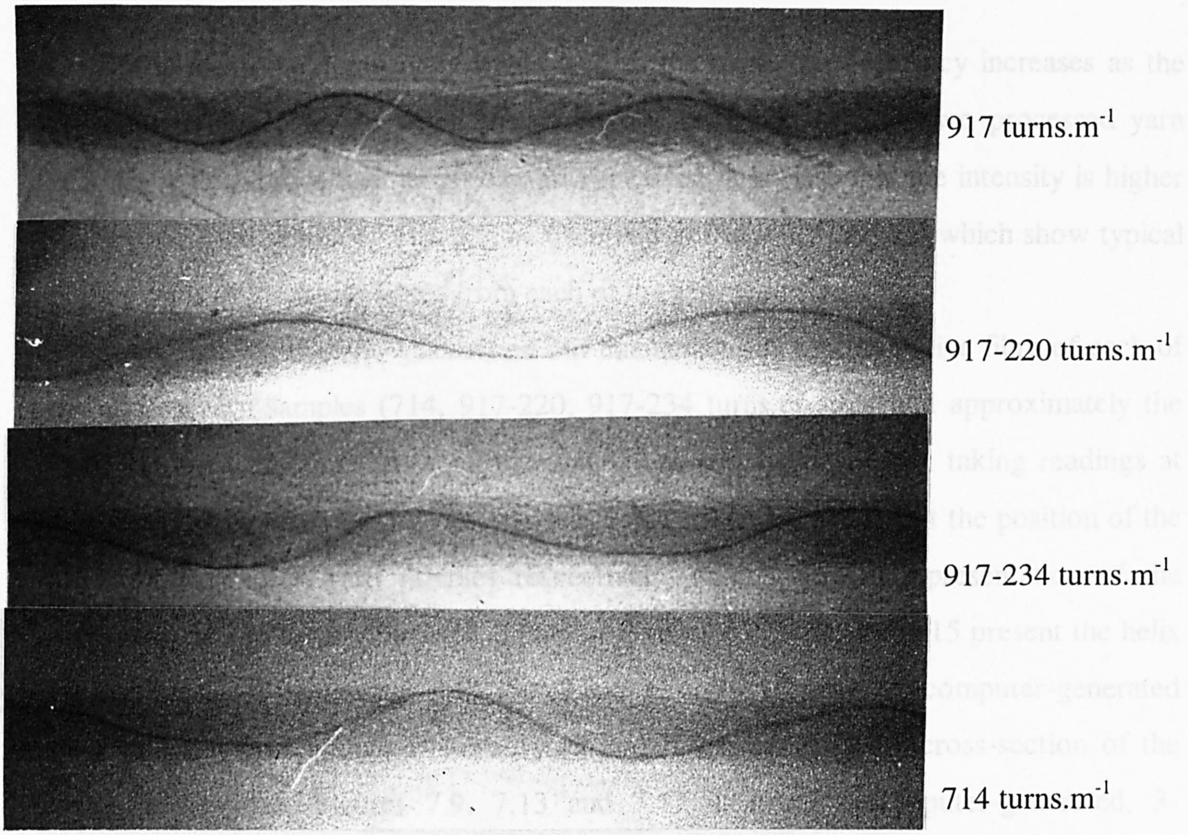


Plate 7.5 Tracer Fibres of the Four Yarn Samples (magnification×7)

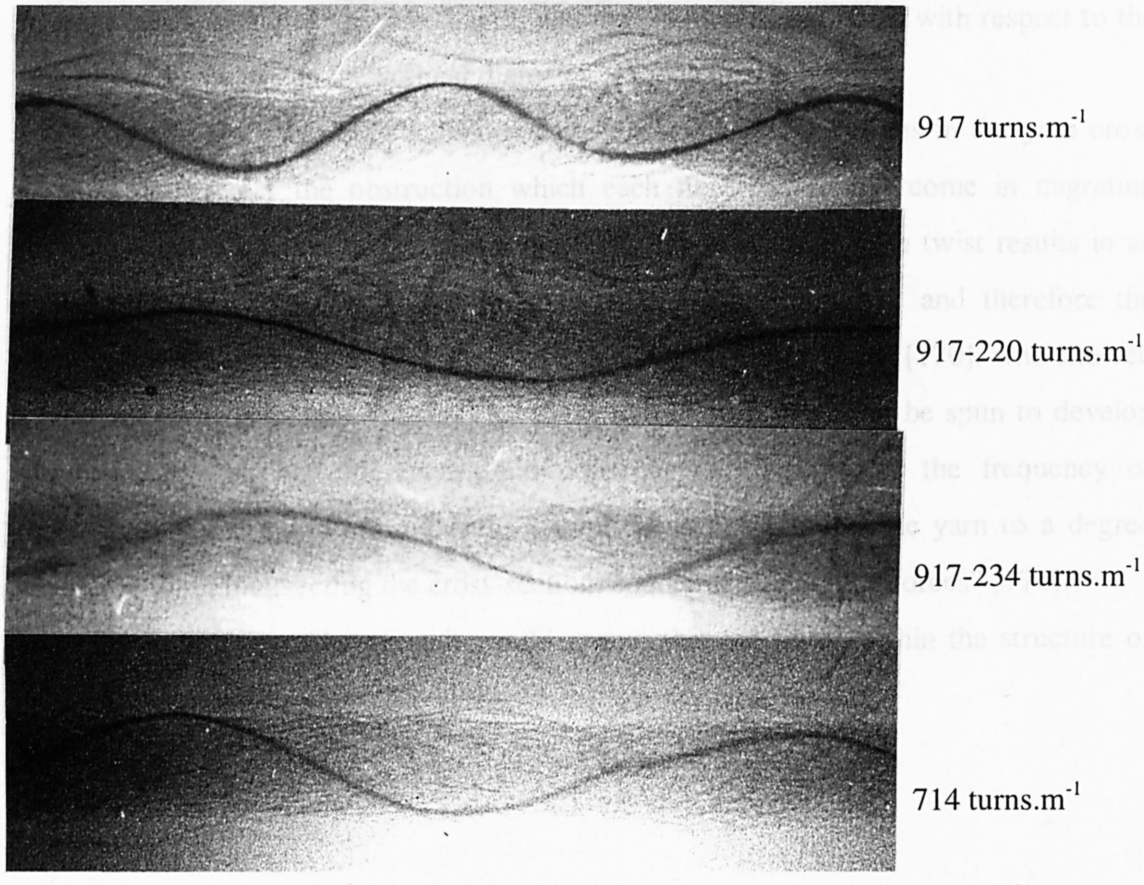


Plate 7.6 Tracer Fibres of the Four Yarn Samples (magnification ×10)

The mean migration intensity as well as the migration frequency increases as the twist factor increases but when comparison is made between the two processed yarn samples with unprocessed yarns of equivalent twist, it is clear that the intensity is higher in the processed samples. This can be observed in Plates 7.5 and 7.6 which show typical photographs of the tracer fibres from each of the four yarn samples.

Another experiment was carried out examining one representative fibre of each of the chosen yarn samples (714, 917-220, 917-234 turns.m^{-1})that had approximately the same net twist amount. The total examined yarn length was 5 mm, taking readings at intervals of 0.1 mm along the yarn. Figures 7.6, 7.10 and 7.14 present the position of the tracer fibre of each yarn samples respectively, with a parallel representation of the irregularity of the *horizontal yarn diameter*. Figures 7.7, 7.11, and 7.15 present the helix envelope of these yarn samples. Figures 7.8, 7.12 and 7.16 show the computer-generated shape of each fibre along the tested yarn length viewed from the cross-section of the yarn. Furthermore, Figures 7.9, 7.13 and 7.17 illustrate a computer-generated, 3-dimensional representation of the examined length of each tracer fibre in the structure of a yarn based on data of the yarn length, and the position of the fibres with respect to the horizontal diameter and the vertical diameter of the yarns.

Morton [162] has stated that "the greater the number of fibres in the yarn cross section, the greater the obstruction which each fibre has to overcome in migrating through a given fraction of the yarn radius". An increase in the yarn twist results in an increase of the forces acting on the fibre in the radial direction, and therefore the migration increases rapidly. This was confirmed by Hearle and Gupta [170], who showed that as the twist increases, "the shorter the length of yarn that must be spun to develop the necessary tension differences, and consequently, the greater the frequency of reversals. The migration effect increases until the twist compacts the yarn to a degree where the fibre, intersecting the cross-section, counteracts the radial forces" [176].

From these considerations it would appear that the fibres within the structure of the partially untwisted ring-spun yarns were at a lower tension.

Table 7.3 Normal Yarn 714 turns.m^{-1} (Measurements every 0.1 mm of the Yarn Length)

No	Diam×40 Indication	Fibre×40 Indication	Length Yn mm	Diameter mm	Fibre Pos. mm	Distance l mm	Depth (°)	Depth (mm)	r/R	Y	(Y_1-Y_2)	$(Y\text{-Mean }Y)^2$	$((Y_1-Y_2)/l)^2$
1	3.0	1.8	0.0	0.240	0.144		209	0.0000	-0.2000	0.0400		0.0261	
2	3.0	2.1	0.1	0.240	0.168	0.1	237	0.0694	-0.4000	0.1600	0.1200	0.0017	1.4400
3	2.9	2.3	0.2	0.232	0.184	0.1	250	0.1017	-0.5862	0.3436	0.1836	0.0202	3.3723
4	2.8	2.4	0.3	0.224	0.192	0.1	257	0.1190	-0.7143	0.5102	0.1666	0.0953	2.7744
5	2.8	2.3	0.4	0.224	0.184	0.1	289	0.1984	-0.6429	0.4133	0.0969	0.0448	0.9397
6	2.7	1.9	0.5	0.216	0.152	0.1	304	0.2356	-0.4074	0.1660	0.2473	0.0013	6.1150
7	2.8	1.6	0.6	0.224	0.128	0.1	295	0.2133	-0.1429	0.0204	0.1456	0.0328	2.1191
8	2.7	1.1	0.7	0.216	0.088	0.1	290	0.2009	0.1852	0.0343	0.0139	0.0280	0.0193
9	2.7	0.9	0.8	0.216	0.072	0.1	308	0.2455	0.3333	0.1111	0.0768	0.0082	0.5901
10	2.6	0.6	0.9	0.208	0.048	0.1	310	0.2802	0.5385	0.2899	0.1788	0.0078	3.1980
11	2.5	0.4	1.0	0.200	0.032	0.1	285	0.2182	0.6800	0.4624	0.1725	0.0681	2.9742
12	2.8	0.6	1.1	0.224	0.048	0.1	278	0.2009	0.5714	0.3265	0.1359	0.0156	1.8460
13	2.8	1.0	1.2	0.224	0.080	0.1	243	0.1141	0.2857	0.0816	0.2449	0.0144	5.9975
14	2.7	0.9	1.3	0.216	0.072	0.1	234	0.0918	0.3333	0.1111	0.0295	0.0082	0.0869
15	2.8	1.6	1.4	0.224	0.128	0.1	231	0.0843	-0.1429	0.0204	0.0907	0.0328	0.8227
16	2.8	2.2	1.5	0.224	0.176	0.1	242	0.1116	-0.5714	0.3265	0.3061	0.0156	9.3711
17	3.0	2.5	1.6	0.240	0.200	0.1	255	0.1438	-0.6667	0.4444	0.1179	0.0590	1.3904
18	2.9	2.3	1.7	0.232	0.184	0.1	279	0.2034	-0.5862	0.3436	0.1008	0.0202	1.0162
19	2.8	2.2	1.8	0.224	0.176	0.1	287	0.2232	-0.5714	0.3265	0.0171	0.0156	0.0293
20	2.6	1.9	1.9	0.208	0.152	0.1	296	0.2455	-0.4615	0.2130	0.1135	0.0001	1.2885
21	2.5	1.8	2.0	0.200	0.144	0.1	308	0.2753	-0.4400	0.1936	0.0194	0.0001	0.0377
22	2.5	1.7	2.1	0.200	0.136	0.1	308	0.2753	-0.3600	0.1296	0.0640	0.0052	0.4096
23	2.5	1.3	2.2	0.200	0.104	0.1	298	0.2505	-0.0400	0.0016	0.1280	0.0400	1.6384
24	2.8	0.9	2.3	0.224	0.072	0.1	308	0.2753	0.3571	0.1276	0.1260	0.0055	1.5864
25	2.9	0.5	2.4	0.232	0.040	0.1	303	0.2629	0.6552	0.4293	0.3017	0.0519	9.1023
26	2.8	0.4	2.5	0.224	0.032	0.1	319	0.3026	0.7143	0.5102	0.0810	0.0953	0.6553
27	2.8	0.5	2.6	0.224	0.040	0.1	290	0.2306	0.6429	0.4133	0.0969	0.0448	0.9397
28	2.9	0.8	2.7	0.232	0.064	0.1	279	0.2034	0.4483	0.2010	0.2123	0.0000	4.5077
29	2.8	1.2	2.8	0.224	0.096	0.1	274	0.1910	0.1429	0.0204	0.1805	0.0328	3.2596
30	2.8	1.4	2.9	0.224	0.112	0.1	276	0.1959	0.0000	0.0000	0.0204	0.0406	0.0416
31	2.9	1.8	3.0	0.232	0.144	0.1	282	0.2108	-0.2414	0.0583	0.0583	0.0205	0.3395
32	3.0	2.2	3.1	0.240	0.176	0.1	293	0.2381	-0.4667	0.2178	0.1595	0.0003	2.5445
33	3.0	2.3	3.2	0.240	0.184	0.1	300	0.2554	-0.5333	0.2844	0.0667	0.0069	0.4444
34	3.0	2.3	3.3	0.240	0.184	0.1	312	0.2852	-0.5333	0.2844	0.0000	0.0069	0.0000
35	3.0	2.2	3.4	0.240	0.176	0.1	324	0.3150	-0.4667	0.2178	0.0667	0.0003	0.4444
36	2.7	1.7	3.5	0.216	0.136	0.1	326	0.3199	-0.2593	0.0672	0.1506	0.0180	2.2669
37	2.6	1.4	3.6	0.208	0.112	0.1	311	0.2827	-0.0769	0.0059	0.0613	0.0383	0.3757
38	2.6	1.2	3.7	0.208	0.096	0.1	313	0.2877	0.0769	0.0059	0.0000	0.0383	0.0000
39	2.9	1.1	3.8	0.232	0.088	0.1	300	0.2554	0.2414	0.0583	0.0523	0.0205	0.2740
40	2.8	0.9	3.9	0.224	0.072	0.1	304	0.2654	0.3571	0.1276	0.0693	0.0055	0.4801
41	2.8	1.0	4.0	0.224	0.080	0.1	284	0.2158	0.2857	0.0816	0.0459	0.0144	0.2108
42	2.8	1.1	4.1	0.224	0.088	0.1	285	0.2182	0.2143	0.0459	0.0357	0.0242	0.1276
43	2.9	1.4	4.2	0.232	0.112	0.1	282	0.2108	0.0345	0.0012	0.0447	0.0401	0.2001
44	3.0	2.0	4.3	0.240	0.160	0.1	284	0.2158	-0.3333	0.1111	0.1099	0.0082	1.2083
45	3.0	2.4	4.4	0.240	0.192	0.1	295	0.2430	-0.6000	0.3600	0.2489	0.0251	6.1946
46	3.0	2.5	4.5	0.240	0.200	0.1	307	0.2728	-0.6667	0.4444	0.0844	0.0590	0.7131
47	3.0	2.5	4.6	0.240	0.200	0.1	318	0.3001	-0.6667	0.4444	0.0000	0.0590	0.0000
48	2.9	2.3	4.7	0.232	0.184	0.1	337	0.3472	-0.5862	0.3436	0.1008	0.0202	1.0162
49	2.9	1.8	4.8	0.232	0.144	0.1	342	0.3596	-0.2414	0.0583	0.2854	0.0205	8.1439
50	2.7	1.1	4.9	0.216	0.088	0.1	344	0.3646	0.1852	0.0343	0.0240	0.0280	0.0575
51	2.8	0.7	5.0	0.224	0.056	0.1	332	0.3348	0.5000	0.2500	0.2157	0.0024	4.6529
		Mean Diameter		0.225		Minimum	209	0.0000			Mean	0.0253	
						Maximum	344	0.3646			r.m.s.	0.1589	
								Mean Fibre Position		0.2015		Mean	1.9453
	Migration Frequency		1.2666								Rate (I) of Migration		1.3947

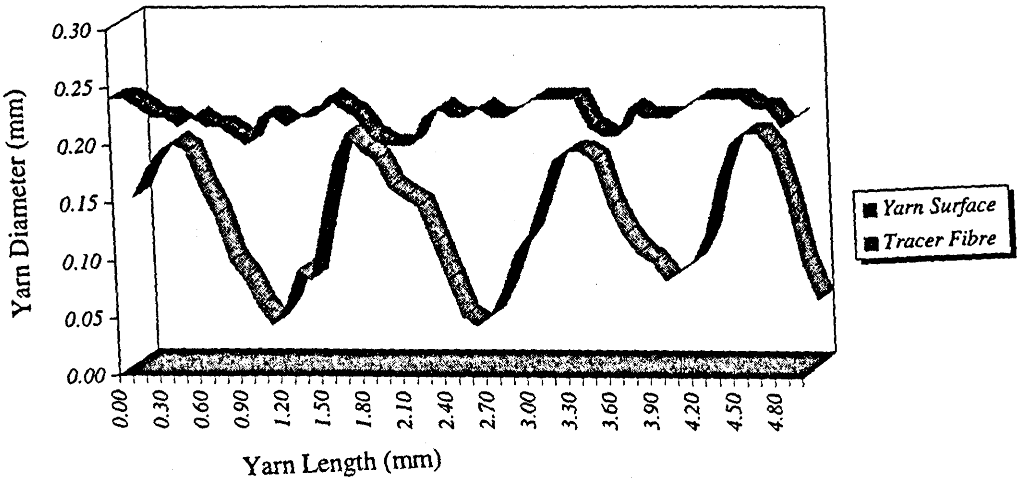


Fig. 7.6 2-Dimensional Representation of a Tracer Fibre in the Normal Yarn 714 turns.m^{-1}

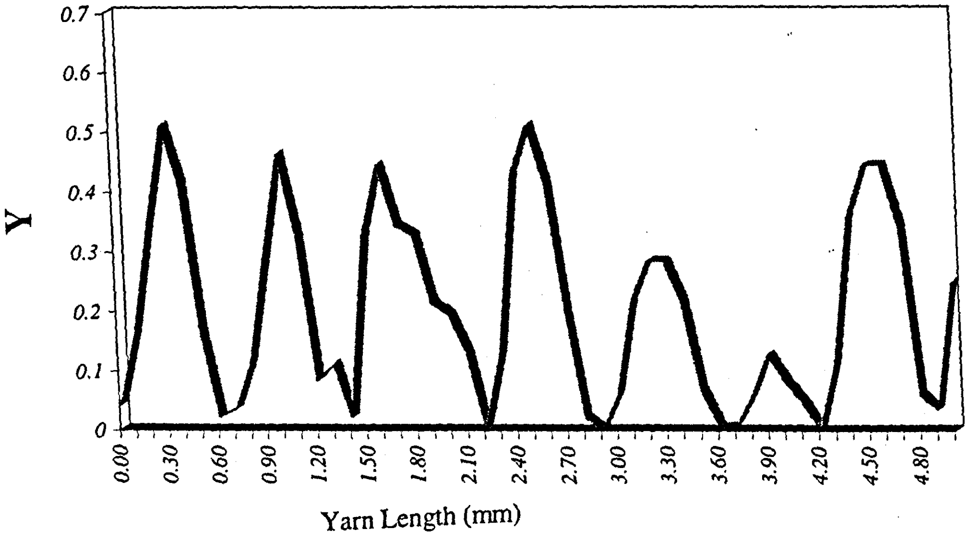


Fig. 7.7 Helix Envelope of Normal Yarn 714 turns.m^{-1}

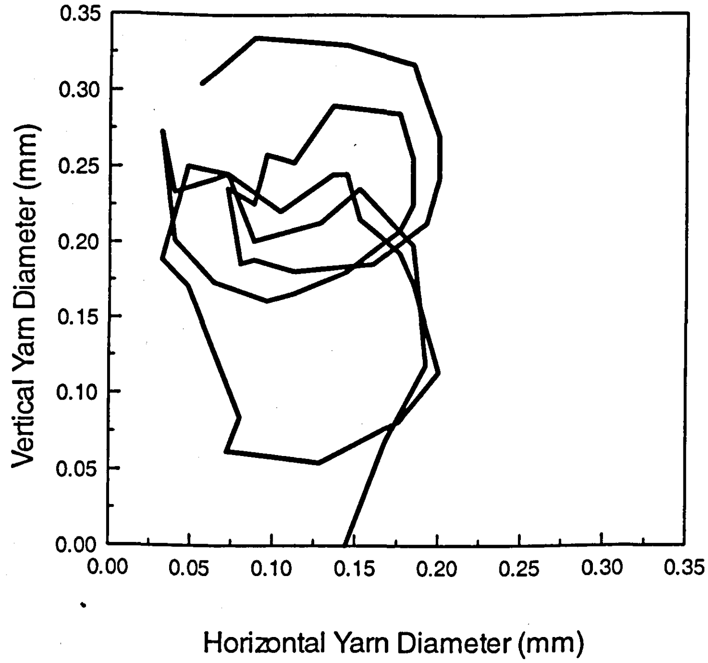


Fig. 7.8 Configuration of a Tracer Fibre in Normal Yarn 714 turns.m^{-1}, Viewed from the Cross-Section, Along the Yarn

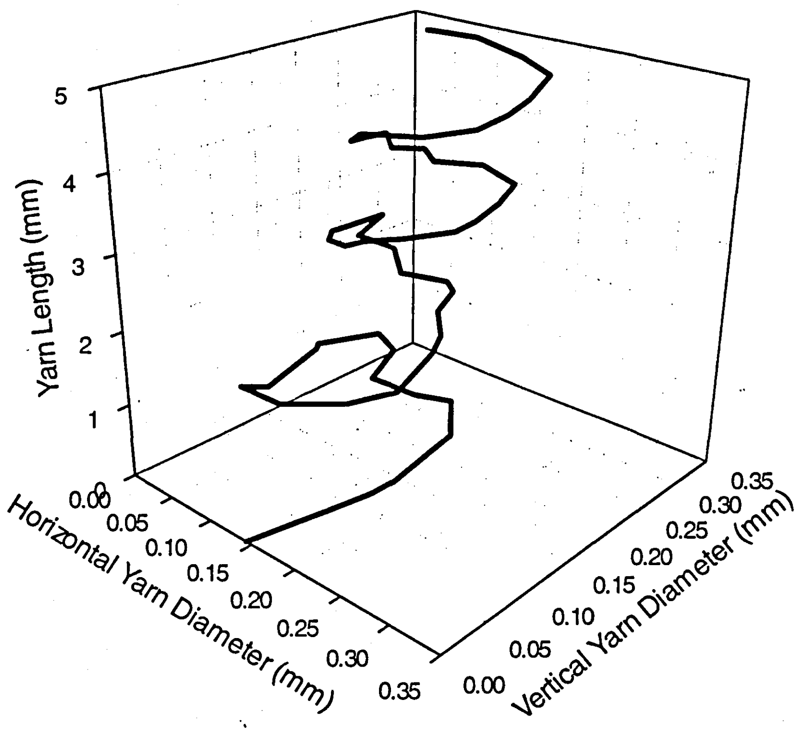


Fig. 7.9 3-Dimensional Configuration of a Tracer Fibre in Normal Yarn 714 turns.m^{-1} (Computer Generated)

Table 7.4 Processed Yarn 917-220 turns.m^{-1} (Measurements every 0.1 mm of the Yarn Length)

No	Diam×40	Fibre×40	Length Yn	Diameter	Fibre Pos.	Distance l	Depth (°)	Depth (mm)	r/R	Y	(Y_1-Y_2)	$(Y-\text{Mean } Y)^2$	$((Y_1-Y_2)/l)^2$
	Indication	Indication	mm	mm	mm	mm							
1	3.0	1.7	0.0	0.240	0.136		197	0.0000	-0.1333	0.0178		0.0465	
2	3.0	2.0	0.1	0.240	0.160	0.1	205	0.0198	-0.3333	0.1111	0.0933	0.0150	0.8711
3	2.9	2.3	0.2	0.232	0.184	0.1	216	0.0471	-0.5862	0.3436	0.2325	0.0122	5.4069
4	2.9	2.4	0.3	0.232	0.192	0.1	235	0.0942	-0.6552	0.4293	0.0856	0.0384	0.7329
5	3.0	2.4	0.4	0.240	0.192	0.1	245	0.1190	-0.6000	0.3600	0.0693	0.0160	0.4796
6	3.2	2.3	0.5	0.256	0.184	0.1	249	0.1290	-0.4375	0.1914	0.1686	0.0018	2.8424
7	3.4	2.2	0.6	0.272	0.176	0.1	258	0.1513	-0.2941	0.0865	0.1049	0.0216	1.1004
8	3.3	1.8	0.7	0.264	0.144	0.1	255	0.1438	-0.0909	0.0083	0.0782	0.0507	0.6122
9	3.3	1.5	0.8	0.264	0.120	0.1	253	0.1389	0.0909	0.0083	0.0000	0.0507	0.0000
10	3.1	0.9	0.9	0.248	0.072	0.1	257	0.1488	0.4194	0.1759	0.1676	0.0033	2.8088
11	3.0	0.5	1.0	0.240	0.040	0.1	239	0.1910	0.6667	0.4444	0.2686	0.0445	7.2138
12	2.9	0.3	1.1	0.232	0.024	0.1	233	0.1761	0.7931	0.6290	0.1846	0.1565	3.4066
13	2.9	0.3	1.2	0.232	0.024	0.1	221	0.1463	0.7931	0.6290	0.0000	0.1565	0.0000
14	3.0	0.6	1.3	0.240	0.048	0.1	209	0.1166	0.6000	0.3600	0.2690	0.0160	7.2368
15	2.9	1.0	1.4	0.232	0.080	0.1	205	0.1066	0.3103	0.0963	0.2637	0.0188	6.9530
16	3.0	1.5	1.5	0.240	0.120	0.1	212	0.1240	0.0000	0.0000	0.0963	0.0545	0.9276
17	2.9	1.9	1.6	0.232	0.152	0.1	213	0.1587	-0.3103	0.0963	0.0963	0.0188	0.9276
18	3.0	2.3	1.7	0.240	0.184	0.1	226	0.2331	-0.5333	0.2844	0.1881	0.0026	3.5393
19	3.0	2.4	1.8	0.240	0.192	0.1	239	0.3026	-0.6000	0.3600	0.0756	0.0160	0.5709
20	2.9	2.5	1.9	0.232	0.200	0.1	250	0.3298	-0.7241	0.5244	0.1644	0.0847	2.7019
21	3.0	2.7	2.0	0.240	0.216	0.1	259	0.3522	-0.8000	0.6400	0.1156	0.1653	1.3369
22	3.1	2.6	2.1	0.248	0.208	0.1	280	0.4042	-0.6774	0.4589	0.1811	0.0508	3.2798
23	3.0	2.3	2.2	0.240	0.184	0.1	278	0.3993	-0.5333	0.2844	0.1745	0.0026	3.0434
24	3.0	2.0	2.3	0.240	0.160	0.1	277	0.3968	-0.3333	0.1111	0.1733	0.0150	3.0044
25	2.9	1.5	2.4	0.232	0.120	0.1	280	0.4042	-0.0345	0.0012	0.1099	0.0539	1.2083
26	2.8	1.2	2.5	0.224	0.096	0.1	274	0.3894	0.1429	0.0204	0.0192	0.0454	0.0369
27	3.0	1.0	2.6	0.240	0.080	0.1	263	0.3621	0.3333	0.1111	0.0907	0.0150	0.8227
28	3.0	0.7	2.7	0.240	0.056	0.1	259	0.3522	0.5333	0.2844	0.1733	0.0026	3.0044
29	3.0	0.6	2.8	0.240	0.048	0.1	247	0.3224	0.6000	0.3600	0.0756	0.0160	0.5709
30	2.9	0.5	2.9	0.232	0.040	0.1	243	0.3125	0.6552	0.4293	0.0693	0.0384	0.4796
31	2.8	0.7	3.0	0.224	0.056	0.1	233	0.2877	0.5000	0.2500	0.1793	0.0003	3.2131
32	2.9	0.9	3.1	0.232	0.072	0.1	225	0.2678	0.3793	0.1439	0.1061	0.0080	1.1262
33	3.0	1.3	3.2	0.240	0.104	0.1	224	0.2654	0.1333	0.0178	0.1261	0.0465	1.5901
34	3.0	1.6	3.3	0.240	0.128	0.1	224	0.2654	-0.0667	0.0044	0.0133	0.0524	0.0178
35	3.1	2.0	3.4	0.248	0.160	0.1	235	0.2926	-0.2903	0.0843	0.0798	0.0222	0.6375
36	3.3	2.3	3.5	0.264	0.184	0.1	245	0.3174	-0.3939	0.1552	0.0709	0.0061	0.5027
37	3.0	2.7	3.6	0.240	0.216	0.1	257	0.3472	-0.8000	0.6400	0.4848	0.1653	23.5042
38	2.9	2.2	3.7	0.232	0.176	0.1	273	0.3869	-0.5172	0.2675	0.3725	0.0012	13.8727
39	2.8	2.0	3.8	0.224	0.160	0.1	287	0.4216	-0.4286	0.1837	0.0839	0.0025	0.7033
40	2.8	1.7	3.9	0.224	0.136	0.1	300	0.4538	-0.2143	0.0459	0.1378	0.0351	1.8976
41	2.7	1.4	4.0	0.216	0.112	0.1	300	0.4538	-0.0370	0.0014	0.0445	0.0538	0.1984
42	2.8	1.1	4.1	0.224	0.088	0.1	296	0.4439	0.2143	0.0459	0.0445	0.0351	0.1984
43	2.7	1.0	4.2	0.216	0.080	0.1	285	0.4166	0.2593	0.0672	0.0213	0.0276	0.0454
44	2.8	0.7	4.3	0.224	0.056	0.1	278	0.3993	0.5000	0.2500	0.1828	0.0003	3.3410
45	2.8	0.6	4.4	0.224	0.048	0.1	268	0.3745	0.5714	0.3265	0.0765	0.0087	0.5857
46	2.8	0.5	4.5	0.224	0.040	0.1	252	0.3348	0.6429	0.4133	0.0867	0.0324	0.7523
47	2.7	0.6	4.6	0.216	0.048	0.1	240	0.3050	0.5556	0.3086	0.1046	0.0057	1.0946
48	2.7	0.9	4.7	0.216	0.072	0.1	227	0.2728	0.3333	0.1111	0.1975	0.0150	3.9018
49	2.7	1.3	4.8	0.216	0.104	0.1	228	0.2753	0.0370	0.0014	0.1097	0.0538	1.2043
50	2.7	1.8	4.9	0.216	0.144	0.1	229	0.2778	-0.3333	0.1111	0.1097	0.0150	1.2043
51	2.8	2.5	5.0	0.224	0.200	0.1	250	0.3298	-0.7857	0.6173	0.5062	0.1474	25.6275
		Mean Diameter		0.235		Minimum	197	0.0000			Mean	0.0385	
						Maximum	300	0.4538			r.m.s.	0.1963	
								Mean Fibre Position		0.2334		Mean	3.0068
	Migration Frequency		1.2753								Rate (I) of Migration		1.7340

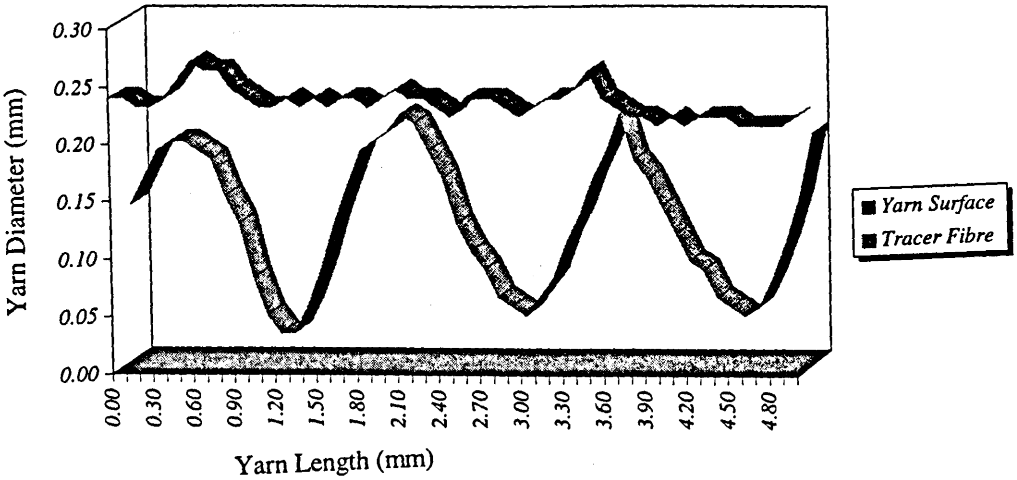


Fig. 7.10 2-Dimensional Representation of a Tracer Fibre in the Partially Untwisted Yarn 917-220 turns.m^{-1}

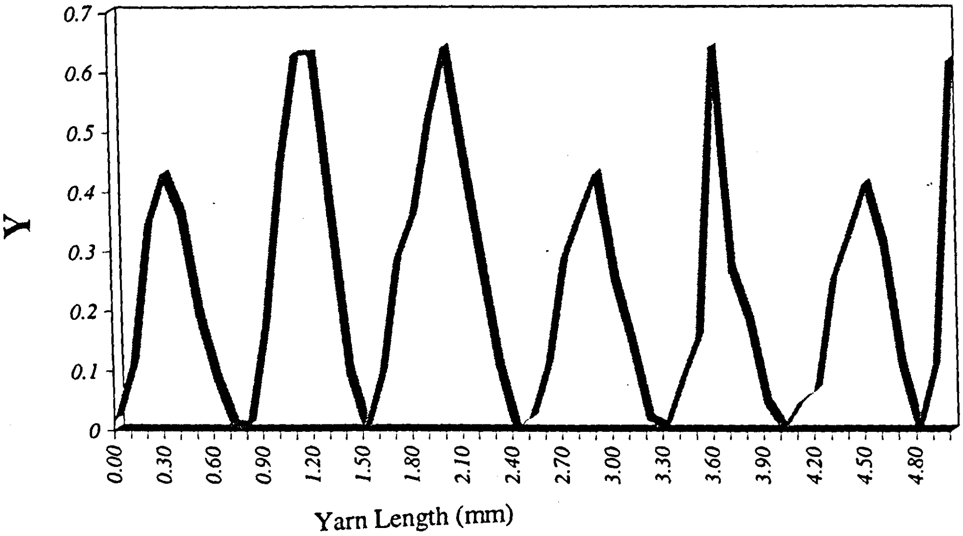


Fig. 7.11 Helix Envelope of Partially Untwisted Yarn 917-220 turns.m^{-1}

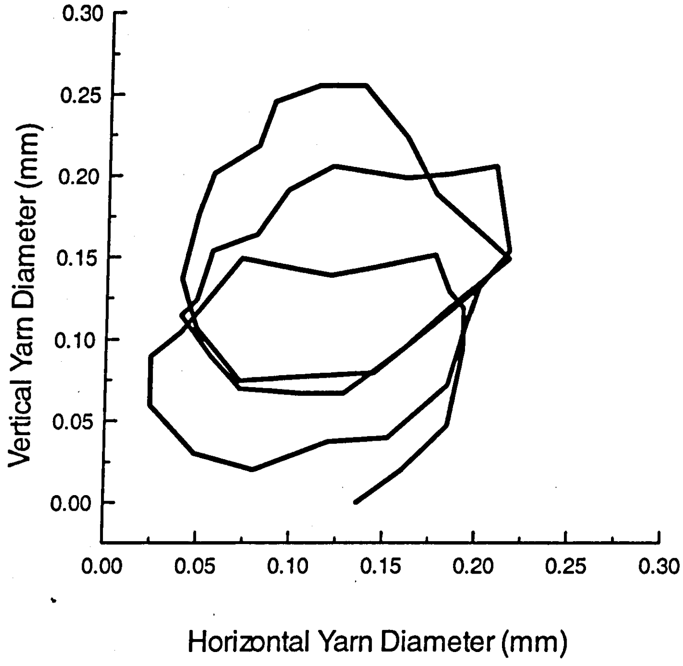


Fig. 7.12 Configuration of a Tracer Fibre in Partially Untwisted Yarn 917-220 turns.m^{-1}, Viewed from the Cross-Section, Along the Yarn

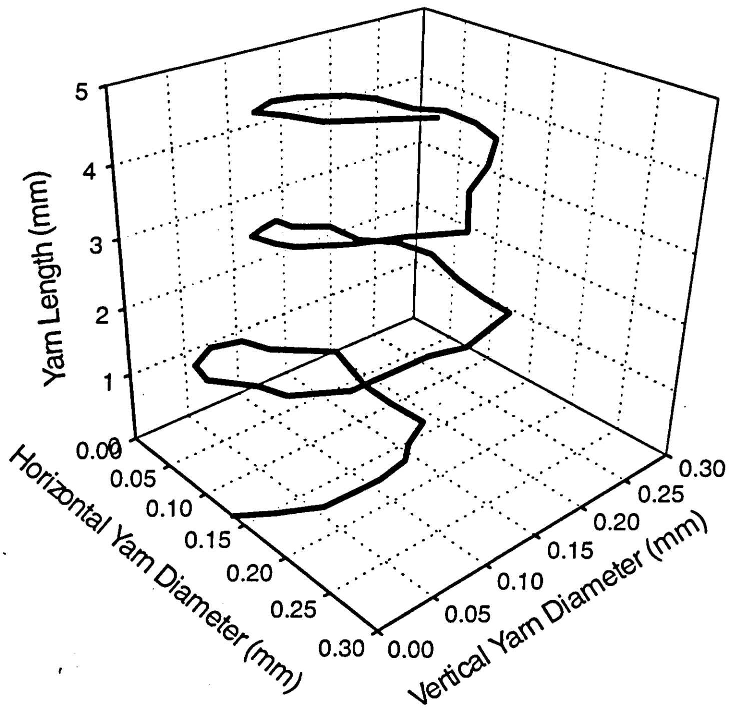


Fig. 7.13 3-Dimensional Configuration of a Tracer Fibre in Partially Untwisted Yarn 917-220 turns.m^{-1} (Computer Generated)

Table 7.5 Processed Yarn 917-234 turns.m^{-1} (Measurements every 0.1 mm of the Yarn Length)

No	Diam×40 Indication	Fibre×40 Indication	Length Yn mm	Diameter mm	Fibre Pos. mm	Distance l mm	Depth (°)	Depth (mm)	r/R	Y	$(Y_1\text{-}Y_2)$	$(Y\text{-Mean }Y)^2$	$((Y_1\text{-}Y_2)/l)^2$
1	3.5	3.1	0.0	0.280	0.248		162	0.1116	-0.7714	0.5951		0.1761	
2	3.4	2.9	0.1	0.272	0.232	0.1	180	0.1562	-0.7059	0.4983	0.0968	0.1042	0.9376
3	3.1	2.3	0.2	0.248	0.184	0.1	182	0.1612	-0.4839	0.2341	0.2641	0.0034	6.9769
4	3.0	1.8	0.3	0.240	0.144	0.1	186	0.1711	-0.2000	0.0400	0.1941	0.0183	3.7687
5	3.0	1.0	0.4	0.240	0.080	0.1	182	0.1612	0.3333	0.1111	0.0711	0.0041	0.5057
6	3.1	0.5	0.5	0.248	0.040	0.1	164	0.1166	0.6774	0.4589	0.3478	0.0804	12.0955
7	3.0	0.3	0.6	0.240	0.024	0.1	149	0.0794	0.8000	0.6400	0.1811	0.2159	3.2798
8	3.0	0.5	0.7	0.240	0.040	0.1	132	0.0372	0.6667	0.4444	0.1956	0.0724	3.8242
9	3.0	1.2	0.8	0.240	0.096	0.1	117	0.0000	0.2000	0.0400	0.4044	0.0183	16.3575
10	3.0	1.8	0.9	0.240	0.144	0.1	117	0.0000	-0.2000	0.0400	0.0000	0.0183	0.0000
11	2.8	2.3	1.0	0.224	0.184	0.1	137	0.0496	-0.6429	0.4133	0.3733	0.0566	13.9327
12	2.9	2.5	1.1	0.232	0.200	0.1	162	0.1116	-0.7241	0.5244	0.1111	0.1218	1.2346
13	3.0	2.5	1.2	0.240	0.200	0.1	179	0.1538	-0.6667	0.4444	0.0799	0.0724	0.6389
14	3.1	2.2	1.3	0.248	0.176	0.1	190	0.1810	-0.4194	0.1759	0.2686	0.0000	7.2138
15	2.8	1.6	1.4	0.224	0.128	0.1	186	0.1711	-0.1429	0.0204	0.1555	0.0240	2.4165
16	2.7	1.1	1.5	0.216	0.088	0.1	185	0.1686	0.1852	0.0343	0.0139	0.0199	0.0193
17	2.8	0.9	1.6	0.224	0.072	0.1	182	0.1612	0.3571	0.1276	0.0933	0.0023	0.8697
18	3.0	1.0	1.7	0.240	0.080	0.1	167	0.1240	0.3333	0.1111	0.0164	0.0041	0.0270
19	2.9	1.0	1.8	0.232	0.080	0.1	161	0.1091	0.3103	0.0963	0.0148	0.0063	0.0219
20	3.0	1.2	1.9	0.240	0.096	0.1	156	0.0967	0.2000	0.0400	0.0563	0.0183	0.3171
21	2.8	1.3	2.0	0.224	0.104	0.1	151	0.0843	0.0714	0.0051	0.0349	0.0290	0.1218
22	2.7	1.6	2.1	0.216	0.128	0.1	151	0.0843	-0.1852	0.0343	0.0292	0.0199	0.0852
23	2.9	1.9	2.2	0.232	0.152	0.1	162	0.1116	-0.3103	0.0963	0.0620	0.0063	0.3847
24	2.8	2.0	2.3	0.224	0.160	0.1	179	0.1538	-0.4286	0.1837	0.0874	0.0001	0.7632
25	2.8	1.7	2.4	0.224	0.136	0.1	183	0.1637	-0.2143	0.0459	0.1378	0.0168	1.8976
26	3.0	1.6	2.5	0.240	0.128	0.1	184	0.1662	-0.0667	0.0044	0.0415	0.0292	0.1720
27	2.9	1.3	2.6	0.232	0.104	0.1	184	0.1662	0.1034	0.0107	0.0063	0.0271	0.0039
28	2.7	1.1	2.7	0.216	0.088	0.1	188	0.1761	0.1852	0.0343	0.0236	0.0199	0.0557
29	2.8	1.1	2.8	0.224	0.088	0.1	189	0.1786	0.2143	0.0459	0.0116	0.0168	0.0135
30	2.7	1.0	2.9	0.216	0.080	0.1	175	0.1438	0.2593	0.0672	0.0213	0.0117	0.0454
31	2.9	1.0	3.0	0.232	0.080	0.1	164	0.1166	0.3103	0.0963	0.0291	0.0063	0.0847
32	3.0	1.2	3.1	0.240	0.096	0.1	148	0.0769	0.2000	0.0400	0.0563	0.0183	0.3171
33	2.9	1.7	3.2	0.232	0.136	0.1	156	0.0967	-0.1724	0.0297	0.0103	0.0212	0.0106
34	2.8	1.9	3.3	0.224	0.152	0.1	159	0.1042	-0.3571	0.1276	0.0978	0.0023	0.9570
35	2.8	2.2	3.4	0.224	0.176	0.1	178	0.1513	-0.5714	0.3265	0.1990	0.0228	3.9593
36	2.7	1.9	3.5	0.216	0.152	0.1	207	0.2232	-0.4074	0.1660	0.1605	0.0001	2.5776
37	2.8	1.5	3.6	0.224	0.120	0.1	203	0.2133	-0.0714	0.0051	0.1609	0.0290	2.5882
38	2.7	0.9	3.7	0.216	0.072	0.1	207	0.2232	0.3333	0.1111	0.1060	0.0041	1.1238
39	2.7	0.6	3.8	0.216	0.048	0.1	204	0.2158	0.5556	0.3086	0.1975	0.0178	3.9018
40	2.8	0.4	3.9	0.224	0.032	0.1	193	0.1885	0.7143	0.5102	0.2016	0.1121	4.0627
41	2.8	0.7	4.0	0.224	0.056	0.1	177	0.1488	0.5000	0.2500	0.2602	0.0056	6.7706
42	3.0	1.2	4.1	0.240	0.096	0.1	167	0.1240	0.2000	0.0400	0.2100	0.0183	4.4100
43	3.0	1.1	4.2	0.240	0.088	0.1	172	0.1364	0.2667	0.0711	0.0311	0.0109	0.0968
44	3.0	1.2	4.3	0.240	0.096	0.1	176	0.1463	0.2000	0.0400	0.0311	0.0183	0.0968
45	3.0	1.5	4.4	0.240	0.120	0.1	176	0.1463	0.0000	0.0000	0.0400	0.0308	0.1600
46	3.0	2.0	4.5	0.240	0.160	0.1	170	0.1314	-0.3333	0.1111	0.1111	0.0041	1.2346
47	3.0	2.4	4.6	0.240	0.192	0.1	183	0.1637	-0.6000	0.3600	0.2489	0.0341	6.1946
48	2.8	2.3	4.7	0.224	0.184	0.1	198	0.2009	-0.6429	0.4133	0.0533	0.0566	0.2837
49	2.8	2.1	4.8	0.224	0.168	0.1	211	0.2331	-0.5000	0.2500	0.1633	0.0056	2.6656
50	2.9	1.8	4.9	0.232	0.144	0.1	220	0.2554	-0.2414	0.0583	0.1917	0.0137	3.6763
51	2.9	1.3	5.0	0.232	0.104	0.1	224	0.2654	0.1034	0.0107	0.0476	0.0271	0.2262
		Mean Diameter		0.233		Minimum	117	0.0000			Mean	0.0328	
						Maximum	224	0.2654			r.m.s.	0.1811	
								Mean Fibre Position		0.1754		Mean	2.4676
	Migration Frequency		1.2518								Rate (I) of Migration		1.5708

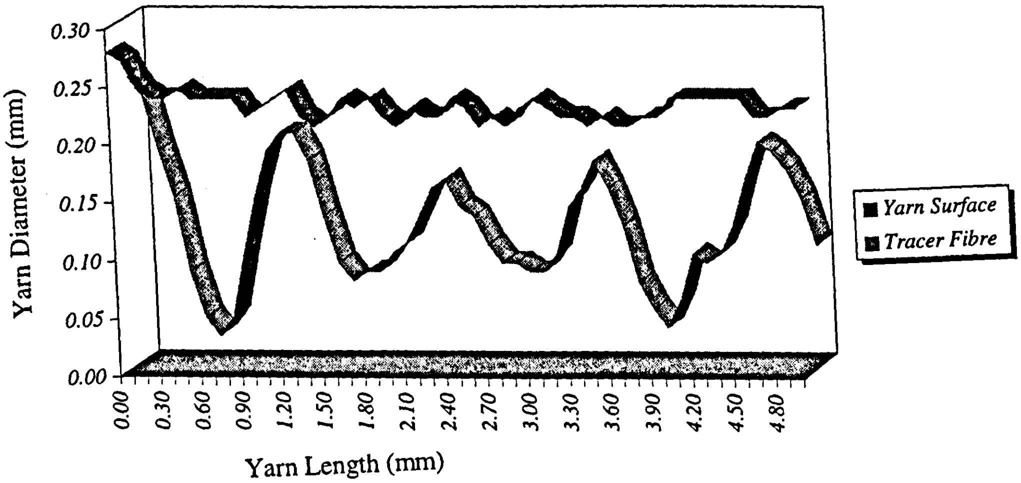


Fig. 7.14 2-Dimensional Representation of a Tracer Fibre in the Partially Untwisted Yarn 917-234 turns.m^{-1}

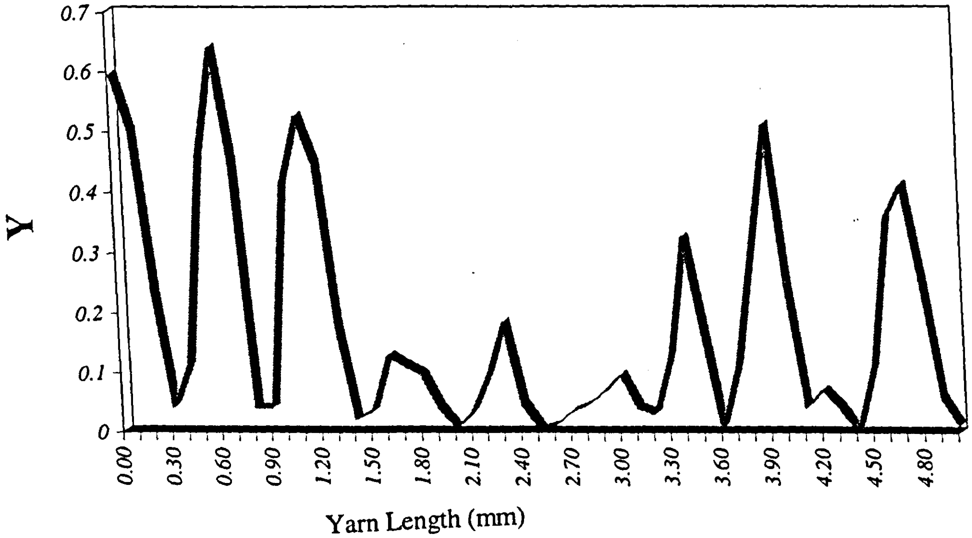


Fig. 7.15 Helix Envelope of Partially Untwisted Yarn 917-234 turns.m^{-1}

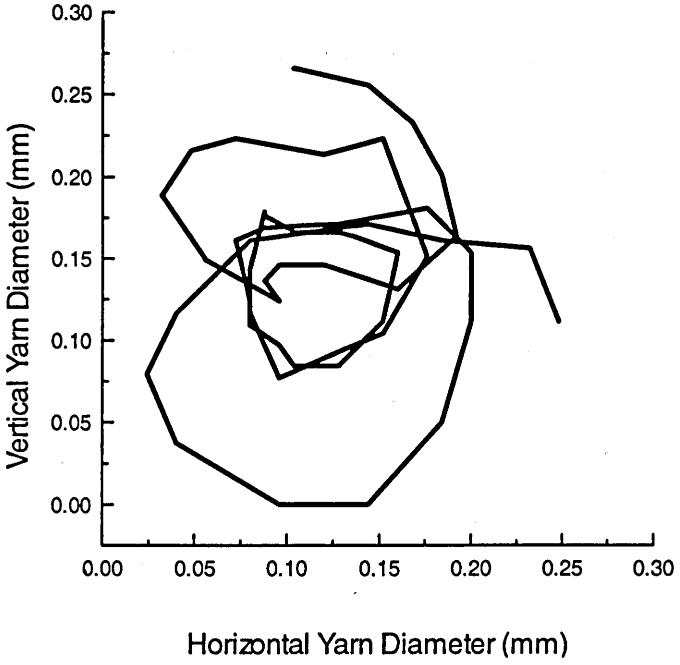


Fig. 7.16 Configuration of a Tracer Fibre in Partially Untwisted Yarn 917-234 turns.m^{-1}, Viewed from the Cross-Section, Along the Yarn

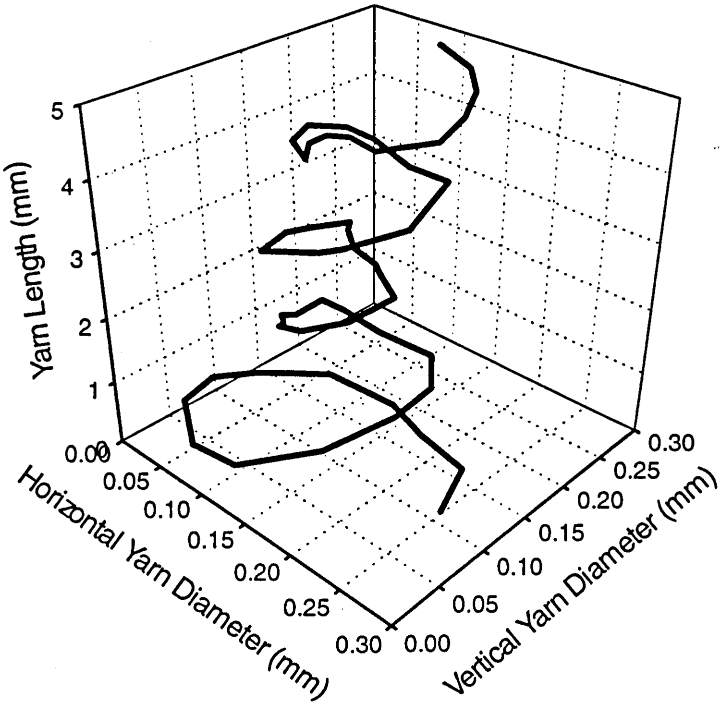


Fig. 7.17 3-Dimensional Configuration of a Tracer Fibre in Partially Untwisted Yarn 917-234 turns.m^{-1} (Computer Generated)

CHAPTER 8

GENERAL CONCLUSIONS - FUTURE WORK

It has been stated that "the physical and mechanical properties and characteristics of knitted fabrics and many of the problems which arise during the knitting and processing thereof are, to a very considerable extent, yarn properties and yarn problems" [1]. Keeping this in mind and considering in parallel the large world-wide demand for plain single jersey knitted garments [79], the necessity to deal with the problem of spirality, aiming for a permanent solution, assumed considerable importance.

At the beginning of the present thesis, a brief reference to developed mathematical models concerning the knitted structure is presented. From this review, a developed model relating yarn twist liveliness with fabric spirality appeared to confirm experimental results of previous workers.

In the first chapter, the nature of spirality is described to familiarise the reader with the problem. This reference is rather brief, since many workers in the past have dealt with the many of the aspects of this defect and have carried out very detailed studies.

A distinction between the factors that significantly contribute to spirality and others which are less significant, was recognised as desirable. Results obtained from preliminary experiments confirmed that the *torsional forces or twist liveliness*, introduced by inserting twist in the yarn during the spinning process, was the main cause of the spiral appearance of some tubular knitted fabrics.

As a result of reviewing and examining the existing methods used for the correction of this fabric distortion it was realised that these methods either had only a temporary effect or negatively influenced other fabric properties and characteristics. Some techniques, described in the patent literature as well others which have appeared in the industry are of doubtful practicality. Even with the use of two-fold yarns, the final net yarn torque often remains unbalanced resulting in the appearance of a distorted fabric [55], although this seems to be the most effective and broadly accepted solution.

The information provided by the available literature led the present worker towards an investigation of the possibility of other methods on reducing spirality. It became evident that although the method of unwinding yarn from its package affected the twist to a small degree, it did not influence the yarn torque significantly and consequently no alteration in the spirality angle was noticed.

The next step was concerned with the application of the false twisting principle to short staple yarns. It was thought that a disturbance in the torque could lead to a spirality reduction. It became obvious that this method was unsuccessful. The results, obtained from these preliminary attempts, made clear that the most promising method would provide the yarn with a reduced torsional energy, and this was achievable by real reduction of the twist.

The steaming process is well-established as a process for relaxing the torsional stresses present in yarns. However, this process is a temporary solution because spirality reappears after any wet treatment of the fabric.

On this basis, it was decided to steam a highly twisted, single short-staple, ring-spun yarn and then introduce counterbalancing torsional force by partially opposing that existing in the yarn. This could be achieved by partially untwisting, to a level 20-25% of the original twist, the steamed yarn.

The first observations from yarn so processed brought an unexpected result; although the yarn had a net twist in the Z direction, it formed snarls also in the Z direction. Thus, the experiment confirmed that the twist direction in a snarl of a ring-spun yarn is opposite to the direction of the active torsional forces present in the yarn.

When this processed yarn was knitted on a circular knitting machine, a second unexpected result was observed: although the yarn had net twist in the Z direction, the fabric was distorted slightly, exhibiting an S spirality. Thus, it is possible to produce fabrics exhibiting spirality in the opposite direction to the ring-spun yarn twist direction.

The washing of such fabrics resulted in the appearance of zero or, in some cases, very small spirality angles. This occurred because the two torsional couples present in the yarn could cancel each other in the wet environment.

Numerous experiments were carried out using this new method. They confirmed the initial results, indicating that a permanent reduction or elimination of the spirality had been achieved.

It was beyond the range of this one research investigation to test the vast range of yarns, twists and materials that would be required to provide completely precise information, but a widening of the range of removed twist would give an indication of the extent to which the alteration in the yarn torque affected the spirality angle.

Experimental Results

From the literature it can be found that an increase in twist results in an increase in the yarn linear density [177] that it is probably a consequence of an increase of the yarn diameter [178,179] as the yarn contracts in length. On the contrary, other investigators [180,181] support the opinion that an increase in twist results in a reduction of the diameter as the yarn is free from lateral constraint. In agreement with this statement another worker [182] states that "twist causes the fibres to be compacted and, as a rule then, the diameter reduces". From both parts of the main experimental work (chapters 4 and 6) it became evident that untwisting under dynamic conditions resulted in a slight reduction in the yarn linear density and an increase in the yarn thickness-diameter.

Where yarn evenness is concerned, no significant alteration due to the untwisting was found despite the statement that "an increase in twist without permitting yarn contraction is accompanied by an increase in the regularity" [183].

A decrease in the twist increases the hairiness of yarns of low original twist whereas it reduces in yarns with high twist factors. Investigating the effect of twist on hairiness, it has been stated that it results in diminution of the hairiness [180,184]. In other cases it has no effect [185].

Reduction in twist means a reduction in yarn strength. This was and is apparent from the overall results of the experiments carried out throughout the work reported in this thesis. At this point it is useful to emphasise firstly that the original yarns were highly twisted and secondly, to refer to a statement that "yarn strength is of secondary importance in knitting: if yarn characteristics such as uniformity, flexibility, elasticity and smoothness obtain, there is little doubt the yarns will be strong enough for ordinary needs" [186]. If these two points are taken into consideration, reduction in yarn strength for the sake of spirality reduction is not of much consequence.

Investigations of the yarn abrasion resistance and the friction on a metal surface showed that as the twist reduced, the yarn became less resistant to abrasion indicating probable changes in the yarn structure, whereas there was no particular effect on the friction characteristics.

As far as the spirality is concerned, it was found that when the new method was used, the spirality angle reduces as the twist inserted in the opposite direction increased. The lack of any equipment for measuring the yarn torque directly, left this field unexplored. It was also found that the "time factor" (ageing) was of paramount importance. In the new method, it is essential that the yarn is knitted immediately after the partial untwisting process as this ensures the maximum benefit in terms of spirality reduction. This may be because the torsional energy newly introduced to yarn is trapped in the yarn loop configuration. Results obtained from an attempt that was made to untwist non-steamed yarns showed that steaming was an essential stage in the successful application of this method.

Investigation of the effect of yarn lubrication and fabric take-down tension on the spirality angle showed that yarn lubrication did not affect the spirality whereas the use of take-down tension in knitting resulted in fabrics with lower spirality angles than those of fabrics produced without applying this tension. This is a positive factor since take-down tension is invariably used in commercial knitting.

The final chapter of this thesis reports experimental work carried out for a more detailed examination of the effect of the partial untwisting yarn process on knitted fabric spirality. Investigation of fibre migration was thought to be essential since there was experimental evidence that a change in yarn structure occurs during partial untwisting. It could be said that although the results obtained were in agreement with those of previous workers, it did not yield any additional information. Thus a great number of questions was left to be answer in the future.

Future Work

Any future worker will still face numerous difficulties in attempting to explain the detailed effects of torque in short staple yarns. Although it is hardly within the scope of this section to enter a detailed discussion of questions arising from this project, some brief notes are not out of place.

Firstly it is necessary to understand the actual effect of the steaming process on the torsional energy stored in the yarn. Furthermore, it is also necessary to understand the fabric wetting and drying processes which cause the fabric spirality to reappear.

A further step in this work concerns the torque itself. In the past, many devices have been constructed and modified in attempting to measure yarn torque. It would be essential to construct such an apparatus if scientific work in this field is to continue.

A beginning has been made in the investigation of the modification of the yarn structure due to the partial untwisting process. A clear picture of the detailed yarn structure and changes in yarn structure will require considerable additional work. Apart the great experimental work that has to be carried out, a mathematical model of a plain knitted structure formed from a partially untwisted yarn would be very helpful.

Another factor that is of crucial importance is the effect of yarn ageing on yarn produced by the new method. Until a method for retaining and stabilising the yarn after partial untwisting is available, it is easier to combine the two processes (partial untwisting and knitting). This is achieved when the untwisting is carried out on-line so that the partially untwisted yarn is directly led to the knitting zone (Plate 8.1). Considering the cost of investment required for such a device, it is important that the construction of a very small new device, that could untwist the yarns in a way similar to the two-for-one principle, is explored.

Finally, although the application of false twisting to untwist the short staple yarn was unsuccessful, it seems that more work, taking into account some of the features of the new method, could be carried out in that area also.

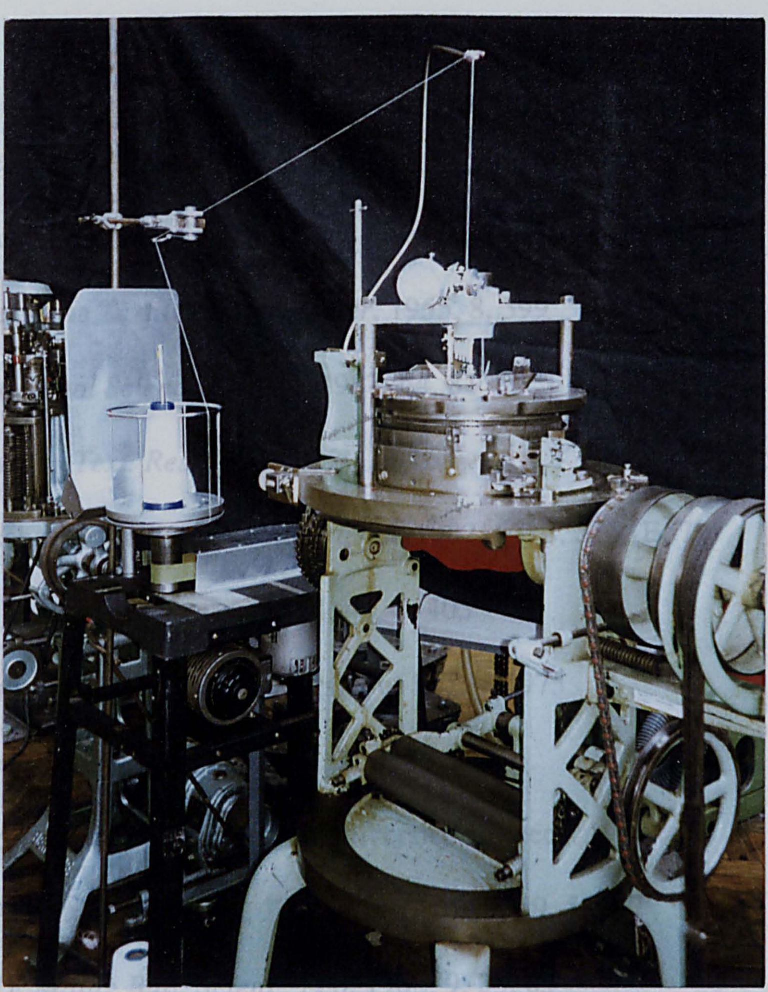


Plate 8.1 On-Line Partial Yarn Untwisting and Knitting

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APPENDIX I

EXCERPTS FROM THE LITERATURE CONCERNING THE EFFECT OF STEAMING ACTION ON THE YARNS.

R. Meredith, *J. Text. Inst.*, 1958, 49, 6, T295

The fall in rigidity observed is consistent with the idea that this is caused by the breaking of hydrogen bonds between chain molecules in the non-crystalline regions, and that, at saturation regain, one molecule of water is bound to each accessible polar group which would otherwise be linked to a similar polar group in a neighbouring chain molecule by means of a hydrogen bond.

◆

[98] J.W.S. Hearle, R.H. Peters: 'Moisture in Textiles', *The Textile Institute*, Manchester, 1960

The fall in rigidity due to increase of moisture is consistent with the supposition that this is caused by the breaking of hydrogen bonds between chain molecules in the non-crystalline regions and that, at saturation regain, one molecule of water is bound to each accessible polar group which would otherwise be linked by means of a hydrogen bond to a similar polar group in a neighbouring chain molecule.

◆

R.G. Farger, A.M. Williams, *Shirley Inst. Memoirs*, 1923, 2, 55

The behaviour of cotton is that of many other colloidal gels. With increase of temperature and water content, the gel becomes more plastic and more easily deformed by pressure. If too much moisture is present the gel will be too plastic and not give a sharp impression. If dried by heating while deformed, the "set" will be more or less permanent through a reduction in the swelling capacity.

A.R. Urquhart, *J. Text. Inst.*, 1929, 20, T125

When the cellulose is formed inside the cotton hair it is precipitated in the presence of water, and the hydroxyl groups will have water molecules attached. As the hair dries up these groups will be freed, and it is reasonable to assume that there will be a tendency for the cellulose molecules to rearrange themselves so that the residual valencies of the hydroxyl groups will be mutually satisfied, as such a rearrangement will cause a reduction in the potential of the system. This process is likely to go on, when the cotton is dried out at room temperature, until all the adsorbed water has been removed. It may be noted here that the cellulose micelles in the cotton hair are probably very long in comparison with their cross-section, and X-ray investigation has indicated that they are arranged in spiral formation. In these circumstances it seems probable that in addition to the rearrangement of the molecules in the micelles there may be actual deformation (twisting) of the micelles themselves, in order to bring free hydroxyl groups nearer to each other, and this may explain the latent strain present in the dry hairs, which is to a large extent removed by immersion in water.

◆

[106]. D. Behr, *Knitting Technique*, Nov. 1992, 14, 6, 409

Setting of textile fibre fabrics is understood to be the loosening of cross and auxiliary valency bonds between fibre molecules, reorientation of these chain molecules followed by a new, tensionless arrangement of same at a higher degree of orientation.

◆

M. Chaikin, N.H. Chamberlain, *J. Text. Inst.*, 1955, 46, 1, T25

The low modulus observed at very low rates of strain may be accounted for in terms of such process as unfolding of molecular chains in the non-crystalline regions of the fibre, which involves rotation of segments of the chains around single bonds with small activation energy barriers, it being assumed that time is sufficiently allowed under these conditions of slow deformation for weak secondary bonds between molecules or segments of molecules to be broken when the stress is applied.

[99]. W.E. Morton, J.W.S. Hearle, 'Physical Properties of Textile Fibres', *Textile Institute* Manchester, 1986

In the presence of water, the minimisation of free energy by crystallisation is always in competition with minimisation by forming hydrogen bonds by association with water. This is brough about by swelling, or by the attempt to go into solution.

The formation of the fibre occurs in the wet state, and it is thus highly swollen. When drying occurs, the fibrils will associate, as already suggested, but, like any crystallisation of long-chain units, appreciable disorder might be introduced owing to some entanglement or mis-matching of fibrils. Subject to these limitations, the material would be expected to collapse down to a somewhat disordered modification of the model already discussed, which, in its idealised form without any disorder, would be the presumed minimum-energy state for dry natural cellulose.

What happens on re-exposure to water? Experimentally, it is known that there is a progressive increase in absorption as humidity increases and that in liquid water there is limited swelling but not solution of the material. One can suggest three reasons why the fibrillar network does not dissociate completely in water:

a. once strain is relieved by some opening up, regions where fibrils are in crystallographic register with one another may remain as stable entities;

b. as a variant of (a), it may be that a dynamic equilibrium is established in which there are always some fibrils associated together, although the actual groups are continually changing;

c. there may be some tie-molecules linking separate fibrils together.

At any ordinary relative humidity, the network would be partly opened up, whereas in water, where much chemical processing is done, the fibre would be much more highly swollen.

... Cross-linking the fibrils together permanently: this gives rise to increase resistance to plastic deformation.

Cotton fibres are hollow fibres of circular cross section that have collapsed. When fibres absorb water, they change in dimensions, swelling transversely and axially.

It is the directly attached water that changes the forces between molecules and breaks cross-links, so that it should have a greater effect than the indirectly attached water on the physical properties of the fibre. On the other hand, it will be the indirectly attached water molecules that will be the first to evaporate, so these would be expected to have the greatest effect on the vapour pressure.

[15]. T.S. Nutting, *HATRA Res. Bul.*, 1960, 4, 6, 18

The increase in twist liveliness of the yarn under water is attributed to the molecular structure of the ***wool*** fibres. The stress of a torsionally strained wool fibre will be borne largely by the system of forces or bonds linking the long chain molecules together. The high initial stress decreases as a function of time, the rate of decrease, or stress relaxation, being accelerated by the presence of moisture. The phenomenon of stress relaxation at constant strain is primarily caused by the breaking of a certain class of inter-molecular bonds which individually are relatively weak and are easily ruptured by water. These are primarily hydrogen bonds. These bonds also have the ability to re-form in a strain-free condition, particularly on drying, and these help to stabilise the new strained fibre configuration. These re-formed bonds will tend to restrain the highly stable original bonds which still support the main stress of the distorted fibre. A singles spun worsted yarn may be considered as a group of such fibres, each fibre containing a number of partially relaxed and re-formed hydrogen bonds. Such yarns on storage tend to become stable or set and to exhibit twist liveliness which decreases with time, rapidly at first and then slowly until a nearly steady value is reached. The rate at which this decay of twist liveliness occurs depends upon the original twist inserted, and the conditions of storage, high humidity assisting in rapid decay. These yarns, when knitted into fabrics, would produce dry relaxed fabric spirality whose extent depended upon the degree of dry twist liveliness. On immersing the yarn in water a great number of hydrogen bonds, including those re-formed, would be broken and thus the restraining influence would be removed from the strong stress-bearing bonds. The twist liveliness would increase as the yarn attempted to remove the strain, and as a consequence the fabric spirality would increase.

In order to knit a highly twisted singles yarn into a fabric which will not spiral, the more permanent bonds linking the molecules must be set. The bonds mainly responsible are thought to be cystine linkages.

APPENDIX II

APPARATUSES-DEVICES AND METHODS USED FOR THE EXAMINATION OF THE YARN AND FABRIC PROPERTIES (CHARACTERISTICS)

Note 1: All the yarn and fabric samples throughout this research were tested using the methods, devices and settings mentioned below, unless otherwise indicated.
Note 2: All the tests were conducted in the standard laboratory testing atmospheric conditions [20±2 °C, 65±2 % R.H.]. The samples were stored for at least 24 hours in these conditions prior to testing.

1. *Yarns*

1.1 Twist Amount

The fully automatic Zweigle D 301 twist tester (Plate II.1) was used for measuring the yarn twist, applying the untwist-twist or "twist contraction" [141] method of testing.

Brief Description of the applied method.

In the "untwisting" stage, twist was removed from the yarn by rotating one yarn end in the opposite direction to that of twist already in the yarn. Due to the twist removal, the yarn elongated up to a point of 5 mm. As soon as the twist removal was completed, the continuous rotation (in the same direction) of the yarn end, started introducing opposite twist into the yarn ("twisting stage"). When a yarn contraction of 5 mm was achieved, the operation of the device was interrupted. By halving the total number of the turns inserted, the value of the actual twist in the yarn was obtained.

Sampling: Ten tests were made for each of the yarn samples. For each test, a yarn length of 50 cm was examined, being pretensioned[1] with a fixed weight placed in the pretension system of the apparatus.

1.2 Strength

The tensile properties (elongation, tenacity, force, work to rupture) of the yarns were tested on the Textechno Statimat M Tensile Tester (Plate II.2) This device is fully automatic and is microprocessor controlled. Its operation is based on the principle of

---

[1] The recommended amount of yarn tension for the twist testing, given in B.S. 2085:1954, is: tex/2 ± 10%. For the examined yarn samples with linear densities 39 tex and 29 tex, loads of 0.196 N and 0.147 N were used correspondingly.

constant rate of elongation. The gauge length was 500 mm and the test speed was fixed at 250 mm.min^{-1}. Twenty five tests were carried out for each yarn sample.

1.3 Evenness - Irregularity

Measurements of the yarn mass variation per centimetre of yarn length (CVm %) were obtained from the Uster Tester 3 system (Plate II.3). The standard procedure recommended by the manufacturer was followed. The yarn was passed through the capacitor armatures (slot) with a speed of 100 mm.min^{-1} and the actual time of each test was one minute (100 m examined yarn length). Thin, thick places and neps were measured at: -50%, +50%, +140 %, +200 % of the yarn diameter respectively.

1.4 Yarn Hairiness

For the measurement of the yarn hairiness, the Shirley Hairiness Tester[2] was used (Plate II.4). It is consisted of three main parts: the hairiness measuring unit, the yarn drive mechanism and the data logging/control computer.

The principle of the hairiness measuring unit has two sequential functions:

a. photoelectric inspection - by means of a photo transistor - of a representative sector (70°) of the yarn circumference, and

b. counting of the number of the protruding hairs in a certain distance (0 to 10 mm) from the yarn axis.

The yarn, to be tested, is passed over an adjustable guide which can be set by means of a micrometer head at a distance of 0 to 10 mm from a light beam. The parallel position of the yarn axis to the light beam enables the protruding hairs to interrupt the beam, resulting in an electric signal to be generated by the photo transistor and to reach the computer. The interpretation and processing of these signals in terms of "hair length" (also made by the computer), results in the "number of hairs per meter" (measuring concept).

The settings used in the experiments were as follows:

Testing yarn length:	10 m;
Yarn speed:	10 m.min^{-1};
Number of tests:	10;

Hair length: 3 mm (i.e., counting hairs longer than this length).

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[2] Information taken from the instruction manual.

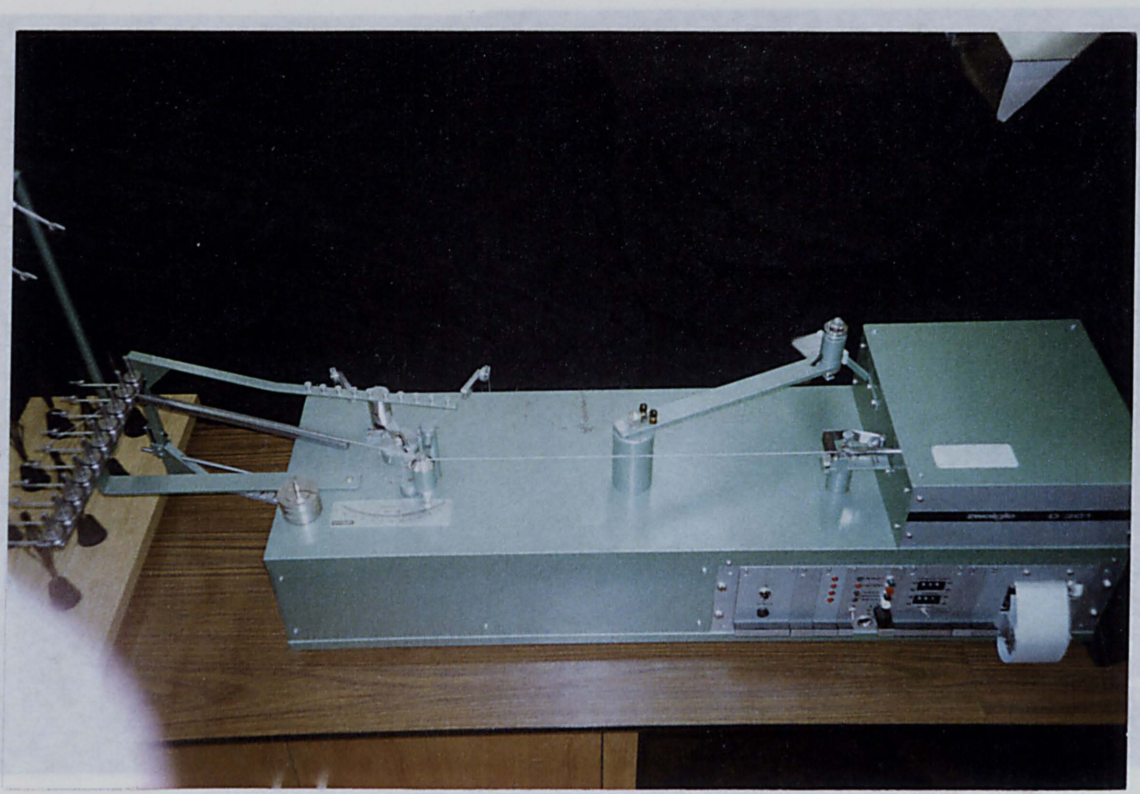

Plate II.1 Zweigle D 301 Twist Tester

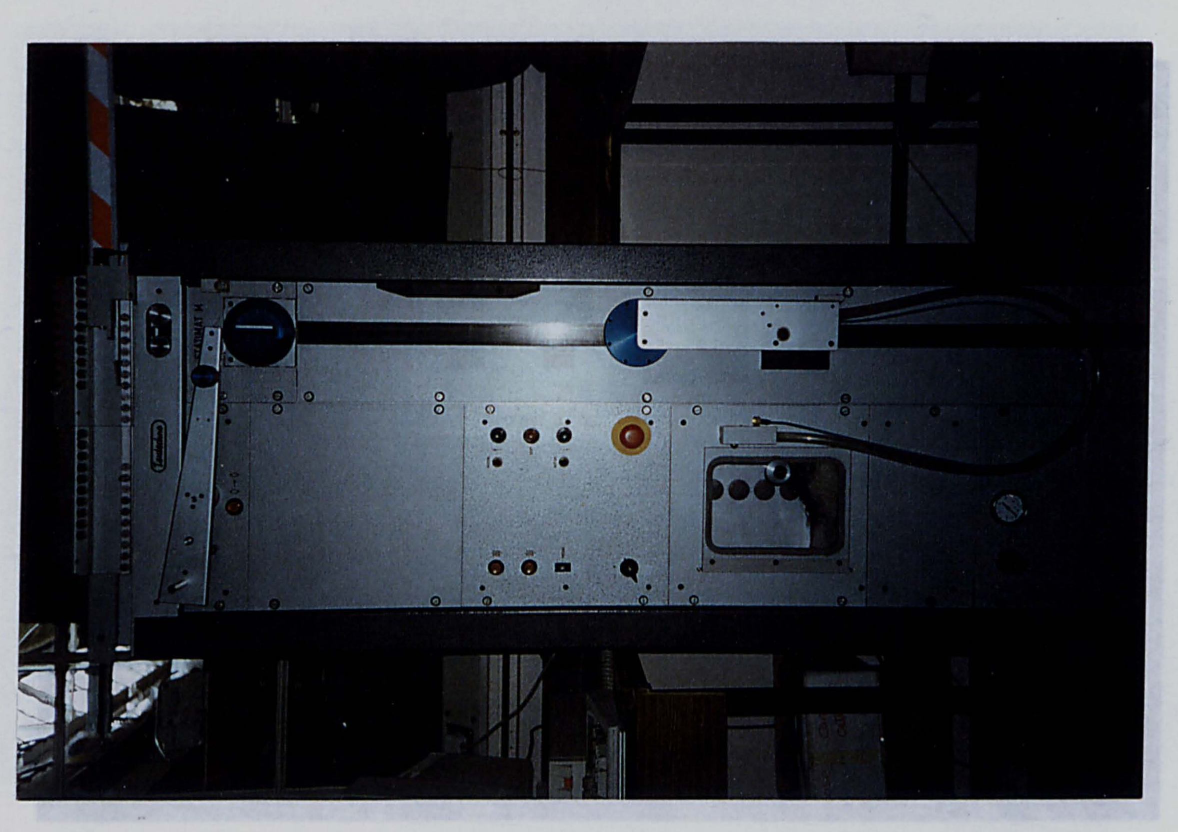

Plate II.2 Textechno Statimat M Tensile Tester

Plate II.3 Uster Evenness Tester 3 System

Plate II.4 Shirley Hairiness Tester

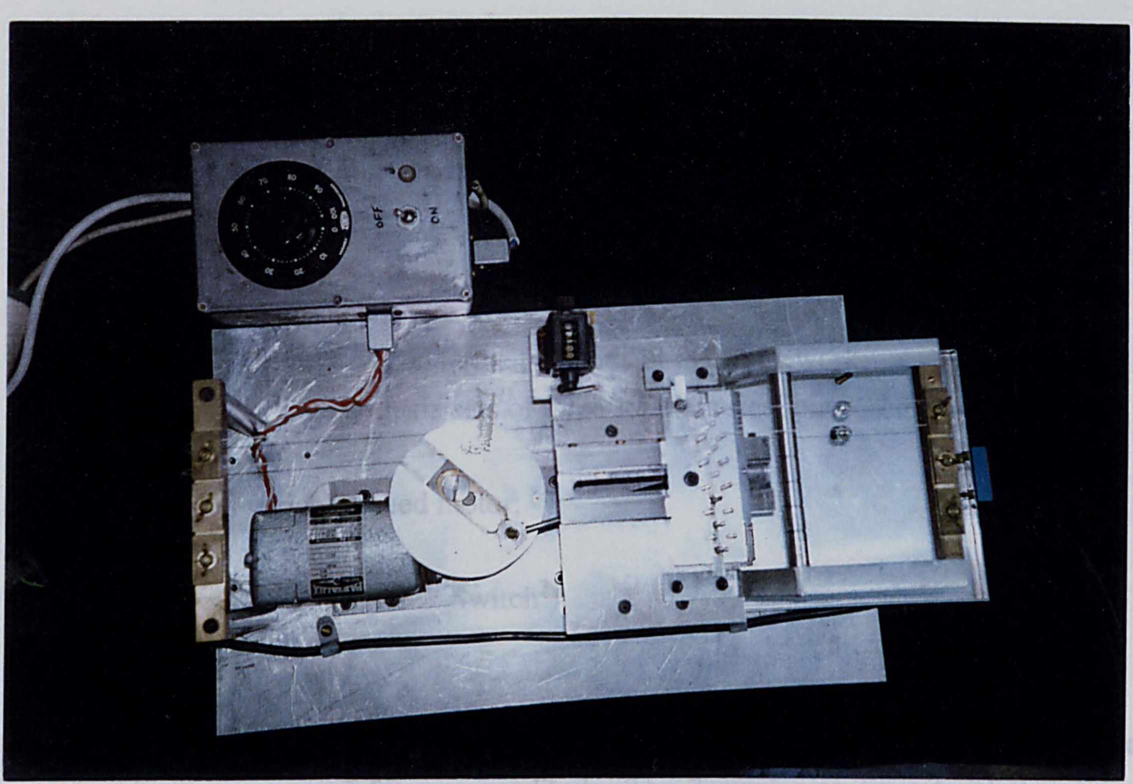

Plate II.5 Yarn Abrasion Resistance Experimental Apparatus

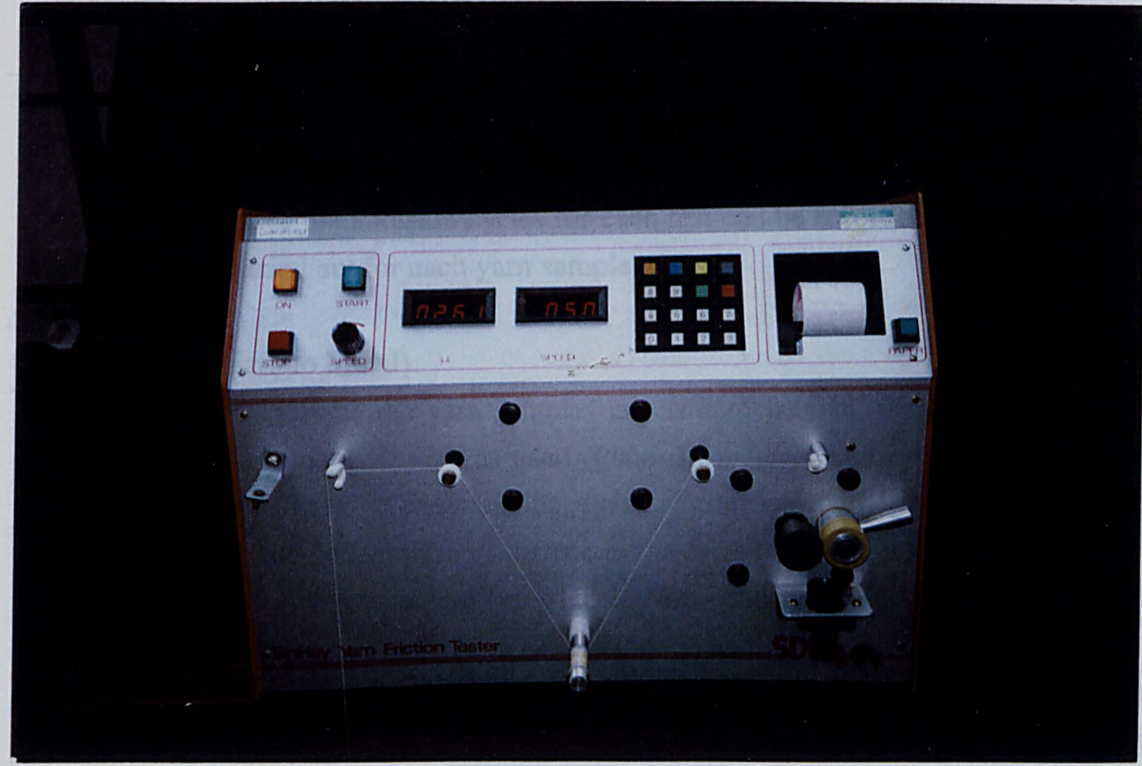

Plate II.6 Shirley SDL 96 Yarn Friction Tester

1.5 Abrasion Resistance

Due to the absence of any standard technique to assess the abrasion resistance of the yarns, an apparatus, being designed and fabricated by Johari [151], was used.

Description of the apparatus (Plate II.5)

It consists of the following parts :

a. Yarn holding bars placed in the two ends of the framework;
b. Rectangular plate with six sets of three stainless steel pins each;
c. Cam;
d. 220 Volts variable speed motor;
e. Light weight tray;
f. Stop motion switch (Reed-Switch[3]);
g. Counter.

The cam, mounted on the motor, drives the rectangular plate which has a retrogressive movement of 80 mm amplitude. The 3 mm pins (in sets of three) are placed, on the rectangular plate, in an isosceles triangle configuration. Each yarn sample is passed through these pins and clamped on the holding bars after being pretensioned with tension of tex/2 ± 10% N [B.S. 2085: 1954]. A fixed weight of 49 mN is suspended from each sample above the tray. After a number of cam rotational cycles, yarn breakage occurs and the weight of 49 mN drops on the tray. This causes an increase in distance between the two armatures of the switch (one of them is mounted on the tray) resulting in the opening of the electric circuit: switch - motor - power supply.

The number of the abrasion cycles for each test can be recorded from the counter. Ten tests were carried out for each yarn sample.

1.6 Friction (Yarn to Metal)

In order to examine the yarn samples in terms of friction, the Shirley Electronic yarn friction tester type SDL 96 was used (Plate II.6). According to the manufacturer[4], this device was designed to measure the dynamic coefficient of friction (μ) of a yarn passing over a stainless steel friction surface in the form of a peg. It was claimed that in this device, a new type of tension transducer were used providing more accurate and reproducible measurements without re calibrating.

The instrument operated by measuring both the input tension T1 and the output tension T2 as the yarn was pulled over the peg by an electronic speed controlling system.

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[3] The reason of selecting this type of switch relates to its sensitivity.

[4] Information taken from the instruction manual.

The coefficient of friction "μ" was calculated by the onboard computer using Amonton's capstan equation: $T2 = T1 \cdot e^{\mu\theta}$,
where θ the angle of contact between the yarn and the peg (angle of wrap).

The instantaneous tension values were recorded ten times per second and converted into μ values which were stored for subsequent statistical processing.

Sampling: Five (5) tests of each of the yarn samples were measured. The tested yarn length in each test was 10 m and the yarn speed was fixed at 50 $m.min^{-1}$. The average of those results were considered as the mean value of the coefficient of friction.

1.7 Yarn Snarliness

The experimental apparatus "Prianic" (Plate II.7) was used for the determination of the yarn snarliness. Complete description of the device can be found elsewhere [135].

2. *Fabrics*

2.1 Thickness

A direct measure of fabric thickness was achieved by positioning the fabric samples on the reference surface of the FAST-1 Compression meter (Plate II.8), and lowering appropriate weights (pressure) onto the fabrics.

According to the manufacturers, pressure of 196 $N.cm^{-2}$ (Pa) and 9.81 $kN.cm^{-2}$ (kPa) was used as standard for the measurements. They claimed that a measure of variation in surface thickness provides good indications of variations in fabric handle, appearance and finish.

Brief description of the apparatus

"The FAST-1 compression meter has a non-contact electronic sensor fixed below a reference surface over which a specially finished object cup is located. This cup covers a test area of 10 cm^2 and provides the initial load of 196 $N.m^{-2}$ (Pa). It is into this that the other load sits to make the combined pressure of 9.81 $kN.m^{-2}$ (kPa). The loads are lowered onto the reference surface by a threaded ring which suspends the cup. The electronic sensor is able to determine the proximity of the lower surface of the cup and hence the fabric thickness, with a resolution of 0.001 mm." [187]

Testing Procedure

1. After the placing of the fabric sample on the reference surface, the object cup (196 $N.m^{-2}$) is lowered carefully on to the fabric and the reading is recorded.
2. The object cup is then raised. The large weight is placed in the cup and the combined weight is lowered on to the same fabric area (the fabric remains stationary).
3. The new reading is recorded. The extra weight is removed and the object cup is raised.

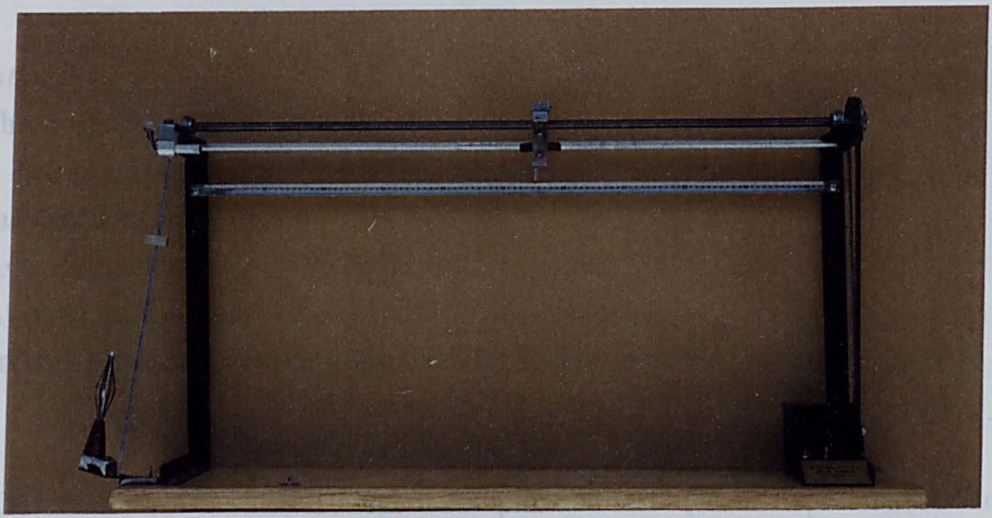

Plate II.7 Yarn Snarliness Tester "Prianic"

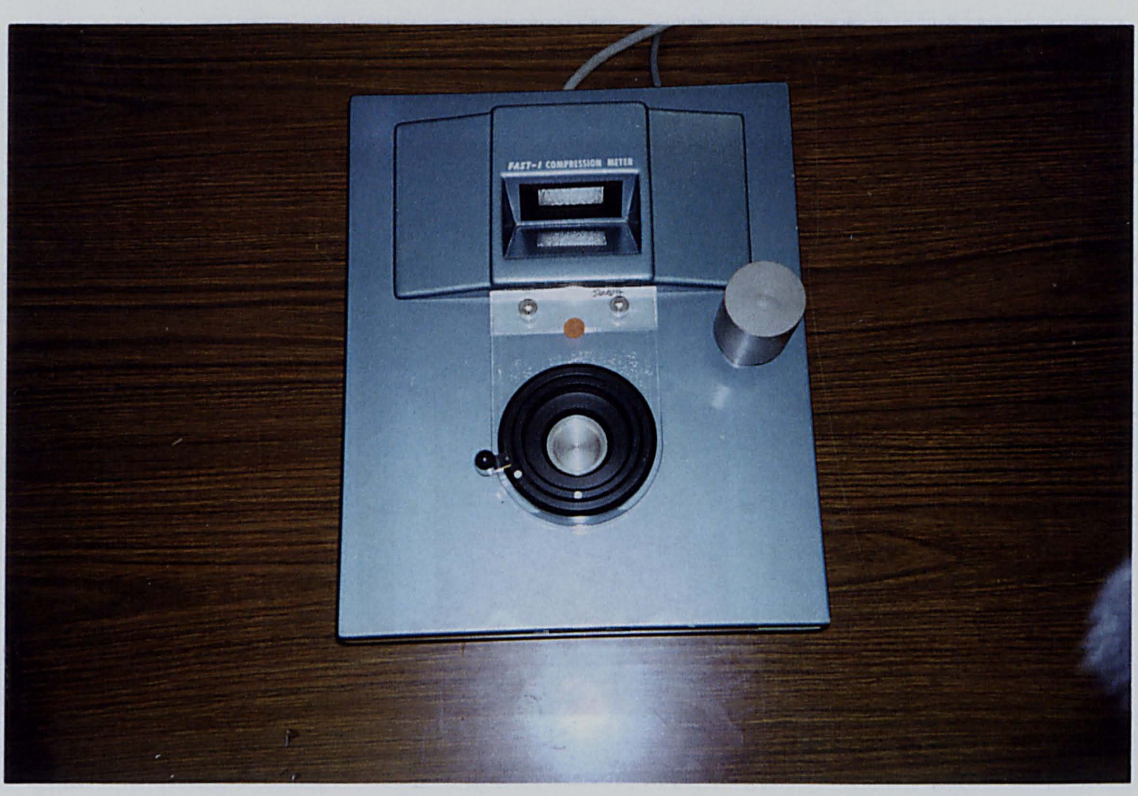

Plate II.8 Fast-01 Fabric Compression Meter

Sampling

Four (4) readings - equivalent number of tested fabric areas - with each weight for each fabric sample were recorded.

Calculations

The readings, obtained from the digital display of the Compression Meter were the "Fabric ***Thickness***" in millimetres (mm)

Surface Thickness:

Average thickness at 196 $N.m^{-2}$: T_2 in mm;

Average thickness at 9.81 $kN.m^{-2}$: T_{100} in mm;

The Surface Thickness (ST) was given by: $ST= T_2-T_{100}$ in mm.

Note: This device was used for the yarn compression tests (Main Experimental Work, Part I) by attaching a special designed accessory (Plates II.9,10,11).

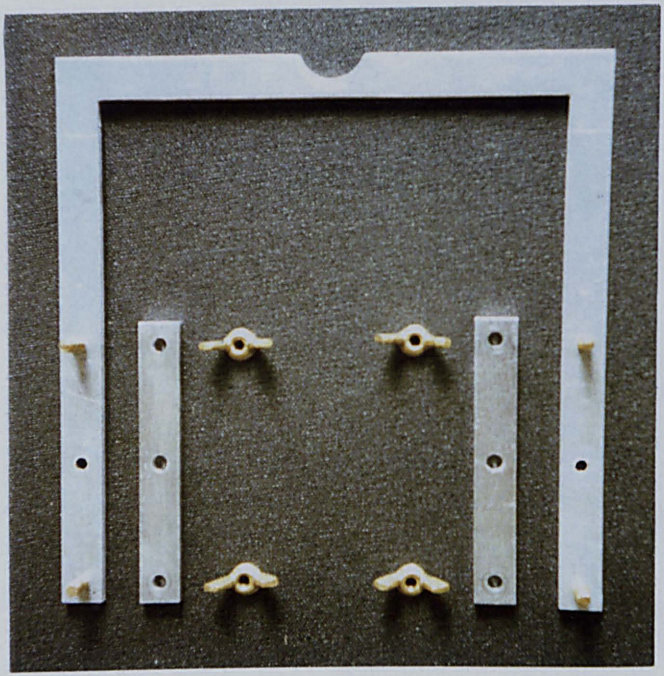

Plate II.9 Accessory for the Measurement of the Yarn Compressibility

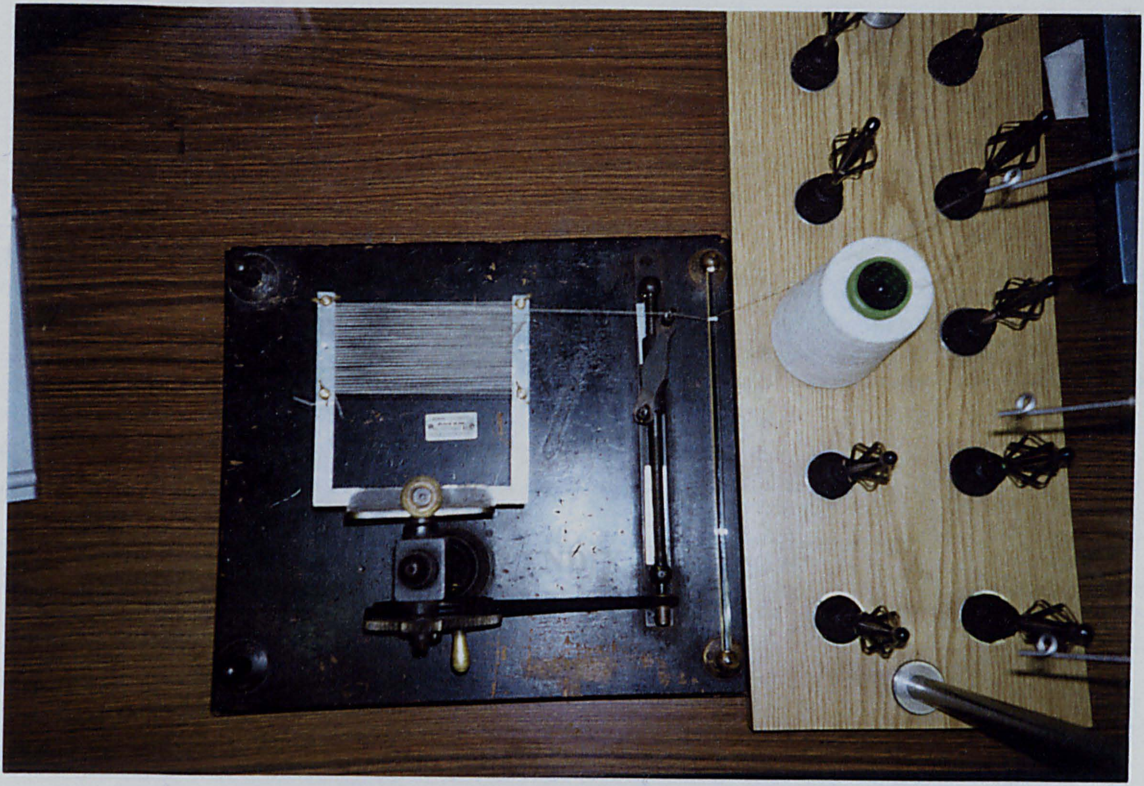

Plate II.10 Preparation for Measurement of the Yarn Compressibility

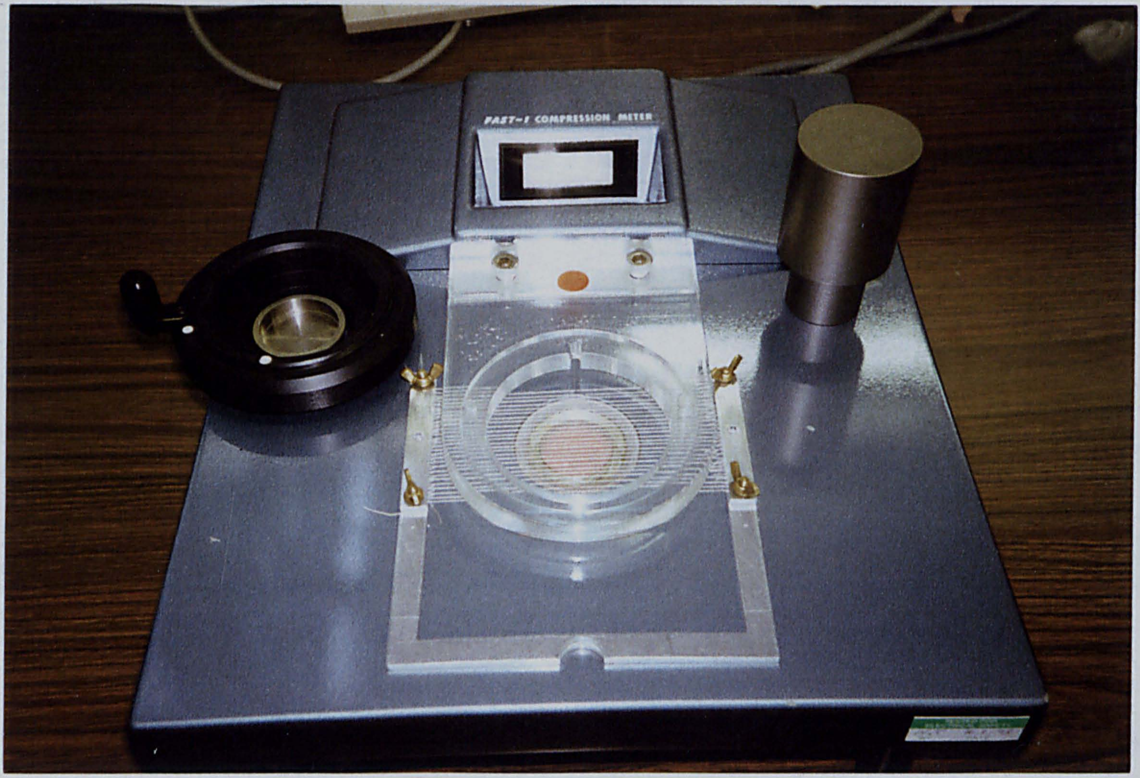

Plate II.11 Measurement of the Yarn Compressibility

APPENDIX III

PCT

REQUEST

The undersigned requests that the present international application be processed according to the Patent Cooperation Treaty.

For receiving Office use only

International Application No.

International Filing Date

Name of receiving Office and "PCT International Application"

Applicant's or agent's file reference (*if desired*) (*12 characters maximum*) JMF/P431

Box No. I TITLE OF INVENTION

IMPROVEMENTS RELATING TO KNITTED FABRICS

Box No. II APPLICANT

Name and address: (*Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country.*)

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☐ This person is also inventor.

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State (*i.e. country*) of nationality: UK

State (*i.e. country*) of residence: UK

This person is applicant for the purposes of: ☐ all designated States ☒ all designated States except the United States of America ☐ the United States of America only ☐ the States indicated in the Supplemental Box

Box No. III FURTHER APPLICANTS AND/OR (FURTHER) INVENTORS

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This person is:

☐ applicant only

☒ applicant and inventor

☐ inventor only (*If this check-box is marked, do not fill in below.*)

State (*i.e. country*) of nationality: GREECE

State (*i.e. country*) of residence: UK

This person is applicant for the purposes of: ☐ all designated States ☐ all designated States except the United States of America ☒ the United States of America only ☐ the States indicated in the Supplemental Box

Name and address: (*Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country.*)

This person is:

☐ applicant only

☐ applicant and inventor

☐ inventor only (*If this check-box is marked, do not fill in below.*)

State (*i.e. country*) of nationality:

State (*i.e. country*) of residence:

This person is applicant for the purposes of: ☐ all designated States ☐ all designated States except the United States of America ☐ the United States of America only ☐ the States indicated in the Supplemental Box

☐ Further applicants and/or (further) inventors are indicated on a continuation sheet.

Box No. IV AGENT OR COMMON REPRESENTATIVE; OR ADDRESS FOR CORRESPONDENCE

The person identified below is hereby/has been appointed to act on behalf of the applicant(s) before the competent International Authorities as: ☒ agent ☐ common representative

ne and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country.)*

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☐ Mark this check-box where no agent or common representative is/has been appointed and the space above is used instead to indicate a special address to which correspondence should be sent.

Box No. V DESIGNATION OF STATES

The following designations are hereby made under Rule 4.9(a) *(mark the applicable check-boxes; at least one must be marked)*:

Regional Patent

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☒ DE Germany ....
☒ DK Denmark ....
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☒ FI Finland ....
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☒ JP Japan
☒ KP Democratic People's Republic of Korea .....
....
☒ KR Republic of Korea ....
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Sheet No. ..3....

Box No. VI PRIORITY CLAIM Further priority claims are indicated in the Supplemental Box ☐

The priority of the following earlier application(s) is hereby claimed:

Country *(in which, or for which, the application was filed)*	Filing Date *(day/month/year)*	Application No.	Office of filing *(only for regional or international application)*
item (1) GB	20/02/93	9303425.4	GB
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This international application contains the following number of sheets:

1. request	:	3	sheets
2. description	:	11	sheets
3. claims	:	4	sheets
4. abstract	:	1	sheets
5. drawings	:	4	sheets
Total	:	23	sheets

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Figure No. ________ of the drawings (if any) should accompany the abstract when it is published.

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Next to each signature, indicate the name of the person signing and the capacity in which the person signs (if such capacity is not obvious from reading the request).

William Jones

WILLIAM JONES YORK

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IMPROVEMENTS RELATING TO KNITTED FABRICS

The invention relates to a method and apparatus for treating yarns to be used for the production of knitted fabric, and also a yarn and a fabric produced by the method and apparatus.

In the textile industry there is well known an undesirable effect called SPIRALITY which commonly appears in single tubular knitted fabrics. Spirality results due to a lack of perpendicularity between courses and wales as the latter follow a spiral path along the axis of the produced fabric. In the case of flat knitted fabrics, the wales follow a sideways direction at an angle to the perpendicular. According to the direction of the inclined wales, two types of Spirality exist, positive or Z-spirality where there is an inclination to the right side of the vertical fabric axis and negative or S-spirality where there is an inclination to the left side of the vertical fabric axis.

It is know that Spirality is mainly due to the yarn "twist liveliness". Highly twisted yarns have a high residual torque providing the knitted fabrics with an increased tendency to spiral (skew). The "twist liveliness" property of a yarn, by acting in each of the individual loops of the knitted structure, causes the lifting of one side of the knitted loop from the plane of the fabric which results in an overall distortion of the fabric surface.

Hitherto, a number of methods have been developed to overcome Spirality. These can conveniently be divided into two types; mechanical and chemical methods.

Mechanical methods include a way of using balanced doubled (plied - fold) yarns, that is, two component single yarns having equal twist amount and same twist direction are combined and twisted as one unit, in the opposite direction, with an appropriate twist amount. This first method has drawbacks in that, although Spirality is eliminated, the two-fold yarn production is expensive and further a garment, knitted by such yarn, is heavier, in fact double in weight.

Another method includes knitting two single yarns, of equal and opposite twist liveliness values, per feeder. This method, (similar to the "plating" process) has drawbacks as aforedescribed. Alternatively, two single yarns of equal and opposite twist liveliness values can be used in a method of knitting alternate courses. Even though this method eliminates the overall Spirality of a knitted fabric, it provides the fabric surface with an undesirable "cockling" effect.

Furthermore, for the above methods, the production of two types of yarns having equal twist amount and opposite twist direction, as well as the actual fabric production process, is costly. In addition, the method is also labour intensive because it requires yarn package marking and inspection for the avoidance of mixing up the yarn types during the fabric production.

Chemical methods of eliminating Spirality include correction of the problem by imposing distortion of the fabric so that the wales straighten out and are subsequently set in a straightened form. Setting can be achieved by using resins, heat, steam or mercerization. However, setting by resin, steam or dry heat is a transient measure, because as soon as the fabric is wet the fault returns. Moreover, setting the twist of a cotton yarn which contains a small percentage of low melt polyester fibres reduces the fibre movements in the yarn but the latter becomes stiff.

It follows from the above that, to date, no single method has been successful in permanently eliminating Spirality without disadvantage.

It is therefore an object of the invention to provide a method which both eliminates or at least substantially mitigates Spirality and which does not suffer from the aforementioned drawbacks.

According to a first aspect of the invention there is therefore provided a method for treating a yarn so as to eliminate Spirality in a knitted fabric comprising:

a) taking a single yarn that has been twisted in a first direction and thereafter set in said first direction; and

b) twisting said yarn in a second opposite direction with respect to said first direction.

According to a further aspect of the invention there is provided a method for treating a yarn so as to eliminate Spirality in a knitted fabric comprising:

a) taking a single yarn and twisting it in a first direction or taking a single yarn that has been twisted in a first direction;

b) setting the said twisted yarn; and

c) twisting said set yarn in a second opposite direction with respect to said first direction.

It will be implicit from the above that the invention involves taking a single yarn that has either been twisted and set in a first direction or taking a single yarn which may or may not have been twisted and twisting and/or setting said yarn in a first direction and then treating the yarn as per the above so that said twisted and set yarn is twisted in a second opposite direction with respect to said first direction.

In the above described method where a twist in a first direction results in the yarn being Z twisted then the said twist in the second direction will be in an S direction and effectively "untwisting" the yarn. Ideally, the amount of twist and untwist, or counter twist, will be balanced so as to ensure that torque created by Z twisting and remaining in the yarn will be balanced by torque created by S twisting so providing for a "balanced yarn". It follows, that the degree of first and second twisting, and the respective directions of same, will vary according to the nature of yarn to be twisted but in any event, will be so practised as to produce a balanced yarn.

Fabrics produced from yarns treated as per the above method typically exhibit no, or at least very little, Spirality before and after processing.

It will be apparent to those skilled in the art that Z twisted yarns produce knitted fabric presenting Z spirality. However, when yarn treated as per the above described method is knitted, and the ensuing knitted fabric is wet processed and dried it can be seen that the Spirality almost disappears depending on the amount of S twist there was inserted. This can be explained if the two counter torsional forces balance each other during the wetting process as was described previously.

We have noticed a curious phenomenon associated with the invention in that, before washing a fabric we can sometimes see Spirality in a direction opposite to that normally anticipated for a given yarn, eg a Z twisted yarn normally exhibits Z-spirality before and after processing, but surprisingly, a Z twisted yarn treated in accordance with the invention exhibits S-spirality of low order before washing.

It follows that yarn treated in accordance with the invention is free of any distorting forces and a permanent twist setting usually is achieved, resulting in the knitted fabric being free of Spirality. Further, we have noticed that the yarn and consequently the knitted fabric is more bulky, fuller and has an unusual handle, similar to that given by a twistless yarn.

It was thought that, since twist supplies the yarn with strength, the treated yarn would be "untwisted" and therefore reduced in strength. It was found that the strength was reduced, as was expected due to the untwisting process, but not seriously. Accordingly, use of the method does not deleteriously affect the yarn and the garment subsequently produced therefrom.

The invention also provides for an apparatus that is adapted to treat the yarn according to the aforementioned methods.

Accordingly, the invention provides for an apparatus for treating a yarn so as to eliminate Spirality in a knitted fabric by said yarn comprising; a feed means for feeding a single yarn, that has been twisted in a first direction and set therein, to a reverse twisting means which twists said yarn in a second opposite direction with respect to said first direction.

Further aspects of the invention include an apparatus which is adapted to treat a yarn that has been twisted in a first direction but not yet set and which therefore further includes a setting means for the purpose of setting said yarn in said first direction prior to transferring said yarn to said reverse twisting means.

A yet further aspect of the invention involves the provision of an apparatus which further includes a first twisting means whereby the apparatus is adapted to feed a single yarn to said first twisting means so as to twist the yarn in a first direction and which also includes a first transfer means which transfers said twisted yarn to a setting means where said yarn is set; and also a second transfer means which transfers said twisted and set yarn to a reverse twisting means which twists said yarn in a second opposite direction with respect to said first direction.

In preferred embodiments of the invention said apparatus includes a means for extracting said yarn from the spinning frame and/or a means for feeding said treated yarn to a knitting machine.

According to a further aspect of the invention, there is provided an apparatus for eliminating Spirality in a knitted fabric comprising:

a) means for extracting yarn from a spinning frame;

b) means for twisting said yarn in a first direction as it is wrapped about a first reel member;

c) means for setting the said twisted yarn; and

d) means for twisting said set yarn in a second opposite direction with respect to said first direction as it is wrapped about a second reel member.

Yarn thus treated as aforedescribed can then be stored on the second reel member prior to use.

Preferably said apparatus includes a knitting machine to which said treated yarn is transferred so as to produce a knitted fabric.

Ideally, the apparatus will be designed to operate so that yarn in accordance with the invention is produced at a rate compatible to the operating rate of the knitting machine.

Embodiments of the invention will now be described by way of example only. With reference to the following examples wherein;

Figure 1 and Table 1 show the Spirality characteristics of a normal and two processed yarns, which processed yarns have been treated in accordance with the method of the invention.

Figure 2 and Table 2 show the Spirality characteristics of further yarns treated in accordance with the invention compared to untreated yarns.

Figure 3 shows the Spirality characteristics of an untreated yarn compared to a set yarn and a treated yarn.

Figure 4 shows the Spirality characteristics of a further yarn compared to a normal yarn, a set yarn and a treated yarn.

Figure 5 shows the Spirality characteristics of a further yarn when treated in accordance with the invention compared to an untreated yarn.

<u>Example 1</u>

The yarn used was a quantity of cotton ring-spun single yarn which was unwaxed and Z-twisted. The yarn had a count of Nec 20 (30 Tex) and a twist amount of 734 tpm (≈18.6 tpi) or twist factor (tpi/√Nec) of 4.17.

This yarn was steam set in a steaming machine Sanderson under pressure of 10 psi in 105°C for a time of 20 minutes.

The "untwisting" process took place on a two-for-one Volkmann VTS-08 twisting frame. The least tension was used in the "yarn tensioning" accessory in the used spindle of the machine. The twist amount of 111 tpm in S-direction was inserted in the set yarn, leaving the yarn with a Z direction twist and an actual measured net twist amount of approximately 620 tpm.

Following conventional processing the yarn was then knitted on a Wildt Model 5 circular, one feeder (single jersey) machine. The machine had a diameter of 9" and a number of 420 needles (gauge E14). This machine had a cam box revolving in the anti–clockwise direction (as looked at from above) and no arrangement for positive feed of the yarn to the knitting point had been done. After calculation, the loop length was found to be 4.83 mm.

The produced fabric was fully wetted by immersion in a basin full of warm water (40–45°C) and dried in normal atmospheric conditions (20°C, 65%)

The Spirality angle of this "processed 1" fabric, before and after the wetting process was measured. For comparison, a non processed yarn ("normal"), having the same original specifications as the "processed 1" yarn, was also knitted and subjected to the same wetting and drying processes keeping exactly the same settings in all the processing stages. The obtained results are shown in Table 1.

Example 2

The above experiment was repeated except in that the amount of S direction twist in the "untwisting" stage was 163 tpm, resulting in a net twist of approximately 576 tpm (14.6 tpi). The Spirality angles of this "process 2" fabric are also shown in Table 1.

Results

It can be seen from Table 1 that the Spirality of an untreated cotton ring–spun yarn both before and after wetting is 23 degrees. In contrast, treating the yarn according to the first method and thus inserting twist in the order of 111 tpm in S direction reduced Spirality to 3 degrees before wetting and 3 degrees after wetting. Further, treating the yarn such that twist of a magnitude of 163 tpm in the S direction was inserted resulted in Spirality of -2 degrees before wetting and 1 degree after wetting. Clearly, by selectively controlling the amount of twist inserted into the yarn one can control the degree of Spirality in the knitted fabric.

These results are illustrated graphically in Figure A.

Further experimental results are shown in Table 2, Figures 2, 3, 4 and 5.

Turning firstly to Table 2, it can be seen that row 1 shows the results of a normal yarn both before and after wetting. The angle of Spirality being 31 degrees and 26 degrees respectively.

On row 2, it can be seen that steaming this yarn results in a reduction in Spirality from 31 degrees to 13.5 degrees before wetting, and from 26 degrees to 13.5 degrees after wetting. Further, it can be seen that the wetting process has no effect on the Spirality of a steamed yarn.

In contrast, towards the bottom of Table 2, it can be seen that yarns treated in accordance with the invention, having a variable degrees of untwist, as referenced by numbers 154, 163, and 175, have a significantly reduced angle of Spirality both before and after wetting, the Spirality before wetting being 2 degrees or less from the vertical fabric axis.

These results are illustrated in Figure 2 where it can be graphically seen that untwisting of the yarns in the method in accordance with the invention produces a significant reduction in the angle of Spirality.

In Figure 3 a comparison is made between a) a yarn which came directly from a spinning frame; b) the same yarn as a) after steaming (setting process); and c) the yarn processed with the new method. As can be seen again, the new method produces significantly enhanced results both before and after wetting. The best results being achieved before wetting.

Using a different yarn, these results were repeated and are illustrated in Figure 4.

The difference in Spirality between normal and processed yarns is illustrated in Figure 5 where it can be seen that treating the yarns in accordance with the invention produces a significant decrease in the angle of spirality.

The working of the aforementioned method, when using a single yarn that has been twisted in a first direction and set, involves the provision of at least a reverse twisting means which is adapted to twist said yarn in a second opposite direction with respect to said first direction. Further, said reverse twisting means incorporates a control means such that an operator can determine the degree of reverse twist to be inserted into the yarn.

In the instance where a single yarn which has been twisted in a first direction but not yet set is to be used, then the apparatus is further provided with a setting means so that said twisted yarn can be set prior to transferring to said reverse twisting means.

In a further instance where a single yarn has neither been set or twisted, the apparatus includes a first twisting means for twisting said yarn in a first direction; and suitable means for transferring said yarn to a setting means where said yarn is set in said first direction; suitable means for transferring said set twisted yarn to a reverse twisting means where said yarn is twisted in a second opposite direction with respect to said first direction.

The amount of reverse twist inserted into the yarn will be determined by the amount of twist provided in, and remaining in, the yarn by twisting in said first direction. Ideally, the amount of reverse twist or "untwisting" will equal the amount of first twist provided in, and remaining in said yarn, so as to provide a yarn which is balanced and thus not exhibiting Spirality when a knitted fabric is provided.

CLAIMS

1. A method for treating a yarn so as to eliminate Spirality in a knitted fabric comprising;

a) taking a single yarn which has been twisted in a first direction and thereafter set in said first direction; and

b) twisting said set yarn in a second opposite direction with respect to said first direction.

2. A method according to Claim 1 wherein the stage;

a) involves;

   i) taking a single yarn that has been twisted in a first direction; and

   ii) setting said twisted yarn in said first direction; and then

b) twisting said set yarn in a second opposite direction with respect to said first direction.

3. A method according to Claim 1 wherein said stage;

a) involves;

   i) taking a single yarn;

   ii) twisting said yarn in a first direction;

   iii) setting said twisted yarn; and then

b) twisting said set yarn in a second opposite direction with respect to said first direction.

4. A method according to any preceding Claim wherein the amount of twist in said first direction, and remaining in said yarn, determines the amount of twist in said second direction so that twist in said second direction is equal to said twist in the yarn from the said first direction.

5. A method according to any preceding Claim which further includes an initial stage of extracting yarn from a spinning frame and then treating the yarn as described in Claims 1-4 above.

6. A method according to any preceding Claim which further includes a final stage of feeding said treated yarn to a knitting machine.

7. An apparatus for treating a yarn so as to eliminate Spirality in a knitted fabric comprising;
a feed means for feeding a single yarn, that has been twisted in a first direction and set therein, to a reverse twisting means which twists said yarn in a second opposite direction with respect to said first direction.

8. An apparatus according to Claim 7 wherein the feed means is adapted to feed a single yarn that has been twisted in a first direction to a setting means which sets the twisted yarn and which further includes;
a transfer means which transfers said twisted and set yarn to a reverse twisting means which twists said yarn in a second opposite direction with respect to said first direction.

9. An apparatus according to Claims 7 or 8 wherein the feeding means is adapted to feed a single yarn to a first twisting means which twists said yarn in a first direction and which further includes;
a first transfer means which transfers said twisted yarn to a setting means which sets said twisted yarn; and

a second transfer means which transfers said set twisted yarn to a reverse twisting means which twists said yarn in a second opposite direction with respect to said first direction.

10. An apparatus according to Claims 7-9 wherein there is further provided a control means which determines the amount of twist in the yarn from the first twisting process and adjusts the reverse twisting means so that the amount of twist conferred by twisting in said second opposite direction can be selectively controlled and adjusted until it approximately equals the amount of twist provided, and remaining in said yarn, by twisting in said first direction.

11. An apparatus according to Claim 9 wherein there is further provided an initial extraction means for extracting yarn from a spinning means.

12. An apparatus according to Claims 7-11 wherein there is further provided a means for transferring said treated yarn to a knitting machine.

13. An apparatus according to Claim 12 wherein there is further provided a knitting machine.

14. An apparatus for treating a yarn so as to eliminate Spirality in a knitted fabric comprising a means for feeding a single set yarn that has been twisted in a first direction to a twisting means where said yarn is twisted in a second opposite direction with respect to said first direction; a transfer means for transferring said oppositely twisted yarn to a knitting means; and a knitting means where said yarn is knitted into a fabric.

15. A yarn produced by a method in accordance with the invention.

16. A yarn produced by the apparatus in accordance with the invention.

17. A knitted fabric produced in accordance with the method of the invention.

18. A knitted fabric produced by the apparatus in accordance with the invention.

19. A knitted garment produced in accordance with the method of the invention.

20. A knitted garment produced by the apparatus in accordance with the invention.

ABSTRACT

The invention relates to a method and apparatus for manufacturing a yarn which when knitted into a fabric does not exhibit Spirality. Further, the invention provides for a yarn and a knitted fabric when manufactured by the method or apparatus of the invention. Spirality in the knitted fabric is eliminated as a result of treatment of the yarn. Which involves balancing torsional forces in the yarn such that twist in a first direction is counter balanced by twist in a second opposite direction.

TABLE 2

Angle of Spirality (degrees)

No	T.F.	Condition	Bef. Wetting	After Wetting	Difference
1	3.22	Normal	31.0	26.0	-5.0
2	3.22	Steamed	13.5	13.5	0.0
Difference			17.5	12.5	
3	4.04	Normal	38.5	23.5	-15.0
4	4.04	Steamed	19.0	11.0	8.0
Difference			19.5	12.5	
5	4.04	Untwist 154	1.5	3.5	2.0
6	4.04	Untwist 163	-2.0	3.0	5.0
7	4.04	Untwist 175	1.5	6.5	5.0

Fig. 4 Spirality of fabrics produced from these yarns of the same net Z twist (Nec 20)

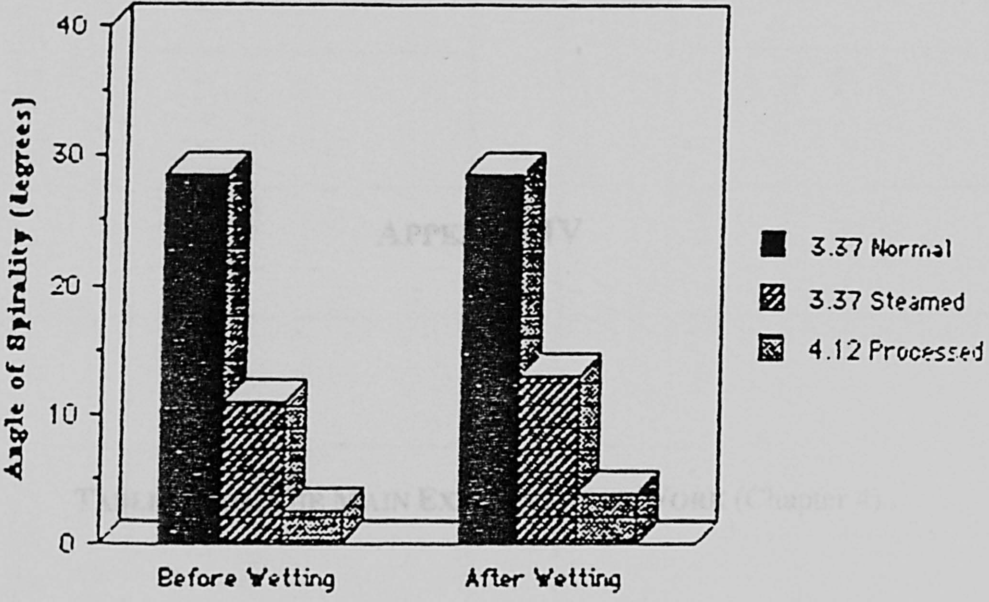
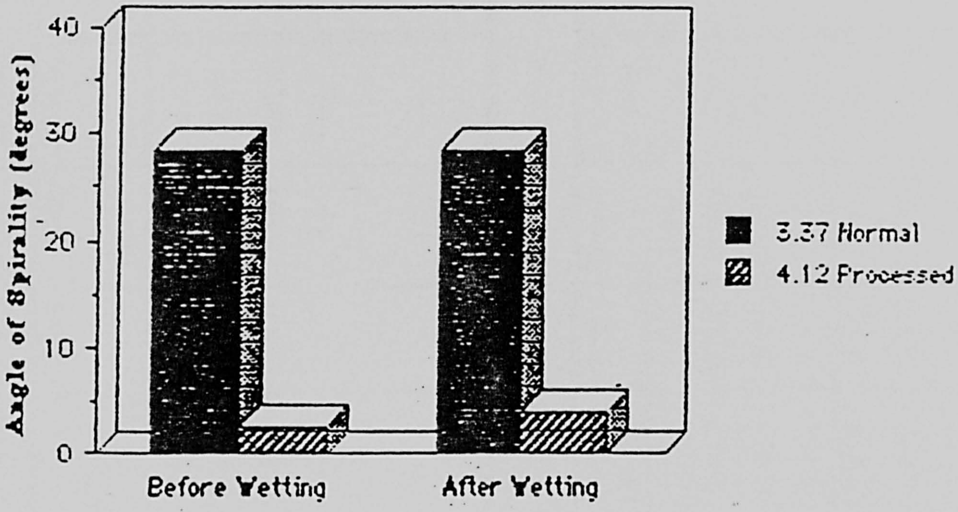


Fig. 5 Difference in Spirality



EXPERIMENTAL DEVICE SERVING THIS NEW METHOD

Today, this new method could be applicable in the knitting industry with an extra cost for the untwisting process.

In order to avoid any extra yarn and fabric production costs, a modified Two-for-One spindle unit mount on the knitting machine, is going to be used in the near future. Also, an on-line system for detecting the spirality and adjusting the modified device will fulfil the expectations of the whole project.

APPENDIX IV

TABLES FROM THE MAIN EXPERIMENTAL WORK (Chapter 4)

Table IV.1 Testing Results Obtained by Examining Yarn & Fabric of **“39 tex NORMAL TF 32.3”**

Nominal S Untwist	Linear Density	Evenness	Hairiness	Thickness 2.04 N.m^{-2}	Elongat.	Tenacity	Actual Net Z Twist	Spirality ° (0 days)		Spirality ° (13 days)		THICKNESS (mm)		THICKNESS (13 days) (mm)	
turns.m^{-1}	tex	CVm %	Hairs.m^{-1}	mm	%	cN.tex^{-1}	turns.m^{-1}	B. W.	A. W.	B. W.	A. W.	2.04 N.m^{-2}	102 N.m^{-2}	2.04 N.m^{-2}	102 N.m^{-2}
0	40.48	13.28	81.62	0.410	7.20	12.92	531.7	13.0	15.0	-	-	2.648	1.736	-	-
111	39.40	13.03	95.18	0.403	5.54	8.97	447.6	2.5	5.5	3.5	10.5	2.430	1.492	2.434	1.532
121	39.04	12.33	89.83	0.433	5.84	9.04	460.8	1.5	5.0	3.0	9.5	2.555	1.741	2.680	1.525
133	37.74	12.91	79.35	0.432	5.60	8.19	449.7	1.0	7.0	1.0	9.5	2.649	1.632	2.538	1.585
142	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
154	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
163	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table IV.2 Testing Results Obtained by Examining Yarn & Fabric of **“39 tex STEAMED TF 32.3”**

Nominal S Untwist	Linear Density	Evenness	Hairiness	Thickness 2.04 N.m^{-2}	Elongat.	Tenacity	Actual Net Z Twist	Spirality ° (0 days)		Spirality ° (13 days)		THICKNESS (mm)		THICKNESS (13 days) (mm)	
turns.m^{-1}	tex	CVm %	Hairs.m^{-1}	mm	%	cN.tex^{-1}	turns.m^{-1}	B. W.	A. W.	B. W.	A. W.	2.04 N.m^{-2}	102 N.m^{-2}	2.04 N.m^{-2}	102 N.m^{-2}
0	39.82	13.06	71.45	0.417	6.83	11.80	520.9	10.0	14.5	-	-	2.471	1.476	-	-
111	38.64	12.19	81.04	0.435	5.09	7.53	437.5	0.5	8.0	-1.0	6.5	2.124	1.240	2.520	1.453
121	38.22	12.74	76.24	0.461	5.18	7.47	446.1	0.5	9.0	-2.0	4.0	2.474	1.532	2.518	1.432
133	37.10	13.14	74.38	0.436	4.41	5.99	436.2	-3.5	2.5	-1.5	4.5	2.505	1.507	2.458	1.469
142	37.52	13.08	71.05	0.452	4.77	6.40	436.9	-4.0	2.0	-2.5	5.0	2.363	1.472	2.424	1.475
154	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
163	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table IV.3 Testing Results Obtained by Examining Yarn & Fabric of "**39 tex NORMAL TF 33.4**"

Nominal S Untwist	Linear Density	Evenness	Hairiness	Thickness 2.04 N.m^{-2}	Elongat.	Tenacity	Actual Net Z Twist	Spirality ° (0 days)		Spirality ° (13 days)		THICKNESS (mm)		THICKNESS (13 days) (mm)	
turns.m^{-1}	tex	CVm %	Hairs.m^{-1}	mm	%	cN.tex^{-1}	turns.m^{-1}	B. W.	A. W.	B. W.	A. W.	2.04 N.m^{-2}	102 N.m^{-2}	2.04 N.m^{-2}	102 N.m^{-2}
0	40.00	12.14	68.54	0.391	6.84	14.33	554.7	16.5	16.5	-	-	2.764	1.770	-	-
111	38.96	12.96	72.29	0.402	6.40	11.93	475.4	7.0	11.0	5.0	12.5	2.390	1.464	2.525	1.577
121	38.68	12.43	74.06	0.420	6.42	10.35	465.1	2.5	10.0	4.5	11.0	2.660	1.665	2.675	1.562
133	39.18	13.25	72.57	0.436	5.88	9.55	454.9	1.5	8.0	2.0	10.0	2.468	1.594	2.586	1.591
142	38.56	13.15	68.78	0.419	6.01	9.11	449.0	0.0	7.5	1.0	10.0	2.550	1.578	2.575	1.610
154	39.20	12.61	76.11	0.411	5.45	8.29	449.8	-0.5	8.0	0.5	12.5	2.521	1.542	2.855	1.685
163	39.20	12.47	67.99	0.401	5.53	8.91	447.7	-1.0	4.5	0.5	9.0	2.498	1.543	2.865	1.746

Table IV.4 Testing Results Obtained by Examining Yarn & Fabric of "**39 tex STEAMED TF 33.4**"

Nominal S Untwist	Linear Density	Evenness	Hairiness	Thickness 2.04 N.m^{-2}	Elongat.	Tenacity	Actual Net Z Twist	Spirality ° (0 days)		Spirality ° (13 days)		THICKNESS (mm)		THICKNESS (13 days) (mm)	
turns.m^{-1}	tex	CVm %	Hairs.m^{-1}	mm	%	cN.tex^{-1}	turns.m^{-1}	B. W.	A. W.	B. W.	A. W.	2.04 N.m^{-2}	102 N.m^{-2}	2.04 N.m^{-2}	102 N.m^{-2}
0	39.50	13.01	54.83	0.406	6.91	13.13	553.3	10.0	13.0	-	-	2.531	1.501	-	-
111	39.28	12.57	63.72	0.423	5.72	9.91	466.0	1.0	7.5	0.0	5.0	2.230	1.228	2.423	1.451
121	39.52	12.74	53.06	0.435	6.08	9.67	457.4	-2.0	7.0	0.5	3.5	2.517	1.517	2.455	1.422
133	38.66	13.97	60.71	0.437	5.94	8.60	453.8	-2.0	4.5	-1.0	5.0	2.534	1.513	2.428	1.484
142	39.40	13.65	56.38	0.430	5.42	7.78	454.4	-2.5	1.0	-1.0	5.0	2.394	1.452	2.500	1.519
154	38.62	13.19	61.49	0.428	4.94	7.47	438.7	-5.5	2.5	0.0	3.5	2.285	1.418	2.778	1.601
163	38.52	12.89	59.74	0.421	4.70	6.94	444.1	-5.5	2.5	-2.0	5.5	2.443	1.447	2.680	1.628

Table IV.5 Testing Results Obtained by Examining Yarn & Fabric of **"39 tex NORMAL TF 39.5"**

Nominal S Untwist	Linear Density	Evenness	Hairiness	Thickness 2.04 N.m^{-2}	Elongat.	Tenacity	Actual Net Z Twist	Spirality ° (0 days)		Spirality ° (13 days)		THICKNESS (mm)		THICKNESS (13 days) (mm)	
turns.m^{-1}	tex	CVm %	Hairs.m^{-1}	mm	%	cN.tex^{-1}	turns.m^{-1}	B. W.	A. W.	B. W.	A. W.	2.04 N.m^{-2}	102 N.m^{-2}	2.04 N.m^{-2}	102 N.m^{-2}
0	39.20	12.07	63.15	0.384	7.90	15.78	642.1	28.0	22.0	-	-	2.642	1.845	-	-
111	38.98	12.45	65.42	0.371	6.69	13.33	539.6	17.0	18.5	11.5	14.0	2.365	1.480	2.590	1.600
121	40.04	11.99	56.51	0.393	6.83	13.47	531.8	5.0	13.0	11.0	14.0	2.584	1.616	2.641	1.619
133	38.60	12.43	50.15	0.396	7.04	14.13	518.1	9.5	15.0	10.0	13.5	2.652	1.684	2.387	1.551
142	40.44	12.41	51.87	0.392	6.25	12.07	514.5	8.0	12.0	9.0	13.5	2.488	1.613	2.567	1.660
154	38.84	12.46	57.34	0.392	5.75	11.37	492.6	3.5	9.0	8.0	14.0	2.363	1.500	2.850	1.754
163	39.48	12.68	55.63	0.380	6.21	12.13	500.2	2.5	10.0	1.5	9.5	2.617	1.606	2.861	1.712

Table IV.6 Testing Results Obtained by Examining Yarn & Fabric of **"39 tex STEAMED TF 39.5"**

Nominal S Untwist	Linear Density	Evenness	Hairiness	Thickness 2.04 N.m^{-2}	Elongat.	Tenacity	Actual Net Z Twist	Spirality ° (0 days)		Spirality ° (13 days)		THICKNESS (mm)		THICKNESS (13 days) (mm)	
turns.m^{-1}	tex	CVm %	Hairs.m^{-1}	mm	%	cN.tex^{-1}	turns.m^{-1}	B. W.	A. W.	B. W.	A. W.	2.04 N.m^{-2}	102 N.m^{-2}	2.04 N.m^{-2}	102 N.m^{-2}
0	40.32	12.46	46.01	0.387	7.10	13.20	630.1	14.5	19.0	-	-	2.466	1.532	-	-
111	39.50	13.80	47.37	0.421	6.30	11.08	531.6	1.0	10.0	4.0	10.0	1.963	1.125	2.502	1.508
121	40.44	13.18	42.96	0.413	6.97	12.29	531.9	-2.5	7.5	4.0	9.0	2.523	1.514	2.400	1.490
133	38.72	12.83	36.79	0.410	6.50	10.85	511.1	-2.5	9.5	2.5	8.5	2.466	1.540	2.469	1.521
142	40.68	12.45	39.76	0.409	6.77	12.79	513.6	-1.0	8.0	2.5	9.0	2.412	1.519	2.410	1.532
154	38.80	13.00	43.25	0.411	6.02	10.89	486.6	-2.5	7.5	2.0	10.0	2.350	1.465	2.777	1.660
163	39.08	13.08	37.91	0.403	5.81	10.10	481.0	-2.5	6.0	2.5	9.0	2.474	1.498	2.644	1.600

Table IV.7 Testing Results Obtained by Examining Yarn & Fabric of "**29 tex NORMAL TF 32.4**"

Nominal S Untwist	Linear Density	Evenness	Hairiness	Thickness 2.04 N.m^{-2}	Elongat.	Tenacity	Actual Net Z Twist	Spirality ° (0 days)		Spirality ° (13 days)		THICKNESS (mm)		THICKNESS (13 days) (mm)	
turns.m^{-1}	tex	CVm %	Hairs.m^{-1}	mm	%	cN.tex^{-1}	turns.m^{-1}	B. W.	A. W.	B. W.	A. W.	2.04 N.m^{-2}	102 N.m^{-2}	2.04 N.m^{-2}	102 N.m^{-2}
0	29.90	14.10	58.84	0.338	7.00	14.06	616.9	16.0	20.0	-	-	2.278	1.360	-	-
111	29.56	13.64	60.67	0.356	6.16	11.40	537.2	6.5	11.5	4.0	14.5	2.187	1.197	2.390	1.283
129	29.38	14.84	67.75	0.361	5.79	9.24	523.7	2.0	11.0	2.5	14.0	2.547	1.408	2.290	1.250
147	30.28	12.85	61.25	0.363	5.01	7.75	528.5	0.0	12.0	1.5	12.5	2.452	1.316	2.334	1.281
163	30.52	12.92	63.88	0.375	4.74	6.91	522.0	-3.5	9.5	0.5	11.0	2.203	1.234	2.523	1.330
182	28.82	13.54	68.61	0.352	4.95	6.60	511.0	-6.0	9.5	-1.5	11.0	2.278	1.227	2.558	1.365
200	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
220	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table IV.8 Testing Results Obtained by Examining Yarn & Fabric of "**29 tex STEAMED TF 32.4**"

Nominal S Untwist	Linear Density	Evenness	Hairiness	Thickness 2.04 N.m^{-2}	Elongat.	Tenacity	Actual Net Z Twist	Spirality ° (0 days)		Spirality ° (13 days)		THICKNESS (mm)		THICKNESS (13 days) (mm)	
turns.m^{-1}	tex	CVm %	Hairs.m^{-1}	mm	%	cN.tex^{-1}	turns.m^{-1}	B. W.	A. W.	B. W.	A. W.	2.04 N.m^{-2}	102 N.m^{-2}	2.04 N.m^{-2}	102 N.m^{-2}
0	29.60	14.56	67.91	0.351	6.40	11.13	619.5	9.5	12.0	-	-	2.057	1.163	-	-
111	28.74	14.53	59.25	0.358	5.08	8.21	537.3	-3.5	7.0	-1.5	9.5	2.298	1.465	2.291	1.212
129	28.80	13.61	55.20	0.373	5.35	8.32	537.9	-3.5	4.0	-2.0	9.5	2.329	1.233	2.327	1.165
147	28.82	13.89	59.75	0.396	4.81	7.82	529.5	-6.5	3.5	-3.5	9.0	2.127	1.182	2.209	1.207
163	29.00	13.64	58.45	0.371	4.21	5.81	502.1	-7.5	3.0	-3.5	7.5	2.077	1.150	2.240	1.184
182	29.16	13.02	60.92	0.369	4.04	5.89	499.9	-8.0	3.0	-5.5	4.5	2.185	1.160	2.285	1.268
200	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
220	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table IV.9 Testing Results Obtained by Examining Yarn & Fabric of **"29 tex NORMAL TF 34.9"**

Nominal S Untwist	Linear Density	Evenness	Hairiness	Thickness 2.04 N.m^{-2}	Elongat.	Tenacity	Actual Net Z Twist	Spirality ° (0 days)		Spirality ° (13 days)		THICKNESS (mm)		THICKNESS (13 days) (mm)	
turns.m^{-1}	tex	CVm %	Hairs.m^{-1}	mm	%	cN.tex^{-1}	turns.m^{-1}	B. W.	A. W.	B. W.	A. W.	2.04 N.m^{-2}	102 N.m^{-2}	2.04 N.m^{-2}	102 N.m^{-2}
0	28.66	14.92	53.13	0.333	6.74	13.33	665.7	20.0	18.5	-	-	2.400	1.450	-	-
111	29.88	14.30	57.15	0.327	6.16	12.11	575.8	5.5	14.5	6.0	13.0	2.206	1.193	2.478	1.374
129	28.40	14.72	53.34	0.343	6.14	12.38	573.8	3.5	15.0	4.0	15.5	2.577	1.436	2.224	1.240
147	28.94	14.77	49.83	0.346	5.49	9.80	556.0	-1.0	15.5	3.5	15.5	2.416	1.305	2.484	1.396
163	28.64	15.06	50.92	0.351	5.67	9.62	544.2	-1.5	10.0	3.0	15.5	2.267	1.238	2.440	1.335
182	28.60	14.01	51.67	0.337	5.72	9.28	536.4	-3.0	8.0	0.5	13.5	2.375	1.302	2.496	1.377
200	28.60	13.81	48.95	0.347	5.28	8.95	513.8	-4.0	9.5	1.5	9.0	2.281	1.180	2.807	1.478
220	28.30	13.35	49.74	0.359	4.84	7.23	521.7	-7.0	8.5	1.0	10.0	2.292	1.272	2.707	1.446

Table IV.10 Testing Results Obtained by Examining Yarn & Fabric of **"29 tex STEAMED TF 34.9"**

Nominal S Untwist	Linear Density	Evenness	Hairiness	Thickness 2.04 N.m^{-2}	Elongat.	Tenacity	Actual Net Z Twist	Spirality ° (0 days)		Spirality ° (13 days)		THICKNESS (mm)		THICKNESS (13 days) (mm)	
turns.m^{-1}	tex	CVm %	Hairs.m^{-1}	mm	%	cN.tex^{-1}	turns.m^{-1}	B. W.	A. W.	B. W.	A. W.	2.04 N.m^{-2}	102 N.m^{-2}	2.04 N.m^{-2}	102 N.m^{-2}
0	29.88	13.48	53.33	0.341	6.79	12.03	660.4	10.0	15.5	-	-	2.255	1.214	-	-
111	29.16	13.99	51.09	0.356	5.36	9.45	566.7	-0.5	8.0	0.0	11.0	2.405	1.472	2.214	1.222
129	29.60	14.05	50.52	0.359	5.64	10.02	568.9	-4.0	8.5	0.0	10.0	2.310	1.264	2.210	1.192
147	28.98	14.39	47.20	0.365	4.61	8.30	551.5	-2.5	7.0	0.0	9.0	2.160	1.187	2.387	1.250
163	28.70	14.04	45.41	0.381	5.46	8.69	543.8	-6.0	5.5	-3.0	7.0	2.170	1.150	2.268	1.226
182	29.56	14.82	48.29	0.388	5.05	8.80	530.7	-8.0	6.5	-6.5	6.5	2.195	1.163	2.380	1.277
200	28.90	14.74	46.80	0.377	4.77	7.42	521.9	-10.0	2.0	-1.5	5.0	1.972	1.103	2.526	1.317
220	28.02	14.45	50.12	0.354	5.46	9.08	511.7	-11.0	2.0	-4.5	6.5	2.102	1.170	2.508	1.296

Table IV.11 Testing Results Obtained by Examining Yarn & Fabric of "**29 tex NORMAL TF 38.6**"

Nominal S Untwist	Linear Density	Evenness	Hairiness	Thickness 2.04 N.m^{-2}	Elongat.	Tenacity	Actual Net Z Twist	Spirality ° (0 days)		Spirality ° (13 days)		THICKNESS (mm)		THICKNESS (13 days) (mm)	
turns.m^{-1}	tex	CVm %	Hairs.m^{-1}	mm	%	cN.tex^{-1}	turns.m^{-1}	B. W.	A. W.	B. W.	A. W.	2.04 N.m^{-2}	102 N.m^{-2}	2.04 N.m^{-2}	102 N.m^{-2}
0	29.38	14.17	54.87	0.329	7.14	14.63	742.3	27.0	27.5	-	-	2.466	1.536	-	-
111	29.50	13.58	46.03	0.327	6.79	13.65	632.9	13.0	24.5	9.0	18.5	2.404	1.294	2.543	1.447
129	29.40	14.19	47.53	0.349	6.38	12.72	608.3	7.5	19.0	5.0	14.5	2.620	1.441	2.410	1.282
147	28.76	14.53	44.15	0.316	6.15	13.03	593.2	2.0	17.0	6.0	20.0	2.405	1.347	2.357	1.300
163	29.76	14.72	40.99	0.343	6.19	12.82	603.5	1.5	14.0	6.0	19.0	2.262	1.260	2.582	1.463
182	28.92	14.83	44.93	0.336	6.15	13.03	584.7	-2.5	11.5	5.0	15.0	2.216	1.205	2.644	1.513
200	30.18	14.42	32.75	0.323	5.85	11.51	575.6	-4.5	12.0	4.5	14.0	2.176	1.239	2.797	1.493
220	30.24	15.01	36.40	0.377	5.77	11.70	558.0	-5.0	8.5	2.5	11.5	2.255	1.300	2.717	1.472

Table IV.12 Testing Results Obtained by Examining Yarn & Fabric of "**29 tex STEAMED TF 38.6**"

Nominal S Untwist	Linear Density	Evenness	Hairiness	Thickness 2.04 N.m^{-2}	Elongat.	Tenacity	Actual Net Z Twist	Spirality ° (0 days)		Spirality ° (13 days)		THICKNESS (mm)		THICKNESS (13 days) (mm)	
turns.m^{-1}	tex	CVm %	Hairs.m^{-1}	mm	%	cN.tex^{-1}	turns.m^{-1}	B. W.	A. W.	B. W.	A. W.	2.04 N.m^{-2}	102 N.m^{-2}	2.04 N.m^{-2}	102 N.m^{-2}
0	29.68	13.53	47.03	0.323	7.55	14.31	731.2	15.5	24.0	-	-	2.430	1.371	-	-
111	29.56	14.04	45.52	0.331	6.13	11.88	635.4	0.0	17.0	5.0	14.5	2.411	1.455	2.502	1.285
129	29.14	14.33	37.43	0.356	6.34	11.46	621.5	-1.0	15.5	2.0	13.5	2.517	1.370	2.316	1.273
147	30.00	14.36	37.32	0.345	5.69	11.15	611.6	-4.5	13.5	1.0	14.5	2.300	1.311	2.297	1.305
163	28.90	14.85	36.87	0.367	5.83	10.62	596.5	-4.5	8.0	1.0	13.5	2.108	1.159	2.410	1.295
182	29.48	13.84	40.57	0.362	5.55	10.65	587.5	-7.5	5.5	-1.5	9.0	2.170	1.226	2.382	1.314
200	29.76	13.57	34.86	0.340	5.34	9.63	552.9	-9.5	3.5	0.0	4.0	2.143	1.184	2.466	1.323
220	29.66	14.15	36.83	0.368	5.56	9.83	559.0	-10.5	2.5	-3.5	3.5	2.129	1.176	2.465	1.344

Table IV.A.1 **Hairiness** Testing Results of the Yarn "**39 tex TF 32.3**"

A. NORMAL

S Untwist (turns.m^{-1})	Hairs.m^{-1}	CV %	S.D.
0	81.62	4.51	3.68
111	95.18	4.06	3.86
121	89.83	4.43	3.98
133	79.35	3.80	3.01
142	-	-	-
154	-	-	-
163	-	-	-

B. STEAMED

S Untwist (turns.m^{-1})	Hairs.m^{-1}	CV %	S.D.
0	71.45	3.41	2.44
111	81.04	3.58	2.90
121	76.24	4.38	3.34
133	74.38	5.42	4.03
142	71.05	3.28	2.33
154	-	-	-
163	-	-	-

Table IV.A.2 **Hairiness** Testing Results of the Yarn "**39 tex TF 33.4**"

A. NORMAL

S Untwist (turns.m^{-1})	Hairs.m^{-1}	CV %	S.D.
0	68.54	6.99	4.79
111	72.29	5.81	4.20
121	74.06	3.31	2.45
133	72.57	5.93	4.30
142	68.78	2.92	2.01
154	76.11	4.58	3.49
163	67.99	4.57	3.11

B. STEAMED

S Untwist (turns.m^{-1})	Hairs.m^{-1}	CV %	S.D.
0	54.83	6.26	3.43
111	63.72	4.18	2.66
121	53.06	6.90	3.66
133	60.71	4.68	2.84
142	56.38	4.92	2.77
154	61.49	3.66	2.25
163	59.74	8.74	5.22

Table IV.A.3 **Hairiness** Testing Results of the Yarn "**39 tex TF 39.5**"

A. NORMAL

S Untwist (turns.m^{-1})	Hairs.m^{-1}	CV %	S.D.
0	63.15	5.74	3.63
111	65.42	4.10	2.68
121	56.51	3.94	2.22
133	50.15	6.38	3.20
142	51.87	5.00	2.60
154	57.34	2.01	1.15
163	55.63	2.80	1.56

B. STEAMED

S Untwist (turns.m^{-1})	Hairs.m^{-1}	CV %	S.D.
0	46.01	4.68	2.15
111	47.37	7.06	3.34
121	42.96	4.10	1.76
133	36.79	7.71	2.84
142	39.76	9.01	3.58
154	43.25	3.61	1.56
163	37.91	6.06	2.30

Table IV.A.4 **Hairiness** Testing Results of the Yarn "**29 tex TF 32.4**"

A. NORMAL

S Untwist (turns.m^{-1})	Hairs.m^{-1}	CV %	S.D.
0	58.84	6.22	3.66
111	60.67	2.60	1.58
129	67.75	5.35	3.63
147	61.25	3.50	2.15
163	63.88	3.67	2.34
182	68.61	2.88	1.97
200	-	-	-
220	-	-	-

B. STEAMED

S Untwist (turns.m^{-1})	Hairs.m^{-1}	CV %	S.D.
0	67.91	5.09	3.46
111	59.25	3.20	1.90
129	55.20	3.78	2.09
147	59.75	7.21	4.30
163	58.45	3.11	1.82
182	60.92	5.70	3.47
200	-	-	-
220	-	-	-

Table IV.A.5 **Hairiness** Testing Results of the Yarn "**29 tex TF 34.9**"

A. NORMAL

S Untwist (turns.m^{-1})	Hairs.m^{-1}	CV %	S.D.
0	53.13	4.24	2.25
111	57.15	5.46	3.12
129	53.34	4.87	2.60
147	49.83	3.34	1.66
163	50.92	3.78	1.92
182	51.67	4.57	2.36
200	48.95	3.77	1.84
220	49.74	4.84	2.41

B. STEAMED

S Untwist (turns.m^{-1})	Hairs.m^{-1}	CV %	S.D.
0	53.33	3.42	1.82
111	51.09	5.37	2.74
129	50.52	4.32	2.18
147	47.20	5.17	2.44
163	45.41	4.50	2.04
182	48.29	2.96	1.43
200	46.80	5.95	2.78
220	50.12	5.32	2.67

Table IV.A.6 **Hairiness** Testing Results of the Yarn "**29 tex TF 38.6**"

A. NORMAL

S Untwist (turns.m^{-1})	Hairs.m^{-1}	CV %	S.D.
0	54.87	6.19	3.39
111	46.03	5.49	2.53
129	47.53	3.29	1.56
147	44.15	6.08	2.69
163	40.99	5.99	2.46
182	44.93	4.28	1.92
200	32.75	6.02	1.97
220	36.40	5.92	2.15

B. STEAMED

S Untwist (turns.m^{-1})	Hairs.m^{-1}	CV %	S.D.
0	47.03	6.34	2.98
111	45.52	4.76	2.17
129	37.43	4.47	1.67
147	37.32	7.56	2.82
163	36.87	6.64	2.45
182	40.57	6.46	2.62
200	34.86	5.43	1.89
220	36.83	6.10	2.25

Table IV.B.1 **Strength** Testing Results of the Yarn "**39 tex Normal TF 32.3**"

Nominal S Untwist	**Elongation**		**Force**		**Work to Rupture**		**Tenacity**	
turns.m^{-1}	**%**	Variance	**cN**	Variance	**cN.cm**	Variance	**cN.tex^{-1}**	Variance
0	7.20	4.35	516.93	5.13	883.01	8.86	12.92	5.13
111	5.54	7.61	358.67	11.12	506.28	17.69	8.97	11.12
121	5.84	7.89	361.49	16.04	545.92	22.40	9.04	16.04
133	5.60	6.86	327.44	15.59	470.34	18.44	8.19	15.59
142	-	-	-	-	-	-	-	-
154	-	-	-	-	-	-	-	-
163	-	-	-	-	-	-	-	-

Table IV.B.2 **Strength** Testing Results of the Yarn "**39 tex Normal TF 33.4**"

Nominal S Untwist	**Elongation**		**Force**		**Work to Rupture**		**Tenacity**	
turns.m^{-1}	**%**	Variance	**cN**	Variance	**cN.cm**	Variance	**cN.tex^{-1}**	Variance
0	6.84	5.90	573.36	7.42	947.36	12.27	14.33	7.42
111	6.40	4.64	477.27	6.63	751.24	11.12	11.93	6.63
121	6.42	6.43	414.08	9.46	659.20	13.69	10.35	9.46
133	5.88	4.98	381.95	10.46	557.01	13.53	9.55	10.46
142	6.01	6.03	364.25	8.49	552.63	13.47	9.11	8.49
154	5.45	7.33	331.69	17.39	478.98	22.52	8.29	17.39
163	5.53	9.03	356.57	16.42	520.52	23.10	8.91	16.42

Table IV.B.3 **Strength** Testing Results of the Yarn "**39 tex Normal TF 39.5**"

Nominal S Untwist	**Elongation**		**Force**		**Work to Rupture**		**Tenacity**	
turns.m^{-1}	**%**	Variance	**cN**	Variance	**cN.cm**	Variance	**cN.tex^{-1}**	Variance
0	7.90	5.95	631.11	7.52	144.71	13.12	15.78	7.52
111	6.69	5.15	533.01	6.46	867.49	10.22	13.33	6.46
121	6.83	5.94	538.83	7.80	887.52	12.71	13.47	7.80
133	7.04	4.83	565.33	4.77	958.02	9.68	14.13	4.77
142	6.25	6.60	482.67	9.59	748.81	13.97	12.07	9.59
154	5.75	4.17	454.85	7.61	680.90	9.67	11.37	7.61
163	6.21	4.50	485.38	8.42	756.25	11.29	12.13	8.42

Table IV.B.4 **Strength** Testing Results of the Yarn “**29 tex Normal TF 32.4**”

Nominal S Untwist	Elongation		Force		Work to Rupture		Tenacity	
turns.m^{-1}	%	Variance	cN	Variance	cN.cm	Variance	cN.tex^{-1}	Variance
0	7.00	5.64	421.81	7.98	694.52	12.74	14.06	7.98
111	6.16	5.54	342.08	8.64	540.34	12.18	11.40	8.64
129	5.79	6.32	277.25	11.38	402.58	14.74	9.24	11.38
147	5.01	8.44	232.43	12.58	316.55	18.74	7.75	12.58
163	4.74	13.40	207.20	22.15	269.42	31.78	6.91	22.15
182	4.95	13.31	198.07	23.17	254.04	33.73	6.60	23.17
200	-	-	-	-	-	-	-	-
220	-	-	-	-	-	-	-	-

Table IV.B.5 **Strength** Testing Results of the Yarn “**29 tex Normal TF 34.9**”

Nominal S Untwist	Elongation		Force		Work to Rupture		Tenacity	
turns.m^{-1}	%	Variance	cN	Variance	cN.cm	Variance	cN.tex^{-1}	Variance
0	6.74	5.81	399.79	7.24	640.97	11.92	13.33	7.24
111	6.16	5.02	363.22	8.38	540.34	11.27	12.11	8.38
129	6.14	6.37	371.36	8.06	552.07	12.51	12.38	8.06
147	5.49	8.47	294.06	11.87	420.51	18.92	9.80	11.87
163	5.67	6.80	288.73	10.10	410.70	14.92	9.62	10.10
182	5.72	6.10	278.53	9.41	399.58	13.52	9.28	9.41
200	5.28	8.35	268.43	13.62	370.97	19.90	8.95	13.62
220	4.84	9.48	216.91	17.95	286.40	26.22	7.23	17.95

Table IV.B.6 **Strength** Testing Results of the Yarn “**29 tex Normal TF 38.6**”

Nominal S Untwist	Elongation		Force		Work to Rupture		Tenacity	
turns.m^{-1}	%	Variance	cN	Variance	cN.cm	Variance	cN.tex^{-1}	Variance
0	7.14	6.49	438.81	8.14	724.77	14.34	14.63	8.14
111	6.79	5.36	409.57	5.52	669.15	10.45	13.65	5.52
129	6.38	5.03	381.49	5.96	593.65	10.20	12.72	5.96
147	6.15	4.76	390.86	6.77	390.87	9.17	13.03	6.77
163	6.19	4.68	384.60	7.72	580.32	11.49	12.82	7.72
182	6.15	5.70	390.81	7.52	585.12	11.48	13.03	7.52
200	5.85	4.61	345.76	9.30	511.67	13.24	11.51	9.30
220	5.77	6.89	350.90	15.48	509.80	19.74	11.70	15.48

Table IV.B.7 **Strength** Testing Results of the Yarn **"39 tex Steamed TF 32.3"**

Nominal S Untwist	**Elongation**		**Force**		**Work to Rupture**		**Tenacity**	
turns.m^{-1}	**%**	Variance	**cN**	Variance	**cN.cm**	Variance	**cN.tex^{-1}**	Variance
0	6.83	5.87	472.14	7.85	720.38	13.24	11.80	7.85
111	5.09	6.56	301.17	10.24	378.78	15.91	7.53	10.24
121	5.18	8.27	298.95	14.12	380.14	21.09	7.47	14.12
133	4.41	12.30	239.71	18.41	274.00	26.60	5.99	18.41
142	4.77	10.05	255.88	16.75	303.17	26.37	6.40	16.75
154	-	-	-	-	-	-	-	-
163	-	-	-	-	-	-	-	-

Table IV.B.8 **Strength** Testing Results of the Yarn **"39 tex Steamed TF 33.4"**

Nominal S Untwist	**Elongation**		**Force**		**Work to Rupture**		**Tenacity**	
turns.m^{-1}	**%**	Variance	**cN**	Variance	**cN.cm**	Variance	**cN.tex^{-1}**	Variance
0	6.91	5.56	525.06	6.21	810.62	11.18	13.13	6.21
111	5.72	4.98	396.34	10.73	553.10	14.21	9.91	10.73
121	6.08	9.67	98.95	11.73	380.14	16.93	7.47	11.73
133	5.94	5.14	343.87	5.96	480.59	10.92	8.60	5.96
142	5.42	11.03	311.01	13.45	409.06	21.73	7.78	13.45
154	4.94	9.07	298.76	15.71	376.74	23.47	7.47	15.71
163	4.70	7.46	277.74	15.46	339.44	20.66	6.94	15.46

Table IV.B.9 **Strength** Testing Results of the Yarn **"39 tex Steamed TF 39.5"**

Nominal S Untwist	**Elongation**		**Force**		**Work to Rupture**		**Tenacity**	
turns.m^{-1}	**%**	Variance	**cN**	Variance	**cN.cm**	Variance	**cN.tex^{-1}**	Variance
0	7.10	5.67	528.08	5.86	830.04	10.72	13.20	5.86
111	6.30	8.22	443.04	6.86	635.92	13.77	11.08	6.86
121	6.97	5.46	491.44	4.65	761.18	8.53	12.29	4.65
133	6.50	7.02	434.18	10.97	642.24	16.33	10.85	10.97
142	6.77	5.63	511.54	6.60	768.60	10.62	12.79	6.60
154	6.02	4.46	435.65	7.47	634.80	10.46	10.89	7.47
163	5.81	4.52	403.96	7.97	572.80	10.10	10.10	7.97

Table IV.B.10 **Strength** Testing Results of the Yarn "**29 tex Steamed TF 32.4**"

Nominal S Untwist	**Elongation**		**Force**		**Work to Rupture**		**Tenacity**	
turns.m^{-1}	**%**	Variance	**cN**	Variance	**cN.cm**	Variance	**cN.tex^{-1}**	Variance
0	6.40	3.77	33.85	5.26	489.93	7.95	11.13	5.26
111	5.08	8.44	246.21	11.05	310.44	18.30	8.21	11.05
129	5.35	7.51	249.48	13.05	317.25	19.49	8.32	13.05
147	4.81	6.44	234.62	12.21	292.86	16.34	7.82	12.21
163	4.21	10.53	174.31	19.33	187.48	28.30	5.81	19.33
182	4.04	11.02	176.61	18.23	194.10	27.71	5.89	18.23
200	-	-	-	-	-	-	-	-
220	-	-	-	-	-	-	-	-

Table IV.B.11 **Strength** Testing Results of the Yarn "**29 tex Steamed TF 34.9**"

Nominal S Untwist	**Elongation**		**Force**		**Work to Rupture**		**Tenacity**	
turns.m^{-1}	**%**	Variance	**cN**	Variance	**cN.cm**	Variance	**cN.tex^{-1}**	Variance
0	6.79	5.47	360.77	6.56	553.63	12.45	12.03	6.56
111	5.36	5.34	283.39	7.94	371.58	11.44	9.45	7.94
129	5.64	7.01	300.54	8.60	396.47	12.84	10.02	8.60
147	4.61	8.37	248.94	11.94	304.05	19.61	8.30	11.94
163	5.46	7.03	260.76	8.87	342.75	13.59	8.69	8.87
182	5.05	4.83	264.10	9.29	337.98	12.32	8.80	9.29
200	4.77	7.50	222.65	14.63	273.27	20.09	7.42	14.63
220	5.46	8.06	272.27	10.60	366.07	12.86	9.08	10.60

Table IV.B.12 **Strength** Testing Results of the Yarn "**29 tex Steamed TF 38.6**"

Nominal S Untwist	**Elongation**		**Force**		**Work to Rupture**		**Tenacity**	
turns.m^{-1}	**%**	Variance	**cN**	Variance	**cN.cm**	Variance	**cN.tex^{-1}**	Variance
0	7.55	4.29	429.18	4.92	700.78	8.14	14.31	4.92
111	6.13	5.98	356.34	4.91	509.20	9.53	11.88	4.91
129	6.34	5.70	343.65	6.60	496.26	10.78	11.46	6.60
147	5.69	7.13	334.39	9.16	462.99	14.50	11.15	9.16
163	5.83	7.32	318.47	8.03	431.41	12.59	10.62	8.03
182	5.55	4.68	319.61	6.80	439.97	11.73	10.65	6.80
200	5.34	5.10	288.87	8.09	378.25	12.41	9.63	8.09
220	5.56	5.24	294.95	8.55	402.77	13.21	9.83	8.55

Table IV.C.1 **Twist** Testing Results of the Yarn "**39 tex TF 32.3**"

A. NORMAL

Nominal S Untwist turns.m^{-1}	Actual Net Z Twist turns.m^{-1}	C.V. (%)
0	531.7	2.92
111	447.6	2.16
121	460.8	2.43
133	449.7	3.01
142	-	-
154	-	-
163	-	-

B. STEAMED

Nominal S Untwist turns.m^{-1}	Actual Net Z Twist turns.m^{-1}	C.V. (%)
0	520.9	3.14
111	437.5	3.26
121	446.1	3.70
133	436.2	3.08
142	436.9	3.32
154	-	-
163	-	-

Table IV.C.2 **Twist** Testing Results of the Yarn "**39 tex TF 33.4**"

A. NORMAL

Nominal S Untwist turns.m^{-1}	Actual Net Z Twist turns.m^{-1}	C.V. (%)
0	554.7	2.61
111	475.4	3.17
121	465.1	2.78
133	454.9	2.59
142	449.0	2.73
154	449.8	4.14
163	447.7	2.80

B. STEAMED

Nominal S Untwist turns.m^{-1}	Actual Net Z Twist turns.m^{-1}	C.V. (%)
0	553.3	3.81
111	466.0	3.36
121	457.4	3.77
133	453.8	2.64
142	454.4	2.68
154	438.7	4.34
163	444.1	3.61

Table IV.C.3 **Twist** Testing Results of the Yarn "**39 tex TF 39.5**"

A. NORMAL

Nominal S Untwist turns.m^{-1}	Actual Net Z Twist turns.m^{-1}	C.V. (%)
0	642.1	3.21
111	539.6	2.18
121	531.8	3.87
133	518.1	2.89
142	514.5	3.09
154	492.6	5.65
163	500.2	2.79

B. STEAMED

Nominal S Untwist turns.m^{-1}	Actual Net Z Twist turns.m^{-1}	C.V. (%)
0	630.1	3.33
111	531.6	4.16
121	531.9	3.09
133	511.1	2.83
142	513.6	3.15
154	486.6	5.65
163	481.0	3.21

Table IV.C.4 **Twist** Testing Results of the Yarn "**29 tex TF 32.4**"

A. NORMAL

Nominal S Untwist turns.m^{-1}	Actual Net Z Twist turns.m^{-1}	C.V. (%)
0	616.9	4.82
111	537.2	2.37
129	523.7	2.78
147	528.5	4.06
163	522.0	3.61
182	511.0	3.33
200	-	-
220	-	-

B. STEAMED

Nominal S Untwist turns.m^{-1}	Actual Net Z Twist turns.m^{-1}	C.V. (%)
0	619.5	3.09
111	537.3	5.77
129	537.9	2.65
147	529.5	2.33
163	502.1	2.40
182	499.9	2.42
200	-	-
220	-	-

Table IV.C.5 **Twist** Testing Results of the Yarn "**29 tex TF 34.9**"

A. NORMAL

Nominal S Untwist turns.m^{-1}	Actual Net Z Twist turns.m^{-1}	C.V. (%)
0	665.7	3.52
111	575.8	4.93
129	573.8	3.01
147	556.0	2.36
163	544.2	2.16
182	536.4	2.89
200	513.8	3.02
220	521.7	3.43

B. STEAMED

Nominal S Untwist turns.m^{-1}	Actual Net Z Twist turns.m^{-1}	C.V. (%)
0	660.4	4.57
111	566.7	4.42
129	568.9	3.20
147	551.5	4.78
163	543.8	5.25
182	530.7	3.32
200	521.9	4.80
220	511.7	4.56

Table IV.C.6 **Twist** Testing Results of the Yarn "**29 tex TF 38.6**"

A. NORMAL

Nominal S Untwist turns.m^{-1}	Actual Net Z Twist turns.m^{-1}	C.V. (%)
0	742.3	2.61
111	632.9	2.52
129	608.3	3.37
147	593.2	3.50
163	603.5	3.29
182	584.7	3.41
200	575.6	3.66
220	558.0	3.08

B. STEAMED

Nominal S Untwist turns.m^{-1}	Actual Net Z Twist turns.m^{-1}	C.V. (%)
0	731.2	2.56
111	635.4	2.86
129	621.5	3.83
147	611.6	3.48
163	596.5	3.04
182	587.5	1.74
200	552.9	3.22
220	559.0	4.27

APPENDIX V

Table V.1 Spirality Angle (°) after Washing, by Stretching Widthwise(↔) and Lengthwise (↕) the Fabrics (Prior to the Measurement).

Yarn Samples	Without T-Down Tension			With T-Down Tension		
	↔	↕	Mean	↔	↕	Mean
1	15.5	9.5	12.5	6.5	5.0	6.0
2	13.0	13.0	13.0	9.0	5.0	7.0
3	-2.0	-1.0	-1.5	0.5	1.5	1.0
4	-4.5	-1.5	-3.0	-4.0	0.0	-2.0
5	5.5	4.0	5.0	1.5	0.5	1.0
6	18.0	18.0	18.0	6.0	3.0	4.5
7	20.0	20.0	20.0	6.5	3.0	5.0
8	0.5	0.0	0.0	0.0	1.0	0.5
9	2.5	1.0	2.0	3.0	4.0	3.5
10	10.5	13.0	12.0	2.0	1.0	1.5

Table V.2 Difference in Spirality Angle (°) Between Relaxed and Stretched Fabrics

Yarn Samples	Without T-Down Tension			With T-Down Tension		
	Relaxed	Stretched	Dif.	Relaxed	Stretched	Dif.
1	11.0	12.5	1.5	7.0	6.0	-1.0
2	10.0	13.0	3.0	9.0	7.0	-2.0
3	1.0	-1.5	-2.5	-6.0	1.0	7.0
4	0.0	-3.0	-3.0	-0.5	-2.0	-1.5
5	2.5	5.0	2.5	2.0	1.0	-1.0
6	12.5	18.0	5.5	3.5	4.5	1.0
7	12.0	20.0	8.0	6.5	5.0	-1.5
8	1.0	0.0	-1.0	-3.0	0.5	3.5
9	3.0	2.0	-1.0	2.0	3.5	1.5
10	5.0	12.0	7.0	-1.0	1.5	2.5

APPENDIX VI

Tables From The Experimental Work (Chapter 6)

Table VI.1 Yarn Hairiness Testing Results Obtained From the Shirley Hairiness Tester

Samples	Hairs.m^{-1}	C.V. (%)	S. D.
Normal			
39 tex TF 32.3	125.27	4.749	5.95
39 tex TF 33.4	76.64	5.058	3.88
39 tex TF 39.5	64.67	3.997	2.59
29 tex TF 32.4	64.77	7.977	5.17
29 tex TF 34.9	60.88	4.198	2.56
29 tex TF 38.6	43.70	13.948	6.10
Steamed			
39 tex TF 32.3	79.67	6.590	5.25
39 tex TF 33.4	66.25	4.869	3.23
39 tex TF 39.5	53.92	3.704	2.00
29 tex TF 32.4	58.11	4.972	2.89
29 tex TF 34.9	51.50	4.077	2.10
29 tex TF 38.6	48.21	8.400	4.05
Nominal S Untwist 111 turns.m^{-1}			
39 tex TF 32.3	92.74	2.856	2.65
39 tex TF 33.4	75.88	4.081	3.10
Nominal S Untwist 121 turns.m^{-1}			
39 tex TF 32.3	75.96	4.830	3.67
39 tex TF 33.4	72.89	5.554	4.05
Nominal S Untwist 133 turns.m^{-1}			
39 tex TF 32.3	84.57	3.363	2.84
39 tex TF 33.4	82.84	4.967	4.12
39 tex TF 39.5	49.68	4.118	2.05
29 tex TF 32.4	68.54	5.176	3.55
Nominal S Untwist 142 turns.m^{-1}			
39 tex TF 32.3	110.02	13.661	15.03
39 tex TF 33.4	84.48	2.979	2.52
39 tex TF 39.5	46.28	5.595	2.59
29 tex TF 32.4	67.36	6.200	4.18
29 tex TF 34.9	54.01	4.426	2.39

SAMPLES	Hairs.m^{-1}	C.V. (%)	S. D.
NOMINAL S UNTWIST 154 turns.m^{-1}			
39 tex TF 32.3	101.46	4.761	4.83
39 tex TF 33.4	83.48	4.483	3.74
39 tex TF 39.5	47.61	6.711	3.20
29 tex TF 32.4	75.17	5.401	4.06
29 tex TF 34.9	56.94	5.067	2.88
29 tex TF 38.6	47.37	6.146	2.91
NOMINAL S UNTWIST 163 turns.m^{-1}			
39 tex TF 33.4	68.96	4.297	2.96
39 tex TF 39.5	50.24	5.963	3.00
29 tex TF 32.4	71.73	4.134	2.97
29 tex TF 34.9	54.48	5.642	3.07
29 tex TF 38.6	42.48	4.739	2.01
NOMINAL S UNTWIST 175 turns.m^{-1}			
39 tex TF 39.5	44.06	4.373	1.93
29 tex TF 32.4	67.40	6.096	4.11
29 tex TF 34.9	59.00	5.991	3.53
29 tex TF 38.6	43.81	2.206	0.97
NOMINAL S UNTWIST 191 turns.m^{-1}			
29 tex TF 34.9	50.81	7.195	3.66
29 tex TF 38.6	34.48	4.963	1.71
NOMINAL S UNTWIST 206 turns.m^{-1}			
29 tex TF 34.9	57.70	4.249	2.45
29 tex TF 38.6	38.54	3.571	1.38
NOMINAL S UNTWIST 220 turns.m^{-1}			
29 tex TF 38.6	47.20	4.700	2.22

Table VI.2 Yarn Abrasion Resistance Testing Results

SAMPLES	CYCLES	C.V. %
NOMINAL S UNTWIST **111** turns.m^{-1}		
39 tex TF 32.3	83	25.60
39 tex TF 33.4	116	24.47
NOMINAL S UNTWIST **121** turns.m^{-1}		
39 tex TF 32.3	84	27.53
39 tex TF 33.4	104	21.93
NOMINAL S UNTWIST **133** turns.m^{-1}		
39 tex TF 32.3	63	30.26
39 tex TF 33.4	79	25.10
39 tex TF 39.5	200	43.92
29 tex TF 32.4	68	22.31
NOMINAL S UNTWIST **142** turns.m^{-1}		
39 tex TF 32.3	47	27.04
39 tex TF 33.4	70	22.70
39 tex TF 39.5	221	32.94
29 tex TF 32.4	83	32.00
29 tex TF 34.9	104	37.61
NOMINAL S UNTWIST **154** turns.m^{-1}		
39 tex TF 32.3	57	27.90
39 tex TF 33.4	64	24.50
39 tex TF 39.5	208	24.68
29 tex TF 32.4	41	27.00
29 tex TF 34.9	119	26.16
29 tex TF 38.6	218	40.76
NOMINAL S UNTWIST **163** turns.m^{-1}		
39 tex TF 33.4	54	33.14
39 tex TF 39.5	173	27.00
29 tex TF 32.4	46	29.43
29 tex TF 34.9	91	40.81
29 tex TF 38.6	210	29.51
NOMINAL S UNTWIST **175** turns.m^{-1}		
39 tex TF 39.5	155	35.89
29 tex TF 32.4	55	23.23
29 tex TF 34.9	88	16.69
29 tex TF 38.6	200	37.30
NOMINAL S UNTWIST **191** turns.m^{-1}		
29 tex TF 34.9	86	30.22
29 tex TF 38.6	149	38.15
NOMINAL S UNTWIST **206** turns.m^{-1}		
29 tex TF 34.9	61	17.21
29 tex TF 38.6	149	16.77
NOMINAL S UNTWIST **220** turns.m^{-1}		
29 tex TF 38.6	79	7.82

Table VI.3 Yarn Strength Testing Results Obtained From the Statimat M

SAMPLES	ELONGATION		FORCE		WORK TO RUPTURE		TENACITY		TIME
	%	CV%	cN	CV %	cN.cm	CV %	cN.tex^{-1}	CV %	sec
NORMAL									
39 tex TF 32.3	7.37	5.40	567.65	6.71	973.52	9.45	14.19	6.71	8.85
39 tex TF 33.4	7.60	4.15	590.94	5.34	1046.14	8.81	14.77	5.34	9.13
39 tex TF 39.5	8.27	5.99	660.23	6.52	1222.62	11.35	16.51	6.52	9.93
29 tex TF 32.4	6.86	4.44	376.37	6.40	607.72	9.65	12.55	6.40	8.23
29 tex TF 34.9	7.31	5.18	453.16	7.72	768.16	11.13	15.11	7.72	8.77
29 tex TF 38.6	7.73	5.35	492.76	7.16	874.89	11.40	16.43	7.16	9.27
STEAMED									
39 tex TF 32.3	7.11	4.91	486.73	7.82	764.13	11.31	12.17	7.82	8.53
39 tex TF 33.4	7.40	4.78	526.76	7.55	860.85	11.31	13.17	7.55	8.87
39 tex TF 39.5	8.16	4.97	577.79	5.66	984.08	9.18	14.44	5.66	9.80
29 tex TF 32.4	7.01	5.36	371.90	7.65	583.07	12.46	12.40	7.65	8.41
29 tex TF 34.9	6.93	4.04	379.71	9.52	592.84	13.39	12.66	9.52	8.32
29 tex TF 38.6	7.57	5.12	423.97	6.20	702.52	10.29	14.13	6.20	9.08
NOMINAL S UNTWIST 111 turns.m^{-1}									
39 tex TF 32.3	5.53	5.88	331.90	10.76	457.88	15.51	8.30	10.76	6.63
39 tex TF 33.4	5.94	6.06	388.51	11.54	577.43	16.42	9.71	11.54	7.13
NOMINAL S UNTWIST 121 turns.m^{-1}									
39 tex TF 32.3	5.72	8.40	349.77	18.00	494.44	24.80	8.74	18.00	6.87
39 tex TF 33.4	6.03	6.16	365.89	8.78	531.94	14.00	9.15	8.78	7.24
NOMINAL S UNTWIST 133 turns.m^{-1}									
39 tex TF 32.3	5.19	7.44	283.19	14.03	365.73	19.34	7.08	14.03	6.23
39 tex TF 33.4	5.57	7.06	336.34	11.27	457.44	15.93	8.41	11.27	6.68
39 tex TF 39.5	6.76	4.72	505.93	8.10	782.20	11.03	12.65	8.10	8.12
29 tex TF 32.4	5.54	7.07	261.99	13.54	356.15	18.71	8.73	13.54	6.65
NOMINAL S UNTWIST 142 turns.m^{-1}									
39 tex TF 32.3	4.82	13.38	221.78	24.10	275.30	34.41	5.54	24.10	5.79
39 tex TF 33.4	5.54	9.60	288.95	16.56	390.61	23.81	7.22	16.56	6.64
39 tex TF 39.5	6.51	5.24	493.95	6.99	758.43	9.81	12.35	6.99	7.81
29 tex TF 32.4	5.31	6.87	232.11	13.57	303.14	18.82	7.74	13.57	6.37
29 tex TF 34.9	6.18	5.95	299.71	9.70	443.62	12.99	9.99	9.70	7.41

SAMPLES	ELONGATION		FORCE		WORK TO RUPTURE		TENACITY		TIME
	%	CV %	cN	CV %	cN.cm	CV %	$cN.tex^{-1}$	CV %	sec
NOMINAL S UNTWIST **154** turns.m^{-1}									
39 tex TF 32.3	5.09	9.25	277.51	18.02	349.00	27.01	6.94	18.02	6.11
39 tex TF 33.4	4.50	16.62	201.74	29.32	237.67	40.85	5.04	29.32	5.41
39 tex TF 39.5	6.69	6.34	491.05	7.91	735.99	12.55	12.28	7.91	8.03
29 tex TF 32.4	5.15	12.34	244.10	19.76	307.44	29.29	8.14	19.76	6.18
29 tex TF 34.9	6.00	6.02	287.62	8.49	405.47	12.41	9.59	8.49	7.20
29 tex TF 38.6	6.27	5.45	360.86	8.12	520.77	11.52	12.03	8.12	7.53
NOMINAL S UNTWIST **163** turns.m^{-1}									
39 tex TF 33.4	5.49	10.26	275.62	20.56	376.47	28.01	6.89	20.56	6.59
39 tex TF 39.5	6.78	6.11	470.41	6.91	714.19	12.05	11.76	6.91	8.14
29 tex TF 32.4	5.04	15.19	195.35	24.18	248.45	28.86	6.51	24.18	6.05
29 tex TF 34.9	6.10	6.69	272.59	12.26	395.44	16.32	9.09	12.26	7.32
29 tex TF 38.6	6.67	5.12	372.62	9.24	566.52	13.30	12.42	9.24	8.01
NOMINAL S UNTWIST **175** turns.m^{-1}									
39 tex TF 39.5	6.47	5.75	450.84	9.01	667.83	13.78	11.27	9.01	7.77
29 tex TF 32.4	4.86	13.16	180.64	23.49	218.35	31.80	6.02	23.49	5.83
29 tex TF 34.9	5.98	5.37	287.09	7.21	402.98	11.41	9.57	7.21	7.17
29 tex TF 38.6	6.50	5.54	355.48	8.65	520.56	11.92	11.85	8.65	7.80
NOMINAL S UNTWIST **191** turns.m^{-1}									
29 tex TF 34.9	5.40	7.88	248.49	10.40	334.02	16.53	8.28	10.40	6.48
29 tex TF 38.6	5.92	6.66	331.47	9.68	459.16	15.71	11.05	9.68	7.10
NOMINAL S UNTWIST **206** turns.m^{-1}									
29 tex TF 34.9	5.33	12.38	238.95	19.45	310.77	29.36	7.96	19.45	6.40
29 tex TF 38.6	5.74	7.34	290.16	12.60	393.91	18.47	9.67	12.60	6.89
NOMINAL S UNTWIST **220** turns.m^{-1}									
29 tex TF 38.6	5.73	6.85	309.82	9.25	418.06	15.08	10.33	9.25	6.88

Table VI.4 Yarn Twist Testing Results Obtained From the Zweigle Twist Tester

SAMPLES	turns.m^{-1}	C.V. (%)	S. D.	VAR
NORMAL				
39 tex TF 32.3	524.6	1.79	9.44	89.15
39 tex TF 33.4	549.7	1.75	9.63	92.90
39 tex TF 39.5	625.7	3.44	21.58	465.78
29 tex TF 32.4	617.6	3.82	23.62	558.26
29 tex TF 34.9	660.8	3.14	20.77	431.73
29 tex TF 38.6	720.1	3.05	21.98	483.21
STEAMED				
39 tex TF 32.3	520.5	3.32	17.32	300.05
39 tex TF 33.4	544.0	3.80	20.69	428.22
39 tex TF 39.5	631.7	3.17	20.06	402.67
29 tex TF 32.4	599.8	2.21	13.29	176.84
29 tex TF 34.9	656.4	2.14	14.08	198.26
29 tex TF 38.6	738.0	4.02	29.66	880.22
NOMINAL S UNTWIST 111 turns.m^{-1}				
39 tex TF 32.3	441.2	3.03	13.37	178.84
39 tex TF 33.4	469.6	2.92	13.73	188.71
NOMINAL S UNTWIST 121 turns.m^{-1}				
39 tex TF 32.3	435.2	2.41	10.52	110.84
39 tex TF 33.4	469.7	3.16	14.84	220.45
NOMINAL S UNTWIST 133 turns.m^{-1}				
39 tex TF 32.3	428.6	2.97	12.74	162.48
39 tex TF 33.4	461.9	3.40	15.73	247.65
39 tex TF 39.5	508.4	5.26	26.75	715.82
29 tex TF 32.4	520.1	3.95	20.56	422.76
NOMINAL S UNTWIST 142 turns.m^{-1}				
39 tex TF 32.3	435.5	2.37	10.33	106.72
39 tex TF 33.4	438.3	2.92	12.84	164.90
39 tex TF 39.5	504.2	3.64	18.35	336.84
29 tex TF 32.4	522.3	5.35	27.96	782.01
29 tex TF 34.9	544.7	3.40	18.55	344.23

Samples	**turns.m^{-1}**	C.V. (%)	S. D.	Var
Nominal S Untwist **154** turns.m^{-1}				
39 tex TF 32.3	417.5	3.70	15.47	239.61
39 tex TF 33.4	434.4	5.13	22.29	496.93
39 tex TF 39.5	481.8	3.41	16.45	270.62
29 tex TF 32.4	525.5	2.89	15.21	231.38
29 tex TF 34.9	532.0	2.35	12.51	156.66
29 tex TF 38.6	581.5	4.19	24.39	595.16
Nominal S Untwist **163** turns.m^{-1}				
39 tex TF 33.4	446.9	2.64	11.83	140.10
39 tex TF 39.5	491.5	3.25	15.98	255.61
29 tex TF 32.4	506.2	4.04	20.48	419.73
29 tex TF 34.9	532.4	3.27	17.42	303.60
29 tex TF 38.6	584.9	2.75	16.08	258.76
Nominal S Untwist **175** turns.m^{-1}				
39 tex TF 39.5	484.9	5.47	26.54	704.54
29 tex TF 32.4	493.6	2.82	13.95	194.71
29 tex TF 34.9	519.4	4.46	23.16	536.71
29 tex TF 38.6	557.6	4.43	24.73	612.04
Nominal S Untwist **191** turns.m^{-1}				
29 tex TF 34.9	518.8	1.63	8.48	71.94
29 tex TF 38.6	558.6	2.30	12.89	166.26
Nominal S Untwist **206** turns.m^{-1}				
29 tex TF 34.9	520.0	4.47	23.27	541.77
29 tex TF 38.6	553.2	2.80	15.51	240.84
Nominal S Untwist **220** turns.m^{-1}				
29 tex TF 38.6	543.9	3.94	21.48	461.43

APPENDIX VII

Refractive Indices (n) of Some Textile Fibres and Mountant Liquids [166]

Fibres	$\frac{n_\gamma + n_\alpha}{2}$	Liquid	n
Wool	1.550	Water	1.330
Cotton	1.557	Glycerine	1.456
Silk	1.567	Ethylene Bromide	1.537
Flax	1.562	Castor Oil	1.476
Viscose Rayon	1.536	Methyl Salicilate	1.546
Acetate Rayon	1.473	Tricresyl Phosphate	1.556

FACTORS AFFECTING FIBRE POSITION IN THE YARN

FIBRE FACTORS:

Physical Properties: Length, Fineness, Coefficient of Fibre Friction, Shape of the Cross-Section, Type of Fibre or its Chemical Identity

Mechanical Properties: Tensile Modulus, Bending modulus or flexural Rigidity, Elastic Recovery, Torsional Rigidity, Extendibility

YARN FACTORS: Yarn Count, Amount of Twist in the Roving, Amount of Twist to be put in the yarn

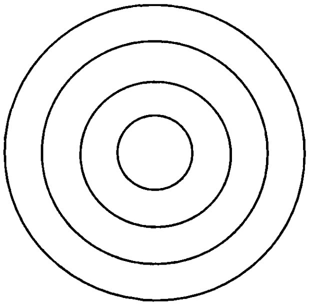
IDEALISED MIGRATION [169,188]

Expression of the radial position in terms of (r / R) implies two methods:

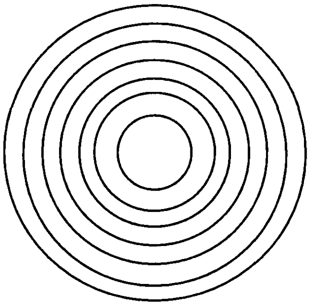
a. Division into elements of equal radial spacing and, thus, of increasing area as the radius increases.

b. Division into zones of equal area, so that the fibres are equally distributed between all zones. In order to achieve this, the radial position should be expressed in terms of $(r / R)^2$.

It is not practical to measure the length along the fibre and so the parameters are calculated in terms of the length z along the yarn.



a



b

Morton [189] states that other things being equal he could expect the inside places of a yarn to be occupied by fibres having:

i. a higher Young's modulus;
ii. lower torsional rigidity;
iii. greater thickness;
iv. greater length.

A fibre having a low torsional modulus will take twist easily and without appreciable bending. If the modulus is high the fibre will bend and thus tend to move towards the yarn surface.

Production of the Yarn Containing Black Tracer Fibres

An attempt to apply the method for introducing the tracer fibres in the main mass of the white fibres, described in previous publications, turned out to be unsuccessful due to problems concerning mainly the dyed material. The lack of antistatic treatment of the material led to a failure of sliver formation. It was then decided to insert the black dyed fibres in the stage of the drawing process on the drawframe.

Six (6) coloured "white" slivers of count 3 ktex (3 $g.m^{-1}$) were fed to the draw-frame, where the draft was set to be 5.1. A quantity of 0.1 g black dyed fibres were hand-distributed on every one (1) metre of that feeding "lap" (consisted of one (1) metre of the six slivers).

Twenty five (25) metres of this "lap" were drafted. Therefore,
the 25 m × 6 m = 150 metres of sliver × 3 $g.m^{-1}$ = 450 g of material passed through the draw-frame should (in ideal conditions) contain:
25 × 0.1 g = 2.5 g of black fibres, that means 0.55% of tracer fibres after the first passage.

The count of the sliver from the first passage was:
18 g.m^{-1}÷ 5.1 draft = 3.5 g.m^{-1}(3.5 ktex). Therefore, since the percentage of the black fibres in the sliver was 0.55%, the weight of these fibres per metre of that “blend” sliver should be 0.0019 g.

For the second passage, three “white” slivers and three “blended” slivers (from the first passage) were fed to the draw-frame. Attention was paid to the placement of the blended slivers between the white ones in an attempt to achieve a better blending. the approximate percentage of the black fibres present in the final sliver (and consequently in the yarn) was calculated as following:

For every one (1) metre of the “lap” for the second passage:
3 “white” slivers × 3 g.m^{-1} = 9.0 g
3 “blended” slivers × 3.5 g.m^{-1} = 10.5 g
Total 19.5 g

In this quantity, a weight of 3 × 0.0019 g = 0.058 g of black fibres was present, that means the percentage of the black fibres in the yarn was about:

$$0.058 \text{ g} \div 19.5 \text{ g} \times 100\% = \mathbf{0.3\%}$$

After a careful preliminary observation of the fibres under the “Projectina” microscope, it was found that the tracer fibres were individual and well distributed along the yarn length (avoiding the appearance of two or three fibres jammed each other).

Table VII. A : Normal Yarn **714 turns.m^{-1}**

No	**Diameter**	**Depth***	**M.F.P.**	**r.m.s.**	**Rate (I)**	**Freq.**
1	0.23	0.231	0.2097	0.1808	1.0620	0.8478
2	0.26	0.260	0.1688	0.1450	0.7916	0.7878
3	0.24	0.226	0.2705	0.2787	1.8017	0.9330
4	0.24	0.191	0.1644	0.2329	1.2238	0.7583
5	0.23	0.196	0.2564	0.3017	2.0236	0.9682
6	0.23	0.246	0.2942	0.2595	1.8252	1.0152
7	0.24	0.206	0.3200	0.2626	1.5552	0.8547
8	0.24	0.201	0.2249	0.2095	1.4188	0.9774
9	0.23	0.243	0.3232	0.2625	1.6506	0.9074
10	0.23	0.181	0.1527	0.1343	0.8530	0.9166
11	0.22	0.260	0.3151	0.2612	1.8207	1.0062
12	0.24	0.221	0.2657	0.2604	1.5223	0.8439
13	0.22	0.196	0.2172	0.2645	1.2689	0.6925
14	0.24	0.263	0.3047	0.2465	1.4410	0.8438
15	0.23	0.275	0.1838	0.1544	1.0438	0.9756
Mean	**0.23**	**0.226**	**0.2448**	**0.2303**	**1.4201**	**0.8886**

Table VII. B : Processed Yarn **917-220 turns.m^{-1}**

No	**Diameter**	**Depth***	**M.F.P.**	**r.m.s.**	**Rate (I)**	**Freq.**
1	0.20	0.213	0.3232	0.3418	2.9258	1.2356
2	0.21	0.218	0.1656	0.2164	1.4179	0.9459
3	0.22	0.248	0.2420	0.2661	1.5745	0.8540
4	0.20	0.191	0.2521	0.2402	1.8338	1.1017
5	0.21	0.184	0.2481	0.2371	1.6878	1.0276
6	0.21	0.188	0.3173	0.3134	2.2016	1.0140
7	0.24	0.270	0.2631	0.3132	1.6534	0.7619
8	0.22	0.159	0.2642	0.2871	1.7331	0.8711
9	0.21	0.181	0.1196	0.1349	0.8001	0.8563
10	0.20	0.270	0.3259	0.3483	2.5816	1.0698
11	0.21	0.283	0.2485	0.2364	1.5890	0.9701
12	0.21	0.221	0.2868	0.2970	2.0607	1.0013
13	0.19	0.233	0.3240	0.3253	2.4753	1.0982
14	0.23	0.228	0.2745	0.2866	1.4377	0.7240
15	0.24	0.255	0.2546	0.1966	1.1719	0.8604
Mean	**0.21**	**0.223**	**0.2606**	**0.2694**	**1.8096**	**0.9595**

Note: M.F.P. = Mean Fibre Position * Diameter, Depth in millimetres

Table VII. C : Processed Yarn **917-234 turns.m^{-1}**

No	Diameter	Depth*	M.F.P.	r.m.s.	Rate (I)	Freq.
1	0.23	0.248	0.2418	0.2985	1.4143	0.6838
2	0.24	0.241	0.1218	0.1262	0.8811	1.0074
3	0.24	0.208	0.2806	0.2113	1.3814	0.9436
4	0.24	0.293	0.3885	0.3375	2.8413	1.2152
5	0.22	0.223	0.2261	0.2549	1.8810	1.0651
6	0.19	0.203	0.2883	0.3000	2.0809	1.0013
7	0.21	0.208	0.2351	0.2192	1.6216	1.0679
8	0.19	0.236	0.2354	0.2431	1.7507	1.0394
9	0.23	0.228	0.2780	0.2424	1.4224	0.8469
10	0.20	0.203	0.3415	0.2809	1.7894	0.9194
11	0.20	0.181	0.1804	0.2957	1.6496	0.8052
12	0.23	0.196	0.1947	0.2363	1.3001	0.7940
13	0.20	0.184	0.1613	0.1843	1.3703	1.0733
14	0.23	0.278	0.2913	0.2887	1.5632	0.7815
15	0.23	0.265	0.1732	0.1796	0.9539	0.7667
Mean	**0.22**	**0.226**	**0.2425**	**0.2466**	**1.5934**	**0.9340**

Table VII. D : Normal Yarn **917 turns.m^{-1}**

No	Diameter	Depth*	M.F.P.	r.m.s.	Rate (I)	Freq.
1	0.22	0.218	0.2345	0.2325	1.5212	0.9444
2	0.22	0.241	0.2621	0.2931	1.8945	0.9329
3	0.21	0.223	0.1861	0.2520	1.8942	1.0849
4	0.24	0.263	0.2196	0.2844	1.8615	0.9448
5	0.20	0.231	0.2545	0.3090	2.3117	1.0798
6	0.21	0.241	0.2228	0.2638	1.8851	1.0314
7	0.21	0.231	0.3145	0.3165	2.0688	0.9436
8	0.20	0.223	0.2718	0.3171	2.4536	1.1169
9	0.20	0.198	0.2268	0.2910	2.4063	1.1963
10	0.23	0.164	0.1487	0.1632	1.1585	1.0245
11	0.20	0.156	0.2160	0.2689	2.3379	1.2548
12	0.19	0.166	0.3350	0.3346	3.0381	1.3107
13	0.18	0.218	0.2784	0.2776	2.4629	1.2805
14	0.18	0.171	0.2865	0.2961	2.2047	1.0746
15	0.19	0.241	0.2665	0.3256	2.2812	1.0112
Mean	**0.21**	**0.212**	**0.2483**	**0.2817**	**2.1187**	**1.0821**

Note: M.F.P. = Mean Fibre Position * Diameter, Depth in millimetres