FREE FIBRE-END TEXTURED YARNS

A Dissertation submitted in fulfillment of the requirements for

the degree of

Master of Science and Engineering

BY

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Being an account of work carried out in the Department of Textile industries, Leeds University, under the supervision of Dr. M.J.Denton B.Sc, D.Sc, C.Text., F.Inst.P, F.T.I., Reader in Textile Industries.

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October, 1988

dedicated to me Mum and Dad,

brothers and sisters, friends.....

ABSTRACT

The effectiveness of the Texspun' process in improving the spun-like characteristics of air-jet textured continuous-filament yarns was investigated by studying the effect of the process variables on the size, frequency and stability of the loops formed on the yarn surface and the physical properties of the yam, as well as the process variables of the Texspun process and the properties of Texspun yams. An attempt was also made to analyse the mechanism of loop trapping and breakage, as well as the possible causes of inconsistency in the performance of the Texspun device.

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CHAPTER ONE

1.1 INTRODUCTION

1.1.1 THE CONCEPT OF TEXTURED YARNS.

Texturing is essentially the introdction of fine crimps (loops, folds, coils, crinkles or other distortions) along the length of the originally straight and parallel filaments of continuous-filament, synthetic-fibre yarns.

Dating back to the early 1950's when it first gained recognition, texturing in its various forms has progressed through the development stages until acceptable performance levels of the individual techniques have been achieved. Exploration into methods for improving the bulk properties and spun-like appearance of continuous-filament yarns has been pursued earnestly by both machine and yarn manufacturers. They have been motivated principally by the urge to produce continuous-filament yarns which satisfy the recent desire for a return to traditionl natural fibre fabric characteristics, to take advantage of properties such as stretch, offered by some types of textured yarns and to take control of a market that was relatively new and unexploited.

The main properties that are potentially conferred, by texturing, to continuous-filament yarns and the fabrics made from them include, amongst others, good hygroscopicity, opacity, handle and bulk. They also endeavour to eliminate as far as possible the bright 'glitter' due to the smooth, glass-like surfaces of the untextured filaments as well as their clammy feel to the skin.

These improved properties, coupled with the inherent strength, resistance to chemicals, moths, mildew and micro-organisms of the synthetic fibres make them excellent supplements and even substitutes for natural fibres in many applications.

Further, they posses good elastic properties and abrasion resistance, good crease-resistance and recovery from deformations, easy-care properties and generally show rugged performance. The other major advantage is their potential ability to be processed to suit any desired end-use. More-over, the synthetic-fibre raw materials from which textured yarns are made are readily available at any time and do not require the growth and maturity which is characteristic of natural fibres.

Texturing has thus been developed to impart to continuous-filament yarns some of the characteristics of spun natural staple fibres without the need to cut the filaments into staple, and with a much shorter processing route than the series of operations which would normally be carried out when using conventional staple spinning methods.

1.1.2 TEXTURING TECHNIQUES

Broadly, all texturing techniques, except one, are thermo-mechanical processes; the one exception is a purely mechanical method. The former take advantage of the thermoplastic properties of synthetic filament materials so that the fibre modification takes place by the interaction of heat and mechanical deformation. In this group are included the mechanical stufferbox, edge crimping, impact texturing, gear crimping, knit-de-knit, hot-air/steam jet texturing and false-twist texturing and drawtexturing techniques. Of these, for functional, technical and commercial reasons, several are no longer used, being overshadowed by, in particular, the hot-air/steam jet and false-twist methods. Air-jet texturing involves no heat-setting in its basic form and the yarn crimp is both created and maintained mechanically, independently of the thermoplastic properties of the supply yarn.

A. MECHANICAL STUFFER-BOX

The yarns are fed, confined and compressed into a small, usually heated tube called a stuffer-box, against the plug of yarn already in the box. The compression causes the filaments to fold into sharp bends and a saw-tooth crimp to be set into the filaments as the

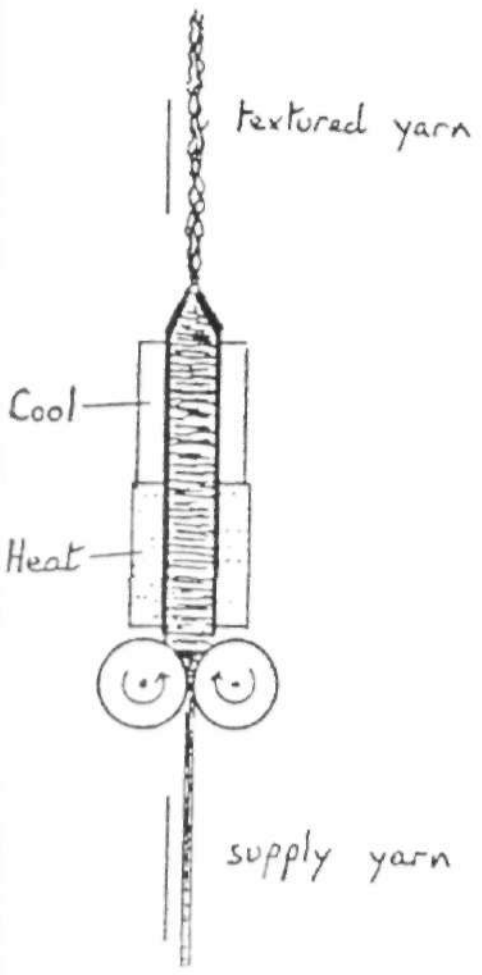


Fig.1 Mechanical Stufferbox

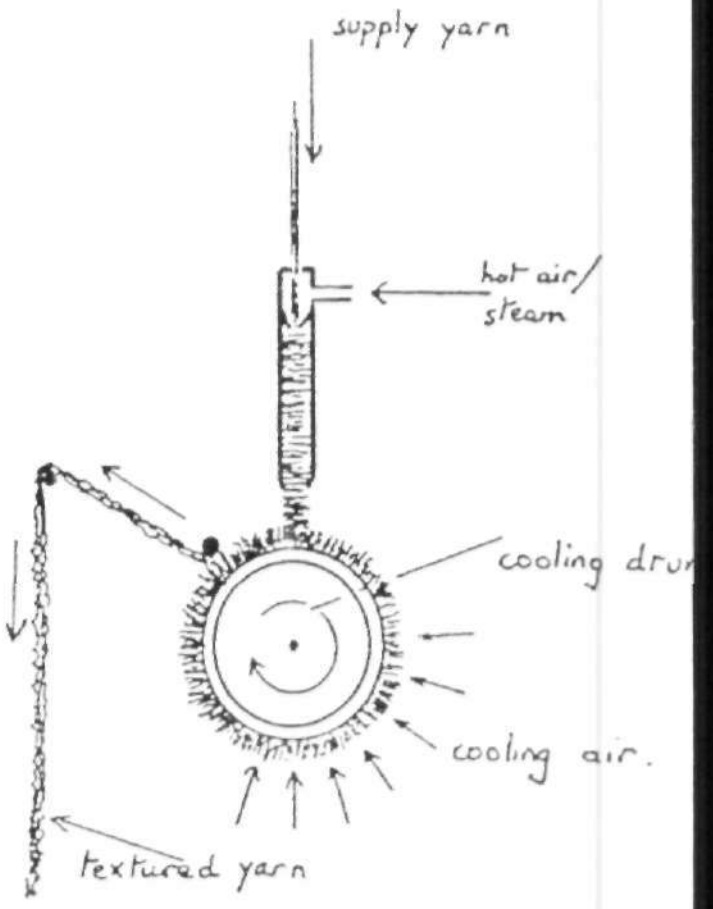


Fig.2 Hot-air/steam jet

yarn cools. These yarns have only a moderate degree of extensibility but a high level of bulk. In a modern variant of this process, partially oriented yarn (POY) is preheated around draw godets before entering an unheated stuffer-tube(Fig. 1).

B. HOT AIR/STEAM JET TEXTURING

This is basically a modification of the stuffer-box crimping method and is now primarily used for the manufacture of heavy decitex textured yarns. The continuous-filament yarn is injected by a jet of hot air or steam into a stuffer-tube against the compressed plug of yarn previously injected. The force with which the filaments are laid in the tube while plasticized by the elevated temperatures causes them to fold in a haphazard, indeterminable manner. The plug of yarn is withdrawn from the other end of the tube and is transported around the circumference of a slowly rotating perforated drum through which cold ambient air is drawn. The crimp obtained is similar to that from the mechanical stuffer-box method but is less well defined because a lower pressure is exerted on the plug of yarn in the stuffer-tube.

The process is usually incorporated in a continuous line to form a spin-draw-texture system from spinning to texturing, or may be adapted for fully oriented, partially-oriented and unoriented filament yarns. It is mainly used for continuous-filament yarns in the range 1000-4000 dtex, generally referred to as bulked continuous-filament yarns (BCF). Such yarns are principally used in the carpet industry. (Fig. 2).

C. IMPACT TEXTURING

This method was introduced by Mitsubishi of Japan [20] and is similar in principle to hot air/steam jet texturing. The continuous-filament yarn is transported by a hot fluid jet and spat onto a slowly rotating drum the surface of which is covered with fine spikes which is covered with fine spikes very much like card-wire. The way in which the plasticized filaments are propelled onto the cooling drum causes them to take on a 3-dimensional crimp. The yarn is then wound onto a package. Yarns produced by this

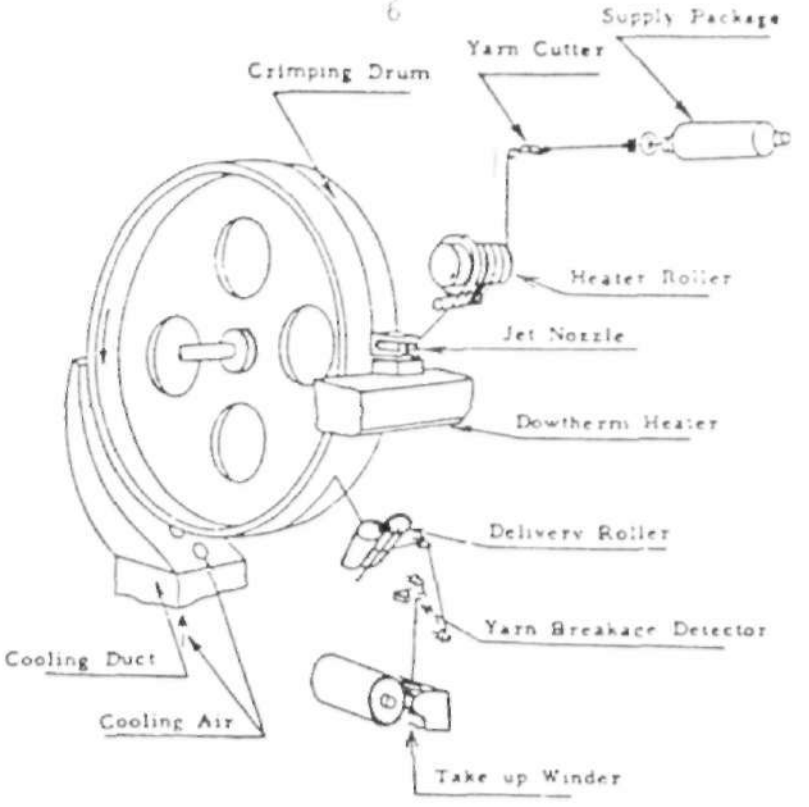


Fig. 3 Impact Texturing

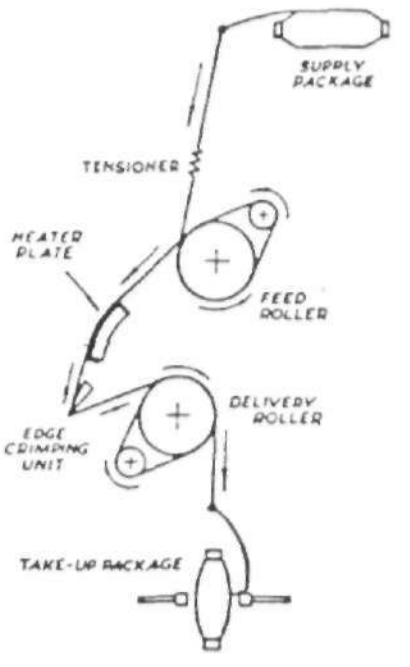


Fig.4 EDGE CRIMPING

method were suggested for the upholstery and carpet industries but achieved no commercial success (Fig. 3).

D. EDGE CRIMPING

The yarn is heated and then almost immediately drawn over a dulled knife edge as the filaments cool. The result is that the filaments are stretched on their outer side as they bend around the blade edge, and their cross-sections have a flat side due to the scraping contact with the edge. The resulting helical spring-like crimp with coils of alternating directions (reversing helices) confers high extensibility. Edge crimping is now practically extinct (Fig. 4).

E. KNIT-DE-KNIT CRIMPING

In this method (which is also called 'crinkle' crimping) the yarn is knitted into a continuous tubular length of plain fabric on a small single-feed knitting machine. The fabric is then flattened and wound on to a 'cheese' and steamed in an autoclave. Alternatively, heater plates may be fitted on the machine between the knitting head and the fabric take-up.

Stitch shape configurations are then set in the filaments, all of which have the same crimp in phase with each other. The fabric tube is then unravelled and rewound.

Yarns produced by this method are used mainly in ladies' underwear, sweaters, knitted outerwear garments and blouses. When used in knitting, the machine gauge must not match closely the crimp gauge of the yarn associated with the knit-de-knit stitch length, otherwise the fabric appearance changes as the knit-de-knit crimp changes from in-phase to out-of-phase with the knitted stitch.

Fabrics produced from these yarns have good uniformity, a lofty handle and excellent stretch and recovery characteristics but have a bouclé texture. The yarn applications are therefore limited and depend on fashion changes (Fig. 5).

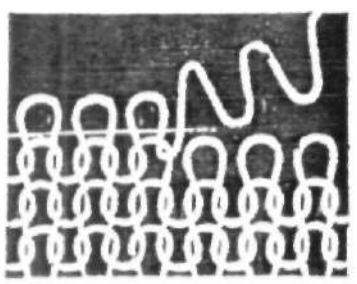


Fig.5 Knit-de-knit crimping

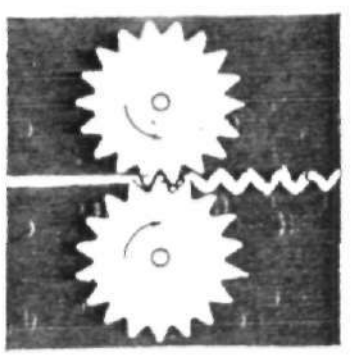


Fig.5 Gear crimping

This method is still used, though only to a very limited extent for obvious reasons. The output is therefore small and mainly for applications where the unique character of the yarns offer very attractive advantages.

F. GEAR CRIMPING

Gear crimping, also referred to as the crinkle method, consists of passing a filament yarn at moderate tension between the enmeshing teeth of a pair of matched gears or sinkers in a closed heated chamber. The configuration of the teeth is permanently set in the yarn structure as it cools outside the chamber. This method, like the knit-de-knit process gives an 'in-phase' crimp configuration.

G. FALSE TWIST TEXTURING

This method is presently the most widely used texturing technique, accounting for about 90% of all apparel textured yarn output.

A suitably tensioned thermoplastic yarn is gripped and rotated by a twisting device situated between two positive feed roller systems. A 'false twist' is inserted so that a steady twist level is maintained upstream of the twisting device whilst the yarn becomes untwisted on passing through the twisting device so that the twist downstream is zero. A heater and a cooling zone are placed in the twisted section of the yarn path so that the crimp associated with the twist is set into the yarn (FIG 6). This causes the filaments of the yarn to try to return to their twisted form when they are not under tension.

The twist set into the filaments before untwisting also makes them twist-lively and, having unbalanced bending and torsional forces [1 3 15], their buckling, coiling and snarling tendency gives them their characteristic bulk, high stretch and retractive power [13]. Nowadays the process is carried out as a combined draw-texture operation, and can be adapted to process unoriented or partially-oriented filament yarns. An additional stabilization (thermosetting) treatment is sometimes given to the textured yarn at an overfeed of 10-15% (from full extension) in a second heater on the texturing machine to

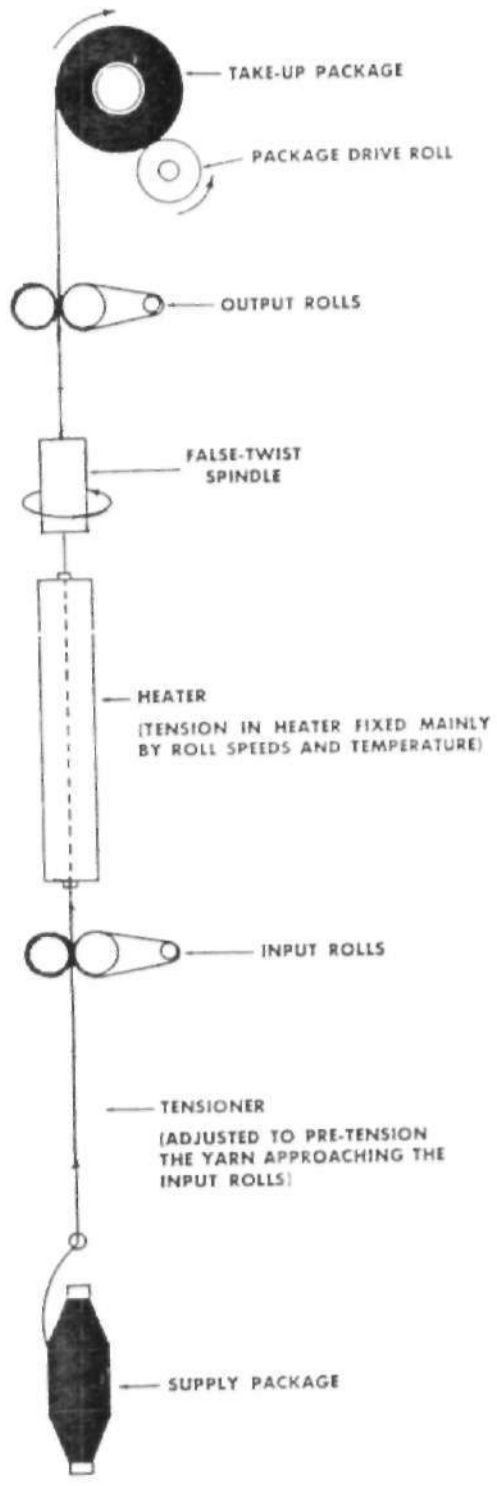


Fig.6 False twist texturing

reduce the stretch and shrinkage characteristics and twist-liveliness whilst retaining bulkiness.

Two yarns processed with opposite twist are sometimes doubled together in order to balance the twist-liveliness.

Single-heater false-twist textured yarns, usually of nylon are used for stockings,tights, swimwear and other stretch-to-fit garments where good extensibility and recovery are of prime importance. Two-heater processed yarns, usually of polyester, are used in applications where bulk and texture, but very low stretch are required.

H. AIR-JET TEXTURING

All the texturing techniques so far discussed rely on the mechanical distortion of the thermoplastic filaments at elevated temperatures to develop the desired crimp which generates their open structure, bulk, characteristic high extensibility under quite low stresses and other additional characteristics [16 25] .

Air-jet texturing is, however, a purely mechanical process [5] which does not depend on heat and the thermoplstic properties of the fibre or any chemical change. It is by far the most versatile of all the texturing techniques, enabling continuous-filament yarns with characteristics closer to those made from staple fibres of natural origin to be obtained. The yarn surface is covered with fixed resilient loops in place of the protruding 'hairs' or 'fuzz' on spun staple fibres. The characteristics extend from those of very fine spun-like types resembling combed yarns to neppy or flamé-type effect or fancy yarns [3] of a comprehensive range, as well as any degree of blending (comingling or intermingling) between fibres of different decitex and origin. The fact that the process does not rely on the thermoplastic properties of the fibres means it can be used on non-thermoplastic types, such as viscose, and on natural fibres as well as mixtures with syntetics of any composition, so long as some of the fibres in the composite have a sufficient continuity (length). This obviously offers greater scope for yarn formation.

1.2.1 PRINCIPLE OF AIR-JET TEXTURING

Basically, a continuous-filament yarn is wetted and then overfed through an air-jet device where it is subjected to a vortex of violent turbulence created by a cold air stream at supersonic speed [9 16 19 20 21]. The overfeed and the action of the turbulent asymmetric air stream causes a haphazard, wild and whirling entanglement, and the large instantaneous changes in aerodynamic forces cause the formation of a series of small loops spaced at random along the filaments. When the bundle intergrates [9] just outside the nozzle exit the loops entangle with each other. The entangled loops are held in place by interfilament friction [2] and are consolidated by tension while withdrawing the bulked yarn from the jet.

The increase in bulk due to loop formation and interentanglement is accompanied by the yarn contracting from its original length [10 19]. This creates a retractive force or tension in the yarn [5 6 12 22] the magnitude of which depends on the effectiveness of texturing and the take-up speed. This tension also pulls out the loose loops.

1.2.2 METHODS OF AIR-JET TEXTURING

Several Authors have classified air-jet texturing conveniently by the way in wich the continuous-filament yarns are fed into the jet. Generally, a single textured yarn emerges from the jet nozzle, irrespective of the method employed.

(a) SINGLE END TEXTURING [3 5 19]

A single multifilament yarn is fed into the air-jet. The resulting yarn is known as a single's air-jet textured yarn.

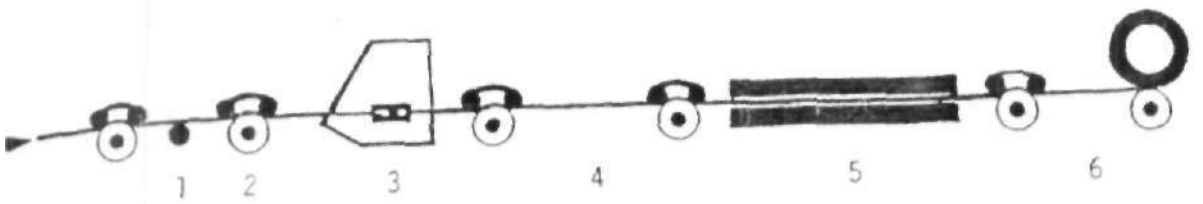


Fig.7 Air-texturing zones

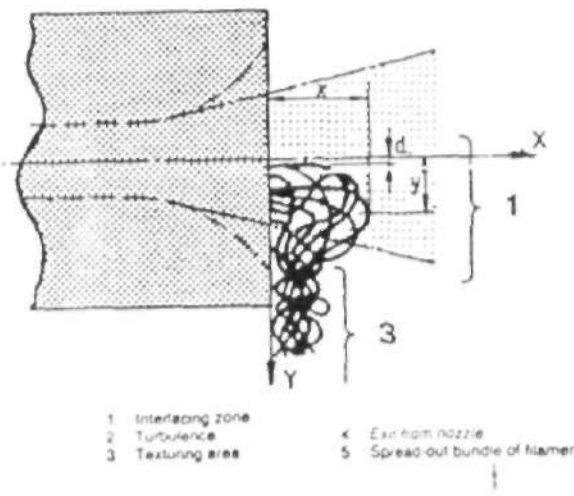
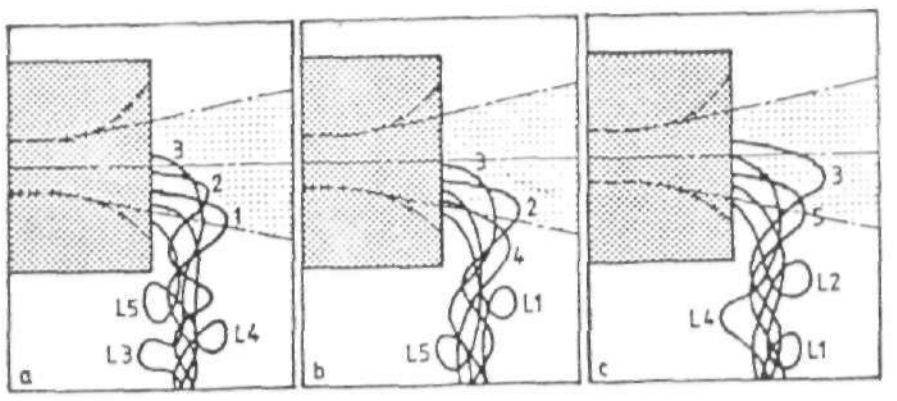


Fig.8 Loop integration at the lower part of jet nozzle exit.



Schematic illustration of the mechanism of loop formation

Fig. 9

(b) PARALLEL END TEXTURING [3 5 19]

When at least two separate and possibly different multifilament yarns are fed into the same jet at the same speed. The resulting yarn is a parallel air-textured yarn. This method could be said to incorporate the so-called comingling, intermingling or interlacing under the broad name 'blending', but these processes are not, strictly speaking 'air-texturing' since no substantial entanglement of loops occurs.

(c) DIFFERENTIAL MULTIFEED TEXTURING (CORE/EFFECT)

Where at least two separate and possibly different multifilament yarns are fed into the jet with at least two different speeds [2 3 5 19] . The yarn from the slowest running feed usually forms the core which is relatively straight and is the stress-bearing component, while the other(s) form the effect or sheath component around and finely inter-entangled with the core. Various fancy effects can be achieved by this method, since individual yarn feed rates may be constant or varying.

Progress in methods of air-jet texturing have been reviewed by several Authors at different times [1 3 4 5 9 12 32] . A typical modern air-jet texturing machine has as many as 6 process zones, possibly incorporated in a continuous draw-texture process where thermoplastic fibres alone are being processed (Fig. 7).

(1). DRAWING ZONE [4 5 7 10]

Allows partially oriented (POY) and unoriented yarns to be processed by first drawing on hot or cold drawing pins [2 19] .

(2). FEEDING ZONE

Where the yarns are fed into the jet by a pair or pairs feed rollers at controlled overfeed rates depending on the final yarn requirement.

(3). TEXTURING ZONE

This consist mainly of the jet which is usually contained in a sound-proof enclosure with a pre-wetting system and its associated water feed and return piping [2 20] . At least one yarn is passed through the wetting head or trough. The wetting operation enhances the efficiency, stability and uniformity of bulking [3 4 9 12 16] .

Wetting heads are usually considered more advantageous [6 10] . They require filtered water [19 20] and dispense flow-rates of between 0.5-2.0 litres per hour depending on the yarn being processed. They are constructed in such a way that they make allowances for gradual blockage of the head orifice [20] by soluble finishes used on the fibres of the yarn. Additives, specially designed to improve the process, may be incorporated in the water.

A linear density increase of between 50-150% results, depending on the type of yarn, its velocity through the jet system and other process parameters. The yarn leaves the jet approximately at right angles to the jet axis, with virtually all the water blown from the yarn by the turbulent action of the air flow in the jet.

(4). STABILIZING ZONE

The yarn passes from the texturing zone to a stabilizing zone where it is mechanically stretched by input and output rollers running at constant speed ratios. The tension generated by the stretch (usually 5-15%) [2 6 9] further removes regions of poor and loose entanglement which can slip even under low stresses, while tightening the more stable entanglements and reducing the sizes of the stable loops. The yarn core is compacted, resulting in enhanced interfilament friction with attendant loop uniformity and stability.

(5). HEAT-SETTING (THERMOSETTING) ZONE [2 4 5 19]

The yarn is overfed into a heat-setting chamber. Because of the low tension with which it is passed through this region, filament shrinkage can take place, which further compacts the core of the yarn. The sizes of wild snag-causing loops are yet further reduced, stabilized and set by the relaxation [6 7 10] . Loop configuration and mechanical

stability of the yarn are improved, as well as any tendency towards residual shrinkage [5] in subsequent processing. This heat-setting operation is a requirement related to the fibre properties (as it is in a normal fabric finishing sequence). It is not an operation essential to the air texturing process itself.

(6). TAKE-UP ZONE

The resulting yarn is wound on a package under controlled tension using a package build with favourable unwinding characteristics [2] .

The basic zones are 2,3,4 and 6 in any air texturing machine.Zones 1 and 5 are usually incorporated to facilitate the processing of unoriented and partially oriented filament yarns. Because of the various different demands resulting from the wide range of end-products and in order to optimize the particular yarn characteristics required, different jet-cores may be necessary for different types of yarns.

1.2.3 PROCESS VARIABLES

The main process variables that affect the quality of the air-jet textured yarn are :-

Type of supply yarn and its characteristics,

Feed rates of input and output rollers (overfeed),

Wetting of supply yarn and any finishes present,

Jet design and air pressure,

Process speed,

Draft in the stabilizing zone,

Heat treatment (heatsetting) temperature and

Degree of relaxation.

SUPPLY YARN

The number, type, colour, quality and decitex of the continuous-filament yarn as well

as the number of filaments per end and the feeding method (single, parallel end e.t.c.,) determines the type and characteristics of the product. The bending rigidity of the individual filaments of the parent yarn has an influence on the mechanism of loop formation [9] . Finer filaments and lower bending modulus favour the formation of finer, more frequent loops. A greater number of filaments increases the probability of loop formation and entanglement as well as their retention.

DRAW ZONE

As stated previously, the drawing zone is optional and is required only when unoriented and partially-oriented yarns are used. Although drawing and the temperature at which it is carried out affect the ultimate characteristics of the yarn, it fundamentally affects only the inherent thermal and mechanical properties of the fibres and does not in any way influence the process of loop formation itself.

FEED ZONE

The only way the creeling or feeding zone affects the process relates to the ease with which the yarns can be withdrawn at high speeds without obstructions. Input feed system are necessary to control the rate of feed to the air-jet, otherwise the yarn shoots out of the jet nozzle due to the high acceleration imparted by the supersonic flow [9] . The rate of feeding relative to the take-up from the jet nozzle (overfeed rate) determines the size and frequency of loops formed along filament lengths because it is this excess that is used for loop formation and entanglement. Yarns textured with greater than 40 % overfeed rate show an increased tendency to snagging and are therefore not very suitable for fabrics especially designed for apparel, although up to, and over 100 % overfeeds are used for the effect component(s) of core and effect yarns [19] .

Both overfeed and take-up must be kept constant to avoid positional variability along the yarn length and ensure easy reproducibility. Consequently machines are often equipped with variable drives [3] to ensure optimum settings for any requirement.

WETTING

The effect that wetting has on the process is not entirely understood. It has been suggested that improved efficiency is achieved by the interaction of increased inertia of the air stream or of the wetted filaments (which aids their separation). It is more likely, however, that improved filament lubrication reduces the interfilament sliding friction, thereby enhancing relative displacement of the filaments and hence increasing the possibility of loop formation [4 12 13] . Because of the improved texturing efficiency, wetting is also claimed to increase the average tension in the yarn as it emerges from the nozzle [16].

FINISHES

Spin finishes added to the filaments during extrusion influence the effectiveness of wetting. Originally applied to enhance interfilament cohesion, reduce friction between filaments and guides and reduce generation of static electricity [2 15] , finishes could also help lock in the formed loops after texturing [19].

However, a considerable amount of finish is lost in the drawing zone (as fumes and charred residue) and washed out during wetting and by the action of the jet [19] . The extent to which this occurs depends upon their make-up and interaction with water. Spin finishes may lead to residue deposits within the jet orifice and can impair the filament separation which is an essential first step in the mechanism of loop formation and entanglement.

Since loop stability depends on interfilament friction, the type of finish on the yarn is also important in determining yarn performance [9] . In extreme cases, spin finishes can be detrimental to the process. However, specially designed finishes could be added to the wetting supply to enhance the texturing itself [20].

AIR JET AND TEXTURING ZONE

The most significant parameters in the texturing zone itself include the jet design and air pressure. The cross-section of the nozzle, annular clearance [9 22] and the length of the region of turbulence (Fig. 13c) and mutual contact between the yarn and the air stream are critical factors that have a profound influence on the product. Air pressure must be uniform [5] and its flow turbulent in the yarn passageway. It is essential that the air is free from debris and oil and is cool enough to avoid condensation.

Loop size, frequency and, therefore yarn bulk increase with increasing air pressure (all other interacting factors being constant and favourable). Low air pressures may give inadequately bound loops resulting in yarn irregularities, fabric snagging and generally poor product quality.

Texturing speed affects the linear density of the yarn especially after stretch stabilization. As speed increases the texturing is less effective as the dwell time in the jet is shorter. Linear density therefore reduces as speed increases, especially at higher speeds.

The stretch applied in the stabilizing zone improves the quality of the textured yarn in the manner previously described.

As the overfeed rate is increased in the heatsetting region, breaking elongation is increased, the 'velcro' effect and residual shrinkage [5] are reduced while tenacity is relatively unaffected [17]. The yarn speed and tension , the temperature of the heater [3] and that of the environment influence filament behaviour and the mechanism of heat transfer, which thus affects the ultimate yarn properties.

Higher shrinkage tensions are observed at elevated temperatures and long heater dwell times. Heater geometry, power, temperature and length dictate the necessary dwell time for a particular fibre type. Increase in yarn temperature in the heater generally reduces residual shrinkage [17].

1.2.4 CHARACTERISTICS OF AIR-JET TEXTURED YARNS

Air-jet textured yarns are soft, bulky yarns which satisty the requirements for fabrics used in apparel, furnishings, some industrial fabrics and a number of other end-uses. As described previously the yarn surface is covered with loops analogous to the protruding fibres on the surface of spun yarns. Their size, geometry and distribution essentially determine the yarn bulkiness and other properties. The number of filaments which form loops and entanglements increase the linear density of the resultant yarn; at the same time the tenacity decreases because these filaments or parts of them no longer participate in tensile stress-bearing since they are slack and generally not in the yarn core [17 21] . The increase in linear density and decrease in strength jointly contribute to a drop in tenacity [10], modulus and elongation characteristics. The textured form achieved and the increased specific volume remain virtually unchanged at loads normally encountered during subsequent processing and during wear [16 19] .

1.2.5 ADVANTAGES OF AIR-JET TEXTURING

The method is a continuous, relatively economical [6] process which can conveniently be incorporated into a draw-texture scheme. It can accept the widest range of raw materials (input yarns) and produce the widest variety of required products.

Heavy packages for direct processing can be made and the finished textured yarn does not require any folding, twisting or rewinding.

1.2.6 FIELDS OF APPLICATION

Applications of air textured yarns are naturally determined by their resultant properties. They can be grouped into 3 main categories, based on their end-use suitability.

[5].

(i) BULKY YARNS

-Ranging between 1000-7000 decitex, with coarse filaments greater than 6.5 dtex/filament. Some types of covered fancy yarns [2], used mainly for home furnishings, especially upholstery, carpets and occasionally for apparel fabrics such as coatings fall in this group.

(ii) TECHNICAL YARNS

Consist mainly of yarns of filaments of medium fineness between (2.5-6.5 dtex) where the non-slip feature is of major importance, e.g., in shoe laces, bonded fabrics and sewing threads.

Their use in the Automotive industry in particular is credited to their resilience and good abrasion properties as well as structural stability. The projecting loops facilitate much better adhesion with polymeric coatings in laminated and coated fabrics. This feature has enabled air textured yarns to penetrate the tyre cord [21] and belt drives manufacturing sectors. In most of these applications, these yarns show characteristics superior to yarns made by other texturing techniques.

(iii) APPAREL YARNS

These include yarns with fine and ultrafine filaments ranging from less than 1 dtex to 2.5 dtex per filament and are mainly used in fine and normal apparel. Examples are woven and knitted sports and leisurewear, decorative fabrics [33], half hose, shirtings, swimwear, dungarees. Other important uses are in neckties, ladies' and men's outerwear and suiting fabrics, men's socks. Anorak and skiwear fabrics [2 4 9 21] where the combined advantages of continuous-filament yarns and spun yarns are exploited, also employ significant quantities of air textured yarns.

Immitation of cotton and linen fabrics can be achieved, particularly when a slub effect is exaggerated. Air textured yarns can give good performance in virtually all textile applications.

1.2.7 TECHNOLOGY OF AIR-JET TEXTURING

The basic principle of air texturing has not changed since its commercialization in 1953 by Dupont. What has changed is the design and manufacture of the machine elements which control the process variables. The most significant of these is the gradual modification of the jet design [4 8 11 16 32] in various ways by different manufacturers thereby enabling yarns to be produced with greater efficiency and better control of quality.

Typical air-jet texturing machines were exhibited at the most recent ITMA exhibition (Paris 1987) by Barmag (AM4 and FK6-80), Eltex (AT, ABS and AT HS3 models) Murata (Air-jet crimper 335-II), and Giudici (TG 20 Super T). Others shown were fancy effect machines from Gilbos (Dynajet), and Dietze & Schell (DS 60 for texturing giass fibres).

Heberlein were most prominent in showing several types of air-jet cores -the T-series, as well as two types of noise-dampened housings (the LB series housings) into which any of the T-series cores can fit. The assembly can then be fitted into various machines [3 20 24], either built-to-purpose air texturing machines or those suitably converted for air texturing.

The LB-01 housing is designed as one unit, for an air-jet core with its yarn wetting device. It is constructed so that air and water can be fed directly through suitable connections. The LB-02 housing is made to house an air-jet core only, and uses a separate wetting device (such as the Hemawet SW series from the same manufacturer). A special model of the HW series of wetting systems, the HWP-02, filters and meters water through an efficient head designed for uniform application to the yarn before texturing. Additives to enhance texturing, reduce static generation and reduce cleaning (of the jet and wetting head) are sometimes added into the water.

The T-series jet cores can process yarns from very low decitex levels to 50 dtex as

well as industrial yarns up to 5000 dtex. The T-100 series (T100, T110, T140) all have only one air inlet into yarn passageway, while the series T300 (T321, T341,T351) have three inlets (Fig.13c), each arranged at the same diametric angle to the direction of yarn movement, and symmetrically at 120° to one another around the mean flow channel [19 20]. The number and symmetry of the air inlets determines the strength and character of the turbulence created in the nozzle. The cores may generate different loop sizes depending upon the the physical properties of the yarn and the way the process variables are manipulated [2]. Different cores are available for processing single-end, parallel or multifeed inputs.

These cores are claimed to be reliable, efficient and easy to maintain; their high wear resistance is said to ensure good yarn reproducibility over long periods and offer favourable production economies such as low air consumption (6-20 m^3 /hr at 9 bar) from smallest to the largest diameter cores , and at high operating speeds.

Special jets for such air texturing and intermingling are also available from Fibreguide and from Enka & Technica [20].

1.2.8 THE MECHANISM OF LOOP FORMATION AND LOOP STABILITY

Over the years, various suggestions have been put forward to try and explain the mechanism of loop formation in air-texturing [26 27 28 29 30 31]. A reasonable theory must take into consideration the activity in the texturing jet, influenced by the interaction of the process variables. The most acceptable description at present is one proposed by Acar et al [16]. They suggest that under the action of the turbulent, supersonic air flow, the first event that takes place is the separation of the filaments. And because of the free excess offered by the overfeed, some filaments will move faster than others (i.e., are displaced longitudinally relative to the others). The amount of displacement will depend on how early the filament is separated from the others during the time the yarn first contacts the air stream, as well as the local drag forces instantaneously experienced by the filament in

the vortex. Asymmetry in the air stream is thus essential in generating longitudinal displacement. The filaments continuosly change their position within the nozzle due to the effects of the turbulent swirling air, inhibited by interfilament frictional interactions.

Acar et al [16] showed that the velocity distribution varies from the jet center to the walls of the yarn passageway irrespective of the number of air inlets of the jet such that, in the turbulence, individual filaments experience variations in the drag force acting on them. They also showed that the nature of the velocity distribution is such that the filaments occupy the lower half of the nozzle exit (Fig. 8).

At any instant, the fastest moving filament is blown out of the jet nozzle along the direction of the air flow at a speed much greater than the texturing speed, and moves as far as its excess length and the combined effects of interfilament friction and drag forces allow. It then is suddenly jerked, as a result of which it flops back under the effect of the sudden deceleration. Acar suggests that it then entangles and threads the bow or loop formed by the sudden motion and the right-angles direction change occuring at this point and is incorporated into the previously integrated bundle as well as into other filaments emerging from the nozzle exit, thus forming a stable entanglement (Fig. 9).

Different filaments are subjected to different stages of this process at any time and at random, resulting in mass entanglements and consequently yarn shortening and tension build-up. This tension then sets up favourable conditions for further loop formation and entanglement within the yarn structure as the yarn is taken up at right angles to the jet axis.

Acar et al found that loops formed actually vary in nature and size in accordance with the cumulative forces acting on the filaments at the time of loop formation.

Loop stability is one of the most important properties of good air-textured yarns. It is usually required to be of a high degree, although in isolated cases it may depend on the end-use of the yarn.

The quality of a jet core is therefore not only judged by the yarn throughput possible and the energy consumption, but also by the structure and stability of the loops on the yarn it produces under load [19] . The general principle used in determining loop stability consist of evaluating the residual length of a sample to which a static load is applied for a controlled time [3 19] .

Loop stability depends on the structure of the entanglements in the yarn. Kollu [18] established the presence of cross-over loops and bows or non-crossing in his analysis of air-jet textured yarn structure. The general distribution of these in the structure dictate the quality of the yarn.

According to Simmen [19] a large number of wildly blown loops do not improve the synthetic feel of fabrics made from air-jet textured yarns, but a large number of small loops and bows impart to it a more crisp hand.

Although, as previously mentioned, loop size, frequency and uniformity are dependent upon the jet, machine setting and the parent yarn, their creation is influenced mainly by the mechanism of entanglement.

CHAPTER TWO

2.1 THE 'TEXSPUN' FREE FIBRE-END DEVICE

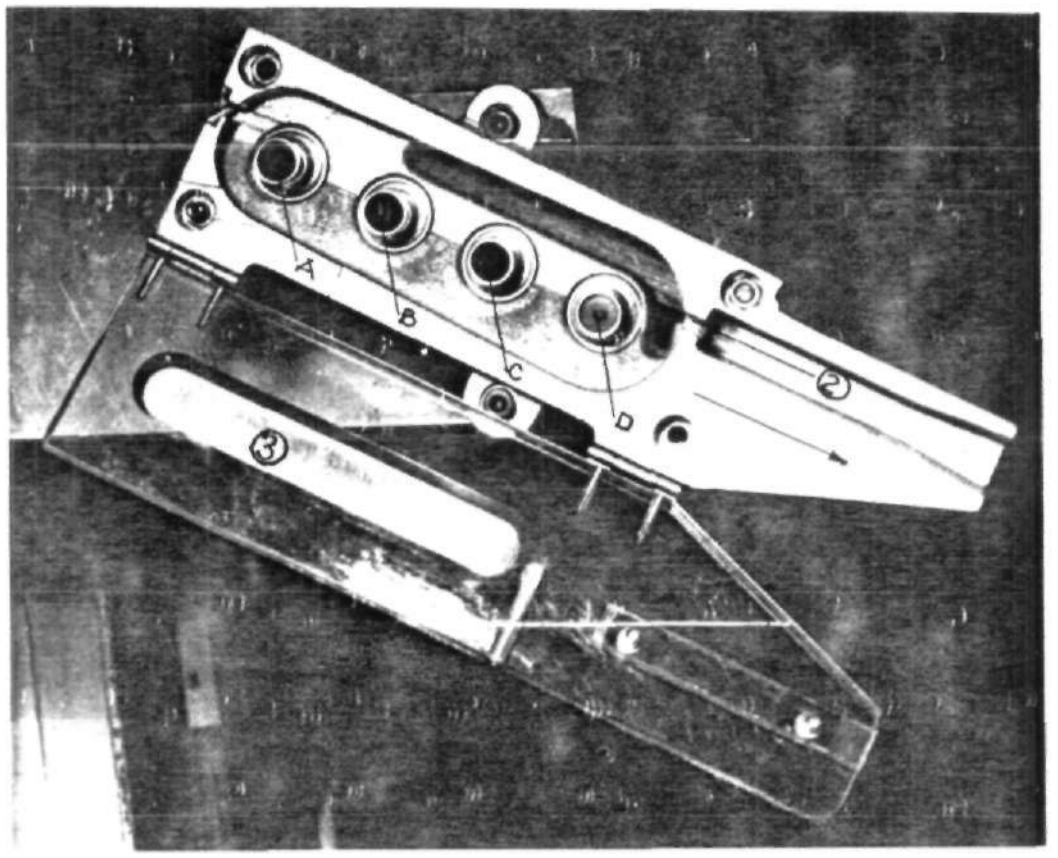
2.1.1 INTRODUCTION

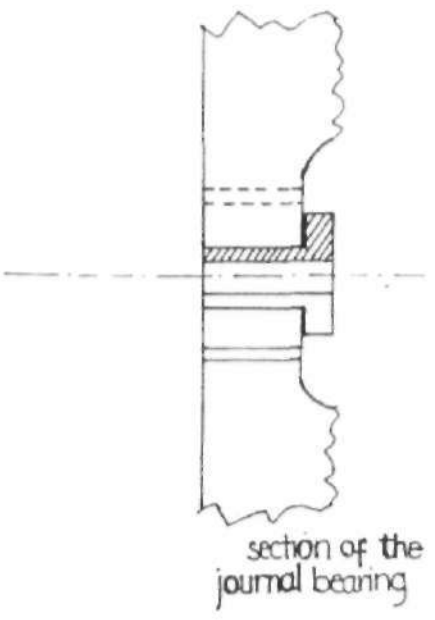
The economic advantages offered by air-jet textured yarns, combined with their attractive aesthetic and functional qualities make them an interesting proposition. As in all fields of Technology, methods are being sought to further improve the qualities of air textured yarns, mainly their spun-like characteristics. Strides in this direction were made by BARMAG in 1983, when they introduced the 'TEXSPUN' ® free fibre-end device, designed to break the looped filaments on the air textured yarn, thus converting them into free fibre ends as in spun staple-fibre yarns. In addition to further enhancing other characteristics, particularly the hand, reducing the shine, the tendency to pilling and dirt pick-up, the Texspun process also is claimed to add the advantage of eliminating the yarn handling and unwinding problems [1 4] encountered with ordinary air-textured yarns particularly in rewinding (e.g., pirning, warping e.t.c.) and in weaving. When projectile looms are used, snagging and the 'velcro' behaviour of the air-jet textured yarn prevents smooth yarn unwinding so that pick tension across the fabric width varies. It may also slow down the projectile so that it does not reach the projectile box properly, and, in extreme cases may distort its path within the shed. This problem is exaggerated when weaving on Jet looms, where the picking momentum is comparatively small, and the medium is less capable of confining the yarn to the required path.

2.1.2 THE DEVICE

The Texspun device is shown in FIG 10a, along with sectional diagrams of its important operating parts (FIG 10b-10c).

It consists of four polished stainless steel cylindrical rollers A, B, C, and D arranged





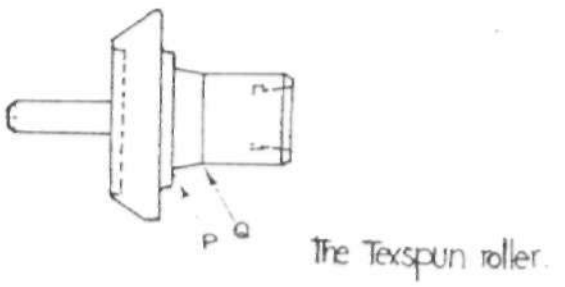


Fig. 10 The Texspun device

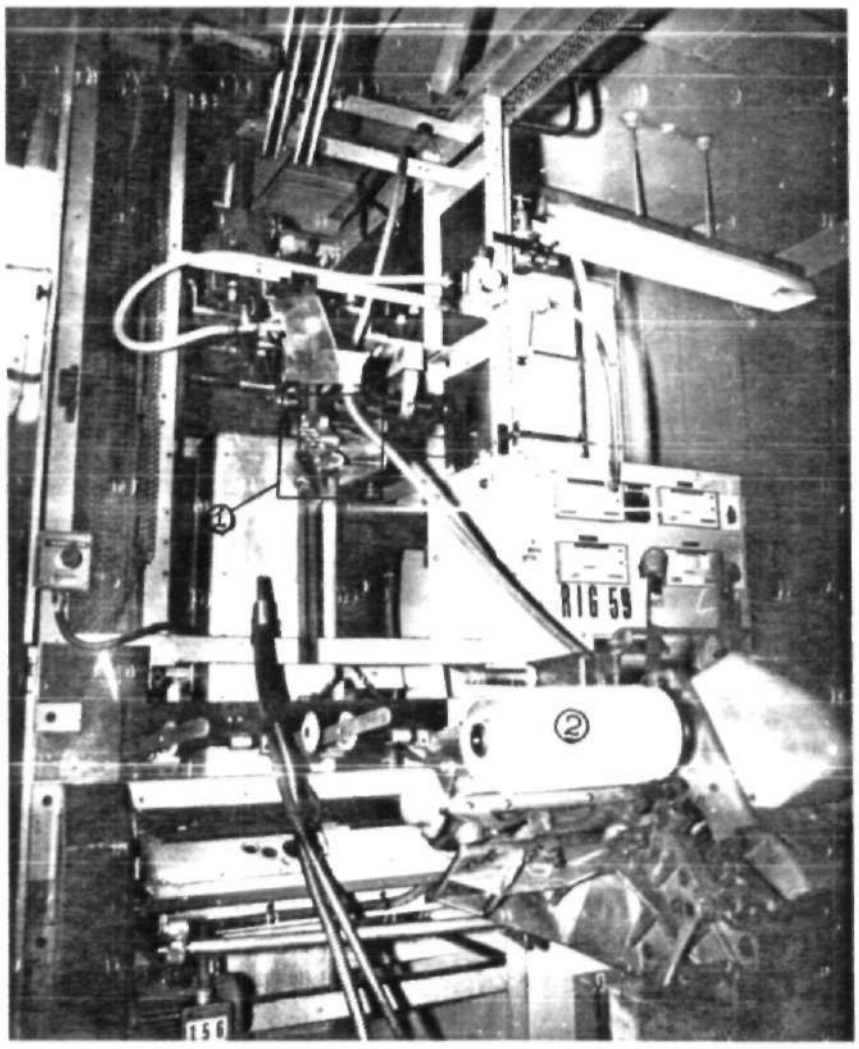


FIG. 10 POSITION OF THE DEVICE ON THE MACHINE.

in a line between a pair of feed (1) and take-up (2) guide eyes kept 134 mm apart. The shaft-centres of adjacent rollers are 30 mm apart and each roller is 11.5 mm in diameter (outer diam.) and of 19 mm overall length of which 14.5 mm projects outwards to form the functional part of the roller. The distance between the feed guide eye and roller A is 20 mm, and that between roller D and the take-up guide eye is 23 mm.

Each roller is mounted on two bearings:-

- A Journal bearing into which one end of the coated roller shaft fits and links the assembly to the main body of the device and

-A roller bearing at the other end of the shaft on which the roller cylinder drum is directly mounted.

The Jounal bearing is unlubricated and is constructed with a very small clearance such that the coated shaft fits in tightly - enough to prevent axial as well as free rotary motion. The roller bearing also constrains axial movement, so that the roller is kept fixed at all times and only smooth rotary motion is possible. The device is fitted with a transparent flap (3) which is used to cover the yarn and the roller arrangement after threading, and also facilitates 'fly' extraction via a slot at the back of the device.

The position of the device mounted on the machine is indicated by (1) in Fig. 11. (2) shows the take-up unit.

2.2 PRINCIPLE OF THE TEXSPUN PROCESS

The air-jet textured yarn is guided into the device by the feed guide eye and wrapped at least 360 degrees (clockwise, conventionally) around each roller. When the threading is completed and the thread path is stable, the incoming and outgoing parts of the yarn wrap lie side-by-side in contact as shown in FIG 12 and the plan view in Fig. 24a.

As the yarn is withdrawn, the in-coming section traps and holds the loops of the out-going section against the solid metal of the roller. If the yarn tension is sufficiently high,

as the yarn moves on, the trapped loop is pulled and broken, forming a pair of free fibre-ends.

The purpose of the inclined section of the roller PQ (FIG 10b) is to enhance and maintain the close contact between the in- and out-going sections of the yarn and, therefore, better loop trapping.

2.3 PROCESS VARIABLES

For any air-jet textured yarn subjected to the texspun process, the following variables affect the final yarn characteristics.

(1). The type, linear density, filament number of the yarn to be processed and its degree of texturing including loop size and frequency;

(2). The number of rollers of the device used;

(3). The side wrap angle, which defines the arc over which the in-coming section presses on the out-going section before the breaking sequence operates.

(4). The number of wraps around each roller. Although this refers basically to the wrap angle, it also determines the way in which a yarn section leaves one roller and interacts with the wraps on the next roller in order to generate a geometry to enhance the efficiency of the Texspun process (FIG ~~24~~).25

(5). Different combinations of the number of wraps on different numbers of rollers used at a time. These may produce changes in the characteristics of the yarn produced.

(6). Processing tension - is directly related to the pressure with which the in-coming section of the yarn holds the loops of the outgoing section and has an effect on the efficiency of the process as well as the nature of the 'hairs' obtained. Some tensions, lower than that needed to generate the critical filament breaking forces, may just cause

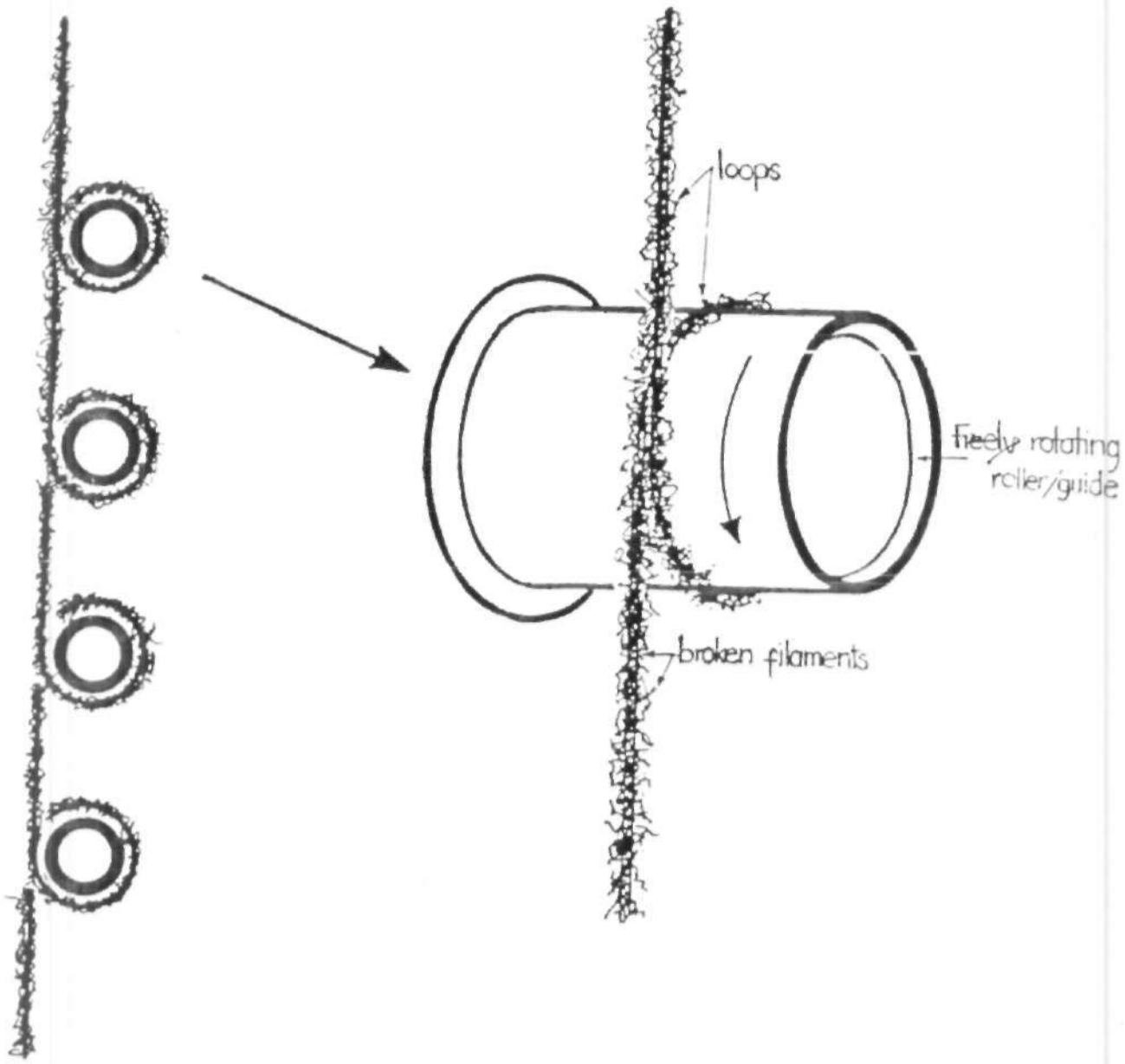


Fig.12 Air-textured yarn wrapped on the texspun roller

pulling of the existing loops into larger ones, without actually breaking them.

(7). Processing speed - affects the 'suddenness' with which the loops are stretched on commencement of the breaking sequence. This factor is bound to interact with several others, such as take-up tension, interfilament friction, the friction between the filaments and the roller surface and filament denier, to affect the loop breakage mechanism.

2.4 RESPONSE VARIABLES - YARN CHARACTERISTICS

The effectiveness of the Texspun device in breaking the loops on the yarn surface can best be assesed by measuring the related primary property - the yarn hairiness. Assuming all the loops are broken, we will expect each loop to be replaced by two hairs. However, the principle and the complications involved in the measurement of hairiness may make the results of this method difficult to interpret for a truly practical characterization.

Certain other properties of the yarn will be directly affected by the Texspun process, particularly the Linear density, the tensile properties (such as the modulus, elongation and breaking mechanism, tenacity, work-to-rupture), abrasion and the snagging characteristics. These parameters are more readily measurable, with cheaper, more readily available equipment and with comparatively greater accuracy. Their measurement may furnish information not only about the effectiveness of the device (by virtue of possible functional relationships) but also directly evaluate the properties of the processed yarn, as well as assist the interpretation of the test results of hairiness. They may also facilitate the prediction of the applications for which the yarns would be suitable.

2.5 SCOPE OF RESEARCH

In order to obtain as much information as possible about the device, yarns of good loop formation must be used. Tests can be carried out on a single roller with a single wrap or multiple rollers with single or multiple wraps. A number of factors may be investigated, such as the overfeed rate during yarn formation, take-up tension, type of the air-jet textured yarn (single, parallel or differentially fed yarns), air pressure used, type of filaments and linear density and the speed at which the process is carried out.

2.5.1 EXPERIMENTAL DESIGN

The approach that has been adopted is to divide the study into four stepwise series of experiments of the same basic design (randomized block factorial experiment) since the effectiveness of the process is likely to be affected by several different factors.

Throughout this research -

- An effective air pressure of 8.5 bar was used, and was kept constant;

- A Heberlein 'Hemajet' (series T300) core was used with a pair of 167/F72 decitex continuous-filament Polyester yarns;

- A constant take-up speed of 300 m/min was used. Other factors are varied at multiple levels each; the wrap angle was varied by adopting a series or parallel arrangements or a combination of both in order to study any trends or effects.

The investigation also attempted to confirm if the effects of individual rollers and wraps on them are additive or otherwise, and if for any particular combination of different wraps on rollers a correction factor(s) for each roller (the correction factor determined mainly by the wrap angle and the geometry of the presentation of the yarn from a reference roller to the next, while other variables were kept constant) was appropriate to quantify the performance of the device.

Although different trends are possible with the large number of different combinations of number of wraps and rollers, the geometry and the number of wraps (and hence the wrap angle) are thought to be particularly important, with tension playing an over-riding role. It was considered that if the experimental design adopted could prove this, then a suitable scheme for prediction of the performance of other combinations could be put together.

CHAPTER THREE

At first the effect of stabilizing tension on the textured yarns was assesed. This enabled the effects due to stabilization to be from those caused by the device.

Basic threading combinations were taken in the first three parts of the study:

PART 1 Investigates the effect of 1 to 3 wraps on a single roller;

PART 2 Investigates the effect of different combinations of wraps ranging from 1 to 3 on two rollers;

PART 3 Investigates the effect of selected wrap combinations from 1 to 3 on all four rollers;

PART 4 Investigates the effects of representative examples of other forms of wrap angle variation and geometry.

The main elements involved in each experiment are:-

(a) A completely randomized order of experimentation as well as measurement of yarn characteristics, aimed at minimizing as much as possible the residual variation.

This may be caused by 'nuisance' factors which are outside the control of the experimenter, such as machine performance variation due to power supply fluctuations as well as deterioration and depreciation, calibration shifts of meters and gauges during testing, effects of atmospheric conditions on processing and testing. Randomisation also reduces any form of bias and systematic experimental error likely to be introduced.

The procedure used was as follows:-

A group of treatments were labelled in order from 0 to N. The table of random numbers (Table 30) [4] was entered at any point at random, and, moving along the sequence the numbers were divided by N+1. The remainder obtained corresponds to the number of one of the treatments 0 to N and indicates it is selected; When a remainder valued at 0 is obtained, the number is ignored. This was done until all the treatments were selected and labelled 1 to N+1 in accordance with the order determined by the manipulation of the random numbers.

(b) Blocking of the experiments was considered desirable since the study extended through several days, and observations made on the same day or week may show better agreement. In this study a block is an overfeed rate for a type of yarn construction; A randomized sequence of treatments at different levels were carried out on one of these in a day. A standard [37] number of replications on each of the response variables on individual treatments was carried out.

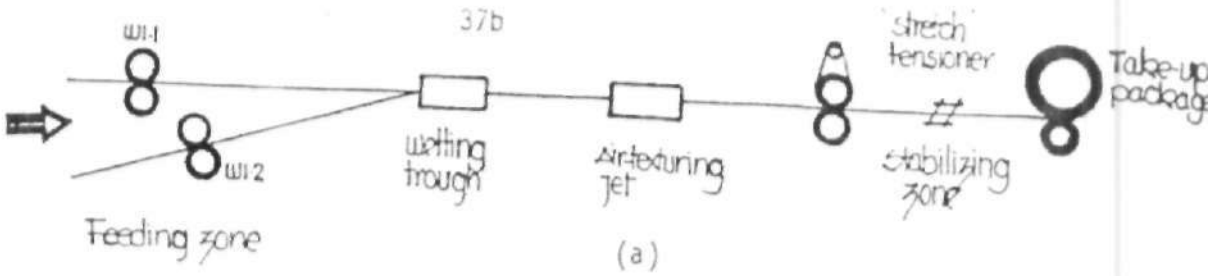
With this approach, conventional statistical analysis of the experimental results is possible, and estimates can be assigned to main or individual factor effects, their interactions as well as residual variation.

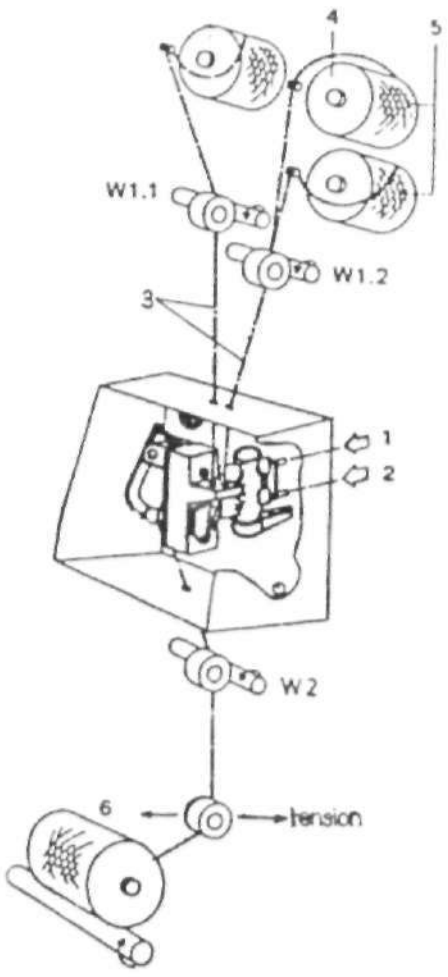
3.1 EXPERIMENTAL PROCEDURE

3.2 YARN FORMATION

The machine used in texturing the yarns is a converted False-twist texturing machine - 'RIG 59', based on a Scragg SDS 8 layout, adapted for air texturing by fitting the relevant parts. The main zones are as shown in Fig. 13.

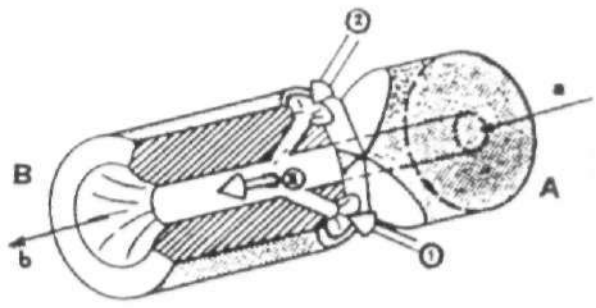
Two 167/72 decitex fully drawn Polyester continuous-filament yarns were fed by two feed systems (W1.1 and W1.2 in Fig. 13) through guides, then through the wetting trough, the air-texturing jet, take-up system, the stretch stabilizing zone and finally to the package :





(b) Diagram of the purpose-built single-head texturing machine

1 Water
2 Compressed air
3 Core/effect feed
4 Single yarn
5 Parallel feed
6 Take-up



(c) Schematic diagram of the standard-core HemaJet nozzle (T300 series)
1, 2, 3 Air inlets

A Yarn entry
B Yarn exit

a Feed yarn
b Textured yarn

Fig. 13

(a) at the same overfeed rate to form a parallel textured yarn,

(b) at different overfeed rates to form a sheath-and-core textured yarn.

The ratio of the speeds of feed systems 1 (directly driven by the motor via a timing belt) and 2 was varied by changing the intermediate gear between them. In this study, a 26 teeth flanged gear wheel was used to drive the second feed system via a timing belt so that the speed of this feeder exceeds that of the first by 35%. This was chosen because it gave adequate loop formation at lower overfeeds suitable for testing.

The first series of experiments were carried out without the Texspun device, with tension and other variables as used in all the experiments so as to be able to asses the effect of take-up tension on the various properties of the textured yarn and in order to separate the effects due to the device. The subsequent series of experiments were carried out with the Texspun device placed in the stretch-stabilization zone. This procedure was used to make all the yarns.

The Rothschild electronic tensiometer (TYPE R 1192, with interchangeable testing heads) was used to measure the stabilization tension and a tachometer was used to measure the speeds of all feed rollers. The parameters used are as shown.

Table 1: Feed speeds

OVERFEED RATE (%)	INPUT SPEEDS (m/min) Parallel Feed 1	Feed 2	Sheath/Core Feed 1	Feed 2	OUTPUT SPEED(m/min)
25	375	375	375	410	300
50	450	450	450	575	300

Tensions used :

LOW (L) = 85 cN

HIGH (H)=180 cN

LINEAR DENSITY

The samples were conditioned in a standard atmosphere [5] (in accordance with BS 1051 - 65 ±2% Relative Humidity, 20±2°C. A one-meter girth, power driven Wrap reel with suitable guides and tensioning system was used to wind 100 m skeins from each sample. The mass of each test skein was taken in the same atmosphere using a Precisa (model 510 C) weighing balance. The average of the calculated linear density for ten different tests on each specimen are as shown in the tables.

TENSILE PROPERTIES

The tensile properties of the yarns were measured using the Textechno Statimat M (TYPE FPA/M), a constant rate of extension automatic testing machine, with an IBM Computer and Screen, and a printer (EPSON FX-800) attached. This was done in the standard atmosphere.

A rather long gauge length - 500 mm was chosen. Small filament loops or free-fibre ends may be drawn straight into the yarn core during tensile testing. A short length is more likely to have an unrepresentative number of loops per unit length and loops of different sizes than a long length. When unbroken filament loops are drawn into the yarn core, they can effectively contribute to tensile stress-bearing of the yarn and will therefore introduce more variability in the test results than would be the case for longer lengths.

A testing speed of 200 mm/min was chosen because it gave an average breaking time of about 20 seconds [5 6] on initial test runs. Averages of 50 tests on each specimen are shown on tables in section 3.3.

HAIRINESS

The 'Shirley' yarn hairiness tester (from Shirley Developments Ltd.) was used to measure the yarn hairiness. The equipment consists mainly of a variable speed yarn drive mechanism, the hairiness measuring system and data logging and control computer which displays output serially on an RS 232 C serial interface. It has also an analogue output system for attaching a chart recorder when required.

The measuring system consists of an L.E.D. light source and phototransistor system, arranged so that the projecting fibres on the yarn surface interrupt the light beam as the yarn passes through. A calibrated movable micrometer-head guide (of range 0-10mm) maintains the yarn at a preset distance from the beam source, so that this distance determines the minimum height of the projecting hairs from the yarn axis before they are counted. This optical head is mounted on the front panel of the instrument, with a system of draw guides on the left, and take-off rollers on the right side of the panel. An adjustable air exhaust, placed just below the take-off rollers draws the yarn downwards from the rollers.

A micrometer height of 1mm from the beam source and a testing speed of 60 m/min was used instead of the recommended critical settings of 3mm, 60 m/min because some of the yarns studied showed zero readings on this standard.

A test length of 60 m was used, and 10 tests conducted on each sample. The average results are shown in the tables in section 3.3.

3.3 EXPERIMENTAL RESULTS:

3.3.1 EFFECT OF STABILIZING TENSION ON THE PHYSICAL PROPERTIES OF AIR TEXTURED YARNS

The series A graphs show the variation of several properties of the yarns with increase in stabilizing tension.

LINEAR DENSITY

Graph B1, drawn from table 2, shows exclusively the variation of linear density for the four air textured yarns studied, right from the post-jet region (where tension is assumed to be small).

Generally, there is a sharp decrease in linear density from the postjet region when even a small tension is applied. This decrease becomes less prominent as tension is increased. Although this initial behaviour is more evident for the sheath-and-core yarns, the parallel feed types show a more pronounced decrease at higher tensions.

This can be attributed mainly to the structure of the yarns. Under the same processing conditions, the sheath-and-core (SC) yarn has greater combined yarn overfeeds during its formation, by virtue of the higher sheath overfeed (hence higher tex value of the yarn). The sheath component therefore forms loops of greater size than those made by the core component. These are less stable and are drawn out to a smaller size to a greater extent than those of the core, so that the overall effect is that the SC yarn shows a more significant drop in linear density.

At higher tensions, the tex decrease is similar to that of parallel air textured yarns, although less pronounced, apparently because of the more efficient 'locking' of larger loops in the yarn structure at this stage.

Generally, the higher the overfeed used in constructing the yarn, the greater the drop in linear density on the application of tension.

Table 2:

(a) Average Linear Density

		Post-Jet	L(15cN)	M(85cN)	H(180cN)
25%	Par	41.75	38.43	37.15	36.40
	Sc	49.06	42.95	41.50	40.55
50%	Par	50.10	40.20	37.18	36.18
	Sc	58.87	42.73	41.03	40.27

(b) Average % Elongation

25%	Par		14.81	14.37	13.98
	Sc		14.03	13.45	13.12
50%	Par		14.43	13.92	13.48
	Sc		13.87	13.85	13.28

(c) Average Breaking Force (cN)

25%	Par		1042.24	1112.28	1165.52
	Sc		820.76	877.75	901.95
50%	Par		912.97	1073.06	1142.79
	Sc		795.22	871.20	893.69

(d) Tenacity cN/tex

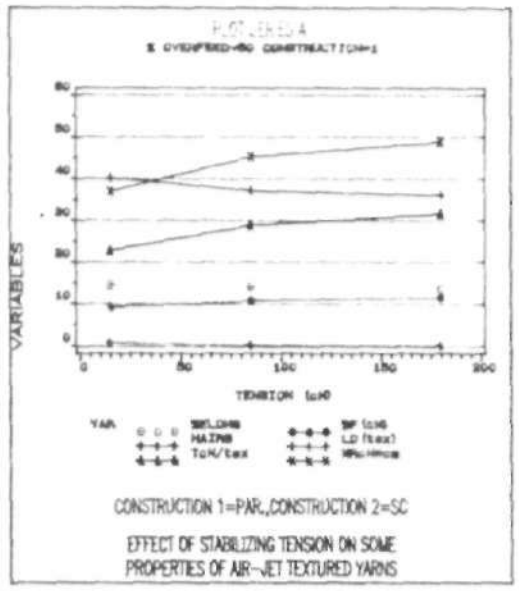
25%	Par		27.12	29.94	32.02
	Sc		19.11	21.15	22.24
50%	Par		22.71	28.86	31.59
	Sc		18.61	21.23	22.19

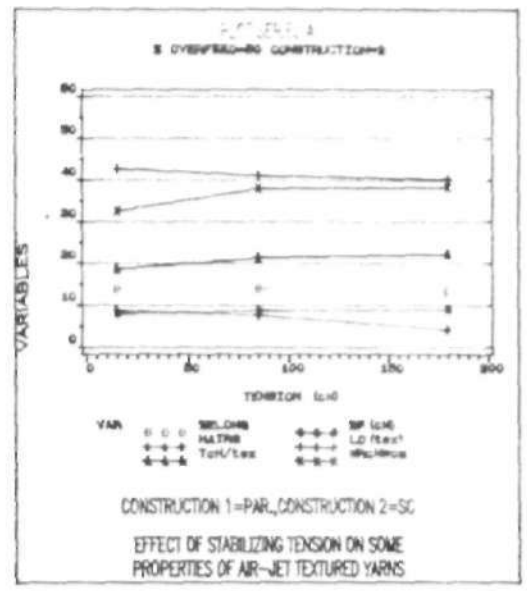
(e) Work-to-Rupture cN*cm

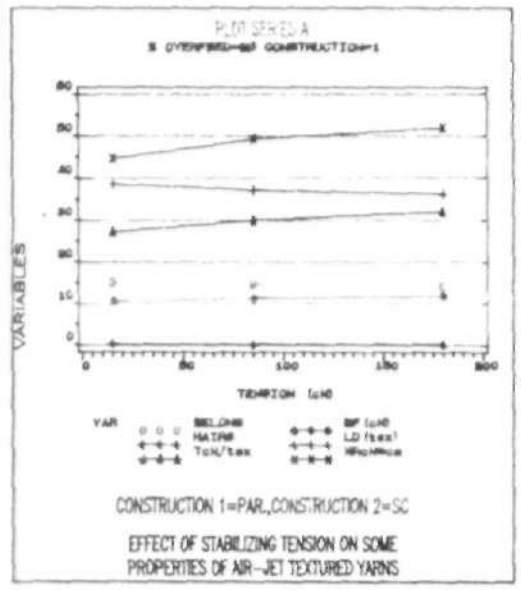
25%	Par		4452.03	4917.24	5182.29
	Sc		3404.49	3658.72	3803.42
50%	Par		3708.37	4530.12	4891.84
	Sc		3262.60	3805.51	3834.88

(f) Hairiness

25%	Par		1.39	0.47	0.60
	Sc		55.64	28.61	22.56
50%	Par		6.91	1.03	0.33
	Sc		75.23	87.32	41.98


VARIABLES
TENSION (cN)
CONSTRUCTION 1=PAR.,CONSTRUCTION 2=SC
EFFECT OF STABILIZING TENSION ON SOME
PROPERTIES OF AIR-JET TEXTURED YARNS


VARIABLES
TENSION (cN)
CONSTRUCTION 1=PAR.,CONSTRUCTION 2=SC
EFFECT OF STABILIZING TENSION ON SOME
PROPERTIES OF AIR-JET TEXTURED YARNS


VARIABLES
TENSION (cN)
CONSTRUCTION 1=PAR.,CONSTRUCTION 2=SC
EFFECT OF STABILIZING TENSION ON SOME
PROPERTIES OF AIR-JET TEXTURED YARNS

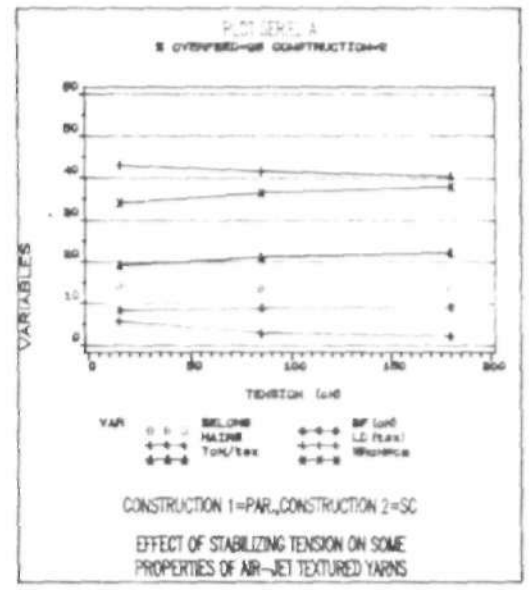
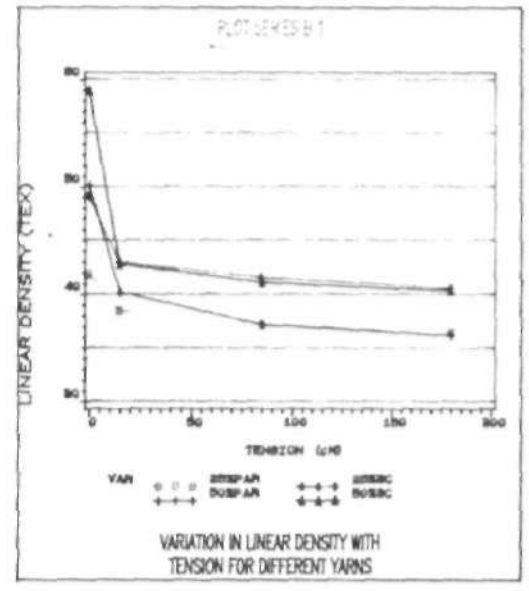

VARIABLES
TENSION (cN)
CONSTRUCTION 1=PAR.,CONSTRUCTION 2=SC
EFFECT OF STABILIZING TENSION ON SOME
PROPERTIES OF AIR-JET TEXTURED YARNS

FIGURE 14


LINEAR DENSITY (TEX)
TENSION (cN)
VARIATION IN LINEAR DENSITY WITH
TENSION FOR DIFFERENT YARNS

BREAKING FORCE

The breaking force increases slightly with increase in stabilizing tension; this change may be more significant between low to medium than medium to high tensions. This is the expected result for, as tension is increased, more filaments which had formed unstable loops are drawn into the yarn core and therefore contribute to the yarn's capacity to resist breaking.

The higher breaking force shown by the low overfeed parallel yarn (25 %) compared to the yarn made with 50 % overfeed arises because its lower overfeed allows fewer loops or loops of smaller size, so that there are more filaments in the yarn core to resist breaking.

At higher overfeeds, more loops are formed or the loops formed are larger so that the number of load bearing filaments is reduced. As stabilizing tension is increased, more loops are effectively pulled out of the filaments which are then able to contribute to stress-bearing.

Overfeed has a much smaller influence on the breaking force of the sheath-and-core yarns. The loops formed in the high overfeed SC yarns are larger and appear to be much more stable than in the parallel air- -textured yarns so that the increase in breaking force with stabilizing tension is much smaller than it is in the parallel air textured yarns.

The main difference in the magnitude of breaking force between the parallel and sheath-and-core yarns arises mainly from the overfeed, which relates inversely to the number of filaments in the yarn core which participate in tensile stress-bearing.

In particular, the sheath component makes very little contribution in the SC yarn where loads are supported mainly by the core component.

TENACITY

Sometimes called the specific strength, this represents the stress at break, expressed in units of force (cN) per tex.

This varies in a similar way to the average breaking force and the work-to-rupture for the same reasons; yarns made from higher overfeeds show lower values compared to those made with lower overfeeds in parallel yarns. The reverse is true for the SC yarns. Proportional changes are greater because of the combined effect of increased strength and decreased linear density.

ELONGATION

Not surprisingly, as the yarns have been initially stabilized under low tensions, the percentage elongation at break decreases very slightly with further increase in stabilizing tension, but the difference in behaviour between one yarn type and another is relatively small.

Generally, as tension is increased, the linear density decreases until the yarn is completely stabilized (just before it breaks). The same applies to the percentage elongation, with the 'natural' elongation of the filaments in the core persisting after that due mainly to the structure of the textured yarn.

HAIRINESS

Generally, the hairiness decreases with increase in stabilization tension because the loops formed on the yarn have been pulled out to smaller sizes, so that there are fewer of them which are of such size as to be detected by the hairiness testing device at the beam height used. The parallel yarns show more of this trend than the sheath/core, especially at higher overfeeds. This proves that the loops of the sheath/core yarns are more stable to tension and this is greater at higher overfeeds.

As expected, at any given tension, the sheath/core yarns are more hairy than their parallel counterparts. The tenacity and work-to-rupture increase with increase in stabilizing tension; the breaking force does so only very slightly. These relationshps are not exactly linear over the tension range used.

CHAPTER FOUR

4.1 EXPERIMENTAL RESULTS FOR THE TEXSPUN PROCESS (1):

SINGLE ROLLER

Fig. 15 shows the magnified photographs of the 50% parallel yarn (a) and 50% SC yarn (b), all stabilized at 180 cN. Fig. 15 (c) shows that of the 50% SC yarn treated with 1 wrap on a single roller of the Texspun device at the same tension. The part labelled (1) shows a typical loop on the surface of a textured yarn; typical 'pulled out' loop (2) and broken loop (3) are also shown.

Mean values of the results obtained for the first part of the study, in which one roller of the texspun device was used, with different number of wraps ranging from 1 to 3 are shown in table 3.

A randomized block factorial experiment was designed for this part because several response variables (properties of the yarn) are observed simultaneously, which happen to depend on several factors, all of which are at more than one level each. The main factors involved are :-

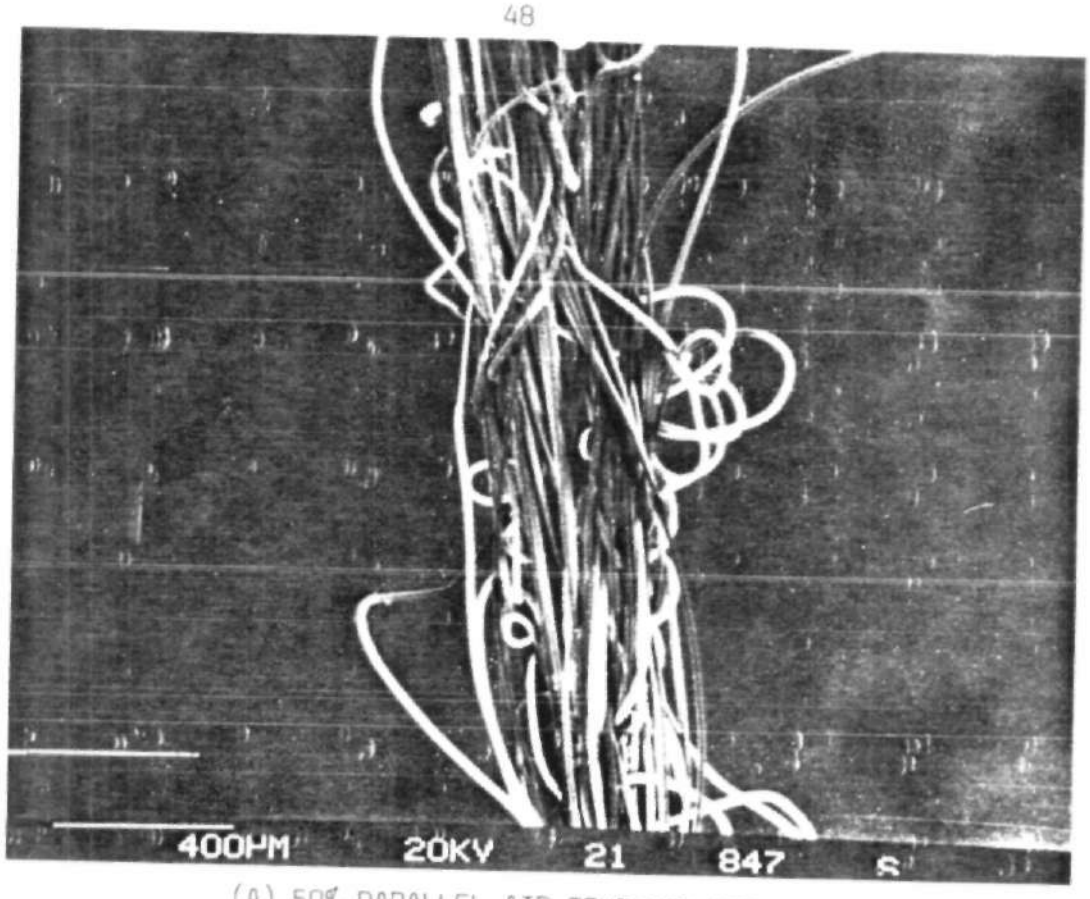
Stabilizing tension - 2 levels

Overfeed - 2 levels

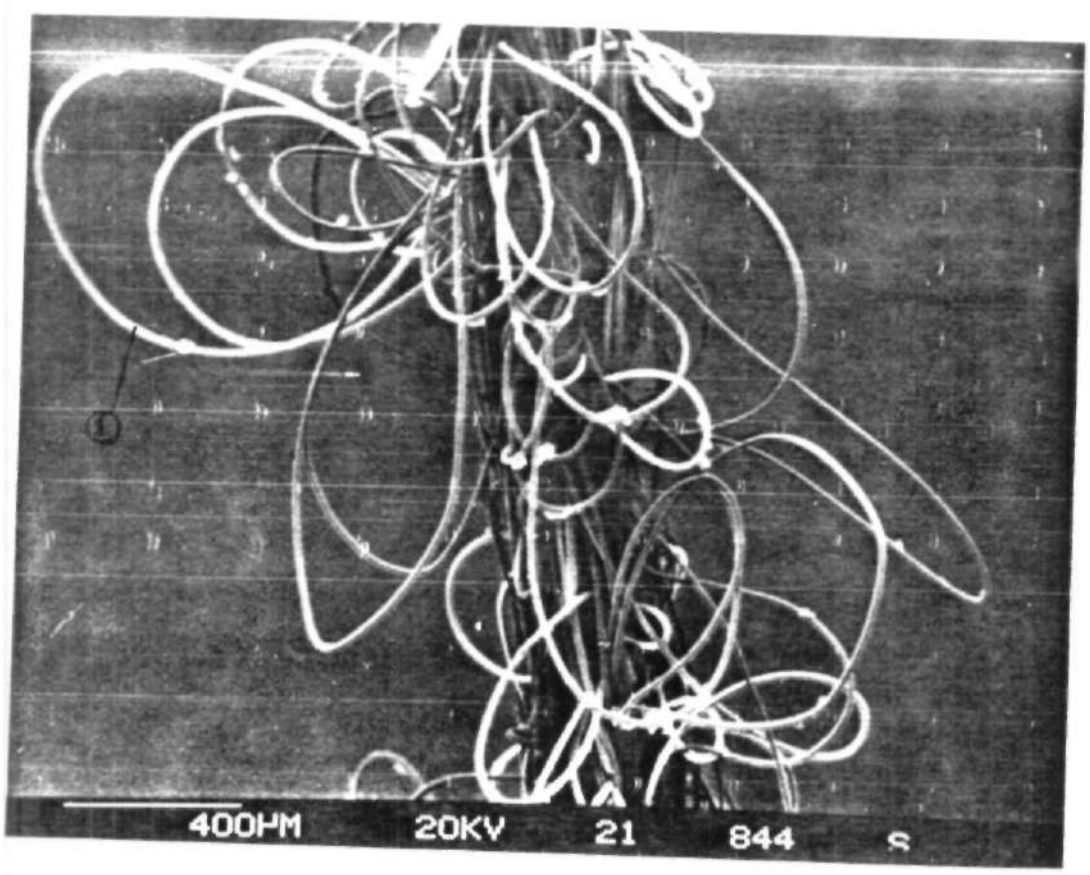
Number of wraps on the roller - 3 levels

Yarn construction - 2 types.

The first 3 factors are quantitative, having direct numerical expressions; the 4 th factor is semi-qualitative because its magnitude can be expressed only after computation, on the basis of the method by which the various inputs to the yarn processing are chosen



(A) 50% PARALLEL AIR-TEXTURED YARN.



(B) 50% SC YARN

FIG.15 PHOTOMICROGRAPHS OF STABILIZED TEXTURED YARNS.

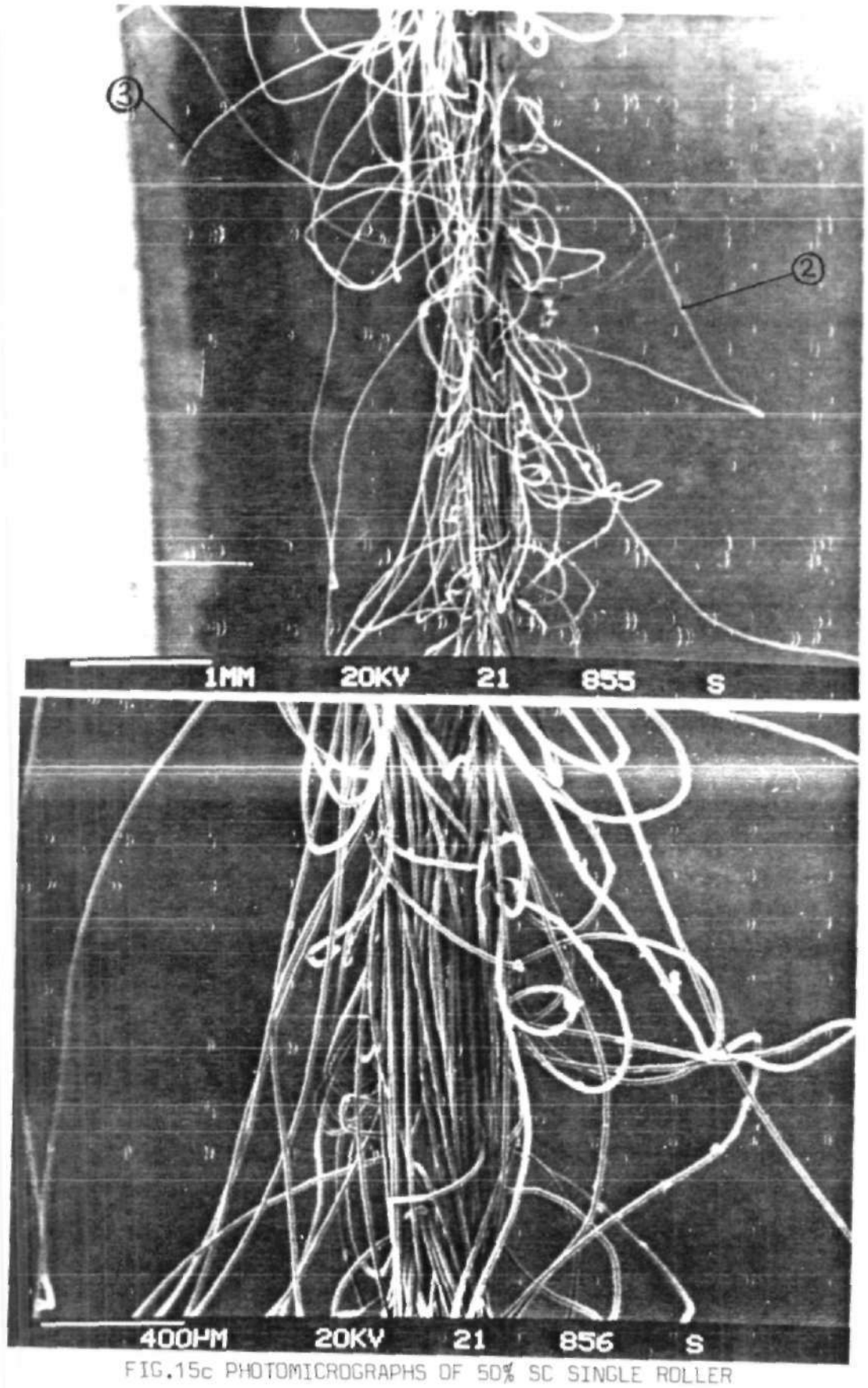


FIG.15c PHOTOMICROGRAPHS OF 50% SC SINGLE ROLLER TEXSPUN YARN.

and adjusted relative to each other, as explained in the previous chapter. It is defined entirely by the relative overfeeds of the two component yarns which formed the textured structure used in the study. The curves shown in the C series plots facilitate a visual assesment of the pattern of variation with number of wraps and stabilizing tension of the different yarn properties. A close look at the curves for each yarn of a particular overfeed and construction under treatment with 1, 2 and 3 wraps on one roller shows that the shapes are exactly the same; no visual difference can be discerned. A typical variation of the yarn properties with increasing number of wraps at 180 cN stabilizing tension is shown in the plots of series B2 to B7. It is obvious that there is some significant variation which may be due to the number of wraps used.

Generally, however, the changes are not so well shown in terms of measurable yarn properties in a way to make easy the assesment of the effects of the number of wraps.

Since a considerable amount of 'fly' (the portions of loops which have been broken) was lost, it is possible that the linear density of the yarns, particularly the sheath/core type (which showed more of this loss) will decrease. Although the proportion of the weight of 'fly' lost to the weight of a given length of yarn is very small, it could be measurable.

Observation of the curve B2, however, shows that this trend towards weight loss is not followed exactly. In fact from the 0 wrap level (for yarn stabilized at 180 cN but on which the Texspun device was not used) to when 1 wrap was used, an increase in linear density is observed, contrary to the expectations of a significant decrease due to the stretching of the yarn as well as any possible fibre loss. When two wraps were used, a slight decrease was observed; the trend reverses again for 3 wraps. It may be concluded, therefore, that fibre loss can be ignored in relation to linear density change. A comparison of B1 (at 180 cN tension point) and B2 shows that there is a little difference between the curves for 25 % SC and 50 % SC because the 50 % showed a very slightly greater reduction in linear density than its 25 % counterpart after using the Texspun device. The linear density changes in the parallel feed yarns follow a similar pattern as in

Table 3: Results for one roller

(a) Average Linear Density

		1 wrap		2 wraps		3 wraps	
		M	H	M	H	M	H
25%	Par	36.92	36.04	37.06	36.09	37.12	36.17
	Sc	41.38	40.78	41.59	40.54	41.59	40.74
50%	Par	36.71	35.85	36.93	35.65	36.82	36.16
	Sc	40.86	40.19	40.87	39.93	40.79	40.20

(b) Average % Elongation

25%	Par	14.23	13.81	13.97	13.63	13.87	13.41
	Sc	12.77	12.27	12.97	12.04	13.01	12.21
50%	Par	13.53	13.36	13.20	13.43	13.41	13.88
	Sc	13.24	11.82	13.32	11.83	12.79	11.87

(c) Average Breaking Force (cN)

25%	Par	1122.47	1184.53	1099.76	1174.43	1105.27	1175.43
	Sc	912.50	932.91	909.19	935.10	908.31	923.38
50%	Par	1105.43	1168.76	1040.25	1159.02	1053.92	1190.81
	Sc	928.23	912.07	926.98	909.84	883.60	904.18

(d) Average Tenacity (cN/tex)

25%	Par	30.40	32.87	29.68	32.54	29.78	32.50
	Sc	22.05	22.88	21.86	23.07	21.84	22.67
50%	Par	30.11	32.60	28.17	32.51	28.62	32.93
	Sc	22.72	22.69	22.68	22.79	21.66	22.49

(e) Average Work-to-Rupture (cN*cm)

25%	Par	4907.34	5228.24	4663.49	5056.72	4677.93	4979.94
	Sc	3578.35	3608.64	3615.79	3548.93	3624.49	3566.75
50%	Par	4554.09	4938.18	4128.90	4909.31	4332.77	5239.76
	Sc	3 18.86	3400.51	3877.98	3406.35	3481.92	3402.64

(f) Average Hairiness

25%	Par	7.37	11.03	0.14	6.35	1.79	2.76
	Sc	162.04	170.53	148.04	170.33	94.17	120.76
50%	Par	7.03	5.31	3.16	5.72	3.11	3.11
	Sc	188.14	197.87	188.00	220.89	118.39	160.38

the SC yarns, the variation being a little more irregular.

At this stabilizing tension, these yarns had lost virtually all of their loops, so that their linear density was almost as low as that of the input continuous-filament yarns (2x16.7 tex). Unlike the SC types, the linear density never exceeded that at zero wraps for any wrap level.

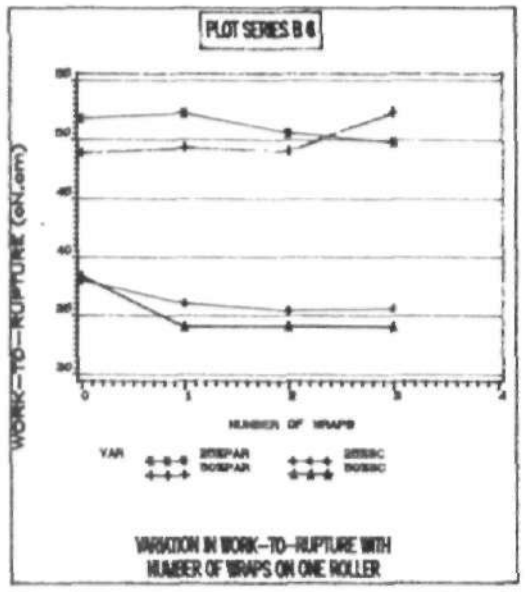
For all the yarns, results of elongation (plot B3),work-to-rupture (B6) and hairiness (B7) seem to show more variation caused by the different number of yarn wraps on the roller of the device. As in the case with linear density, the SC types show a greater response, with both overfeeds behaving in a similar manner (as they do for all other variables, as shown in series B plots). For elongation and work-to-rupture there is an initial dip in the curve as one wrap is used, then a slight but gradual change for 2 wraps; both show a slight increase at 3 wraps.

There is a sharp increase in hairiness (B7) when 1 wrap is used, a smaller increase for 2 wraps and a decrease for 3 wraps.

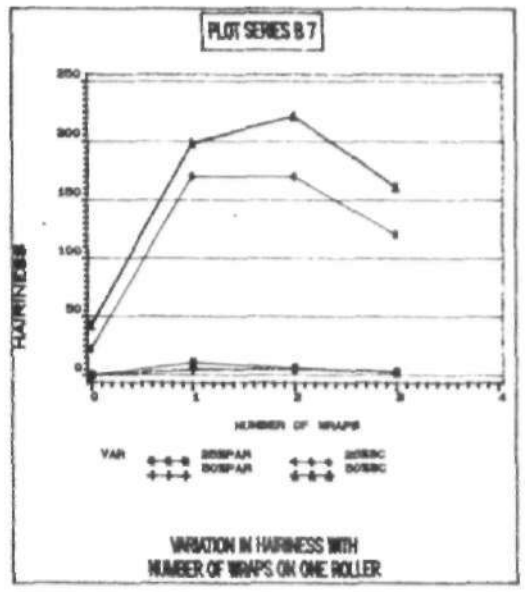
Several reasons may be responsible for this unexpected behaviour (see section 4.3).

For the parallel feed yarns, the variation follows dissimilar patterns for the different overfeeds as the number of wraps is varied; elongation is seen to vary inversely for the 25 % yarn, and shows a slight upward trend for the 50 % yarn. None of the yarns show a significant variation in breaking force (plot B4). The same is true of the tenacity (plot B5) except that the linear density changes are reflected in tenacity measurements. The changes in work-to-rupture shown in plot B6 are more or less consistent with those of % elongation.

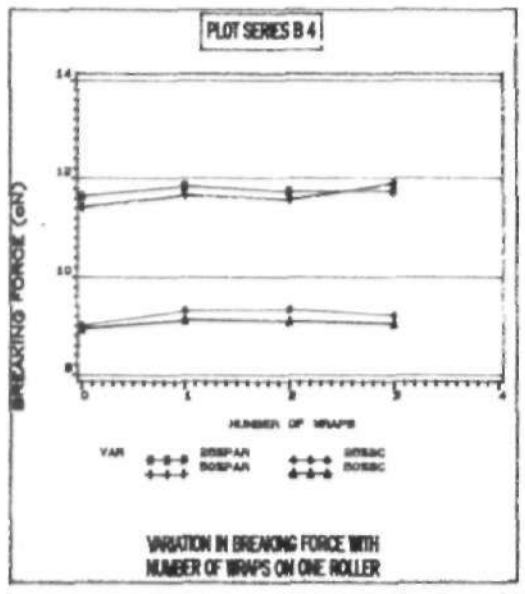
A general trend is observed in the series C,D & E plots with respect to hairiness. The Texspun process at high stabilization tensions result in more hairy yarns because the loops trapped are either broken or drawn out to such sizes as to render them undetectable by the hairiness tester. Unfortunately, the hairiness device cannot distinguish between



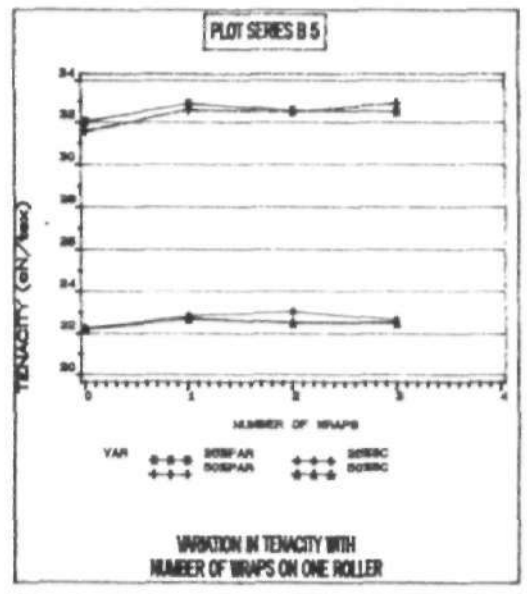
VARIATION IN WORK-TO-RUPTURE WITH NUMBER OF WRAPS ON ONE ROLLER



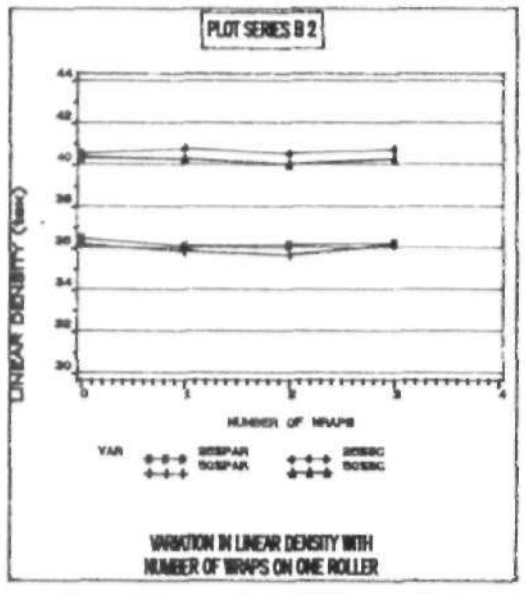
VARIATION IN HAIRINESS WITH NUMBER OF WRAPS ON ONE ROLLER



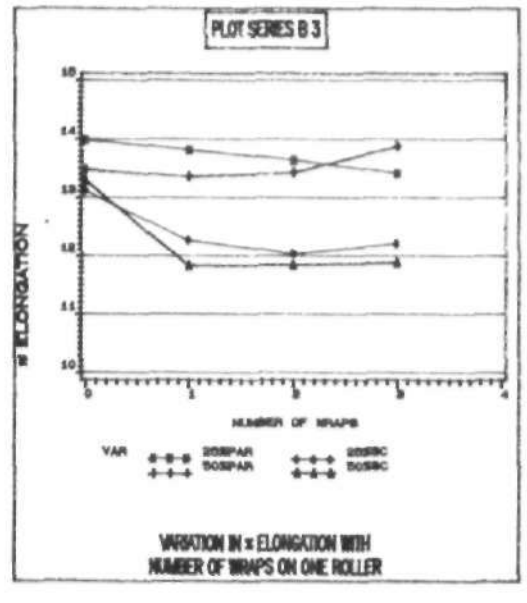
VARIATION IN BREAKING FORCE WITH NUMBER OF WRAPS ON ONE ROLLER



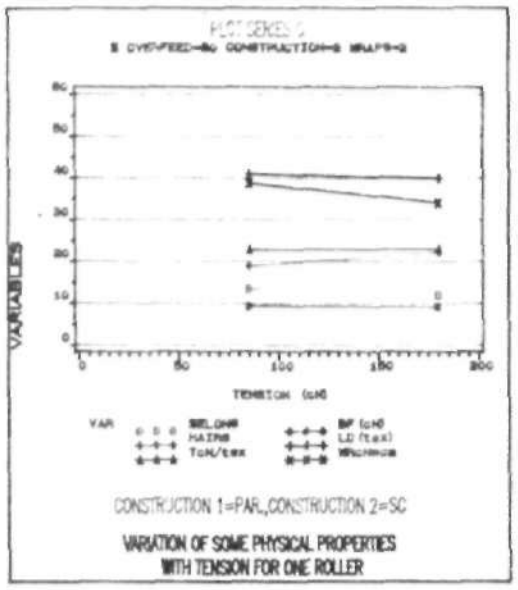
VARIATION IN TENACITY WITH NUMBER OF WRAPS ON ONE ROLLER

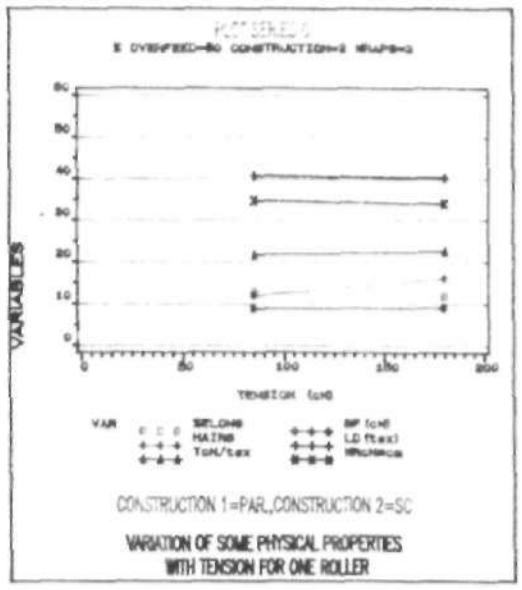


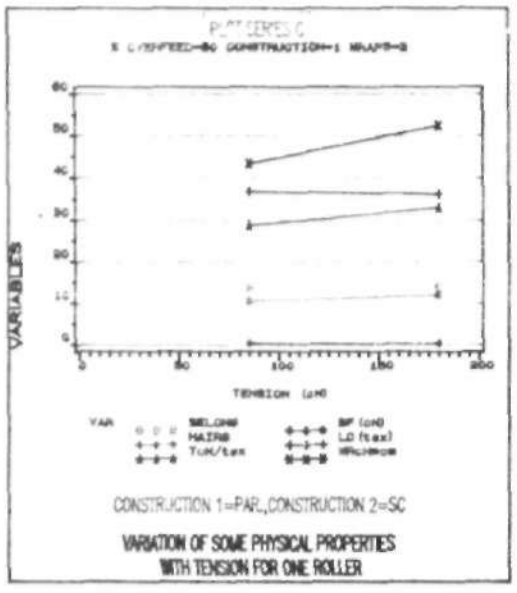
VARIATION IN LINEAR DENSITY WITH NUMBER OF WRAPS ON ONE ROLLER

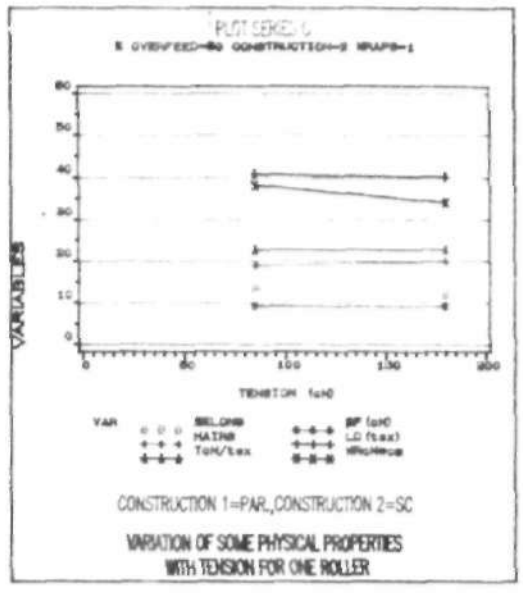


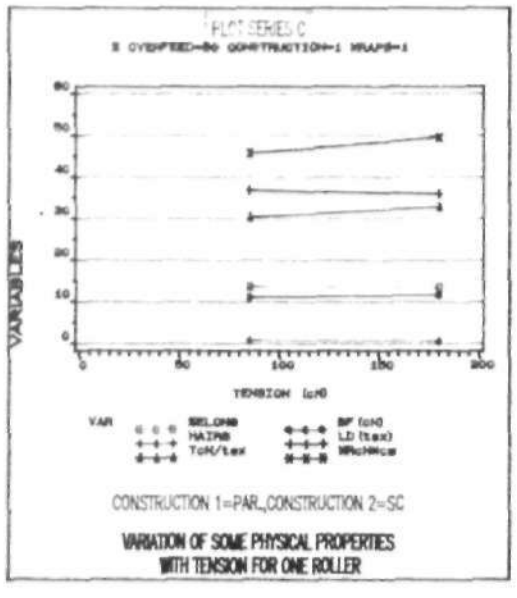
VARIATION IN % ELONGATION WITH NUMBER OF WRAPS ON ONE ROLLER

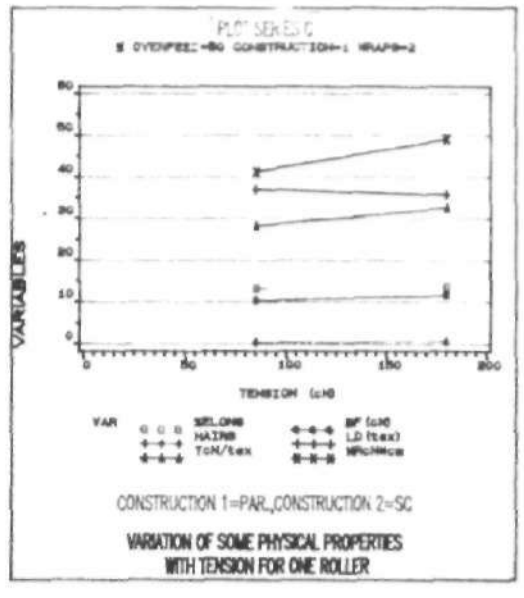

VARIABLES
TENSION (cN)
CONSTRUCTION 1=PAR,CONSTRUCTION 2=SC
VARIATION OF SOME PHYSICAL PROPERTIES
WITH TENSION FOR ONE ROLLER

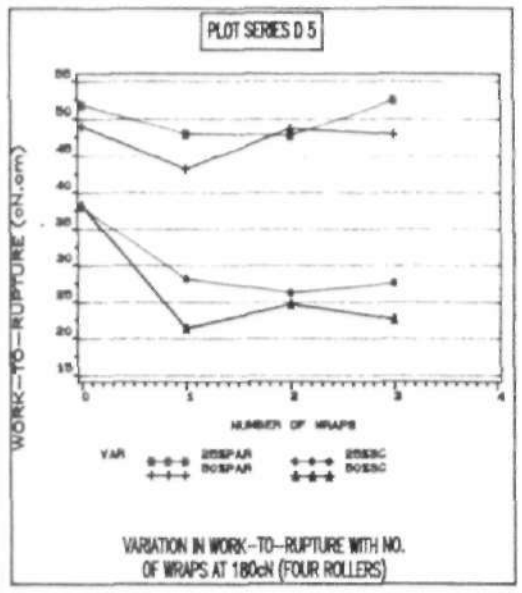

VARIABLES
TENSION (cN)
CONSTRUCTION 1=PAR,CONSTRUCTION 2=SC
VARIATION OF SOME PHYSICAL PROPERTIES
WITH TENSION FOR ONE ROLLER


VARIABLES
TENSION (cN)
CONSTRUCTION 1=PAR,CONSTRUCTION 2=SC
VARIATION OF SOME PHYSICAL PROPERTIES
WITH TENSION FOR ONE ROLLER

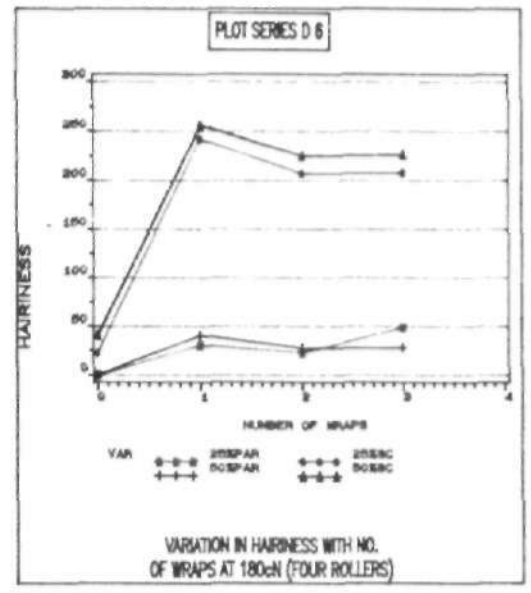

VARIABLES
TENSION (cN)
CONSTRUCTION 1=PAR,CONSTRUCTION 2=SC
VARIATION OF SOME PHYSICAL PROPERTIES
WITH TENSION FOR ONE ROLLER


VARIABLES
TENSION (cN)
CONSTRUCTION 1=PAR,CONSTRUCTION 2=SC
VARIATION OF SOME PHYSICAL PROPERTIES
WITH TENSION FOR ONE ROLLER

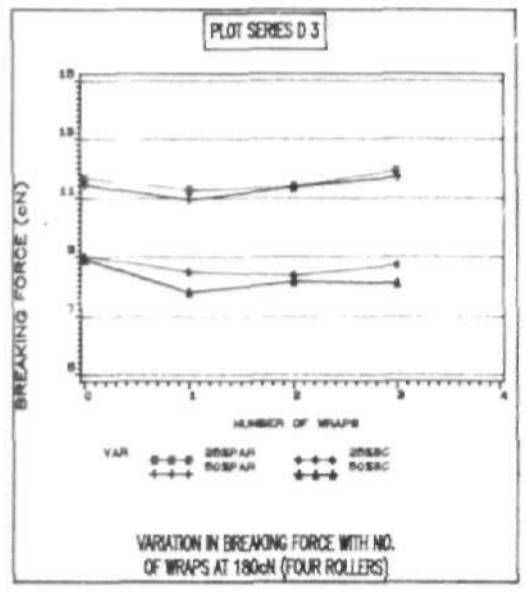

VARIABLES
TENSION (cN)
CONSTRUCTION 1=PAR,CONSTRUCTION 2=SC
VARIATION OF SOME PHYSICAL PROPERTIES
WITH TENSION FOR ONE ROLLER



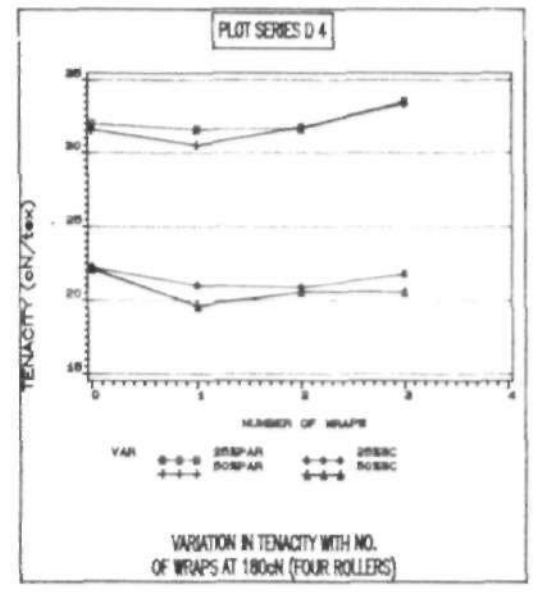
VARIATION IN WORK-TO-RUPTURE WITH NO. OF WRAPS AT 180cN (FOUR ROLLERS)



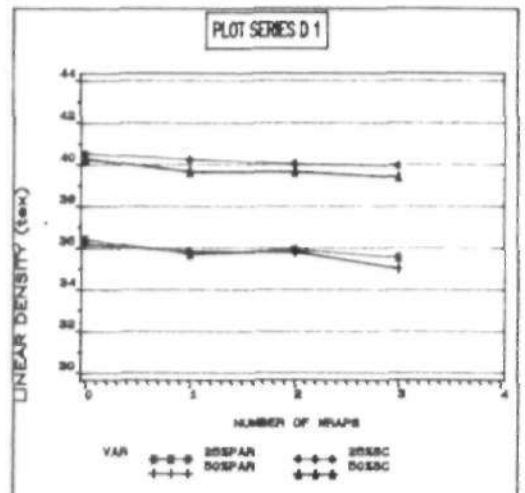
VARIATION IN HAIRINESS WITH NO. OF WRAPS AT 180cN (FOUR ROLLERS)



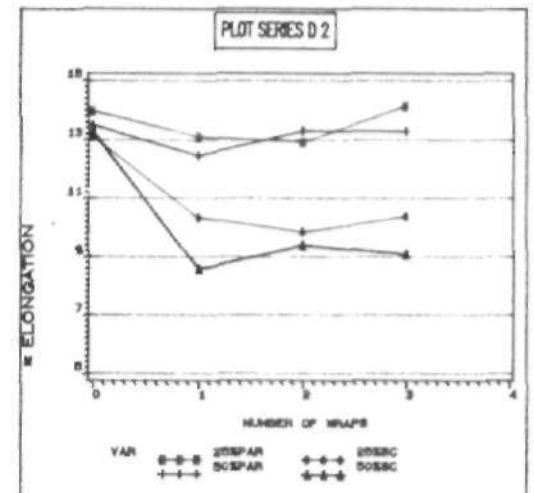
VARIATION IN BREAKING FORCE WITH NO. OF WRAPS AT 180cN (FOUR ROLLERS)



VARIATION IN TENACITY WITH NO. OF WRAPS AT 180cN (FOUR ROLLERS)



VARIATION IN LINEAR DENSITY WITH NO. OF WRAPS AT 180cN (FOUR ROLLERS)



VARIATION IN % ELONGATION WITH NO. OF WRAPS AT 180cN (FOUR ROLLERS)

the broken and unbroken, drawn out loops.

Hairiness increases with increase in the number of wraps for up to 2 wraps per roller for the SC yarns but decreases after 1 wrap for the parallel yarns (F). This is because increase in the number of wraps does not increase the number of loops trapped, and some of the loops trapped get released somehow during the time it takes for them to move round the wraps (i.e. before breaking commences). Hairiness decreases with number of wraps after 1 wrap (D6) for two and four rollers.

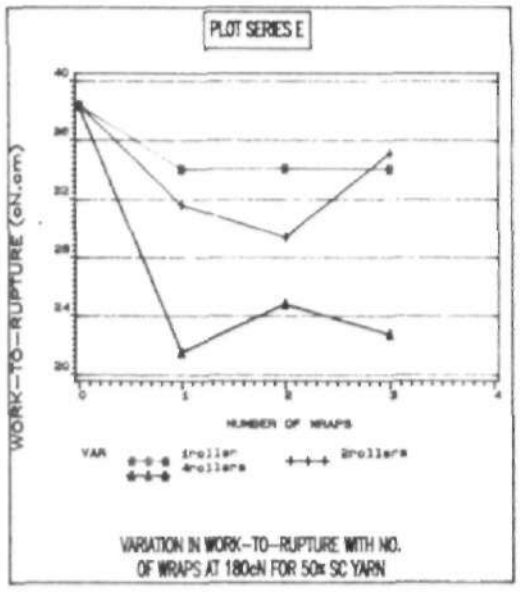
As expected, at any given tension, the SC yarns are more hairy than their parallel counterparts.

It is evident from all the curves that the SC type yarns respond in exactly the same way to treatment with the Texspun device. They also respond in the same manner to different levels of other factors as well as treatment combinations, the only differences arising as a result of the different levels of overfeed.

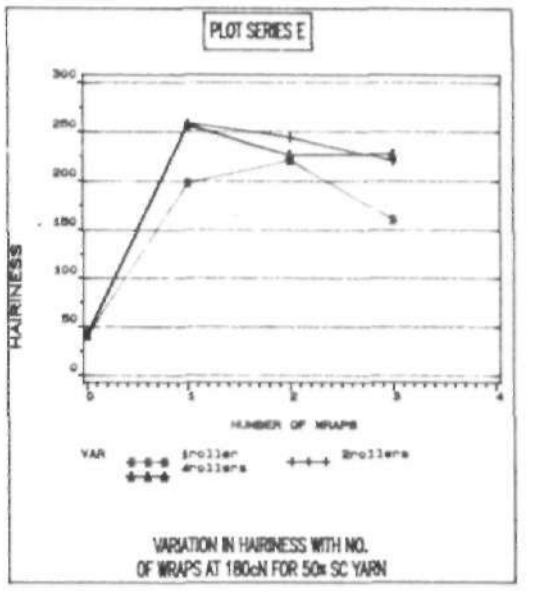
Incidentally, the SC construction is the one that visually and functionally shows a high degree of modification from the ordinary air-textured yarn to 'free fibre-end' yarns. Based on the results obtained, the Texspun device is recommended for this class of yarns.

The parallel-feed type yarns behave differently with respect to all the factors and the response variables, except hairiness (for which their behaviour is similar). This gives reason to believe that it will be difficult to predict, theoretically and practically, the character of these yarns after treatment with the Texspun device since it will differ considerably with the overfeed of the yarn in texturing and the treatment to which it is subsequently subjected.

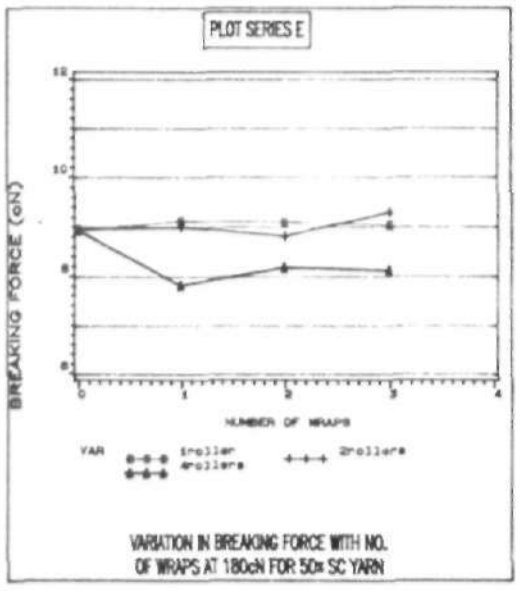
Further, at tensions upto 180 cN, the parallel-feed yarns lose most of their loops created during the texturing process by being drawn into the yarn core. An insignificant proportion is left on the yarn surface, and these predominantly of such reduced sizes and shapes that the loop trapping process is ineffective. This situation is further affected by



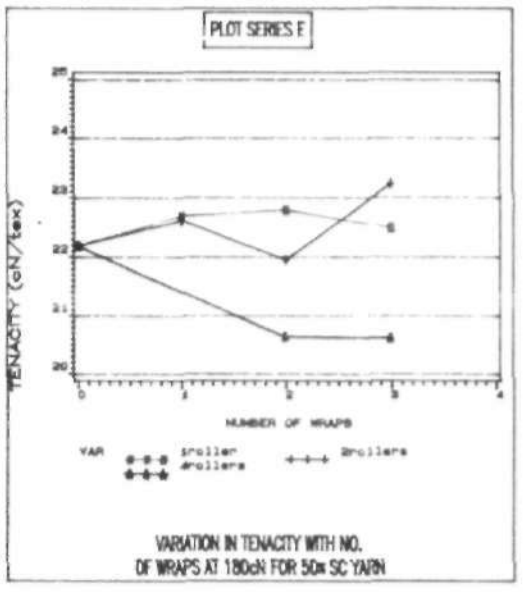
VARIATION IN WORK-TO-RUPTURE WITH NO. OF WRAPS AT 180cN FOR 50x SC YARN



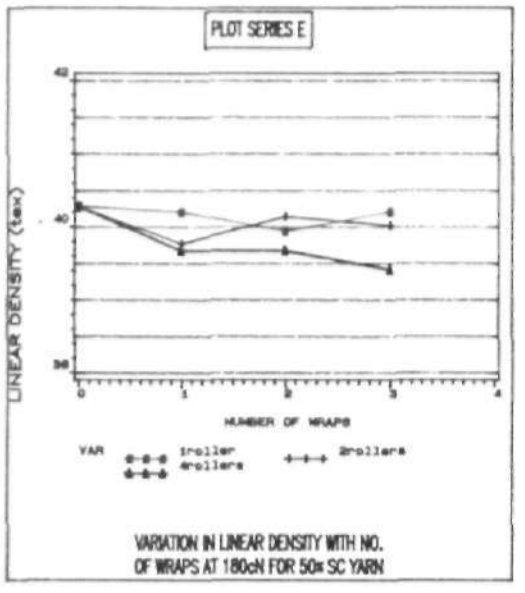
VARIATION IN HAIRINESS WITH NO. OF WRAPS AT 180cN FOR 50x SC YARN



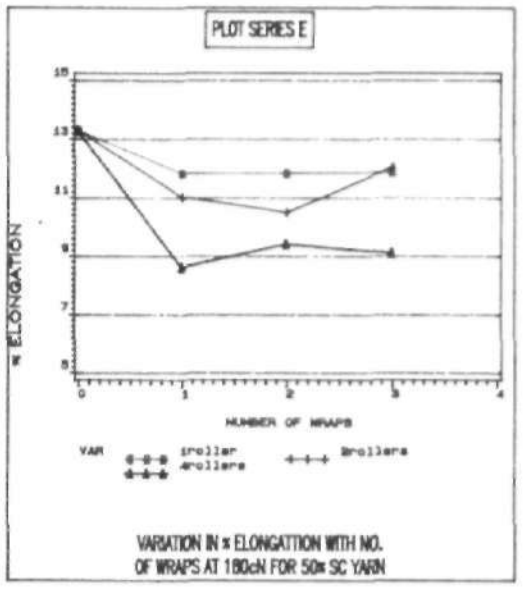
VARIATION IN BREAKING FORCE WITH NO. OF WRAPS AT 180cN FOR 50x SC YARN



VARIATION IN TENACITY WITH NO. OF WRAPS AT 180cN FOR 50x SC YARN



VARIATION IN LINEAR DENSITY WITH NO. OF WRAPS AT 180cN FOR 50x SC YARN



VARIATION IN % ELONGATTION WITH NO. OF WRAPS AT 180cN FOR 50x SC YARN

the fact that some of these loops do not stand a chance of being trapped, by virtue of their position relative to the trapping area. Even those trapped may not be broken, as explained in chapter 7.

For these reasons further analysis will be more biased towards the SC type yarns. This is not inferring that the Texspun device is completely ineffective with parallel yarns. Although no readily measurable improvement is conferred, the product is quite different from both the input (continuous-filament yarns) and the basic air-textured yarn. It shows less glitter, better coherence than the continuous-filament yarns and less 'velcro' behaviour, and should prove less clammy to the skin when made into garments. There will be certain end uses for which its qualities may prove useful, such as lightweight water-proof or water-repellent fabrics.

4.2 ANALYSIS

Because of the low sensitivity of the approach used, a statistical analysis was employed in order to identify effective factors and their various combinations, and to estimate their relative magnitudes.

Assuming the effects of the various factors are additive, a mathematical model can be formulated which can estimate the value of the response variable. If α, β, γ and δ represent effects of overfeed, construction, tension and wraps respectively,

$$Y_{ijkl} = \mu+\alpha_i+\beta_j+\gamma_k+\delta_l+(\alpha\beta)_{ij}+(\alpha\gamma)_{ik}+(\alpha\delta)_{il}+(\beta\gamma)_{jk}+(\beta\delta)_{jl}+(\gamma\delta)_{kl}+(\alpha\beta\gamma)_{ijk}+(\alpha\beta\delta)_{ijl}+(\alpha\gamma\delta)_{ikl}+(\beta\gamma\delta)_{jkl}+(\alpha\beta\gamma\delta)_{ijkl}+\varepsilon_{ijkl} \quad (1)$$

where $\mathbf{Y_{ijkl}}$ = value of the response variable considered, μ = the overall base or mean effect, or intercept, α_i = effect of the $\mathbf{i^{th}}$ level of overfeed, β_j = effect of the $\mathbf{j^{th}}$ construction, γ_k = effect of $\mathbf{k^{th}}$ tension level, δ_l = effect of $\mathbf{l^{th}}$ level of wraps. The 2- and 3-factor terms are first and second order interactions; $(\alpha\beta\gamma\delta)_{ijkl}$ is the third-order interaction term, the effect of the interaction of the $\mathbf{i^{th}}$ level of α with $\mathbf{j^{th}}$ level of β,$\mathbf{k^{th}}$ level of γ and $\mathbf{i^{th}}$ level of δ. ε_{ijkl} = random error.

In this work, several dependent and independent variables are examined simultaneously. Errors introduced could be due to either variability of the 'raw material' and / or experimental technique. Therefore, in addition to the assumption of additivity of the effects, it is also assumed that these errors are normally and independently distributed (homogenous) [35 39 41 43] with mean = 0 and variance = σ^2.

Since the aim of the study is to see if the various factors, singly or with interactions, affect the properties of the yarn, a multivariate analytical scheme was employed for the analysis of variance (ANOVA) because the usual technique of univariate analyses of the response variables will be too long and tedious, and the output to be interpreted quite substantial. This method also has the advantage that, should there be any correlation

between the variables, misleading significant or insignificant effects will not be indicated; it is also more accurate. The analysis of variance procedure for all the response variables are shown in the top portion of table 5a. The null hypothesis formulated prior to the analysis is

$\mathbf{H_o}: \mathbf{R} = 0$

i.e., the effect of any factor (independent variable) or a combination of factors (designated R) on the yarn properties is zero. Stated more explicitly,

$\mathbf{H_o}: \alpha_i = \beta_j = \gamma_k = \delta_l = (\alpha\beta)_{ij} = (\alpha\gamma)_{ik} = (\alpha\delta)_{il} = (\beta\gamma)_{jk} = (\beta\delta)_{jl} = (\gamma\delta)_{kl} = (\alpha\beta\gamma)_{ijk} \cdots = (\alpha\beta\gamma\delta)_{ijkl} = 0.$

In each procedure, the first part is a summary of the more detailed second part, and separates the overall value of the response variable into that accounted by the model (which consists of variations caused by the various factors and their interactions) under the 'source' of variation. The second column gives the degrees of freedom (DF), and refers to the number of independent comparisons possible for the corresponding source of variation. The 'TYPE I SS', also called the 'ANOVA SS' gives the calculated sum of squares of the deviations from the mean caused by the respective sources of variation; the mean square (MS) is obtained by dividing the SS of a particular source of variation by its DF.

The statistic 'F' is the ratio of the MS of a source of variation to the MS of the error term, and is used to test the null hypothesis that the effects due to the factors in the model are equal to zero. These calculated values of F are compared with F values obtained from tables [40] , (values of $\mathbf{F}_{\alpha,\nu_1,\nu_2}$, the 100α percentage point of F distribution having ν_1 DF in the numerator (in this case the MS of a factor) and ν_2 in the denominator (MS of the error, MSE). If

$\mathbf{F_{calc.}} > \mathbf{F}_{\alpha,\nu_1,\nu_2}$

then the result is significant at the α % level, and we therefore reject the null hypotheses that the effect of the factors = 0 and conclude that the factor(s) exert(s) real effects on the

CONSTRUCTION 1=PARALLEL,CONSTRUCTION 2=SHEATH/CORE 1988

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: AVERAGE COUNT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	23	355.44609861	15.45417820	171.58	0.0001	0.987983	0.7770
ERROR	48	4.32346667	0.09007222		ROOT MSE		ACOUNT MEAN
CORRECTED TOTAL	71	359.76956528			0.30012035		38.62430556

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
OFEED	1	3.19623472	35.49	0.0001	1	3.19623472	35.49	0.0001
CONSTRCN	1	337.17716806	3743.41	0.0001	1	337.17716806	3743.41	0.0001
TENSION	1	13.26983472	147.32	0.0001	1	13.26983472	147.32	0.0001
WRAPS	2	0.20051944	1.11	0.3369	2	0.20051944	1.11	0.3369
OFEED*CONSTRCN	1	0.78333472	8.70	0.0049	1	0.78333472	8.70	0.0049
OFEED*TENSION	1	0.01100139	0.12	0.7283	1	0.01100139	0.12	0.7283
OFEED*WRAPS	2	0.02971944	0.16	0.8484	2	0.02971944	0.16	0.8484
CONSTRCN*TENSION	1	0.10200139	1.13	0.2926	1	0.10200139	1.13	0.2926
CONSTRCN*WRAPS	2	0.08308611	0.46	0.6333	2	0.08308611	0.46	0.6333
TENSION*WRAPS	2	0.36526944	2.03	0.1428	2	0.36526944	2.03	0.1428
OFEED*CONSTR*TENSIO	1	0.01150139	0.13	0.7224	1	0.01150139	0.13	0.7224
OFEED*CONSTRC*WRAPS	2	0.02191944	0.12	0.8857	2	0.02191944	0.12	0.8857
CONSTR*TENSIO*WRAPS	2	0.01820278	0.10	0.9041	2	0.01820278	0.10	0.9041
OFEED*TENSION*WRAPS	2	0.11850278	0.66	0.5226	2	0.11850278	0.66	0.5226
WRAP(OFEE*CONS*TENS)	2	0.05780278	0.32	0.7271	2	0.05780278	0.32	0.7271

TESTS OF HYPOTHESES USING THE TYPE III MS FOR WRAP(OFEE*CONS*TENS) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
OFEED*CONSTRCN	1	0.78333472	27.10	0.0350
OFEED*CONSTR*TENSIO	1	0.01150139	0.40	0.5926

Table 5a

CONSTRUCTION 1=PARALLEL,CONSTRUCTION 2=SHEATH/CORE 1988

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: % ELONGATION

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	23	36.71639750	1.59636467	439.87	0.0001	0.995278	0.4606
ERROR	49	0.17420000	0.00362917		ROOT MSE		AELONG MEAN
CORRECTED TOTAL	71	36.89058750			0.06024257		13.07791667

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
OFELD	1	0.78751250	217.00	0.0001	1	0.78751250	217.00	0.0001
CONSTRCN	1	23.08601250	6361.24	0.0001	1	23.08601250	6361.24	0.0001
TENSION	1	5.69531250	1569.32	0.0001	1	5.69531250	1569.32	0.0001
WRAPS	2	0.09370000	12.91	0.0001	2	0.09370000	12.91	0.0001
OFEED*CONSTRCN	1	0.36551250	100.72	0.0001	1	0.36551250	100.72	0.0001
OFEED*TENSION	1	0.00281250	0.77	0.3831	1	0.00281250	0.77	0.3831
OFEED*WRAPS	2	0.06310000	8.69	0.0006	2	0.06310000	8.69	0.0006
CONSTRCN*TENSION	1	3.60461250	993.23	0.0001	1	3.60461250	993.23	0.0001
CONSTRCN*WRAPS	2	0.12270000	16.90	0.0001	2	0.12270000	16.90	0.0001
TENSION*WRAPS	2	0.16410000	22.61	0.0001	2	0.16410000	22.61	0.0001
OFEED*CONSTR*TENSIO	1	1.40281250	386.54	0.0001	1	1.40281250	386.54	0.0001
OFEED*CONSTRC*WRAPS	2	0.73170000	100.81	0.0001	2	0.73170000	100.81	0.0001
CONSTR*TENSIC*WRAPS	2	0.18210000	25.09	0.0001	2	0.18210000	25.09	0.0001
OFEED*TENSION*WRAPS	2	0.41160000	56.71	0.0001	2	0.41160000	56.71	0.0001
WRAP(OFEE*CONS*TENS)	2	0.00280000	0.39	0.6820	2	0.00280000	0.39	0.6820

TESTS OF HYPOTHESES USING THE TYPE III MS FOR WRAP(OFEE*CONS*TENS) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
OFEED*CONSTRCN	1	0.36551250	241.08	0.0038
OFEED*CONSTR*TENSIO	1	1.40281250	1002.01	0.0010

Table 5a

CONSTRUCTION 1=PARALLEL,CONSTRUCTION 2=SHEATH/CORE 1988

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: AVERAGE BREAKING FORCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	23	93.49798750	4.06512989	3107.11	0.0001	0.999329	0.3534
ERROR	43	0.06280000	0.00130833		ROOT MSE		AVBFORCE MEAN
CORRECTED TOTAL	71	93.56078750			0.03617089		10.23458333

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
OFEED	1	0.49501250	378.35	0.0001	1	0.49501250	378.35	0.0001
CONSTRCN	1	84.04561250	64238.48	0.0001	1	84.04561250	64238.68	0.0001
TENSION	1	4.13281250	3158.84	0.0001	1	4.13281250	3158.84	0.0001
WRAPS	2	0.35522500	135.75	0.0001	2	0.35522500	135.75	0.0001
OFEED*CONSTRCN	1	0.09031250	69.03	0.0001	1	0.09031250	69.03	0.0001
OFEED*TENSION	1	0.01711250	13.08	0.0007	1	0.01711250	13.08	0.0007
OFEED*WRAPS	2	0.04232500	16.18	0.0001	2	0.04232500	16.18	0.0001
CONSTRCN*TENSION	1	2.89201250	2210.46	0.0001	1	2.89201250	2210.46	0.0001
CONSTRCN*WRAPS	2	0.29657500	113.34	0.0001	2	0.29657500	113.34	0.0001
TENSION*WRAPS	2	0.23702500	90.58	0.0001	2	0.23702500	90.58	0.0001
OFEED*CONSTR*TENSIO	1	0.43711250	334.10	0.0001	1	0.43711250	334.10	0.0001
OFEED*CONSTRC*WRAPS	2	0.10277500	39.28	0.0001	2	0.10277500	39.28	0.0001
CONSTR*TENSIO*WRAPS	2	0.08207500	31.37	0.0001	2	0.08207500	31.37	0.0001
OFEED*TENSION*WRAPS	2	0.22322500	85.31	0.0001	2	0.22322500	85.31	0.0001
WRAP(OFEE*CONS*TENS)	2	0.04877500	18.64	0.0001	2	0.04877500	18.64	0.0001

TESTS OF HYPOTHESES USING THE TYPE III MS FOR WRAP(OFEE*CONS*TENS) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
OFEED*CONSTRCN	1	0.09031250	3.70	0.1942
OFEED*CONSTR*TENSIO	1	0.43711250	17.92	0.0515

Table 5a

CONSTRUCTION 1=PARALLEL,CONSTRUCTION 2=SHEATH/CORE 1988

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: TENACITY

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	23	1445.48038750	62.84697337	15189.60	0.0001	0.999863	0.2404
ERROR	48	0.19860000	0.00413750		ROOT MSE		TENACITY MEAN
CORRECTED TOTAL	71	1445.67898750			0.06432340		26.75458333

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
OFEED	1	0.58861250	142.26	0.0001	1	0.58861250	142.26	0.0001
CONSTRCN	1	1334.11951250	99999.99	0.0001	1	1334.11951250	99999.99	0.0001
TENSION	1	65.95261250	15940.21	0.0001	1	65.95261250	15940.21	0.0001
WRAPS	2	3.05567500	369.27	0.0001	2	3.05567500	369.27	0.0001
OFEED*CONSTRCN	1	1.52251250	367.98	0.0001	1	1.52251250	367.98	0.0001
OFEED*TENSION	1	0.15961250	38.58	0.0001	1	0.15961250	38.58	0.0001
OFEED*WRAPS	2	0.23432500	28.32	0.0001	2	0.23432500	28.32	0.0001
CONSTRCN*TENSION	1	29.68351250	7174.26	0.0001	1	29.68351250	7174.26	0.0001
CONSTRCN*WRAPS	2	2.15117500	259.96	0.0001	2	2.15117500	259.96	0.0001
TENSION*WRAPS	2	2.02892500	245.19	0.0001	2	2.02892500	245.19	0.0001
OFEED*CONSTR*TENSIO	1	3.18781250	770.47	0.0001	1	3.18781250	770.47	0.0001
OFEED*CONSTRC*WRAPS	2	0.55682500	67.29	0.0001	2	0.55682500	67.29	0.0001
CONSTR*TENSIO*WRAPS	2	0.58532500	70.73	0.0001	2	0.58532500	70.73	0.0001
OFEED*TENSION*WRAPS	2	1.10717500	133.80	0.0001	2	1.10717500	133.80	0.0001
WRAP(OFEE*CONS*TENS)	2	0.54677500	66.08	0.0001	2	0.54677500	66.08	0.0001

TESTS OF HYPOTHESES USING THE TYPE III MS FOR WRAP(OFEE*CONS*TENS) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
OFEED*CONSTRCN	1	1.52251250	5.57	0.1422
OFEED*CONSTR*TENSIO	1	3.18781250	11.66	0.0761

Table 5a

CONSTRUCTION 1=PARALLEL,CONSTRUCTION 2=SHEATH/CORE 1988

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: AVERAGE WORK-TO-RUPTURE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	23	3154.88218750	137.16879076	30009.58	0.0001	0.999930	0.1614
ERROR	43	0.21940000	0.00457083		ROOT MSE		WRUPTURE MEAN
CORRECTED TOTAL	71	3155.10158750			0.06760794		41.89458333

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
OFEED	1	30.69361250	6715.10	0.0001	1	30.69361250	6715.10	0.0001
CONSTRCN	1	2694.88111250	99999.99	0.0001	1	2694.88111250	99999.99	0.0001
TENSION	1	51.05551250	11169.85	0.0001	1	51.05551250	11169.85	0.0001
WRAPS	2	15.28907500	1672.46	0.0001	2	15.28907500	1672.46	0.0001
OFEED*CONSTRCN	1	19.68781250	4307.27	0.0001	1	19.68781250	4307.27	0.0001
OFEED*TENSION	1	0.40051250	87.62	0.0001	1	0.40051250	87.62	0.0001
OFEED*WRAPS	2	0.98057500	107.26	0.0001	2	0.98057500	107.26	0.0001
CONSTRCN*TENSION	1	215.17751250	47076.21	0.0001	1	215.17751250	47076.21	0.0001
CONSTRCN*WRAPS	2	19.29047500	2110.17	0.0001	2	19.29047500	2110.17	0.0001
TENSION*WRAPS	2	10.66352500	1166.47	0.0001	2	10.66352500	1166.47	0.0001
OFEED*CONSTR*TENSIO	1	46.60951250	10197.16	0.0001	1	46.60951250	10197.16	0.0001
OFEED*CONSTRC*WRAPS	2	23.43377500	2563.40	0.0001	2	23.43377500	2563.40	0.0001
CONSTR*TENSIC*WRAPS	2	7.28872500	797.31	0.0001	2	7.28872500	797.31	0.0001
OFEED*TENSION*WRAPS	2	17.94482500	1962.97	0.0001	2	17.94482500	1962.97	0.0001
WRAP(OFEE*CONS*TENS)	2	1.48562500	162.51	0.0001	2	1.48562500	162.51	0.0001

TESTS OF HYPOTHESES USING THE TYPE III MS FOR WRAP(OFEL*CONS*TENS) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
OFEED*CONSTRCN	1	19.68781250	26.50	0.0357
OFEED*CONSTR*TENSIO	1	46.60951250	62.75	0.0156

Table 5a

CONSTRUCTION 1=PARALLEL,CONSTRUCTION 2=SHEATH/CORE 1988 18

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: AVERAGE HAIRINESS

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	23	4871.55447899	211.80671648	1577.23	0.0001	0.998679	4.4056
ERROR	48	6.44594800	0.13429058		ROOT MSE		HARINESS MEAN
CORRECTED TOTAL	71	4878.00042699			0.36645680		8.31798611

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
OFEED	1	52.78267512	393.05	0.0001	1	52.78267512	393.05	0.0001
CONSTRCN	1	4430.05588001	32988.58	0.0001	1	4430.05588001	32988.58	0.0001
TENSION	1	9.67046901	72.01	0.0001	1	9.67046901	72.01	0.0001
WRAPS	2	145.69371319	542.46	0.0001	2	145.69371319	542.46	0.0001
OFEED*CONSTRCN	1	54.86106668	408.53	0.0001	1	54.86106668	408.53	0.0001
OFEED*TENSION	1	2.90927401	21.66	0.0001	1	2.90927401	21.66	0.0001
OFEED*WRAPS	2	3.90873058	14.55	0.0001	2	3.90873058	14.55	0.0001
CONSTRCN*TENSION	1	5.21698835	38.85	0.0001	1	5.21698835	38.85	0.0001
CONSTRCN*WRAPS	2	118.50379703	441.22	0.0001	2	118.50379703	441.22	0.0001
TENSION*WRAPS	2	9.94908203	37.04	0.0001	2	9.94908203	37.04	0.0001
OFEED*CONSTR*TENSIO	1	0.99663668	7.42	0.0090	1	0.99663668	7.42	0.0090
OFEED*CONSTRC*WRAPS	2	1.85418819	6.90	0.0023	2	1.85418819	6.90	0.0023
CONSTR*TENSIO*WRAPS	2	14.25272186	53.07	0.0001	2	14.25272186	53.07	0.0001
OFEED*TENSION*WRAPS	2	10.83232519	40.33	0.0001	2	10.83232519	40.33	0.0001
WRAP(OFEE*CONS*TENS)	2	10.06693103	37.48	0.0001	2	10.06693103	37.48	0.0001

TESTS OF HYPOTHESES USING THE TYPE III MS FOR WRAP(OFEE*CONS*TENS) AS AN ERROR TERM

SOURCE	DF	TYPE III SS	F VALUE	PR > F
OFEED*CONSTRCN	1	54.86106668	10.90	0.0808
OFEED*CONSTR*TENSIO	1	0.99663668	0.20	0.6999

Table 5a

value of the response variables.

PR > F gives the probability of obtaining an F value ($\mathbf{F_{calc}}$) as calculated, or by chance alone, if actually the effect of the corresponding factor were zero. (The computer results indicate the chance in 10,000 of obtaining $\mathbf{F_{calc}}$, usually depicted as the **α-level**).

The Root MSE is the square root of the mean square of the error, and estimates the standard deviation of the error if the model is adequate.

R-square is the square of the multiple regression correlation coefficient (between the dependent and the independent variables) and is given by the ratio of the SS of deviations of the model from the mean to the total SS of all the deviations from the mean. It represents the fraction of the total variation in the values of the response variable explained by the fitted linear relation. An alternative R-square denoted by ADJ-R-SQ [42] is usually more appropriate, having been corrected for the number of parameters in the model according to the relation

$$\text{ADJ-R-SQ} = \frac{1-(1-\text{R-SQ})\,(\text{n-1})}{\text{n-m-1}},$$

where **n** = number of observations, **m** = number of regression parameters in the model excluding the overall mean (base or intercept).

The value of the ADJ-R-SQ gives the measure of the goodness-of-fit of the model.

The second part of the ANOVA table gives a detailed account of the sources used for the test as well as their corresponding properties (SS, F, e.t.c.) with respect to the value of the MSE, all calculated from the equations given in table 4.

Table 5b gives a summary of the significance of the different factors at two other **α-levels**.

Sources of variation	D.F. (degrees of freedom)	S.S (sum of squares)	M.S. (Mean squares)
Between overfeeds (α)	(a-1)	$SS_\alpha = \frac{\sum_i y_{i...}^2}{bcdn} - \frac{y_{...}^2}{abcdn}$	$SS_\alpha/(a-1)$
Between constructions (β)	(b-1)	$SS_\beta = \frac{\sum_j y_{.j..}^2}{acdn} - \frac{y_{...}^2}{abcdn}$	$SS_\beta/(b-1)$
Between tensions (γ)	(c-1)	$SS_\gamma = \frac{\sum_k y_{..k.}^2}{abdn} - \frac{y_{...}^2}{abcdn}$	$SS_\gamma/(c-1)$
Between wraps (γ)	(d-1)	$SS_\gamma = \frac{\sum_l y_{...l}^2}{abcn} - \frac{y_{...}^2}{abcdn}$	$SS_\gamma/(d-1)$
$\alpha\beta$	(a-1)(b-1)	$SS_{\alpha\beta} = \frac{\sum\sum_{ij} y_{ij..}^2}{cdn} - \frac{\sum_i y_{i...}^2}{bcdn} - \frac{\sum_j y_{.j..}^2}{acdn} + \frac{y_{...}^2}{abcdn}$	$SS_{\alpha\beta}/(a-1)(b-1)$
$\alpha\gamma$	(a-1)(c-1)	$SS_{\alpha\gamma} = \frac{\sum\sum_{ik} y_{i.k.}^2}{bdn} - \frac{\sum_i y_{i...}^2}{bcdn} - \frac{\sum_k y_{..k.}^2}{abdn} + \frac{y_{...}^2}{abcdn}$	$SS_{\alpha\gamma}/(a-1)(c-1)$
$\alpha\delta$	(a-1)(d-1)	$SS_{\alpha\delta} = \frac{\sum\sum_{il} y_{i..l}^2}{bcn} - \frac{\sum_i y_{i...}^2}{bcdn} - \frac{\sum_l y_{...l}^2}{abcn} + \frac{y_{...}^2}{abcdn}$	$SS_{\alpha\delta}/(a-1)(d-1)$
$\beta\gamma$	(b-1)(c-1)	$SS_{\beta\gamma} = \frac{\sum\sum_{jk} y_{.jk.}^2}{adn} - \frac{\sum_j y_{.j..}^2}{acdn} - \frac{\sum_k y_{..k.}^2}{abdn} + \frac{y_{...}^2}{abcdn}$	$SS_{\beta\gamma}/(b-1)(c-1)$

Table 4

Sources of variation	D.F.	S.S.	M.S.
$\beta\delta$	$(b-1)(d-1)$	$SS_{\beta\sigma} = \frac{\sum\sum y^2_{.j.l}}{acn} - \frac{\sum y^2_{.j..}}{acdn} - \frac{\sum y^2_{...l}}{abcn} + \frac{y^2_{....}}{abcdn}$	$SS_{\beta\delta}/(b-1)(d-1)$
$\gamma\delta$	$(c-1)(d-1)$	$SS_{\gamma\delta} = \frac{\sum\sum y^2_{..kl}}{abn} - \frac{\sum y^2_{..k.}}{abdn} - \frac{\sum y^2_{...l}}{abcn} + \frac{y^2_{...}}{abcdn}$	$SS_{\gamma}/(c-1)(d-1)$
$\alpha\beta\gamma$	$(a-1)(b-1)(c-1)$	$SS_{\alpha\beta\gamma} = \frac{\sum\sum\sum y^2_{ijk}}{nd} - \frac{\sum\sum y^2_{ij..}}{cdn} - \frac{\sum\sum y^2_{i.k.}}{bdn} - \frac{\sum\sum y^2_{.jk.}}{adn}$	$SS_{\alpha\beta\gamma}/(a-1)(b-1)(c-1)$
		$+ \frac{\sum y^2_{i...}}{bcdn} + \frac{\sum y^2_{.j..}}{acdn} + \frac{\sum y^2_{..k.}}{abdn} - \frac{y^2_{....}}{abcdn}$	
$\alpha\beta\delta$	$(a-1)(b-1)(d-1)$	$SS_{\alpha\beta\gamma} = \frac{\sum\sum\sum y^2_{ij.l}}{nc} - \frac{\sum\sum y^2_{ij..}}{cdn} - \frac{\sum\sum y^2_{i..l}}{bcn} - \frac{\sum\sum y^2_{.j.l}}{acn}$	$SS_{\alpha\beta\gamma}/(a-1)(b-1)(d-1)$
		$+ \frac{\sum y^2_{i...}}{bcdn} + \frac{\sum y^2_{.j..}}{acdn} + \frac{\sum y^2_{...l}}{abcn} - \frac{y^2_{....}}{abcdn}$	
$\alpha\gamma\delta$	$(a-1)(c-1)(d-1)$	$SS_{\alpha\gamma\delta} = \frac{\sum\sum\sum y^2_{i.kl}}{bn} - \frac{\sum\sum y^2_{i.k.}}{bdn} - \frac{\sum\sum y^2_{i..l}}{bcn}$	$SS_{\alpha\gamma\delta}/(a-1)(c-1)(d-1)$
		$- \frac{\sum\sum y^2_{..kl}}{abn} + \frac{\sum y^2_{i...}}{bdn} - \frac{\sum y^2_{..k.}}{abdn} + \frac{\sum y^2_{...l}}{abcdn}$	
		$- \frac{y^2_{...}}{abcdn}$	

Table 4

Sources of variation	D.F.	S.S.	M.S.
$\beta\gamma\delta$	$(b-1)(c-1)(d-1)$	$SS_{\beta\gamma\delta} = \frac{\sum\sum\sum y^2_{.jkl}}{an} - \frac{\sum\sum y^2_{.j.l}}{adn} - \frac{\sum\sum y^2_{.j.l}}{acn}$	$SS_{\beta\gamma\delta}/(b-1)(c-1)(d-1)$
		$- \frac{\sum\sum y^2_{..kl}}{abn} + \frac{\sum y^2_{.j..}}{acdn} + \frac{\sum y^2_{..k.}}{abdn} + \frac{\sum y^2_{..l}}{abcn}$	
		$- \frac{y^2_{...}}{abcdn}$	
$\alpha\beta\gamma\delta$	$(a-1)(b-1)(c-1)(d-1)$	$SS_{\alpha\beta\gamma\delta} = \frac{\sum\sum\sum\sum y^2_{ijkl}}{n} - \frac{\sum\sum\sum y^2_{ijk}}{nd}$	
		$- \frac{\sum\sum\sum y^2_{ij.l}}{nc} - \frac{\sum\sum\sum y^2_{i.kl}}{bn} - \frac{\sum\sum\sum y^2_{.jkl}}{an}$	
		$+ \frac{\sum\sum y^2_{ij..}}{abn} + \frac{\sum\sum y^2_{i.k.}}{bdn} + \frac{\sum\sum y^2_{i..l}}{bcn} + \frac{\sum\sum y^2_{.jk.}}{adn}$	
		$+ \frac{\sum\sum y^2_{..kl}}{abn} + \frac{\sum\sum y^2_{.j.l}}{acn} - \frac{\sum y^2_{i...}}{bcdn} - \frac{\sum y^2_{.j..}}{acdn} - \frac{\sum y^2_{..k.}}{abdn}$	
		$- \frac{\sum y^2_{...l}}{abcn} + \frac{y^2_{...}}{abcdn}$	$SS_{\alpha\beta\gamma\delta}/(a-1)(b-1)\times(c-1)(d-1)$

Table 4

TABLE 5b

Factor	DF	α=0.05	α=0.001	LD	%E	BF	T	WR	H
α	1	4.05	12.35	**	**	**	**	**	**
β	1	4.05	12.35	**	**	**	**	**	**
γ	1	4.05	12.35	**	**	**	**	**	**
δ	2	3.19	8.06		**	**	**	**	**
$\alpha * \beta$	1	4.05	12.35	*	**	**	**	**	**
$\alpha * \gamma$	1	4.05	12.35			**	**	**	**
$\alpha * \delta$	2	3.19	8.06		**	**	**	**	**
$\beta * \gamma$	1	4.05	12.35		**	**	**	**	**
$\beta * \delta$	2	3.19	8.06		**	**	**	**	**
$\gamma * \delta$	2	3.19	8.06		**	**	**	**	**
$\alpha * \beta * \gamma$	1	4.05	12.35		**	**	**	**	*
$\alpha * \beta * \delta$	2	3.19	8.06		**	**	**	**	*
$\beta * \gamma * \delta$	2	3.19	8.06		**	**	**	**	**
$\alpha * \beta * \delta$	2	3.19	8.06		**	**	**	**	**
$\alpha * \beta * \gamma * \delta$	2	3.19	8.06			**	**	**	**

In the table, 'LD'=linear density, '% E'=% elongation 'BF'=Breaking force, 'T'=Tenacity 'WR'=Work-to-rupture and 'H'=Hairiness. ** means that the result is significant at both $\alpha = 0.05$ and $\alpha = 0.001$, * means significance at $\alpha = 0.05$ level only.

A sign in the column of the response variable indicates that the corresponding factor or factor combinations influence this property of the yarn. It can be seen that only the overfeed, construction, tension and overfeed-construction interaction affect the linear density significantly, the first 3 even at $\alpha = 0.0001$. The breaking force, tenacity and work-to-rupture are affected by all the factors and their combinations. All factors, $(\alpha\beta\gamma)$ and $(\alpha\beta\delta)$ interactions affect the hairiness of the yarn. Therefore it would have been wrong from first impressions to conclude that some of the factors or their combinations do not affect the yarn properties. The tests also show that the wrap factor affects every other variable beside linear density, but the common α levels used are not sensitive enough to show this.

The information given below the main ANOVA table tests the hypotheses

$\mathbf{H}_o : (\alpha\beta)_{ij} - (\alpha\beta\gamma\delta)_{ijkl} = 0.$

and

$\mathbf{H}_o : (\alpha\beta\gamma)_{ijk} - (\alpha\beta\gamma\delta)_{ijkl} = 0.$

using $(\alpha\beta\gamma\delta)_{ijkl}$ as the error term. From tables, the $\mathbf{F}_{\alpha,v_1,v_2}$ for these tests are 998.5 for $\alpha = 0.001$ and 18.5 for $\alpha = 0.05$.

It is evident that the ANOVA procedure has also failed to prove that the wrap factor has any influence on the linear density of the yarns. Although this is in agreement with the earlier impression from the curves, the procedure has proved that the number of wraps has an effect on other properties. We do know, however, that the amount of fly lost was due to the texspun device. This point is of special practical significance and is more important to our purpose. It does not really need to be proved statistically significant since we know the causes of suppression of this effect reflected in linear density.

Generally, since the effect of the interaction parameters involved in the mathematical model are significant, the main effects alone have little meaning because their total effect depends on the influence of other factors. Therefore none of the factors or combination terms can be discounted from the model equation even if its effect is small.

At this point, it is instructive to find estimates of the effects of the various factors and interactions , and develop a functional relationship between the response variables and the factiors involved. Computer estimates were obtained using the general linear models procedure, in accordance with the mathematical model given in equation (1) (the output was biased to some extent, and too bulky to have any simple practical meaning).

In the output, estimates of factor effects known to be significant (e.g. 50 % overfeed) are set to zero. This does not mean that they do not exert any effect; rather, the lower overfeed has been depressed (to a negative value) relative to the 50 % . In the same way the effects of 1 and 2 wraps have been depressed relative to 3 wraps on the roller. The application of this method of organization reduces the number of parameters substituted into the general equation since some are valued at zero.

The model may be exclusively valid only for the particular yarns studied. It may not, for instance, accurately estimate a response variable for a 10 % overfeed parallel-feed yarn. This is because most of the response variables do not vary linearly with the factors. The equation must therefore be modified by inserting, in place of the factor effect terms, appropriate linear or polynomial terms which describe the relationship of the response variable with the factor under consideration.

Table 6 shows the computed results of the correlations - the degree of association between any two response variables, r, arranged by overfeed and construction. The calculated coefficients are derived from the relation

$$r = \frac{\sum(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\left\{[\sum(x_i-\bar{x})^2][\sum(y_i-\bar{y})^2]\right\}}} = \frac{\sum x_i y_i - \frac{(\sum x_i)(\sum y_i)}{n}}{\sqrt{\left\{\sum x_i^2-(\sum \frac{x_0^2}{n}\right\}\left\{\sum y_i^2-(\sum y_i \frac{)^2}{n}\right\}}}$$

where n=number of observations, $x_i = i^{th}$ level of the factor, $y_i = i^{th}$ level of the response variable, $\bar{x}$ = overall mean of the factor, $\bar{y}$ = overall mean of the response variable.

The coefficients give two important pieces of information. The sign preceeding the number confirms whether the variational relationship is positively linear (positive slope) or an inverse function. The number itself represents the change of one variable in relation to a change in the other. A maximum value of ±1 indicates that they vary by equal amounts when the level of the factor is varied. These are not conversion factors because the curves relating the response variables to the various factors have at least one observable intercept, and never pass through the origin.

Tables 7-12 give more information about the effects of first-order interactions. In each of the tables, the differences labelled D1 (vertical) and D2 (horizontal) are values due to changing the level of the factors as shown. From these tables, the effect of a particular first -order interaction can be assesed.

OFEED	72	37.5000	12.58772	2700.000	25.00000	50.0000
CONSTRCN	72	1.5000	0.50351	108.000	1.00000	2.0000
WRAPS	72	2.0000	0.82223	144.000	1.00000	3.0000
TENSION	72	132.5000	47.83334	9540.000	85.00000	190.0000
ACOUNT	72	39.6243	2.25104	2780.950	35.53000	42.0000
AELONG	72	13.0779	0.72082	941.610	11.79000	14.2700
AVBFORCE	72	10.2346	1.14794	736.809	8.79000	11.9300
TENACITY	72	29.7546	4.51239	1926.330	21.61000	33.0600
WRUPTURE	72	41.8946	6.66619	3016.410	33.89000	52.4400
HARINESS	72	9.7180	8.28880	598.895	0.01200	22.3080

Table 6

PEARSON CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:PHO=0 / N = 72

	OFEED	CONSTRCN	WRAPS	TENSION	ACOUNT	AELONG	AVBFORCE	TENACITY	WRUPTURE	HARINESS
% OVERFEED	1.00000 0.0000	0.00000 1.0000	0.00000 1.0000	0.00000 1.0000	-0.09426 0.4310	-0.14611 0.2207	-0.07274 0.5437	-0.02018 0.8664	-0.09863 0.4098	0.10402 0.3845
CONSTRUCTION	0.00000 1.0000	1.00000 0.0000	0.00000 1.0000	0.00000 1.0000	0.96809 0.0001	-0.79107 0.0001	-0.94779 0.0001	-0.96064 0.0001	-0.92419 0.0001	0.95298 0.0001
WRAPS	0.00000 1.0000	0.00000 1.0000	1.00000 0.0000	0.00000 1.0000	0.01956 0.8705	-0.04135 0.7302	-0.05506 0.6460	-0.04362 0.7160	-0.05620 0.6392	-0.15176 0.2032
TENSION	0.00000 1.0000	0.00000 1.0000	0.00000 1.0000	1.00000 0.0000	-0.19205 0.1061	-0.39292 0.0006	0.21017 0.0764	0.21359 0.0716	0.12721 0.2869	0.04452 0.7104
AVERAGE COUNT	-0.09426 0.4310	0.96809 0.0001	0.01956 0.8705	-0.19205 0.1061	1.00000 0.0000	-0.68468 0.0001	-0.95618 0.0001	-0.97412 0.0001	-0.91767 0.0001	0.89771 0.0001
% ELONGATION	-0.14611 0.2207	-0.79107 0.0001	-0.04135 0.7302	-0.39292 0.0006	-0.68468 0.0001	1.00000 0.0000	0.76825 0.0001	0.74793 0.0001	0.84425 0.0001	-0.76803 0.0001
AVERAGE BREAKING FORCE	-0.07274 0.5437	-0.94779 0.0001	-0.05506 0.6460	0.21017 0.0764	-0.95618 0.0001	0.76825 0.0001	1.00000 0.0000	0.99641 0.0001	0.98595 0.0001	-0.88827 0.0001
TENACITY	-0.02018 0.8664	-0.96064 0.0001	-0.04362 0.7160	0.21359 0.0716	-0.97412 0.0001	0.74793 0.0001	0.99641 0.0001	1.00000 0.0000	0.97538 0.0001	-0.89889 0.0001
AVERAGE WORK-TO-RUPTURE	-0.09863 0.4098	-0.92419 0.0001	-0.05620 0.6392	0.12721 0.2869	-0.91767 0.0001	0.84425 0.0001	0.98595 0.0001	0.97538 0.0001	1.00000 0.0000	-0.86617 0.0001
AVERAGE HARINESS	0.10402 0.3845	0.95298 0.0001	-0.15176 0.2032	0.04452 0.7104	0.89771 0.0001	-0.76803 0.0001	-0.88827 0.0001	-0.89889 0.0001	-0.86617 0.0001	1.00000 0.0000

Table 7 (overfeed*construction)

(a) Linear density	overfeed %	construction parallel	sheath/core D2
	25	36.56	41.10 4.54
	50	36.35	40.47 4.12
	D1	-0.21	0.63
(b) % Elongation			
	25	13.82	12.55 -1.27
	50	13.47	12.48 -0.99
	D2	-0.35	-0.07

Table 7 (cont'd)

		construction	D2
	overfeed	parallel	sheath/core
(c) Breaking force	%		
	25	1143.65	920.23	-223.42
	50	1119.69	910.82	-208.87
	D2	-23.96	-9.41	
(d) Tenacity			
	25	31.29	22.39	-8.90
	50	30.82	22.51	-8.31
	D1	-0.47	0.12	

		construction	D2
	overfeed	parallel	sheath/core
(e) Work to rupture	%		
	25	4918.94	3590.49	-1328.45
	50	4683.84	3564.71	-1119.13
	D1	-235.10	-25.78	
(f) Hairiness			
	25	4.91	144.31	139.40
	50	4.57	178.95	178.38
	D1	-0.34	34.64	

Table 8 (overfeed*tension)

	overfeed	tension		D2
	%	85	180	
(a) Linear density	25	39.28	38.39	-0.89
	50	38.83	37.99	-0.84
	D1	-0.45	-0.40	
(b) % Elongation	25	13.47	12.89	-0.58
	50	13.25	12.69	-0.56
	D1	-0.22	-0.20	
(c) Breaking force	25	1009.58	1054.29	44.71
	50	989.24	1040.78	51.54
	D1	-20.34	-13.51	
(d) Tenacity	25	25.94	27.76	1.82
	50	25.66	27.67	2.01
	D1	-0.28	-0.09	

Table 8 (cont'd)

	overfeed	tension		D2
(e) Work	%	85	180	
to				
rupture	25	3587.39	4331.53	744.14
	50	4032.42	4216.13	183.71
	D1	-445.03	-115.40	
(f) Hairiness				
	25	68.93	80.29	11.36
	50	84.64	98.88	14.24
	D1	15.71	18.59	

Table 9 (overfeed*wraps)

	No. of wraps	overfeed 25%	overfeed 50%	D2
(a) Linear density	1	38.78	38.40	-0.42
	2	38.82	38.35	-0.47
	3	38.91	38.49	-0.42
(b) % Elongation	1	13.27	12.99	-0.28
	2	13.15	12.95	-0.20
	3	13.13	12.99	-0.14
(c) Breaking force	1	1038.10	1028.62	-9.48
	2	1029.62	1009.02	-20.60
	3	1028.09	1008.12	-19.97
(d) Tenacity	1	27.05	27.03	-0.02
	2	26.79	26.54	-0.25
	3	26.69	26.43	-0.26
(e) Work to rupture	1	4330.64	4177.91	-152.73
	2	4221.23	4080.64	-140.59
	3	4212.28	4114.27	- 98.01

Table 9 (cont'd)

	wraps	25%	50%	D2
(f) Hairiness	1	87.74	99.59	11.85
	2	81.22	104.44	23.22
	3	51.87	71.25	19.38

Table 10 (cnstruction*tension)

	construction	tension(cN)		D2
(a) Linear		85	180	
density				
	parallel	36.76	35.99	-0.77
	sheath/core	41.18	40.39	-0.79
	D1	4.42	4.40	
(b) % Elongation				
	parallel	13.70	13.59	-0.11
	sheath/core	13.02	12.01	-1.01
	D1	-0.68	-1.58	
(c) Breaking force	parallel	1087.85	1175.49	87.64
	sheath/core	911.47	919.58	8.11
	D1	-176.38	-225.91	
(d) Tenacity	parallel	29.46	32.66	3.20
	sheath/core	22.14	22.77	0.63
	D1	-7.32	-9.89	

Table 10 (cont'd)

			tension		
		construction	85	180	D2
(e) Work to rupture		parallel	4544.09	5058.69	514.60
		sheath/core	3666.23	3488.97	-177.26
	D1		-877.86	-1569.72	
(f) Hairiness		parallel	3.77	5.71	1.94
		sheath/core	149.79	173.46	23.67
	D1		146.02	167.75	

Table 11 (construction*wraps)

		wraps	construction		D2
			parallel	sheath/core	
(a) Linear density		1	36.38	40.80	4.42
		2	36.43	40.73	4.30
		3	36.57	40.83	4.26
(b) % Elongation		1	13.73	12.53	-1.20
		2	13.56	12.54	-1.02
		3	13.64	12.47	-1.17
(c) Breaking force		1	1145.29	921.43	-223.86
		2	1118.37	920.28	-198.09
		3	1131.36	904.87	-226.49
(d) Tenacity		1	31.49	22.59	- 8.90
		2	30.73	22.60	- 8.13
		3	30.96	22.17	- 8.79
(e) Work to rupture	1		4906.96	3601.59	-1305.37
	2		4689.61	3612.26	-1077.35
	3		4807.60	3518.95	-1288.65

Table 11 (cont'd)

	wraps	construction parallel	D2 sheath/core	
(f) Hairiness	1	7.69	179.65	171.96
	2	3.84	181.82	177.98
	3	2.69	123.43	120.74

Table 12 (tension*wraps)

	wraps	tension(cN)		D2
(a) Linear density		85	180	
	1	38.97	38.22	- 0.75
	2	39.11	38.05	-01.06
	3	39.08	38.32	- 0.76
(b) % Elongation	1	13.44	12.82	-0.62
	2	13.37	12.73	-0.64
	3	13.37	12.84	-0.43
(c) Breaking force	1	1017.16	1049.57	32.41
	2	994.05	1044.59	50.54
	3	987.78	1048.45	60.67
(d) Tenacity	1	26.32	27.76	1.44
	2	25.59	27.73	2.14
	3	25.48	27.65	2.17
(e) Work to rupture	1	4214.66	4293.89	79.23
	2	4071.54	4230.33	158.79
	3	4029.28	4297.27	267.99

Table 12 (cont'd)

		tension		D2
	wraps	85	180	
(f) Hairiness	1	91.15	96.19	5.04
	2	84.84	100.82	15.98
	3	54.37	71.75	17.38

Because the main interest in this section is to see if there is any difference between the effects of different wrap levels, the wrap factor was separated into its homogenous parts, and, using the least significant difference (LSD, the comparisonwise error rate, where the given alpha is the probability for type 1 error for any particular comparison) and Duncan's new multiple range test (error rate comparable to n-1 orthogonal comparisons tested simultaneously), they were tested to see which of the individual wraps were significantly different from the others. The results are shown in table 5c. In both cases, the means of the particular response variable are arranged in descending order of magnitude adjacent to the corresponding factors that gave rise to them. Means with the same letter are not significantly different. Both tests give essentially the same result. For linear density, the different wraps exert the same effect while for % elongation and breaking force 1 wrap exerts a different effect from 2 and 3 wraps. For tenacity and work-to-rupture, all the wraps exert different effects; 1 and 2 wraps exert significantly different effects from 3 wraps with respect to hairiness.

A separate linear model was formulated, of the same basic form as the first, but in which only the wrap factor is considered in order to estimate their effects. Also, the true relationship of the response variables to the wrap levels is put into the equation because the relationships do not appear to be linear. Therefore, a second degree (quadratic) polynomial regression model was assumed since the wrap factor has two degrees of freedom [34] and the curves show just one bend [42] . The effects of overfeed, construction

CONSTRUCTION 1=PARALLEL,CONSTRUCTION 2=SHEATH/CORE

GENERAL LINEAR MODELS PROCEDURE

T TESTS (LSD) FOR VARIABLE: ACOUNT
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE

ALPHA=0.05 DF=48 MSE=.0000722
CRITICAL VALUE OF T=2.01063
LEAST SIGNIFICANT DIFFERENCE=0.1742

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

T	GROUPING	MEAN	N	WRAPS
	A	38.59375	24	3
	A			
	A	38.59167	24	1
	A			
	A	38.59250	24	2

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: ACOUNT
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE

ALPHA=0.05 DF=48 MSE=.0000722

NUMBER OF MEANS	2	3
CRITICAL RANGE	0.174253	0.183209

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	WRAPS
	A	38.59375	24	3
	A			
	A	38.59167	24	1
	A			
	A	38.59250	24	2

CONSTRUCTION 1=PARALLEL,CONSTRUCTION 2=SHEATH/CORE

GENERAL LINEAR MODELS PROCEDURE

T TESTS (LSD) FOR VARIABLE: AELONG
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE

ALPHA=0.05 DF=48 MSE=.0036292
CRITICAL VALUE OF T=2.01063
LEAST SIGNIFICANT DIFFERENCE=.03497

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

T	GROUPING	MEAN	N	WRAPS
	A	13.12375	24	1
	B	13.05525	24	3
	B			
	B	13.04875	24	2

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: AELONG
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE

ALPHA=0.05 DF=48 MSE=.0036292

NUMBER OF MEANS 2 3
CRITICAL RANGE 0.0349775 0.0367749

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	WRAPS
	A	13.12375	24	1
	B	13.05525	24	3
	B			
	B	13.04875	24	2

Table 5c

CONSTRUCTION 1=PARALLEL,CONSTRUCTION 2=SHEATH/CORE

GENERAL LINEAR MODELS PROCEDURE

T TESTS (LSD) FOR VARIABLE: AVBFORCE
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE

ALPHA=0.05 DF=48 MSE=.0013093
CRITICAL VALUE OF T=2.01063
LEAST SIGNIFICANT DIFFERENCE=.02099

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

T	GROUPING	MEAN	N	WRAPS
	A	10.33375	24	1
	B	10.19000	24	2
	B			
	B	10.18000	24	3

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: AVBFORCE
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE

ALPHA=0.05 DF=48 MSE=.0013093

NUMBER OF MEANS	2	3
CRITICAL RANGE	0.0210012	0.0220804

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	WRAPS
	A	10.33375	24	1
	B	10.19000	24	2
	B			
	B	10.18000	24	3

Table 5c

CONSTRUCTION 1=PARALLEL,CONSTRUCTION 2=SHEATH/CORE

GENERAL LINEAR MODELS PROCEDURE

T TESTS (LSD) FOR VARIABLE: TENACITY
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE

ALPHA=0.05 DF=48 MSE=.0041375
CRITICAL VALUE OF T=2.01063
LEAST SIGNIFICANT DIFFERENCE=.03733

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

T	GROUPING	MEAN	N	WRAPS
	A	27.04000	24	1
	B	26.66250	24	2
	C	26.56125	24	3

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: TENACITY
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE

ALPHA=0.05 DF=48 MSE=.0041375

NUMBER OF MEANS 2 3
CRITICAL RANGE 0.0373469 0.0392661

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	WRAPS
	A	27.04000	24	1
	B	26.66250	24	2
	C	26.56125	24	3

Table 5c

CONSTRUCTION 1=PARALLEL,CONSTRUCTION 2=SHEATH/CORE

GENERAL LINEAR MODELS PROCEDURE

T TESTS (LSD) FOR VARIABLE: WRUPTURE
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE

ALPHA=0.05 DF=48 MSE=.0045708
CRITICAL VALUE OF T=2.01063
LEAST SIGNIFICANT DIFFERENCE=.03924

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

T	GROUPING	MEAN	N	WRAPS
	A	42.54250	24	1
	B	41.63125	24	3
	C	41.51000	24	2

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: WRUPTURE
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE

ALPHA=0.05 DF=48 MSE=.0045708

NUMBER OF MEANS	2	3
CRITICAL RANGE	0.0392539	0.0412711

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	WRAPS
	A	42.54250	24	1
	B	41.63125	24	3
	C	41.51000	24	2

Table 5c

CONSTRUCTION 1=PARALLEL,CONSTRUCTION 2=SHEATH/CORE

GENERAL LINEAR MODELS PROCEDURE

T TESTS (LSD) FOR VARIABLE: HARINESS
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE

ALPHA=0.05 DF=48 MSE=0.134291
CRITICAL VALUE OF T=2.01063
LEAST SIGNIFICANT DIFFERENCE=0.2127

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

T	GROUPING	MEAN	N	WRAPS
	A	9.3367	24	1
	A			
	A	9.2804	24	2
	B	6.3069	24	3

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: HARINESS
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE,
NOT THE EXPERIMENTWISE ERROR RATE

ALPHA=0.05 DF=48 MSE=0.134291

NUMBER OF MEANS	2	3
CRITICAL RANGE	0.212769	0.223703

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN	GROUPING	MEAN	N	WRAPS
	A	9.3367	24	1
	A			
	A	9.2804	24	2
	B	6.3069	24	3

Table 5c

and tension are masked with the intercept and error terms.

$$Y=\omega_o+\omega_1\delta+\omega_2\delta^2 \qquad (2)$$

Y = value of the response variable, δ = number of wraps, ω_o = intercept or base or mean value of the response variable; ω_1,ω_2 are estimates corresponding to WRAPS and WRAPSQ in the computer solution, fitted into the 1st and 2nd degree polynomial terms.

Computer estimates based on this model are shown in table 13. The first part gives a sequential estimate of the intercept, first and then second order polynomial terms according to the order of the variables measured. Usually, a high order model is fitted to the relationship and the regression procedure carried out. The 'TYPE I SS' is the most important in this output. Starting from the bottom of this column, the SS values are divided by the error MS from the ANOVA section above to obtain the F value.

e.g. for the 'WRAPSQ' (wraps squared) term,

$$\mathbf{F}=\frac{0.063}{5.211}=0.012.$$

The same procedure was followed for the other terms in order to identify the actual term that fits the relationship. The F values were then tested against those from tables; ($\mathbf{F}_{\alpha,v_1,v_2}$ at $\alpha = 0.20$ or 0.25 level). From tables, $\mathbf{F}_{0.25,1,69} = 3.12$.

Results from these tests show that the quadratic equation is not suitable for the relation. Actually this means that the relationship between the response variables and the number of wraps are correlated. The apparent non-linearity shown in the curves was probably caused by experimental errors. This can be seen from the low ADJ-R-SQ value (which proves the goodness-of-fit of the model).

SEQUENTIAL PARAMETER ESTIMATES

INTERCEP	38.4243		
INTERCEP	13.0779		
INTERCEP	10.2346		
INTERCEP	26.7546		
INTERCEP	41.8946		
INTERCEP	8.31799		
WRAPS	38.5172	.0535417	
WRAPS	13.1504	-0.03625	
WRAPS	10.3883	-.076875	
WRAPS	27.2333	-.239375	
WRAPS	42.8058	-.455625	
WRAPS	11.3778	-1.5299	
WRAPSQ	38.7263	-.197292	.0427083
WRAPSQ	13.2962	-0.21125	0.04375
WRAPSQ	10.6113	-.344375	0.066875
WRAPSQ	27.6937	-.791875	0.138125
WRAPSQ	44.7288	-2.76313	0.576875
WRAPSQ	6.56562	4.24469	-1.44365

DEP VARIABLE: ACCUNT AVERAGE COUNT

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	2	0.20051944	0.10025972	0.019	0.9809
ERROR	69	359.56905	5.21114559		
C TOTAL	71	359.76957			

ROOT MSE	2.282793	R-SQUARE	0.0006
DEP MEAN	38.62431	ADJ R-SQ	-0.0284
C.V.	5.910251		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|	TYPE I SS	VARIABLE LABEL
INTERCEP	1	38.72625000	2.03113029	19.066	0.0001	107412.26	INTERCEPT
WRAPS	1	-0.19729167	2.30644990	-0.086	0.9321	0.13760208	
WRAPSQ	1	0.06270833	0.57069634	0.110	0.9128	0.06291736	

DEP VARIABLE: AELONG % ELONGATION
ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	2	0.09370000	0.04685000	0.088	0.9160
ERROR	69	36.79688750	0.53328822		
C TOTAL	71	36.89058750			

ROOT MSE	0.7302659	R-SQUARE	0.0025
DEP MEAN	13.07792	ADJ R-SQ	-0.0264
C.V.	5.583962		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > |T|	TYPE I SS	VARIABLE LABEL
INTERCEP	1	13.29625000	0.64975881	20.463	0.0001	12314.29711	INTERCEPT
WRAPS	1	-0.21125000	0.73783358	-0.286	0.7755	0.06307500	
WRAPSQ	1	0.04375000	0.18256646	0.240	0.8113	0.03062500	

Table 13

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DEP VARIABLE: AVBFORCE AVERAGE BREAKING FORCE
ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	2	0.35522500	0.17761250	0.131	0.8770
ERROR	69	93.20556250	1.35080525		
C TOTAL	71	93.56078750			

ROOT MSE	1.162241	R-SQUARE	0.0038
DEP MEAN	10.23458	ADJ R-SQ	-0.0251
C.V.	11.35602		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|	TYPE I SS	VARIABLE LABEL
INTERCEP	1	10.61125000	1.03411193	10.261	0.0001	7541.76211	INTERCEPT
WRAPS	1	-0.34437500	1.17428575	-0.293	0.7702	0.28366875	
WRAPSQ	1	0.06687500	0.29056037	0.230	0.8186	0.07155625	

Table 13

DEP VARIABLE: TENACITY
ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	2	3.05567500	1.52783750	0.073	0.9293
ERROR	69	1442.62331	20.90758424		
C TOTAL	71	1445.67899			

ROOT MSE	4.572481	R-SQUARE	0.0021
DEP MEAN	26.75458	ADJ R-SQ	-0.0268
C.V.	17.09046		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|	TYPE I SS	VARIABLE LABEL
INTERCEP	1	27.62375000	4.06839496	6.807	0.0001	51538.15651	INTERCEPT
WRAPS	1	-0.79187500	4.61986568	-0.171	0.8644	2.75041875	
WRAPSQ	1	0.13812500	1.14312030	0.121	0.9042	0.30525625	

Table 13

DEP VARIABLE: WRUPTURE AVERAGE WORK-TO-RUPTURE
ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	2	15.28907500	7.64453750	0.168	0.8457
ERROR	69	3139.81251	45.50452917		
C TOTAL	71	3155.10159			

ROOT MSE	6.745704	R-SQUARE	0.0048
DEP MEAN	41.89458	ADJ R-SQ	-0.0240
C.V.	16.10161		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|	TYPE I SS	VARIABLE LABEL
INTERCEP	1	44.72375000	6.00203457	7.452	0.0001	126371.24	INTERCEPT
WRAPS	1	-2.76312500	6.81561004	-0.405	0.6864	9.96451875	
WRAPSQ	1	0.57687500	1.68642612	0.342	0.7333	5.32455625	

Table 13

DEP VARIABLE: HARINESS HAIRINESS
ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	2	145.69371	72.84685660	1.062	0.3513
ERROR	69	4732.30671	68.58415527		
C TOTAL	71	4878.00043			

ROOT MSE	8.281555	R-SQUARE	0.0299
DEP MEAN	8.317996	ADJ R-SQ	0.0017
C.V.	99.56202		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|	TYPE I SS	VARIABLE LABEL
INTERCEP	1	6.56562500	7.36956768	0.891	0.3760	4981.60029	INTERCEPT
WRAPS	1	4.24468750	8.36737664	0.507	0.6136	112.34790	
WRAPSQ	1	-1.44364583	2.07038878	-0.697	0.4880	33.34581267	

Table 13

4.3 DISCUSSION

After stretching and stabilizing, the yarn it owes its bulk and other characteristics to its stable filament loops. These are the loops which the Texspun device attempts to break in order to obtain a pair of free fibre-ends from each loop. At first it may seem that the Texspun process will have only a marginal effect on the tensile properties of the yarn, since ideally it acts only on the loops which are on the surface of the yarn, which are not load-bearing. However, critical consideration of the mechanism of loop breakage explains the results obtained.

When a loop is pulled during the breaking process, the 'roots' are pulled outwards from the yarn core. Their extensive entanglements in the yarn core are knotted even more tightly so that filaments enclosed in the various knots are brought closer together (Fig. 15). Consequently the yarn core becomes yet more compacted. The condition gives rise to a different behaviour of the filaments with respect to interfilament friction, and the tensile characteristics change in response to the increased frictional forces.

It appears that results for linear density do not indicate the effectiveness of the Texspun device. Furthermore, the changes in linear density are not entirely in line with expectations. Compared with the observed variations in some tensile properties especially elongation, linear density changes are much less pronounced.

The reasons for the observed behaviour with respect to linear density can be understood by considering the loop breaking mechanism.

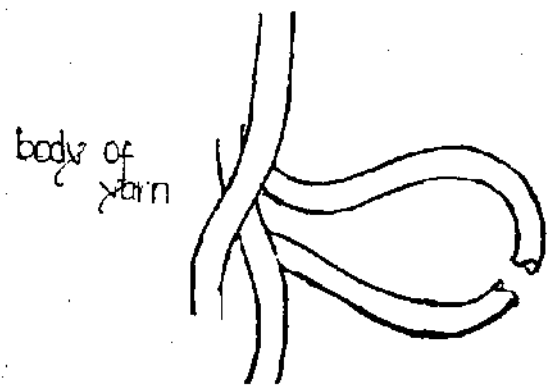
There are basically two ways a loop on the yarn surface can be broken to form free fibre-ends:

311140

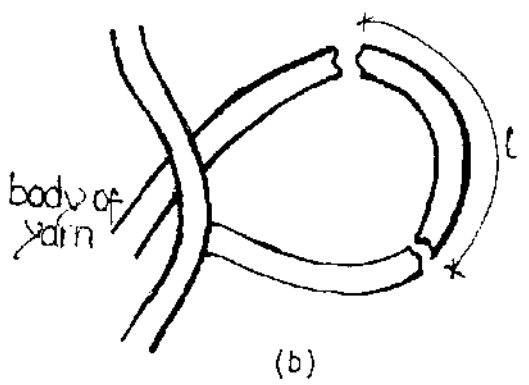
(a) Single-point breakage, where the filament breaks at only one point over the entire length that protrudes to form the loop configuration as in Fig 20a.

(b) Two-point breakage, where the filament breaks at two places over its length,

LIBRARY



(a)



(b)

Fig. 20 Loop Breakage

resulting in a pair of free fibre-ends originating from the yarn core, and a free component (l in Fig 20b) which leaves the yarn as 'fly'. This free component could be responsible for a small decrease in in linear density, the magnitude of which would depend on the number and length of these tiny filaments portions but calculations show this to be negligible. Some of the fly may find its way back into the yarn structure and get re-entangled, so that it still contributes to the linear density of the yarn.

The proportion of the loops broken by this mechanism depends on the number of loops of the outgoing section of the yarn trapped and held by the incoming section.

However insignificant the changes in linear density may appear, they do bear a direct relationship to the number of free fibre-ends created and hence the hairiness values obtained, even though they are related to only one type of breaking mechanism.

The number of free fibre-ends produced do not necessarily have any direct relation to the tensile properties of the yarns. When the Texspun device is used, both stable and some unstable loops are trapped. At this instant, the stabilizing tension exerted cannot pull them back into the yarn core; rather, the mechanism of the system is such that they are more likely to be pulled more out of the core. While this is happening, the filaments of the loops being pulled tighten the yarn core, so that whether they are eventually converted to free fibre-ends or not, they cannot be pulled back into the core at the reigning tension.

CHAPTER FIVE

5.1 EXPERIMENTAL RESULTS FOR THE TEXSPUN PROCESS (2):

TWO ROLLER AND FOUR ROLLER WRAPPINGS

The results obtained by the use of two rollers of the Texspun device with all the possible permutations of wraps ranging from 1-3 are shown in table 15. The pairs of numbers indicate that 2 adjacent rollers are given the stated number of wraps in serial order in the direction of yarn take-up. For example, 12 indicate the first roller is given 1 wrap and the second 2 in that order. The combinations studied were

11, 12, 13,

21, 22, 23,

31, 32, 33,

Tests were carried out on the sheath/core type yarns only. Plot series F show the changes for 50 % overfeed and 25 % overfeed sheath/core yarns at two levels of tension for the variables linear density, % elongation and hairiness. The linear density changes, although significant in some cases, are within a relatively close range. However, the combination that caused the greatest decrease in linear density of the yarns can be seen. If the greatest decrease (due to yarn extension and perhaps a very small contribution from 'fly' loss) is considered as evidence of the greatest Texspun efficiency, the wrap combination 21 (plot F) stands out for the 25 % and 50 % SC yarns. The changes (decrease) for 21 is steeper with increase in tension for 25 % than for the 50 % yarn.

Results obtained for four rollers of the Texspun device are shown in table 16. Plot series D show the variation in some of the properties exhibited by the four yarns when treated with 1,2 and 3 wraps around each roller, at a fixed stabilizing tension of 180 cN. Again the two SC yarns show a similar response as do the two parallel yarns. Plot series

Table 15: Results for 2 rollers

(a) Average Linear Density

		11		12		21		13		31		23		32		22		33	
		M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H
25%	Par																		
	Sc	41.05	40.04	40.35	39.10	40.79	40.21	40.83	40.15	41.00	40.47	41.54	40.68	40.97	40.68	41.14	40.47	41.49	40.63
50%	Par																		
	Sc	40.46	39.77	40.59	39.72	40.77	40.05	40.55	39.83	40.53	39.80	40.65	40.20	40.54	40.13	40.69	40.14	40.80	40.02

(b) Average % Elongation

25%	Par																		
	Sc	12.17	10.00	12.40	8.84	12.28	10.28	11.78	10.19	12.94	12.12	12.83	11.69	12.28	10.96	12.62	11.74	12.97	11.14
50%	Par																		
	Sc	12.66	11.01	12.23	11.36	13.05	11.41	12.77	11.12	12.71	11.53	12.75	10.80	12.47	11.35	12.71	10.48	12.70	12.04

(c) Average Braking Force (cN)

25%	Par																		
	Sc	891.04	861.77	935.35	836.83	909.81	873.11	894.07	868.48	921.21	947.87	904.13	922.51	887.31	866.59	915.75	929.95	913.85	898.52
50%	Par																		
	Sc	929.29	899.03	918.99	881.22	939.64	904.95	912.69	897.89	914.72	915.30	911.13	882.15	902.15	900.70	921.44	881.15	924.77	929.78

(d) Average Tenacity cN/tex

25%	Par																		
	Sc	21.71	21.52	23.18	21.40	22.30	21.71	21.90	21.63	22.47	23.42	21.77	22.68	21.66	21.30	22.26	22.98	22.93	22.11
50%	Par																		
	Sc	22.97	22.61	22.64	22.19	23.05	22.60	22.51	22.54	22.57	23.00	22.42	21.94	22.25	22.44	22.65	21.95	22.67	23.23

Table 15: Results for 2 rollers (continued)

(e) Average Work-to-Rupture (cN*cm)

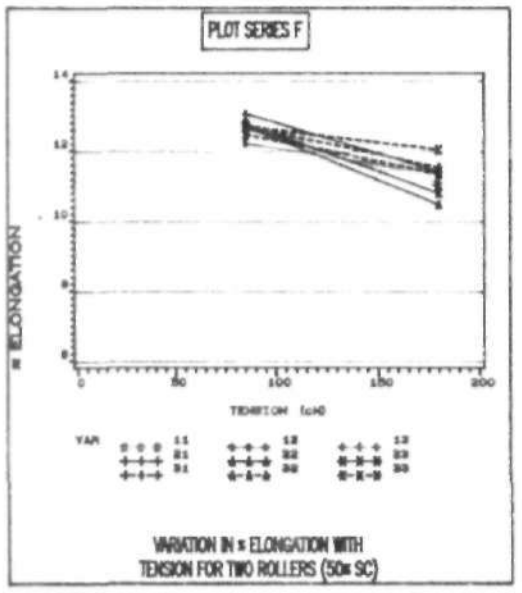
		11		12		21		13		31		23		32		22		33	
		M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H
25%	Par																		
	Sc	3325.04	2688.81	3657.24	2343.44	3477.00	2818.45	3264.00	2799.34	3721.70	3669.75	3565.72	3419.70	3366.25	2953.80	3551.63	3427.07	3653.03	3170
50%	Par																		
	Sc	3677.75	3155.78	3524.85	3124.38	3838.29	3245.08	3619.69	3153.09	3629.01	3384.35	3615.31	3010.24	3498.34	3229.36	3688.68	2932.68	3669.10	3508

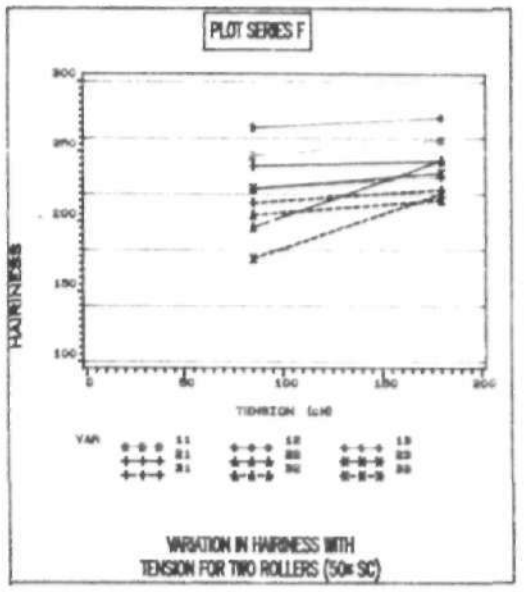
(f) Average Hairiness

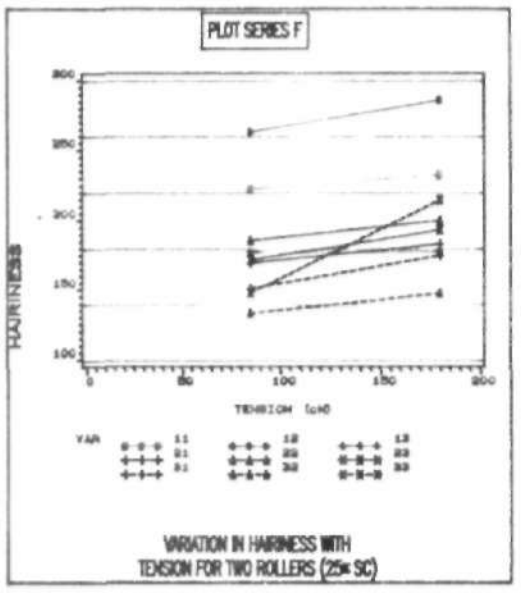
25%	Par																		
	Sc	223.01	232.83	263.45	286.49	169.27	183.22	177.06	177.67	150.99	174.75	171.76	193.12	133.10	147.34	185.85	200.22	147.94	214.
50%	Par																		
	Sc	247.22	258.54	267.28	274.34	232.67	243.23	223.63	232.10	213.29	223.04	223.73	234.83	204.45	215.39	195.88	244.05	173.46	220.

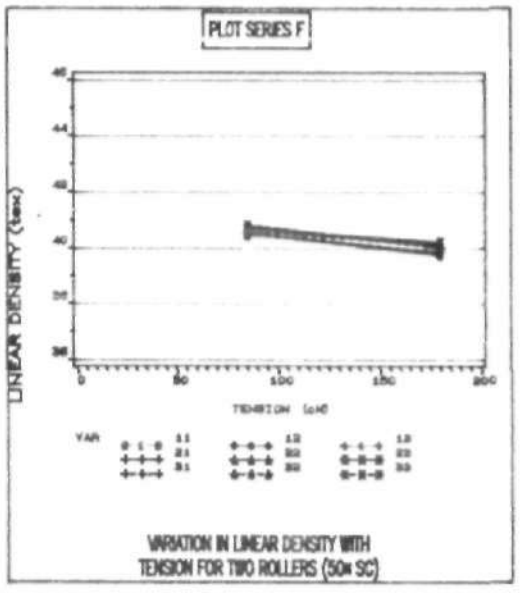
25%	Par																		
	Sc																		
50%	Par																		
	Sc																		

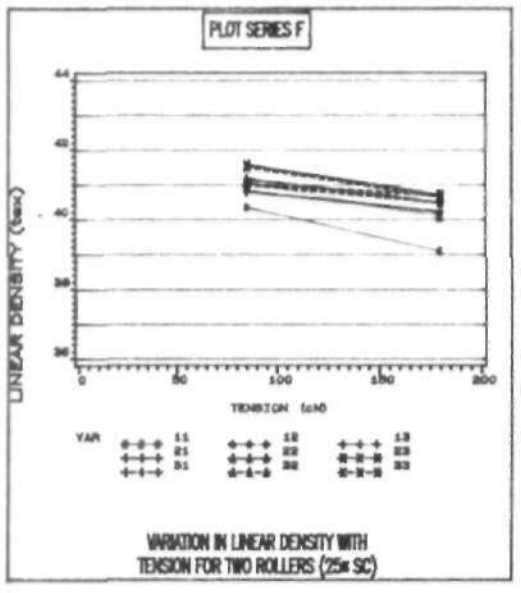
25%	Par																		
	Sc																		
50%	Par																		
	Sc																		

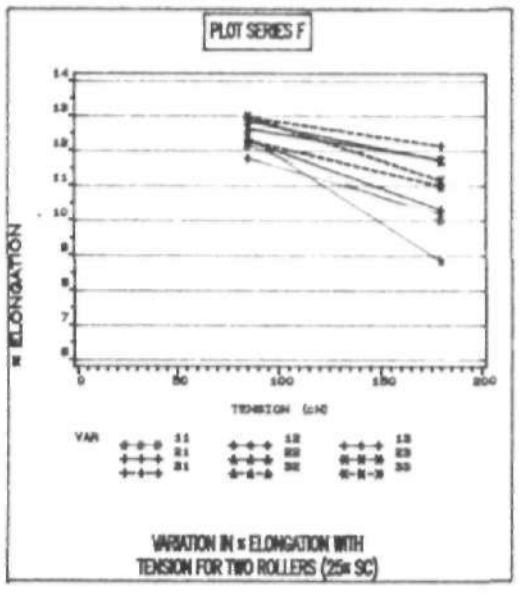

PLOT SERIES F
% ELONGATION
TENSION (cN)
VARIATION IN % ELONGATION WITH
TENSION FOR TWO ROLLERS (50m SC)


PLOT SERIES F
HAIRINESS
TENSION (cN)
VARIATION IN HAIRINESS WITH
TENSION FOR TWO ROLLERS (50m SC)


PLOT SERIES F
HAIRINESS
TENSION (cN)
VARIATION IN HAIRINESS WITH
TENSION FOR TWO ROLLERS (25m SC)


PLOT SERIES F
LINEAR DENSITY (tex)
TENSION (cN)
VARIATION IN LINEAR DENSITY WITH
TENSION FOR TWO ROLLERS (50m SC)


PLOT SERIES F
LINEAR DENSITY (tex)
TENSION (cN)
VARIATION IN LINEAR DENSITY WITH
TENSION FOR TWO ROLLERS (25m SC)


PLOT SERIES F
% ELONGATION
TENSION (cN)
VARIATION IN % ELONGATION WITH
TENSION FOR TWO ROLLERS (25m SC)

E show how the various properties vary with number of wraps for 50 % SC yarn. The situation is shown for a single roller two rollers and four rollers. Four rollers are shown to cause the greatest changes in properties for all the wrap levels.

The results obtained so far indicate that the Texspun process is more effective at elevated tension levels. Results for different number of wraps on one roller at 180 cN are shown, along with selected wrapping arrangement for 2 and 4 rollers in tables 17-22. In the first table of each set (a), the effect of one, two and three wraps was estimated by computing the difference between the values of the response variable of the unmodified textured yarn stabilized at the same tension and that on which one roller with a range of number of wraps was used.

From this, the practical effects of two and four rollers with various wrap arrangements were estimated (labelled 'calculated' and placed beside the corresponding measured values for comparative purposes).

The graphs for the C part of tables 17-22 for all the variables for the four yarns are shown in series G plots. The type of wrapping represented were:-

1 = 1111,

2 = 1221,

3 = 2222,

4 = 3131,

5 = 3333,

where the individual numbers on the right represent the number of wraps on each of a series of four rollers, A, B, C, D.

It can be seen from the tables and graphs that the effect of using multiple rollers of the Texspun device is not exactly the sum of the effects of individual rollers. Actually these results are not surprising when the mechanism of the trapping and breaking process is cosidered.

Table 16: Results for 4 rollers

(a) Average Linear Density

		1111		1221		2222		3131		3333	
		M	H	M	H	M	H	M	H	M	H
25%	Par	36.55	35.68	36.33	35.82	36.46	35.91	36.75	35.60	36.49	35.53
	Sc	40.81	40.26	40.87	40.17	40.86	40.05	40.85	40.34	40.74	39.96
50%	Par	36.45	35.83	36.21	35.65	36.69	35.80	36.76	35.48	36.03	35.02
	Sc	40.43	39.67	40.61	39.61	40.18	39.67	40.41	39.61	40.06	39.41

(b) Average % Elongation

25%	Par	14.46	13.10	14.85	12.97	14.05	12.92	14.21	12.94	14.80	14.14
	Sc	12.45	10.35	12.96	10.58	12.30	9.86	11.74	9.64	12.56	10.38
50%	Par	13.56	12.46	13.61	12.13	14.07	13.30	13.31	12.17	13.74	13.28
	Sc	12.20	8.60	12.07	9.21	11.84	9.41	11.04	9.42	12.06	9.10

(c) Average Breaking Force (cN)

25%	Par	1120.23	1127.47	1152.08	1130.89	1136.03	1138.37	1141.48	1157.47	1140.15	1192.38
	Sc	893.61	848.40	886.27	858.73	84.88	837.47	914.34	860.74	922.01	871.90
50%	Par	1072.77	1092.86	1092.19	1125.29	1126.36	1136.76	1066.65	1091.81	1104.10	1168.53
	Sc	879.07	782.16	860.31	810.37	878.12	819.00	881.53	850.84	908.19	813.05

(d) Average Tenacity cN/tex

25%	Par	30.65	31.60	31.71	31.57	31.16	31.70	31.06	32.51	31.25	33.56
	Sc	22.30	21.05	21.69	21.38	21.66	20.91	22.38	21.34	22.63	21.82
50%	Par	29.43	30.50	30.16	31.56	30.70	31.75	29.02	30.77	30.64	33.37
	Sc	21.74	19.72	21.18	20.46	21.85	20.65	21.81	21.48	22.67	20.63

(e) Average Work-to-Rupture

		1111		1221		2222		3131		3333	
		M	H	M	H	M	H	M	H	M	H
25%	Par	5081.03	4793.15	5419.59	4755.95,	5033.31	4772.98	5074.06	4802.62	5025.15	5251.74
	Sc	3571.16	2819.83	3568.92	2890.81	3418.90	2626.83	3334.45	2606.08	3574.86	2761.67
50%	Par	4511.12	4319.12	4668.23	4381.25	4982.39	4862.76	4367.11	4240.27	4448.51	4785.62
	Sc	3385.15	2148.49	3291.59	2395.95	3289.81	2477.76	3002.19	2496.34	3422.85	2271.70

(f) Average Hairiness

25%	Par	22.79	30.89	24.56	36.65	13.49	23.26	19.26	20.54	15.34	49.17
	Sc	235.94	242.79	235.54	233.21	188.73	207.61	203.18	217.56	191.55	208.36
50%	Par	20.03	40.71	26.84	33.72	17.34	27.73	26.81	35.96	19.47	28.23
	Sc	253.32	256.77	246.36	246.81	219.92	226.27	220.72	230.07	224.16	227.30

Table 17

(a) Average Linear Density (Tex)

		without device (A)	1 wrap X	1 wrap A-X	2 wraps X	2 wraps A-X	3 wraps X	3 wraps A-X
25%	Par	36.40	36.04	0.36	36.09	0.31	36.17	0.23
	Sc	40.55	40.78	-0.28	40.54	0.01	40.74	-0.19
50%	Par	36.18	35.85	0.33	35.65	0.53	36.16	0.02
	Sc	40.27	40.19	0.08	39.93	0.34	40.20	0.07

(b)

		11	calc	22	calc	33	calc	21	calc	23	calc
25%	Par	40.04	41.11	40.47	40.53	40.63	40.93	40.21	40.82	40.68	40.73
50%	Sc	39.77	40.11	40.14	39.59	40.02	40.13	40.05	39.85	40.20	39.86

(c)

		1111	calc	1221	calc	2222	calc	3131	calc	3333	calc
25%	Par	35.65	34.96	35.82	35.06	35.91	35.16	35.60	35.22	35.53	35.48
	Sc	40.26	41.67	40.17	41.09	40.05	40.51	40.34	41.49	39.96	41.31
50%	Par	35.83	34.86	35.65	34.46	35.80	34.06	35.48	35.48	35.02	36.10
	Sc	39.67	39.95	39.61	39.43	39.67	38.91	39.61	39.97	39.41	39.99

Table 18

(a) Average % Elongation

		without device (A)	1 wrap X	1 wrap A-X	2 wraps X	2 wraps A-X	3 wraps X	3 wraps A-X
25%	Par	13.98	13.81	0.17	13.63	0.35	13.41	0.57
	Sc	13.12	12.27	0.85	12.04	1.08	12.21	0.91
50%	Par	13.48	13.36	0.12	13.43	0.05	13.88	-0.4
	Sc	13.28	11.82	1.46	11.83	1.45	11.87	1.41

(b)

		11	calc	22	calc	33	calc	21	calc	23	calc
25%	Par	10.00	11.42	11.74	10.96	11.14	11.30	10.28	11.19	11.69	11.13
50%	Sc	11.01	10.36	10.48	10.38	12.04	10.46	11.41	10.37	10.80	10.42

(c)

		1111	calc	1221	calc	2222	calc	3131	calc	3333	calc
25%	Par	13.10	13.30	12.97	12.94	12.92	12.58	12.94	12.50	14.14	11.70
	Sc	10.35	9.72	10.58	9.26	9.86	8.80	9.64	9.60	10.38	9.48
50%	Par	12.46	13.0	12.13	13.14	13.30	13.28	12.17	14.04	13.28	15.08
	Sc	8.60	7.44	9.21	7.46	9.41	7.48	9.42	7.54	9.10	7.64

Table 19

(a) Average Breaking Force (cN)

		without device (A)	1 wrap X	1 wrap A-X	2 wraps X	2 wraps A-X	3 wraps X	3 wraps A-X
25%	Par	1165.52	1184.53	-19.01	1174.43	-8.91	1175.43	-9.91
	Sc	901.95	932.91	-30.96	935.10	-33.15	923.38	-21.43
50%	Par	1142.79	1168.76	-25.97	1159.02	-16.23	1190.81	-48.02
	Sc	893.69	912.07	-18.38	909.84	-16.15	904.18	-10.49

(b)

		11	calc	22	calc	33	calc	21	calc	23	calc
25%	Par	861.77	963.87	929.95	968.25	898.52	944.81	873.11	966.06	922.51	956.53
50%	Sc	899.03	930.45	881.15	925.99	929.78	914.67	904.95	928.22	882.15	920.33

(c)

		11	calc	22	calc	33	calc	21	calc	23	calc
25%	Par	1127.47	1241.56	1130.89	1221.36	1138.37	1201.16	1157.47	1223.36	1192.38	1205.16
	Sc	848.40	1025.79	858.73	1034.55	837.47	987.67	860.74	1006.73	871.90	987.67
50%	Par	1092.86	1246.67	1125.29	1227.19	1136.76	1207.71	1091.81	1290.77	1168.53	1334.87
	Sc	786.16	967.21	810.37	958.29	819.00	935.65	850.84	951.43	813.05	935.65

Table 20

(a) Average Tenacity (cN/tex)

		without device (A)	1 wrap X	1 wrap A-X	2 wraps X	2 wraps A-X	3 wraps X	3 wraps A-X
25%	Par	32.02	32.87	-0.85	32.54	-0.52	32.50	-0.48
	Sc	22.24	22.88	-0.64	23.07	-0.83	22.67	-0.43
50%	Par	31.59	32.60	-1.01	32.51	-0.92	32.93	-1.34
	Sc	22.19	22.69	-0.50	22.79	-0.60	22.49	-0.30

(b)

		11	calc	22	calc	33	calc	21	calc	23	calc
25%	Par	21.52	23.52	22.98	23.90	22.11	23.10	21.71	23.71	22.68	23.50
50%	Sc	22.61	23.19	21.95	23.39	23.23	22.79	22.60	23.29	21.94	23.09

(c)

		1111	calc	1221	calc	2222	calc	3131	calc	3333	calc
25%	Par	31.60	35.42	31.57	34.76	31.70	34.10	32.51	34.68	33.56	33.94
	Sc	21.05	24.80	21.38	25.18	20.91	25.56	21.34	24.38	21.82	23.96
50%	Par	30.50	35.63	31.56	35.45	31.75	35.27	30.77	36.29	33.37	36.95
	Sc	19.72	24.19	20.46	24.39	20.65	24.59	21.48	23.79	20.63	23.39

Table 21

(a) Average Work-to-Rupture (cN.cm)

		without device (A)	1 wrap X	1 wrap A-X	2 wraps X	2 wraps A-X	3 wraps X	3 wraps A-X
25%	Par	5182.29	5228.24	-45.95	5056.22	126.07	4979.94	202.35
	Sc	3803.42	3608.64	194.78	3548.93	254.49	3566.75	236.67
50%	Par	4891.84	4938.18	-46.34	4909.31	-17.47	5239.76	-347.92
	Sc	3834.88	3400.51	34.37	3406.35	28.53	3402.64	32.24

(b)

		11	calc	22	calc	33	calc	21	calc	23	calc
25%	Par	2688.81	3413.86	3427.07	3294.44	3170.61	3330.08	2818.45	3354.15	3419.70	3312.26
50%	Sc	3155.78	3734.68	2932.68	3777.82	3508.45	3770.40	3245.08	3771.98	3010.24	3774.11

(c)

		11	calc	22	calc	33	calc	21	calc	23	calc
25%	Par	4793.15	5366.09	4755.95	5022.05	4772.98	4678.01	4802.62	4869.49	5251.74	4372.89
	Sc	2819.83	3024.30	2890.81	2904.88	2626.83	2785.46	2606.08	2940.52	2761.67	2856.74
50%	Par	4319.12	5077.20	4381.25	5019.46	4862.76	4961.72	4240.27	5680.36	4785.62	6283.52
	Sc	2148.49	3697.40	2395.95	3709.08	2477.76	3720.76	2496.34	3701.66	2271.70	3705.92

Table 22

(a) Average Hairiness

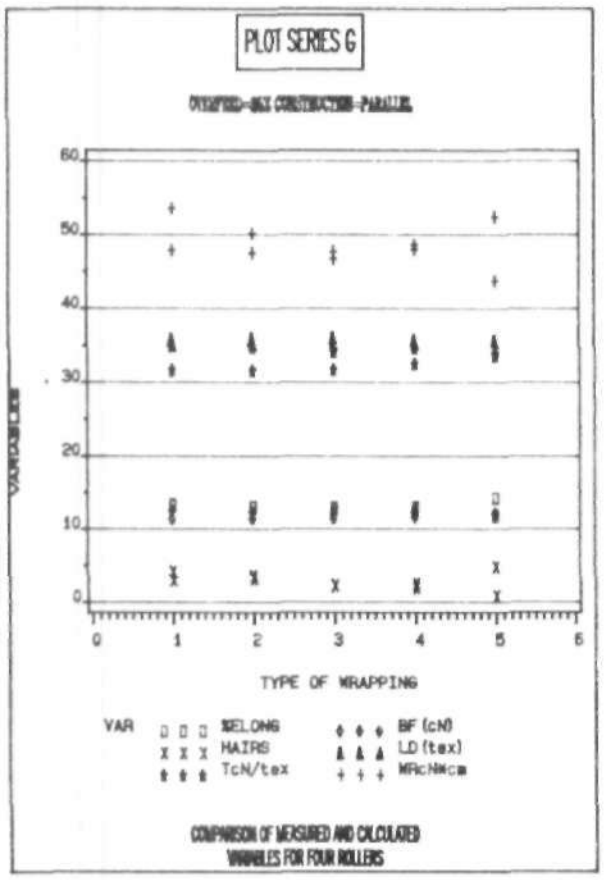
		without device (A)	1 wrap X	1 wrap A-X	2 wraps X	2 wraps A-X	3 wraps X	3 wraps A-X
25%	Par	0.60	11.03	-10.43	6.35	-5.75	2.76	-2.16
	Sc	22.56	170.53	-147.97	170.33	-147.77	120.76	-98.20
50%	Par	0.33	5.31	-4.98	5.72	-5.39	3.11	-2.78
	Sc	41.98	197.87	-155.89	188.00	-146.02	160.38	-118.40

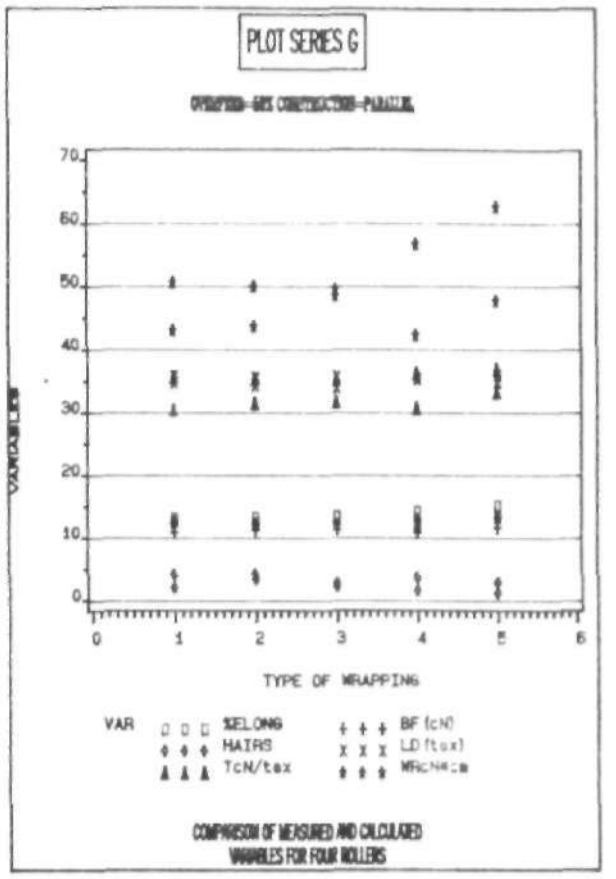
(b)

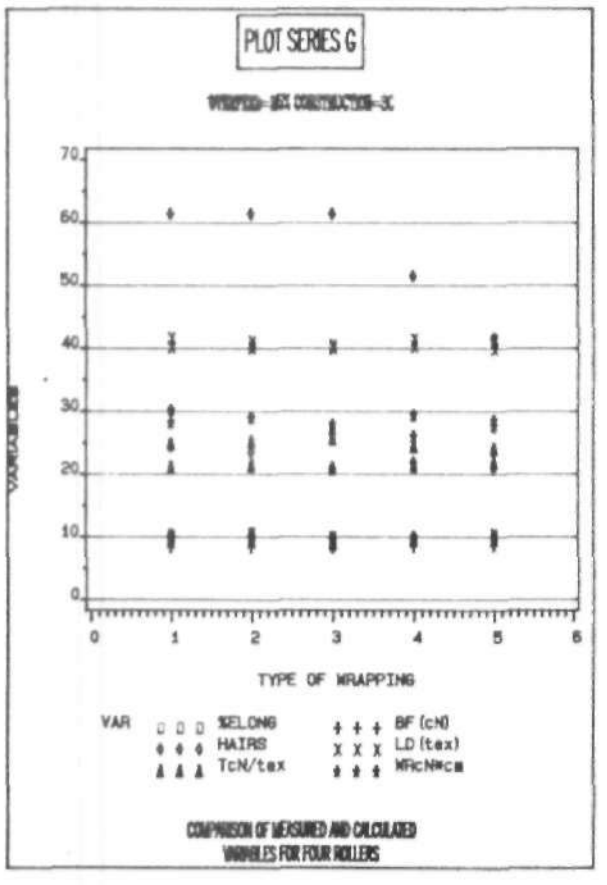
		11	calc	22	calc	33	calc	21	calc	23	calc
25%	Par	232.83	318.50	200.22	318.10	214.78	218.96	183.22	318.30	193.12	268.53
50%	Sc	258.54	353.76	244.05	334.02	220.11	278.78	239.67	343.89	234.83	306.40

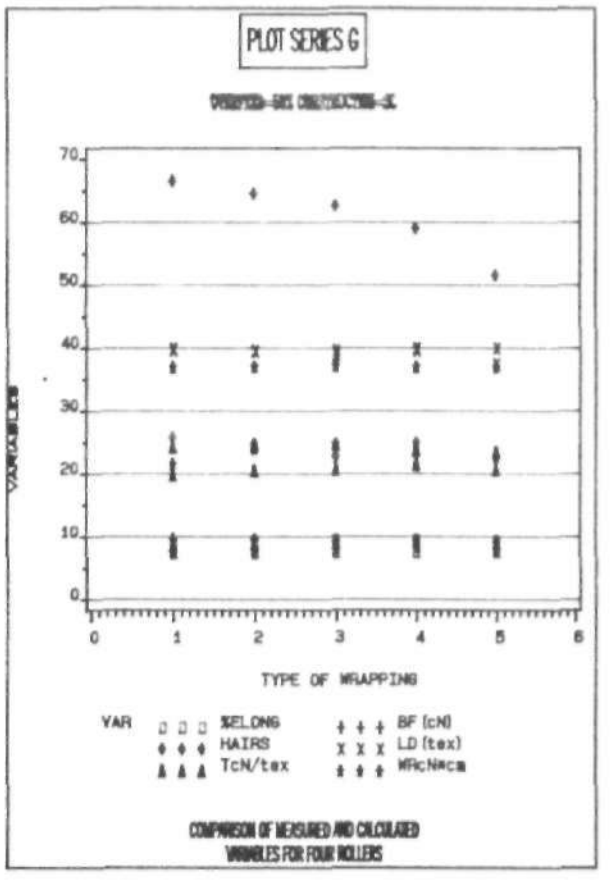
(c)

		11	calc	22	calc	33	calc	21	calc	23	calc
25%	Par	30.89	42.32	36.65	32.96	23.26	23.60	20.54	25.78	49.17	9.24
	Sc	242.79	614.44	233.21	614.04	207.61	613.64	217.56	514.90	208.36	415.36
50%	Par	40.71	20.25	33.72	41.81	27.73	21.89	35.96	15.85	28.23	11.45
	Sc	256.77	665.54	246.81	645.80	226.27	626.06	230.07	590.56	227.30	515.58


PLOT SERIES G
TYPE OF WRAPPING
VAR %ELONG BF (cN)
HAIRS LD (tex)
TcN/tex
COMPARISON OF MEASURED AND CALCULATED
VARIABLES FOR FOUR ROLLERS


PLOT SERIES G
TYPE OF WRAPPING
VAR %ELONG BF (cN)
HAIRS LD (tex)
TcN/tex
COMPARISON OF MEASURED AND CALCULATED
VARIABLES FOR FOUR ROLLERS


PLOT SERIES G
TYPE OF WRAPPING
VAR %ELONG BF (cN)
HAIRS LD (tex)
TcN/tex
COMPARISON OF MEASURED AND CALCULATED
VARIABLES FOR FOUR ROLLERS


PLOT SERIES G
TYPE OF WRAPPING
VAR %ELONG BF (cN)
HAIRS LD (tex)
TcN/tex
COMPARISON OF MEASURED AND CALCULATED
VARIABLES FOR FOUR ROLLERS

Within limits of experimental error, some of the properties can be said to be approximately estimated, especially for the 2222 wrapping. These properties are % elongation, linear density, breaking force and hairiness for the parallel air-textured yarns and elongation, linear density and breaking force for the SC yarns. It should be noted that the actual values of breaking force and work-to-rupture have been multiplied by 0.01 and hairiness by 0.1 in order to fit them into all the graphs for ease of comparison.

When the yarn is wrapped around each of a series of rollers, in a steady state of running, only the loops on one side of the yarn are trapped because it appears that the same side of the yarn is presented to the incoming section at every roller. This means that the same loops stand a chance of being trapped again.

Consequently, the improvement obtained in hairiness per roller decreases progressively as the number of rollers used in the series increased. Improvement may come mainly from breaking the loops which survived the action of the preceeding roller(s), although some additional loops will be trapped and broken because of thread-path wavering and other associated instabilities in the process. This has been adequately confirmed by the results.

At first it may seem that other properties may change in a different manner to hairiness, especially the tensile properties. The results show that the changes appear greater than is the case for hairiness because of the pulling of the loops and free fibre-ends on successive rollers, which in conjunction with the processing tension induce a change in these properties. However, these changes are quite small compared to that expected if it were possible for all the loops on all sides of the yarn to be subjected to the same process.

CHAPTER SIX

6.1 CAUSES OF INCONSISTENCY

Generally, for any yarn treated with the Texspun device under a given set of conditions, the results obtained for any two tests are not exactly the same. The following reasons are advanced for such inconsistency, assuming the measuring devices and their associated accesories are in perfect working condition :-

(1) The untreated air-textured yarn itself showed irregularity in the number of loops per given length, as well as their relative sizes, possibly due to irregular or periodic 'surges' in air pressure in the jet.

(2) It was observed that if the input continuous-filament yarns are wetted below a certain critical level, the same periodicity is introduced (as in 1) as well as variations in loop stability.

(3) From measurements of the speeds of the input and output rollers, it was observed that after running the machine for a long period, heat is generated in the driving systems which resulted in a corresponding very slight increase in their speeds and differences in the speeds of the input and output rollers. This results in small process variations and thus loops of varying sizes and different degrees of stability.

(4) Wavering of the threadline causes the touching wraps of yarn on a roller to move apart so that the loops trapped are released. This factor is very important because it considerably decreases the effectiveness of the Texspun loop trapping and breaking process. A considerable number of loops which otherwise would have been trapped pass round the roller unaffected.

(5) The take-up winder changes its speed in order to accomodate any tension

variations occuring in the take-up region. Sometimes these changes are not smooth enough and the threadline is subjected to tension variations that cause fluctuations in the stabilization tension and irregularities are introduced in the yarn.

(6) The hairiness testing meter can inspect only those protruding loops and free fibre-ends within an angle of approximately 35 degree on each side of the vertical plane of the yarn axis. It cannot detect all the hairs around the circumference of the yarn. This questions the reliability of test results with respect to reproducibility and independence in testing speed. Given the apparent one-sided way in which the texspun device works, an element of chance is introduced into the detection process, and this may introduce inconsistency in the results obtained.

CHAPTER SEVEN

7.1 MECHANISM OF LOOP TRAPPING AND BREAKING

Loop trapping is the first step of the breaking process. The position of the loop on the yarn can best be described by rectangular cartesian coordinates as shown by the line representation in Fig. 23a.

Their position on, and lengths from the yarn surface must be such that they could be caused by the yarn (on the side with which they make contact) to decrease their angle of inclination (α) to the x-axis (parallel to the roller axis) to such a value as to facilitate their being trapped.

As the yarn is wrapped round the roller, it flattens out on the surface, so that only loops over an arc 180° of the flattened-out circumference are actually exposed. Of these, only those with their tips within the quadrant in contact with the incoming section could be trapped (Fig. 23b).

The overall operation can succeed only if the two sections of yarn are in close contact and the projected length of a loop (:loop length refers to the loop height; half the actual length of the filament that forms the configuration) along the x-axis exceeds the boundary defined by the arc of the flattened exiting yarn in contact with the incoming section of yarn. For cases outside these critical considerations, the trapping process is never effected completely.

The chances of a loop being successfully trapped even if its length is adequate decreases as its α tends to $\frac{\pi}{2}$ for yarns in the appropriate quadrant.

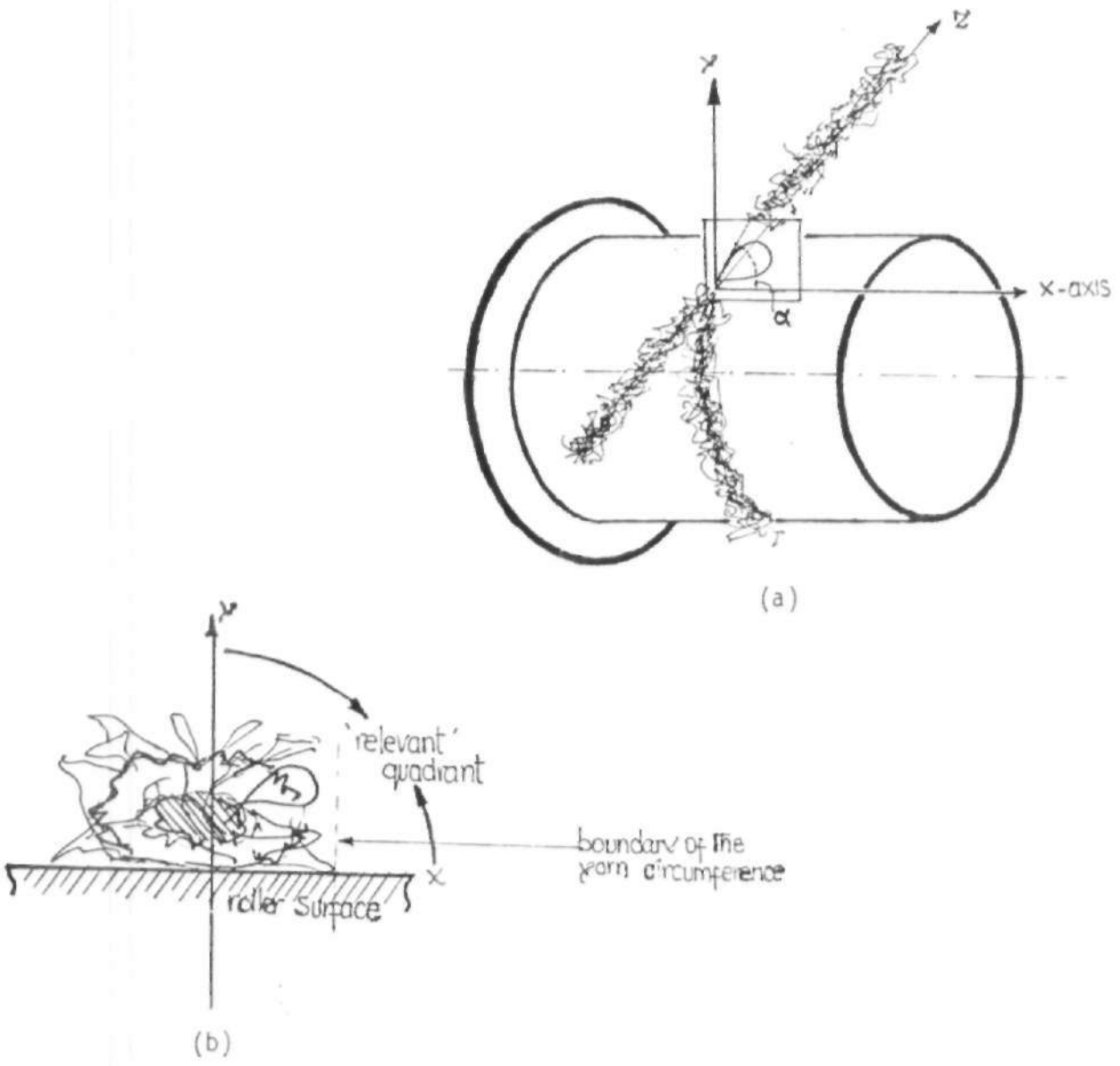

Y
Z
X-axis
α
(a)
Y
'relevant' quadrant
boundary of the yarn circumference
X
roller Surface
(b)

Fig. 23

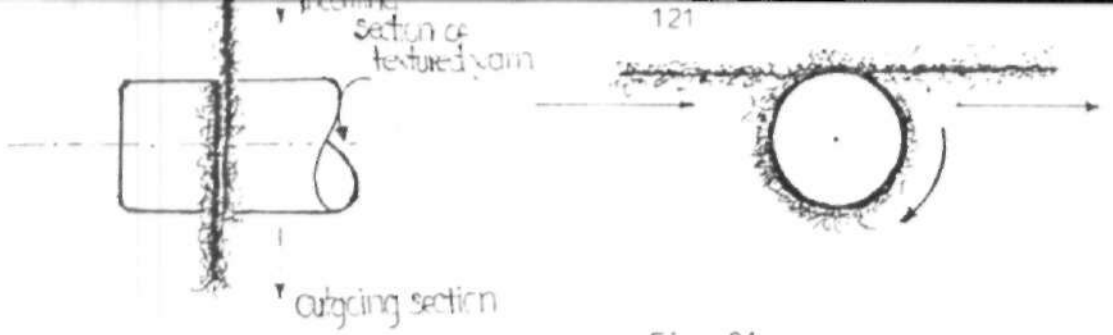

section of
textured yarn
outgoing section

Fig. 24

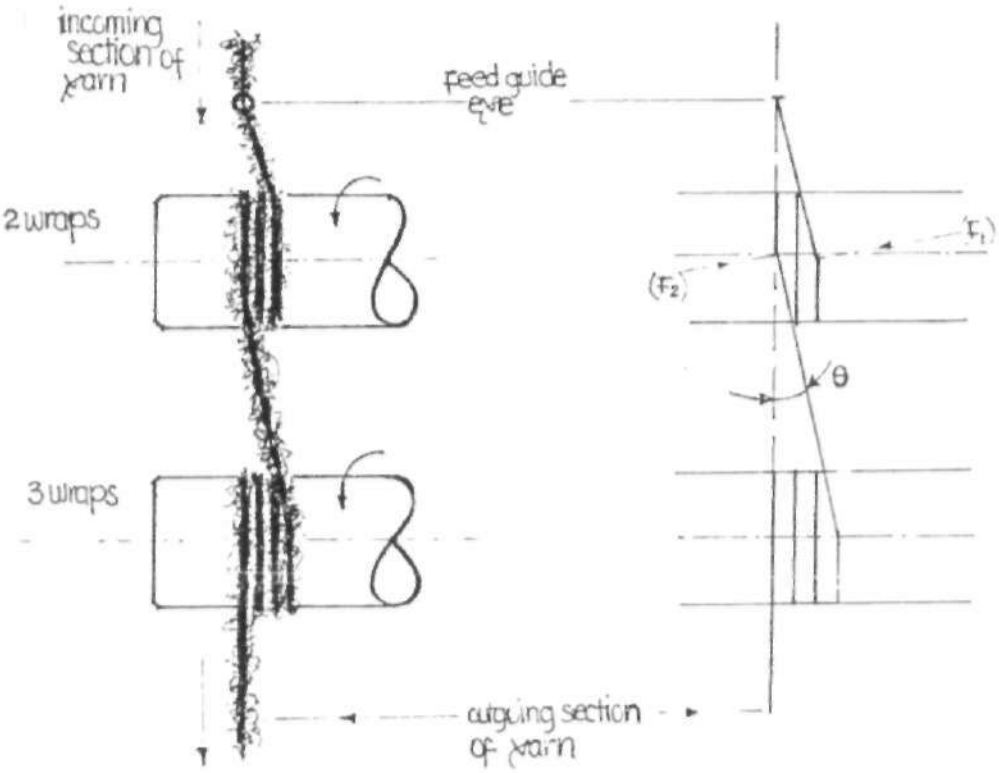

incoming
section of
yarn
feed guide
eye
2 wraps
3 wraps
F_1
F_2
θ
outgoing section
of yarn

Fig. 25

Therefore,

$$\lim_{\alpha \to \frac{\pi}{2}} \mathbf{P}(\mathbf{T}_1)\mathbf{k}_1(\alpha) \tag{3}$$

where $\mathbf{P}(\mathbf{T}_1)$ = probability of trapping a loop, and $\mathbf{k}_1$ = a constant.

Further, the unpredicted relative positions of 'eligible' loops on the outgoing section in contact with the incoming section introduces an element of chance into the process. This situation is true for each roller.

For any number of wraps and rollers under consideration, the threadline maintains an average straight line path between the feed and the take-up guide eyes of the Texspun device. In the steady state, the threadline for one wrap on a single roller is as shown in Fig. 12 and the plan and end views in Fig. 24a and b. The case for more than one roller with single wraps is simply an extension of Fig. 24a.

However, where more than one wrap is used on more than one roller, the geometry of the yarn path varies somewhat, depending on whether the roller is the first in the series of rollers used or otherwise.

Fig. 25a shows the orientation and Fig. 25b its line representation of the case for two wraps on the first roller and three wraps on the second. The way in which the yarn is presented from a preceeding roller to the next changes with the relative number of wraps.

If theta is the yarn presentation angle from one roller to the next, then theta changes for each pair of adjacent rollers. Ideally, in the cases studied (1-3 wraps), θ is maximum for the situation when the first reference roller in the series has three wraps and the second also three.

Since the yarn is under tension, forces are generated which act in the direction of the arrows $\mathbf{f}_1$ and $\mathbf{f}_2$ in Fig. 24b for any one roller. These forces tend to press the yarns closer together and are functions of the respective tensions of the incoming and outgoing sections of the yarn.

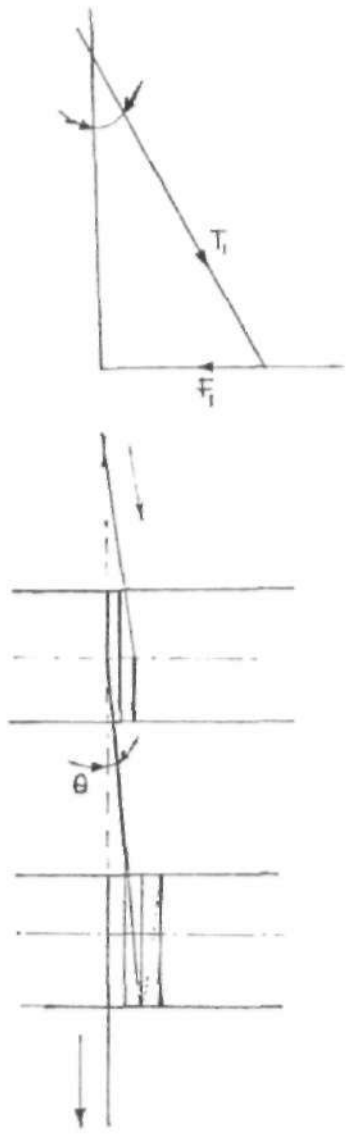


Fig. 26

From Fig. 24c,

$f_1 = T_1 \sin\theta_1$

similarly

$f_2 = T_2 \sin\theta_2$

We must have $f_2 = f_1 + q$, where q represents the frictional force between the series of wrapped yarn and the roller surface

Considering this factor for each roller, the effectiveness of the trapping process is supposed to be improved (by virtue of the yarn wraps under pressure, and the slightly angular presentation of the incoming section from a preceeding point, be it the feed guide eye of the Texspun device or another roller). Ideally, for any one roller,

$$\lim_{\theta \to \theta_{cr}} P(T_j) k_2(\theta) = P(T_j)_{max} \qquad (4)$$

where k_2 = a constant and θ_{cr} = the maximum practical value of θ, called the critical value, above which the in-coming section of the yarn overlaps the yarn wraps on the roller as in Fig. 26. This occured when 4 wraps were used.

Generally, the probability of trapping N loops in a given length of yarn is given by

$$P(NT_j) = \sum_{i=1}^{N} P(T_j) \qquad (5)$$

where i = 1, 2, 3, ...N.

Since only the loops in the 'relevant' quadrant can be trapped, equation (3) becomes

$$P(QT_j) = \frac{\sum_{j=1}^{Q} P(T_j)}{\sum_{i=1}^{N} P(T_i)} \qquad (6)$$

where Q = loops in the relevant quadrant and j = 1, 2, 3, ...Q.

From equations (2) and (3), total number of loops trapped with respect to the quadrant is given by

$$N_Q = P(QT_l)k_2\theta = \frac{k_2\sum_{l=1}^{Q} P(T_l)}{\sum_{l=1}^{N} P(T_l)} \qquad (7)$$

From (7), equation (3) becomes

$$\lim_{\alpha\to\frac{\pi}{2}} k_1k_2\theta\alpha\frac{\sum_{l=1}^{Q} P(T_l)}{\sum_{l=1}^{N} P(T_l)} = 0 \qquad (8)$$

This applies at every roller. However, the fact that a loop trapped on roller A still stands an equal chance of being trapped on any of the rollers B, C, D or even two or more of the subsequent rollers in the series means that the Texspun effect of rollers A, B, C and D are statistically independent.

When a loop is trapped, interfilament friction and the friction between the filament and the metal surface resist slippage of the loop out of confinement, while on the other hand the tension of the outgoing section exerts the pulling force as the yarn moves on.

The trapping friction will be determined by the tension in the penultimate wrap. If this tension is low, the trapped loop may, at best, be pulled out of the yarn core so that it is effectively much longer than it was before, without being actually broken. At reasonably high tensions, the pulling force on the loop and the frictional resistances on the metal surface are greater, so that breaking is favoured.

CHAPTER EIGHT

8.1 CONCLUSIONS

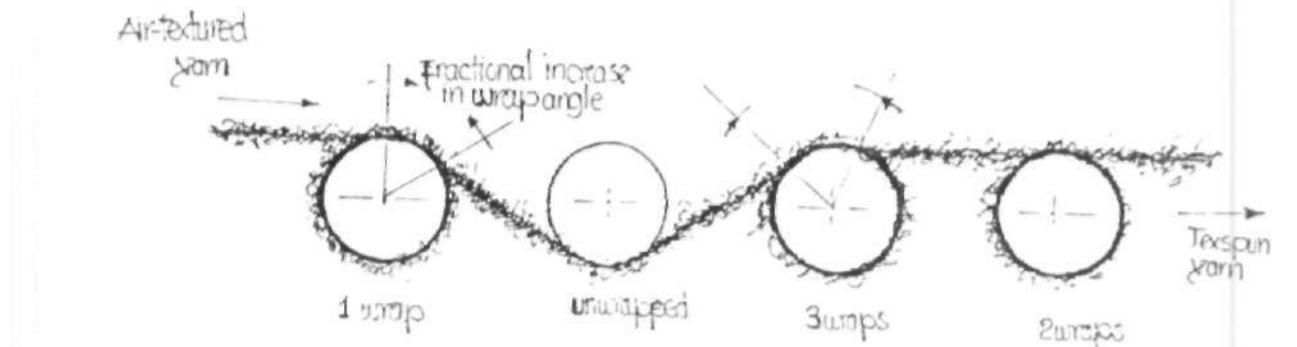
The effectiveness of the Texspun device is practically significant because it determines the 'spun-like' properties of the continuous-filament air-textured yarn. Although products with a certain proportion of unbroken loops may have acceptable qualities, the remaining unbroken loops can still give some problems in certain applications, especially snagging and 'velcro' behaviour. These effects are, however, relatively much reduced.

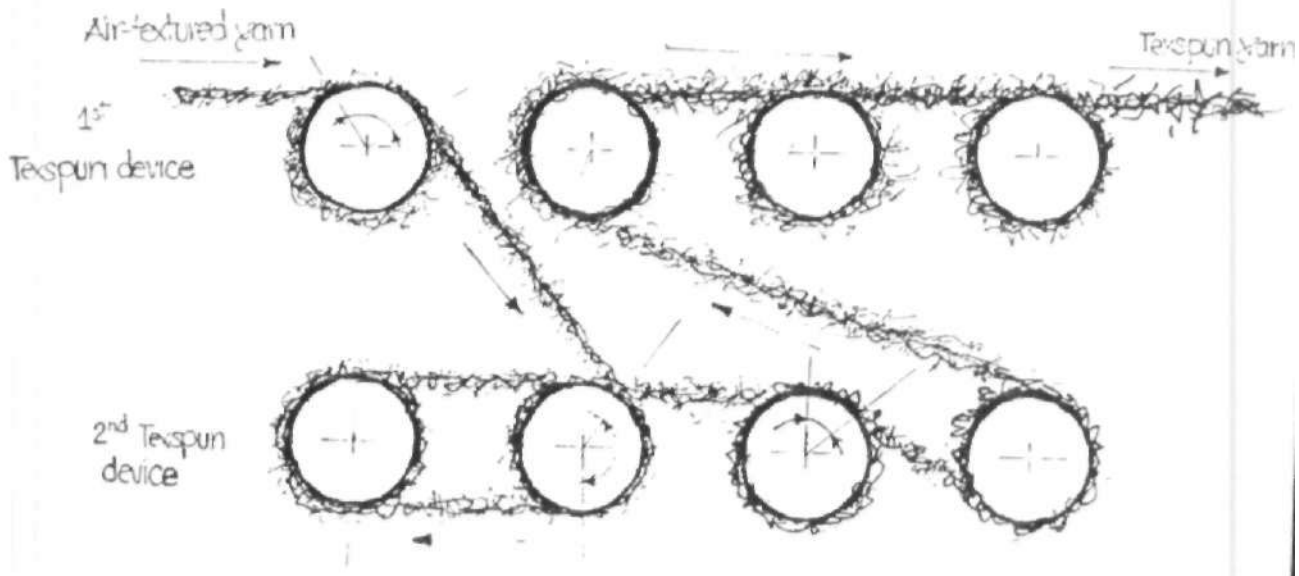
When a multiple number of wraps is used, the geometry created improves the trapping process. But such trapped loops will have to be held for the length of time it takes for them to go through the number of wraps on the particular roller. Should any case of instability (such as thread-path wavering) occur, trapped loops may be released.

The use of multiple wraps does not give a proportional improvement because no significant new trapping is generated by the extra wraps. This is probably why representative examples of other forms of wrapping (which were tried because they could introduce fractional values in the number of wraps used as well as different geometries) did not perform as well as the 'conventional'. (Examples of other methods of wrapping are shown in Fig. 27a and b. The arrangement in Fig. 26b was made by arranging two devices in parallel. However, it was practically unworkable because of threadline instabilities and the shape of the device. No usefull results were obtained for this case).

In the absence of instabilities, trapped loops are expected to be held better by the increased number of wraps, so that the loops are easily and neatly broken.

Generally, the basic physical properties of the parent yarn are not adversely changed by the Texspun process, so that the possible end uses of the yarn are broadened.


Air-textured yarn
Fractional increase in wrap angle
1 wrap
unwrapped
3 wraps
2 wraps
Texspun yarn


Air-textured yarn
1st Texspun device
Texspun yarn
2nd Texspun device

It can be concluded that the effect of individual rollers in a multiple roller arrangement are additive, but this has not been proved by the results because of the overlapping nature of the (statistically independent) effects. This means that the model equations would apply if equations (7) can be estimated.

Generally, the practical reproducibility of product properties with this device will depend, to a considerable extent, on the skill of the operative and their knowledge of the process parameters.

8.2 SUGGESTIONS FOR MODIFICATION OF THE DEVICE

If the Texspun device is accepted in industry as offering satisfactory performance, then its effectiveness is likely to improve when it is modified with emphasis on

- improving the trapping process;

- introducing a way in which the trapping process can take place all round the yarn *circumference*;

- minimizing wavering and other thread-path instabilities.

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