ABSTRACT

Renduchintala, Chaithanya. Relationship between the processing parameters and tensile properties of air textured Kevlar yarns.(Under the direction of Dr.William Oxenham)

Air texturing is an extremely versatile mechanical yarn bulking process that improves the handle and tactile properties of continuous multifilament yarns. Kevlar , poly(p-phenylene terephthalamide) , due to its excellent mechanical and thermal properties has found wide ranging applications in protective clothing, however the filament has poor tactile properties. Air texturing could thus be the process of choice for improving handle by imparting bulk to the multifilament yarn however improvement of the surface characteristics is at the expense of tensile strength of the yarn.

The thesis reports an experimental study which was carried out to determine the influence of the key processing parameters on the resultant tensile strength, strain and moduli properties of the yarn. A further objective of the research work was to develop novel structures that will have good surface properties with minimal compromise in the axial strength.

In order to accomplish this goal, a literature review along with preliminary trials was conducted to document the texturing process and to select the key process variables. Based on these findings a three factorial experiment was conducted to achieve the objectives.

The results showed that processing conditions have an influence over the resultant tensile properties. The study also explores a novel yarn structure that has loops on the surface while the orientation of the core is retained.

RELATIONSHIP BETWEEN THE PROCESSING PARAMETERS AND TENSILE PROPERTIES OF AIR TEXTURED KEVLAR YARNS

by

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BIOGRAPHY

Renduchintala Chaithanya was born on the 24th of March 1978, in Chennai, India. He graduated from DKTE's Textile and Engineering Institute in 1999 with a Bachelor Degree in Textile Technology. He then enrolled at North Carolina State University, where he is currently pursuing a Master of Science degree in Textiles under the supervision of Dr.William Oxenham. His current research topic is "Relationship between the processing parameters and tensile properties of air textured Kevlar yarns".

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I will be forever indebted to my parents and brother. I can never fully repay my father for his encouragement and my mother who has been a constant and endless source of love and support throughout my stay away from home. I will like to thank all of my teachers in KFI for instilling in me value of having faith in myself and my dreams. I will like to thank my grandfather whose dream it was that I should pursue further studies and strive to be my best.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

TENSILE PROPERTIES OF AIR TEXTURED KEVLAR YARNS

SHEATH-CORE KEVLAR YARNS

AIR JET DRAW TEXTURING MACHINE, INSTALLATION & TRIALS

1 INTRODUCTION

In the air-texturing process one or more ends of multifilament yarn are passed through a jet in which air turbulence is maintained. Multifilament yarn or yarns are fed into the jet at a higher rate and withdrawn at a lower rate. The airflow causes the filaments to be blown apart, curled into loops, and recombine to form a yarn with a loopy surface and an in extensible core. [1] Based on yarn feed the process can be classified in three ways.

1. Single end: There is only one multifilament yarn that is fed into the jet from a single source.
2. Parallel fed yarns: A minimum of two multifilament yarns are fed into the jet, the objective of parallel feeding is to blend the filaments of the input yarns into a single cohesive structure.
3. Core-effect yarns: The overfeed of one component is significantly lower than the other. It therefore retains its orientation as the core of the resultant structure.

In this research work single end yarns and core-effect yarns are studied.

The major product categories of air-textured yarns are as follows:

1. Bulky yarns: These yarns are typically very coarse (1500-7000 dtex) and are used in home furnishings and carpets.
2. Technical Yarns: These are relatively inextensible and are used as sewing threads and in reinforcement fabrics.
3. Yarns with spun like characteristics. It is these yarns that have contributed greatly to the growth of the air-texturing process as they tend to lower fabric costs because they replace expensive natural fibers like silk and wool with cheaper synthetics. [2]

Technological advances greatly reduced production cost and improved yarn quality [3]. The process is cost efficient because of the following reasons:

1. High production speeds
2. Texturing jets with low air consumption
3. Availability of suitable feed yarns
4. Reduced cost due to better downstream processing of the yarn [4]

The versatility of the process allows manufactures to air texture a variety of fibers and cater to different market segments like, domestic furnishing, automotive furnishing, apparel, sewing threads and in industrial furnishing. The air-jet textured yarn market has been slowly, yet continually growing since its introduction in the 50s [3].

The chart below outlines the proportion of the major fiber by group as of 1998.

Table 1.1: Propotion of major fiber group used in texturing [5]

Fiber Type	Proportion %
Polyester	35
Nylon	33
Polypropylene	22
Viscose/Acetate	0.5
Glass	2
Others	7.5
Total	100

Kevlar, a polyaromatic amide fiber, provides a unique combination of toughness, high tenacity modulus, and thermal stability. Under water the Kevlar fiber is about twenty times stronger than steel. Due to its outstanding mechanical properties its applications include cut, heat, and bullet / fragment resistant apparel, brake and transmission friction parts, gaskets, ropes and cables, composites, circuit board reinforcement, sporting goods, tires, automotive belts and hoses. [6]

Despite its excellent mechanical properties the tactile properties of Kevlar leave much to be desired. With increasing applications in protective clothing the tactile properties of Kevlar have acquired importance. The spun like feel of air textured yarn, together with the fact that the process is applicable to almost any filament yarn make air-texturing Kevlar a interesting proposition. Kevlar has found increasing application in composite structures, however in Kevlar-epoxy matrix composites the adhesion between filament and the matrix is poor and the composite fails due to delamination. [7] It is probable that the surface loops caused due to air texturing might improve mechanical interlocking and thus postpone the onset of delamination.

Previous work done at North Carolina State University, college of textiles, established that it is possible to texture Kevlar. [8] The study also showed that pre-wetting the filaments improves loop formation in textured Kevlar. The current work was undertaken with the following objectives:

1. To establish critical processing parameters for air texturing of Kevlar.
2. To investigate the individual and combined effects of each of the key processing parameters on the resultant tensile properties of air-textured yarn.
3. Arriving at levels of these variables that will ideally suit an intended application.
4. To develop air textured yarn structures that will find application in composite structures.

2 TENSILE PROPERTIES OF AIR TEXTURED KEVLAR YARNS

2.1 INTRODUCTION

Air streams have been used in the production of textured yarns since the 1950's [9]. Yarns so produced have a characteristic appearance, texture and properties that distinguish them from yarns produced by other processes. Air jet texturing due to the distinct functional, visual and economic advantages offers an ideal process to impart bulk and surface loops to a multi filament yarn [9,10]. The versatility of this process makes it ideally suited for the development of new and fancy yarns [2, 10, 3].

Air jet texturing maybe defined as a process by which a flat synthetic multi-filament yarn is given a spun yarn like appearance, with a compact core and surface loops and bows occurring at irregular intervals along its length [11]. A schematic representation of the process is show in figure 2.1 [12].

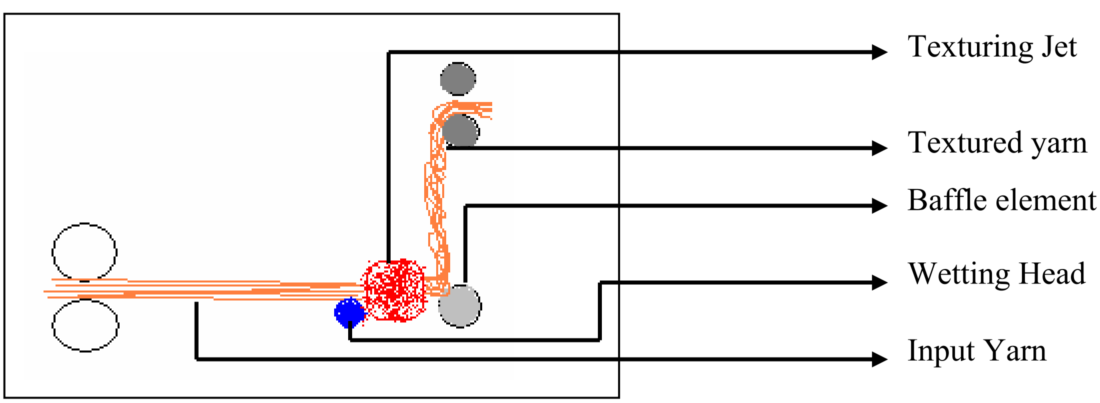


Figure 2.1: Schematic representation of the Air texturing Process

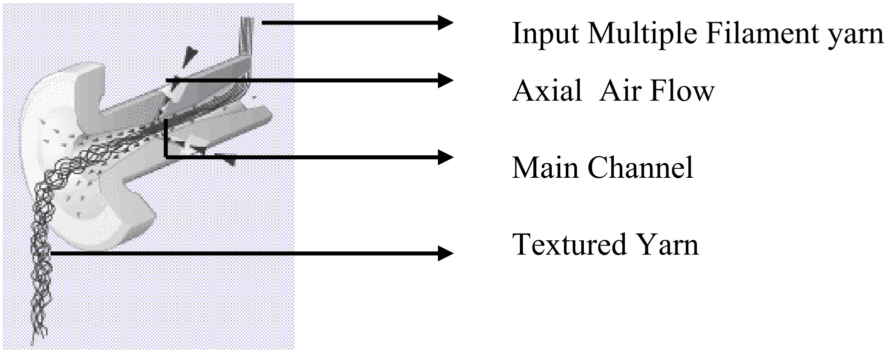


Figure 2.2: Flow of air and material within the jet [14]

The jet insert shown in figure 2.2, above, is the heart of the texturing process. The modern air-jet is essentially a metallic or ceramic nozzle that allows for an inclined airflow at approximately 45° to impact upon pre-wetted overfed filaments within itself. The exit of the nozzle is trumpet shaped and there is a spherical impact element to enhance loop formation [14]. The most widely used nozzle of this type is the Herberlein Hemajet. The main channel of this nozzle varies between 1.5-2.5 mm in diameter and has a approximate length of 30 mm with a very smooth surface finish, as can be seen in figure 2.2 [13]. The design ensures that the velocity of the air stream increases as it passes through the jet. Texturing takes place at the exit of the nozzle. The geometry of the main channel plays a less critical role in the process [9].

Figure 2.3: Arrangement of the Jet and Housing [14]

The arrangement of the jet and its housing is shown in Figure 2. 3. The flow of air within the channel of the jet is described in figure 2.2 [14]. With improvements in the design of the jet, jet-to-jet variations have been significantly reduced [15].

The air texturing process itself is relatively uncomplicated. The new generation of specific purpose machinery gives good control over the process variables. A brief description of the process follows. When an overfed filament yarn (generally pre wetted) enters the nozzle its filaments are carried along in a high velocity air stream that separates them from each other. The yarn is input into the jet at a higher rate than at which it is withdrawn, this difference is know as overfeed in the yarn. Overfeed allows some filaments to move at faster rate than the others. These filaments eventually entangle to form the textured yarn [15]. The yarn is drawn away from the jet at a right angle. The spherical impact element assists in the formation of the yarn by improving the loop stability. The impact element is seen in figure 2.4. [17] Yarns with finer filaments are more suited to texturing. [17] The loops and the entanglements formed through the texturing process are permanent and stability of the loops is a desired property in the yarn. The flow of material within the jet is described in figure 2.4, below.

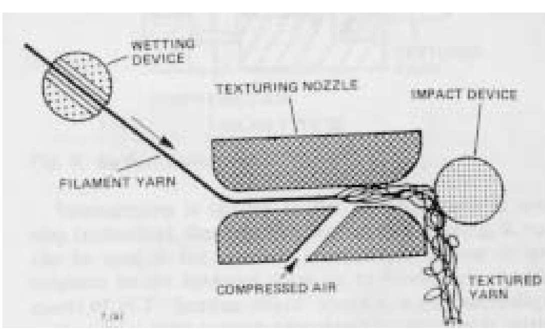


Figure 2.4: Flow of material from the wetting head to its withdrawal after texturing [8]

Kevlar has found growing applications due to its high strength and non-flammable properties. [18] The processing and application of Kevlar yarns has unique problems associated with it. [19] The fibers are very slick, this causes difficulty in weaving and knitting. For this reason, Kevlar filaments are sometimes cut to staple fibers and then spun for use in knitting. The slickness also causes poor hand and poor dimensional stability in woven fabrics. Kevlar has found growing application in composite structures. The strength of the interface region between the fiber and the matrix is much lower than the strength of the fiber. The composite fails when the interface fails and this occurs long before the fibers are broken. Several surface treatments have been used to increase the strength of the interface, however the improvement in strength is limited. Air texturing presents an elegant solution to improving the, hand, dimensional stability of Kevlar fabrics. Since the process randomizes the orientation of fibers in all three directions, resultant composites are expected to be more resistant to delamination due to increased mechanical interlocking.

The mechanical properties of Kevlar are described in the table below.

Table 2.1: Mechanical Properties of Kevlar

Density [g/cc]	1.44
Elastic Modulus[Gpa]	140-170
Tenacity[Gpa]	3.3-3.8
Elongation at Break[%]	2.5-3.5

Preliminary work in assessing the feasibility of air texturing Kevlar was carried out at the college of textiles, NCSU [8]. The investigation found that there is a significant loss in strength due to texturing. This loss is attributed to the disorientation of the filaments due to the loop formation. The investigation further revealed that application of water enhances the efficiency of the loop formation in the air texturing of Kevlar [8]. The study also found that yarn friction increased due to the application of water, as it leads to the removal of spin finish.[8] Initial trials by the author confirmed previous findings with regard to effect of water. It is with this basic understanding that the current research work to systematically investigate the influence of processing parameters on air texturing was undertaken.

2.2 EXPERIMENT OVERVIEW

Preliminary trails were conducted to establish the processing parameters that will be studied in detail. Air pressure, overfeed and speed have the most significant influence on the air texturing process, three levels of each were selected that resulted in 27 samples. A minimum of 10 specimens per sample were tested on a Sintech Tensile Tester to determine the tensile properties of the yarn. In the event of the jaw break a further sample was tested. For the purpose of this research a T341 jet insert was used. The jet is recommended for use on yarns with linear density between 250-2000 at a maximum processing speed of 500 m/min [20]. The linear density of the multi-filament Kevlar yarns used in the research is 600 denier with 670 filaments. The tensile testing of high modulus yarns requires special care while the sample is prepared to ensure that slippage is minimized. A more detailed description of the experiment is given below.

2.2.1 DESIGN OF EXPERIMENT

The objective of the experiment was to understand the effect of individual processing parameters and also their interaction on the resultant properties of the yarn. The yarn that is textured in the jet is stretched between the master roller and a stretch roller. The stretch is needed to stabilize the loops that are formed during texturing. The difference between the stretch and overfeed was maintained at a constant 22%. Thus the linear densities of the all the resultant yarn samples are comparable. Based on the results of the initial trials described in chapter 4.2 the following processing parameters were selected for study. (see appledix for table of results)

Table 2.2: Sample ID with the corresponding processing parameters

SAMPLE ID	AIR PRESSURE (Psi)	(kPa)	SPEED (m/min)	OVERFEED (%)	STRETCH (%)
S1	140	965.2	100	40	18
S2	140	965.2	100	30	8
S3	140	965.2	100	50	28
S4	140	965.2	200	40	18
S5	140	965.2	200	30	8
S6	140	965.2	200	50	28
S7	140	965.2	300	40	18
S8	140	965.2	300	30	8
S9	140	965.2	300	50	28
S10	120	827.3	100	30	8
S11	120	827.3	100	40	18
S12	120	827.3	100	50	28
S13	120	827.3	200	30	8
S14	120	827.3	200	40	18
S15	120	827.3	200	50	28
S16	120	827.3	300	30	8
S17	120	827.3	300	40	18
S18	120	827.3	300	50	28
S19	160	1103.2	100	30	8
S20	160	1103.2	100	40	18
S21	160	1103.2	100	50	28
S22	160	1103.2	200	30	8
S23	160	1103.2	200	40	18
S24	160	1103.2	200	50	28
S25	160	1103.2	300	30	8
S26	160	1103.2	300	40	18
S27	160	1103.2	300	50	28

2.2.2 PRODUCTION OF THE YARN

The yarn package is placed on a creel from which it is unwound into guide tubes that feed it to the drawing rolls (godets). It is important that there be good alignment between the delivery tubes and the godet, this is needed to prevent lapping of the yarn on the godet. The duration of the yarn on the godet is a function of the diameter of the godet, speed and the number of wraps. The contact period between the roller surface and the yarn is determined by the number of times the yarn is wrapped on the roller. The contact period plays a critical role in draw texturing, where it determines the heat that is transferred onto the yarn. Kevlar multi-filament yarn is fully drawn and there is no heat involved [15].

However a minimal stretch between the two godets is essential to maintain tension in the yarn.

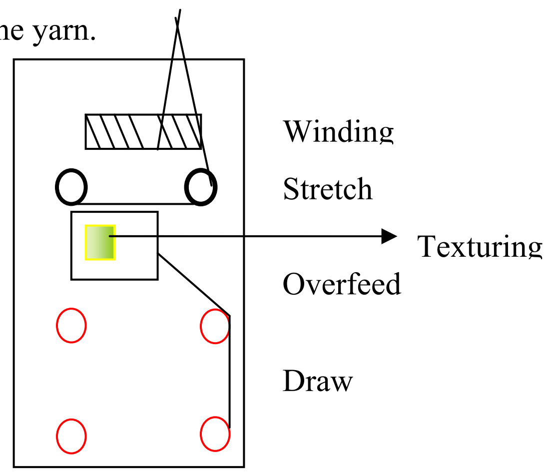


Figure 2.5: Yarn path on the texturing machine

The yarn then enters the texturing box where water is applied to facilitate the texturing process [21]. The yarn then enters the nozzle. The design of the nozzle is critical to the success of the process [22]. As it leaves the nozzle at the other end it is impacted against a spherical baffle element, the supersonic current of air does the texturing. The impact element enhances loop formation. [7] The yarn then exits the texturing box and is then stretched between the rubber sleeved master cylinder and the stretch roller that has a speed exceeding that of the master cylinder to provide the post stabilizing stretch that is necessary for dimensional stability [3, 15]. The textured yarn is then wound onto a package. A schematic diagram is given in figure 2.5. A detailed description of the yarn path is given in figure 4.1, chapter 4.1. A list of the sample numbers with the corresponding processing parameters is listed in table 2.2.

2.2.3 SAMPLE PREPRATION

A minimum of ten specimens for each of the twenty-seven samples was prepared for the purpose of tensile testing.

The procedure for preparing the sample is described below:

1. Cardboard was cut into strips of approximately 15 cms by 1.5 cms.
2. A paper punch was used to make holes at a distance of exactly 10 cms.
3. The yarns are individually taped to the cardboard strip.
4. Epoxy is used to glue the yarns to the cardboard just above the punched region.

The epoxy used was a five-minute epoxy that needed to be applied with care to prevent unnecessary spreading of the epoxy. The tape ensures that the sample is held in place while the epoxy is applied. The yarn should be laid out in straightened conditioned but it should not stretched. The sample mounted on the card board frame is show in figure 2.6.

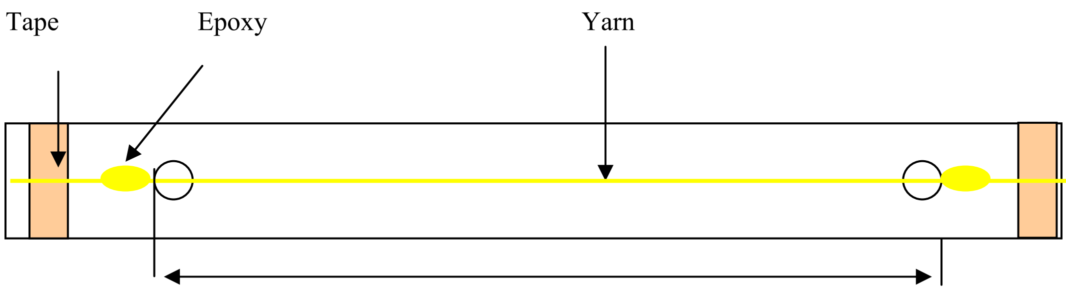


Figure 2.6: Cardboard with yarn, tape and epoxy

The Sintech strength/strain tester was used to conduct the tensile tests. It is controlled by a computer and follows test methods established by ASTM [32]. The load cell used was a 250 lbs cell.

2.3 RESULTS AND DISCUSSION

2.3.1 PRELIMINARY OBSERVATIONS

The preliminary overview of the results obtained indicates that there is a sharp decline in tensile strength after texturing. Tensile Strength of the yarn before texturing was found to be 214.2 cN/Tex. This is attributed to the lack of orientation among the filaments in a textured yarn structure. If one assumes the strength to be directly related to the extent of disorientation in the filaments then is it possible to state that there is a limit to the degree of disorientation that can be caused by the texturing process.

The jet breaks open the bundle of filaments that are overfed into it and loops are formed at the exit of the jet. The stretch in the post-texturing zone helps to set the loops formed at the exit of the nozzle. There is a limit to the volume of filaments that the jet can handle and so there is a limit to the maximum overfeed. The dimensions of the jet and the linear density of the input parent yarn determine this limit. The greater the difference between overfeed and the stretch the more is the initial deformation. For yarns of given linear density when the overfeed is increased to beyond 50%, the stability of the process deteriorates. It might be possible to increase overfeed for finer yarns and coarser yarns might require lesser overfeed.

2.3.2 TENSILE BEHAVIOUR of AIR-TEXTURED KEVLAR YARNS

The discussion below elucidates the tensile behavior of air-textured yarns with the help of typical load-strain curves that were observed at each of the processing conditions.

Tensile strength of the control sample was 214.2 cN/Tex.

2.3.2.1 Effect of Air-Pressure

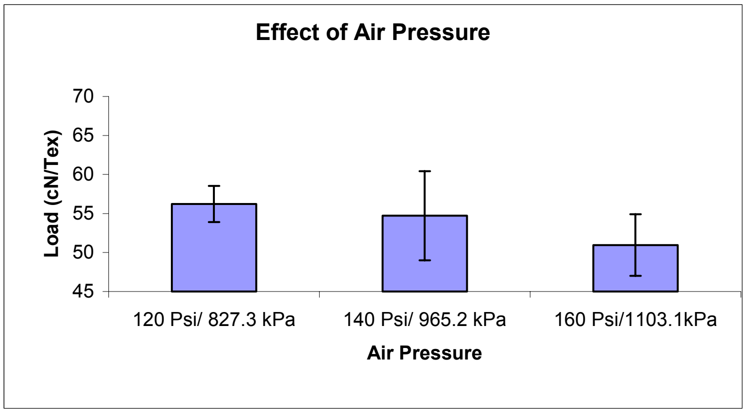


Figure 2.7: Effect of Air Pressure at a speed of 300 m/min and over feed of 50%

The above bar graph shows that there is a decrease in the tenacity when the air pressure is increased. The decrease is attributed to increase in the disorientation among the filaments at higher air pressures. Statistical analysis (See appendix) revealed that pressure has a significant influence on the resultant tensile properties of the yarn (p value less than 0.05).

2.3.2.2 Effect of Speed

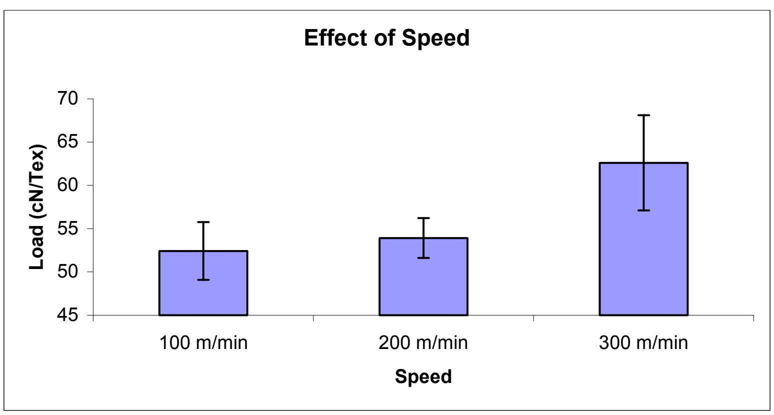


Figure 2.8: Effect of Speed at Air Pressure of 120 Psi/ 827.3 kPa and Overfeed of 50%

Figure 2.8 reveals that at a speed of 300 m/min the mean tensile strength is significantly higher than it is at 100 m/min or at 200 m/min. At higher speeds there is less disorientation of fibers in the yarn that might result in the higher strength. Statistical analysis revealed that speed has a significant influence on the resultant tensile strength of the yarn with a p value of less than 0.05.(see appendix)

2.3.2.3 Effect of Overfeed

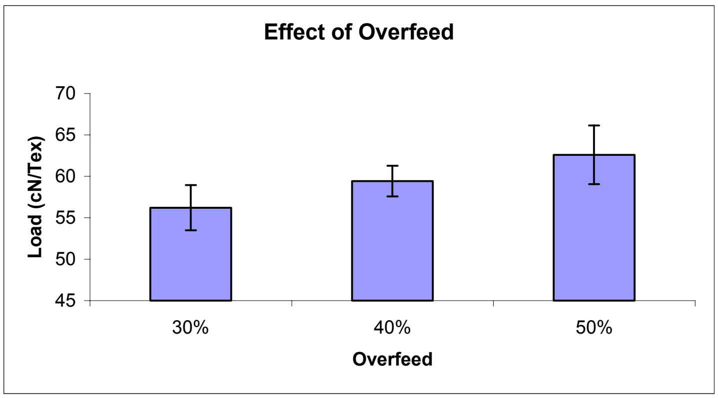


Figure 2.9: Effect of Overfeed at Air pressure of 120 Psi/ 827.3 kPa and speed 300 m/min

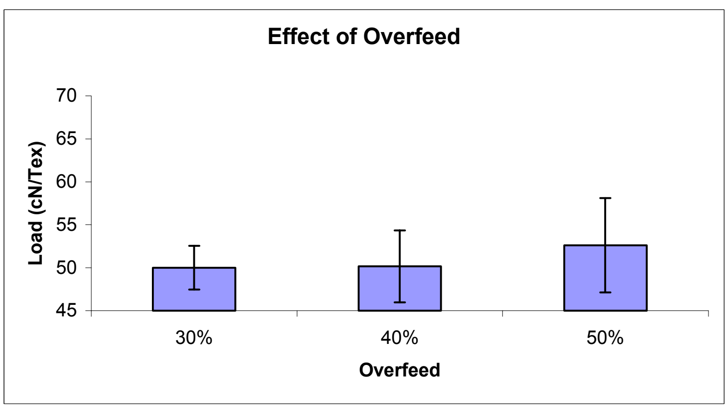


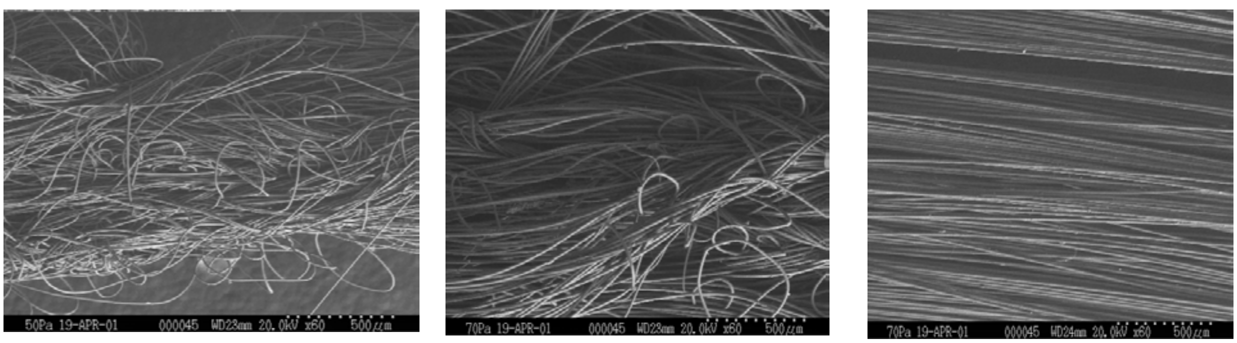
Figure 2.10: Effect of Overfeed at an Air pressure of 160 psi/ 1103.1 kPa speed of 300 m/min

Figures 2.9 and 2.10 reveal the effect of overfeed a low pressure of 120 psi/ 827.3 kPa and at a high pressure of 160 psi/ 1103.1 kPa at speed of 300 m/min. The graphs reveal that there is an increase in the tensile strength as the overfeed is increased. At a higher overfeed there is a greater bulk of filaments in the jet at any given instance since the air is maintained at the same level there is less disorientation of the filaments at higher overfeed. This might result in the higher tensile strength. Statistical analysis revealed that overfeed has a significant influence on the resultant tensile strength of the yarn with a p value of less than 0.05. (see appendix)

2.3.2 STRUCTURAL MODEL OF AIR TEXTURED YARN

To understand the structure of textured yarns pictures of continuous filaments and textured yarns were taken using a scanning electron microscope. The pictures showed intense loop formation in textured yarns. The pictures reveal that the filaments in the core of the yarn are relatively better aligned than the filaments at the surface

Figure 2.11: (a) Intensely textured yarn (b) Relatively oriented core filaments (c) Continuous filament yarns



Further pictures were obtained using optical microscope to draw comparisons between yarns textured at intense conditions and at mild conditions. Processing parameters that resulted in structures shown in figure 2.12 (a, b) are as follows:

Poorly Textured Yarn	Processing Parameters	Intensely Textured Yarn
120 Psi	Air Pressure	160 Psi
300 m/min	Speed	100 m/min
30%	Overfeed	30%

Table 2.3: Sample Processing Parameters for poorly textured yarn and intensely textured yarn

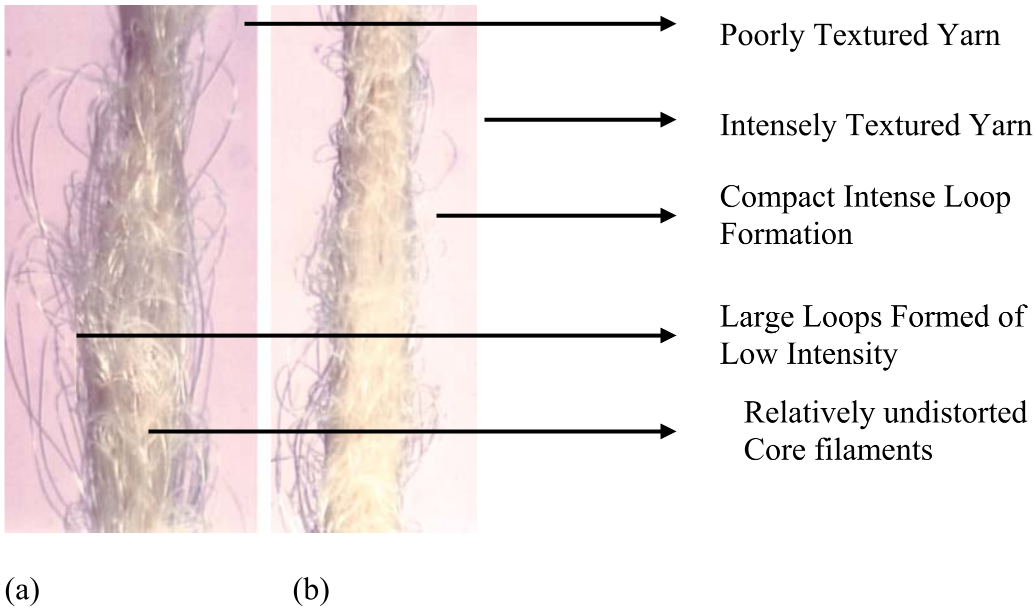


Figure 2.12: Comparison of (a) Poorly Textured yarn with (b) Intensely Textured Kevlar yarn

To explain the findings in the experiments, the SEM pictures and the optical microscope pictures (above) a structural model has been proposed. The model in figure 2.13 describes textured yarn as composed of three basic components.

1. The crimped core
2. The permanent surface loops
3. Entanglements between the two regions

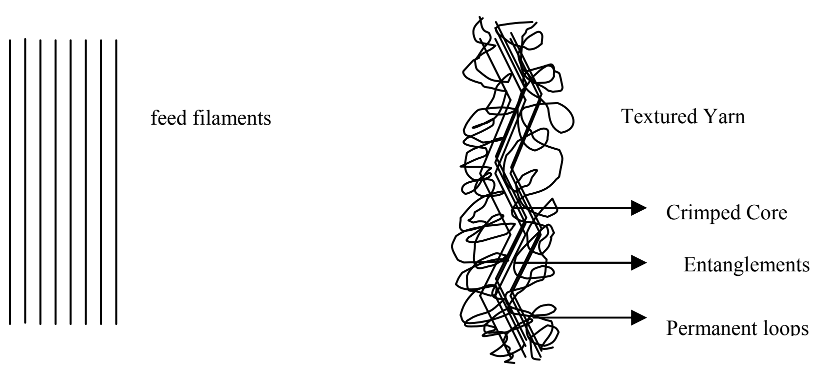


Figure 2.13: Components of Sheath Core yarns

The resultant yarn properties are caused due to these components and due to the interaction between them. Any process variable that will influence one or more of these components will influence the final properties of the yarn.

The structural changes in the yarn due to the process occur in the sequence given below.

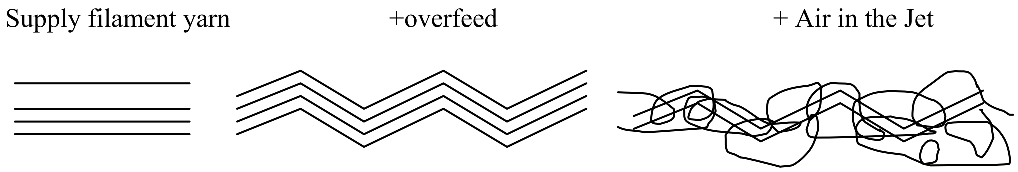


Figure 2.14: The Sequence of structural changes in the yarn

Within the jet air impinges upon the overfed filaments and this causes the structure to open up, entangle with itself and form the permanent loops that characterize the yarn. Figure 2.14 shows that due to overfeed there is crimping of the filaments in the main channel of the jet prior to being acted upon by the high velocity air stream. Some of this crimp is retained in the core of the structure. The proportion of crimp in the core depends on the velocity of the air stream and speed of the process.

When the intensity of texturing is high permanent loop formation propagates all the way to the core of the yarn. Conversely when the intensity of texturing is low the permanent loop formation is largely restricted to the filaments that are closer to the surface of the yarn.

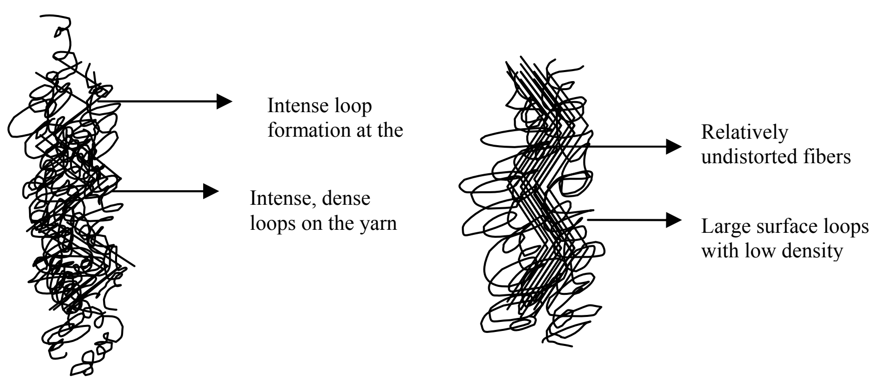


Figure 2.15: Structural comparison of intensely textured yarn(a) to poorly textured yarn(b) based on figure 2.12

The Zig-Zag arrangement of the central filaments is to allow for the buckling of the filaments that will occur due to the overfeed. There is also migration of filaments from the sheath to the core and from the core to the sheath. When a filament is in the core region it is essentially better aligned and while the same filament is on the surface it forms surface loops.

As can be seen in the figure 2.12 and in figure 2.15 the loop formation extends through the entire structure in intensely textured yarn. In poorly textured yarn loop formation is restricted to the filaments that are closer to the surface of the yarn. The Zig-Zag structure of the core region is more pronounced. Higher speeds and overfeed rates are likely to result in such a structure.

2.3.3 EFFECT OF PROCESSING PARAMETERS ON TENSILE PROPERTIES

Statistical analysis was carried out to determine the effect of processing parameters on the tensile properties. The equations described below are applicable within the range of the parameters that were used in the experiment, for yarns of linear density used in the experiment. The results however describe a generic trend that may hold for yarns of other comparable linear densities at similar ranges of processing parameters.

The valid ranges for the processing parameters to be applied in the regression equations that follow are given below

Air pressure: 120 - 160 psi

Speed: 100-300 m/min

Overfeed: 30 - 50%

2.3.3.1 Effect on Strength

Tenacity (cN/Tex) = 56.64 - 0.0975 air pressure + 0.0240 speed + 0.1203 overfeed

The tensile strength of textured yarns increases as the air pressure decreases, speed increases, and overfeed increases.

The higher air pressure causes more permanent loops that do not have good load bearing capacity, since they are not aligned in the axial direction. When speed increases, there is less time for the air jet to act upon the filaments and thus loop formation will be less intensive and thus the fiber orientation will be disrupted to a lesser extent.

High speeds and overfeed impede the formation of permanent loops thus improving the strength. At very high levels over feed the jet begins to 'choke' due to poor penetration of the high velocity air stream into the body of the filaments.

The air pressure has the greatest influence on the resultant tenacity.

2.3.3.2 Effect of Air Pressure, Speed and Overfeed on Failure Strain

Failure strain = 12.9 + 0.0136 air pressure - 0.00619 speed - 0.114 overfeed

The crimped core does not contribute to the actual strain as the initial de-crimping occurs at negligible increase in the load. From the figures above it is apparent that air pressure and reduction in the overfeed increases the entanglements, this leads to the increase in strain at appreciable levels of load. High speed, results in lesser time for the formation of entanglements and permanent loops that results in lower strain at failure. Overfeed has the greatest influence on the resultant failure strain.

2.3.3.3 Effect on the Initial Modulus

The effect of overfeed is described by the equation given below.

E1 = - 0.199 + 0.0442 overfeed

The initial modulus is directly proportional to overfeed only. It is not influenced to a significant degree by the speed and the air pressure. Since it is overfeed that determines the crimp in the core and there are few entanglements between the crimped core and the permanent loops, it is the crimped core largely determines the initial modulus. If the filaments in the crimped core have better alignment or lesser crimp it results in a higher initial modulus.

In all the experiments the difference between overfeed and the stretch was kept at a constant, but the overfeed alone determines the total volume of the filaments in the jet at any given instant. This is indicative of the jet capacity, it might be possible to texture yarn using a higher overfeed with a larger jet and preferably at higher air pressure.

2.3.3.4 Effect of Air Pressure, Speed and Overfeed on the Secondary Modulus

The effect on secondary modulus is described by the equation given below.

E2 = 5.93 - 0.0526 air pressure + 0.0190 speed + 0.130 overfeed

The final modulus is dependent on crimp in the core, entanglements and on the permanent loops. Thus it is affected by all three variables: air pressure, speed, and overfeed. The final modulus relies on number of fibers that are aligned at yarn axial direction. At any given yarn cross-section it is the well-aligned filaments that carry the axial load applied on the yarn. Increase in the permanent loops leads to fewer filaments that are aligned in axial direction at any given instant when the load is applied. Thus the few filaments will break at lower levels of total load and causes the yarn to straighten out until new filaments are straightened. This results in the lower overall modulus of the yarn. As is with initial modulus overfeed has the greatest influence on the secondary modulus.

2.4 CONCLUSIONS

The investigation revealed that the tensile strength of the textured yarns decreases, as the air pressure is increased, speed decreased, and overfeed increased. This is because the crimped core primarily determines the strength of the yarn. The more the filaments in the crimped core the higher the strength. Reducing air pressure, increasing the speed result in less intense texturing and the resultant yarn has a high proportion of filaments in the crimped core. Strain to peak load increases when there is an increase in the air pressure and a reduction in overfeed. The initial modulus is directly proportional to overfeed. The final modulus is dependent on crimp in the core, entanglements and on the permanent loops. Thus it is affected by all three variables: air pressure, speed, and overfeed. It is possible that there is a limiting condition for the intensity of the texture possible at each given speed, air pressure. The limiting condition is attained when the disorientation in the filaments has reached a maximum. Further increase in the air pressure and or reduction in speed or overfeed will then serve no purpose, to the contrary it might prove detrimental to the filaments in the yarn. Thus processing parameters prior the attainment of this 'limiting condition' might describe the most efficient processing condition in terms of intensity of texturing.

These yarns are expected to find application is the making of composites. The loops on the surface should enhance the mechanical interlocking of the yarns to the composite matrix. The results of this study will allow appropriate selection of processing parameters for that purpose. However increasing the intensity of loop formation is at the expense of axial strength. It is of interest to bring together the mutually conflicting demands of retaining high axial strength and increasing intensity of loop formation.

3 SHEATH-CORE KEVLAR YARNS

3.1 OBJECTIVE

The texturing process results in a reduction of the tensile strength of the yarn due to random orientation of filaments.

This study was carried out with the following objectives:

1. To bring together the mutually conflicting requirements of high strength and loops on the surface.
2. To study the structure and the tensile behavior of the yarn.
3. Understand the potential for application of the yarn in composites.

3.2 INTRODUCTION

Sheath-core structures yarn can be achieved by many spinning techniques that are prevalent in the textile industry. Each of these techniques have characteristics that make them ideal for certain types of input filament/fibers, materials and the resultant yarn structures vary greatly form each other. [24]

One technique to produce sheath-core structures is the DREF spinning. This uses staple fiber as input yarn. [25] Air jet spinning is another technique that results in sheath core yarns. The sheath of this yarn is characterized by wrapper fibers that protrude from the core. This technique too is applicable to filament yarns. There are many patented techniques to produce sheath core structures for specific applications such as yarn to produce swade fabric [26] sewing threads for the shoes [27] yarns with electric shields [28]. Wrapping the sheath around the core is yet another technique that is used to produce sheath core yarn structure. The sheath that is usually a continuous holds the core of the wrapped yarn.

It is possible to produce sheath-core yarn using the air texturing process. Proper selection of the jet and processing results in yarn with surface loops while the core retains a very high degree of orientation along the axial direction. Kevlar/Kevlar sheath-core yarns could find applications in composites. The yarn has high surface area due to the sheath fiber. This assists in improving the impact resistance of the composite, while the highly oriented core filaments will maintain high strength along the axis. The typical structure of sheath core yarn is shown in the figure below.

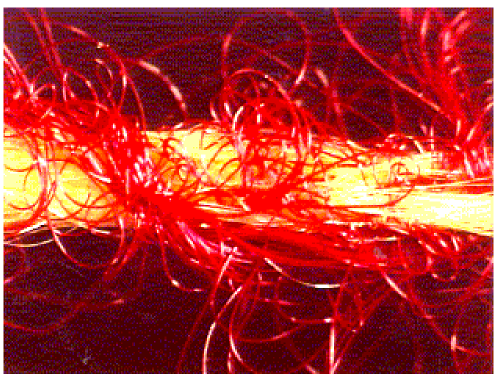


Figure 3.1: Structure of the sheath-core yarn.

The sheath filaments are red and the core filaments are yellow. The structure is obtained by feeding the core filaments at a significantly lower overfeed than the sheath filaments. The low over feed of the core is a distinguishing factor between the Sheath Core and yarns and other Co-textured yarns.

3.3 EXPERIMENT OVERVIEW

Orientation of filaments in the core and the intensity of loops in the sheath are two attributes to that largely determine the tensile properties of sheath-core yarns. Initial trials established that the application of water resulted in uniform, intense surface loops. The yarns used as part of the core had a linear density of 850 denier with 1000 filaments, the yarns used as effect had a linear density of 600 denier, with 670 filaments. The same yarns were selected as core and effect for all of the tensile tests. The first experiment was conducted to determine the optimal levels of sheath overfeed.

The next experiment conducted was to study the influence of speed and core overfeed on tensile properties of the resultant yarn. Based on the results of these tests, a more detailed study on the influence of the core overfeed was later conducted.

There are several important settings that critically influence the resultant properties. The core overfeed, air pressure and the selection of the jet and the effect of water are discussed in detail, followed by a summary of findings.

3.3.1 SETTING THE CORE OVERFEED

Overfeed of the core filament plays a very critical role in the texturing of Sheath-Core yarns. Increasing overfeed of the core filament leads to a reduction in the alignment of the core filaments. Thus to maximize the tenacity it is important to minimize overfeed of the core filaments. However there is a minimal overfeed that is necessary to allow good binding between the sheath and the Core filaments. Increasing overfeed tends to produce a more cohesive yarn structure.

Tests were conducted at 5, 10 and 15 %, overfeed of the core while the effect overfeed was kept at a constant 30%. The higher overfeed of the core filaments the lesser their orientation this results in lower tensile strength. To better understand the effect of the extent of core overfeed Sheath-Core yarns samples were prepared by gradually increasing the core overfeed starting with a minimum of 3 % and increasing it by one percent at a time to 7 %. The sheath overfeed was fixed at 30%.

At a very low over feed there is periodic fluctuation in the tension. This could be due to stick slip in the stretch zone. It is possible that the low level of core over feed causes the stick slip to occur. It is understood from initial trials that the sum of the stretch and the winding tension should be less than overfeed by at least 2-3% to reduce stick slip.

3.3.2 AIR PRESSURE SETTING

As compared to the single yarns higher air pressure is needed to produce good loop formation in Sheath-Core yarns, due to the large size of the jet and greater volume of filaments in the jet.

3.3.3 SELECTION OF THE JET

The TE370 is used in the texturing of Sheath-Core yarns. The initial results show that a cohesive Sheath-Core yarn, with large surface loops, is formed by the use of a nozzle of large orifice size. The large nozzle diameter allows more room for the sheath filaments to wrap around the parallel core filaments and form a cohesive structure. For the yarn of given linear density the Herberlein T341 is inappropriate for the production of Sheath-Core yarn, due to its small orifice. The yarns formed using the smaller jet are not cohesive in structure. Large surface loops have a higher probability of entanglement with the machine parts down stream. Current observations suggest that loop sizes depend on the size of the nozzle diameter and on overfeed.

3.3.4 APPLICATION OF WATER

Application of water results in more intense texturing of the sheath filaments that results in compact loops that do not protrude too far from the body of the yarn. Dry textured yarn shows large lengths of exposed core filaments. The loops are fuzzy and large. The possibility of entanglement with the traversing guide is very high.

The possibility of preferentially applying water to the effect filaments was considered. This however might not be possible, as the secondary spray will wet all filaments that enter the nozzle. Based on these water was used in the texturing of sheath-core yarns.

3.3.5 SAMPLE PREPARATION AND TESTING

The procedure for preparing the sample is described in chapter 2.2.3.

While testing on the sintech tensile testerThe break sensitivity was set at 99.9% The sample was extended until the sheath filaments were broken the results obtained confirmed that there is a second peak caused by the sheath filaments. The Sintech tensile tester was used to conduct the tensile tests. It is possible to vary the load bearing capacity and the stress strain characteristic by varying the processing parameters.

3.3.6 EXPERIMENT 1

To study the level of sheath-overfeed that will produce well covered Sheath –Core yarn. The TE 370 jet was used to texture the yarn.

Table 3.1: Sheath and Core overfeed

	Core	Sheath
1	2%	15%
2	2%	30%
3	2%	70%
4	2%	100%

The air pressure was set to 140 psi/965.2 kPa. The post texturing stretch was set to 3 %. The winding tension was set to 2 %. The speed was set to 150 m/min. Low speeds and relatively moderate pressures were used in this experiment. Minimal Core overfeed is used to ensure a high degree of orientation of the core filaments.

3.3.7 EXPERIMENT 2

The objective of this experiment was to determine the effect of core overfeed on the tensile behavior of the yarn. The jet used was the TE 370.A moderate air pressure of 140 psi/ 965.2 kPa was used. A post stabilizing stretch of 3 % with a winding tension of 2 % was used. The effect yarn overfeed was set to 30 %.

Three levels of speed and overfeed were selected that resulted in nine samples of ten specimens each.

Table 3.2: Levels of Core Overfeed and Speed

Level	Core Overfeed	Speed (m/min)
1	5%	100
2	10%	200
3	15%	300

3.3.8 EXPERIMENT 3

The objective of this experiment was to further study the effects of core overfeed on the tensile behavior of the yarn. The jet used was the TE 370.A high air pressure of 170 psi/1172.1 kPa was used. Core overfeed was varied from 7 to 3 %. Appropriately reduced stretch was used for 3% and 4 % core overfeed, so as to produce yarn under stable tension. A slight reduction in stretch is need at low levels of core overfeed. Overfeed of the effect yarn was 30 %.

3.4 RESULTS AND DISCUSSION

3.4.1 PRELIMNARY OBSERVATIONS

3.4.1.1 Experiment 1

These preliminary trials demonstrated that Sheath-Core yarns could be produced in the given set up. The trials revealed that overfeed determined the cover on the yarn. A overfeed of 15% produces yarn with very poor cover of the sheath filaments this leaves large lengths of core filaments exposed. A overfeed of 100% produces yarn with a very large loop size. However the process is unstable due to the random generation of loops of very large size. These loops tend to get entangled with the traversing guide and these results in the frequent stoppage of the machine. At 70% over feed there is good cover and the loop size reduced. There was no stoppage during the trial. However the run was very short and a few large loops were noticed. At 30% over feed the loop size is reduced. The appearance of the yarn is not adversely affected. A overfeed of 30-40 % seems to be appropriate. Figure 3.2 shows the intensity of loop formation at different levels of sheath overfeed.

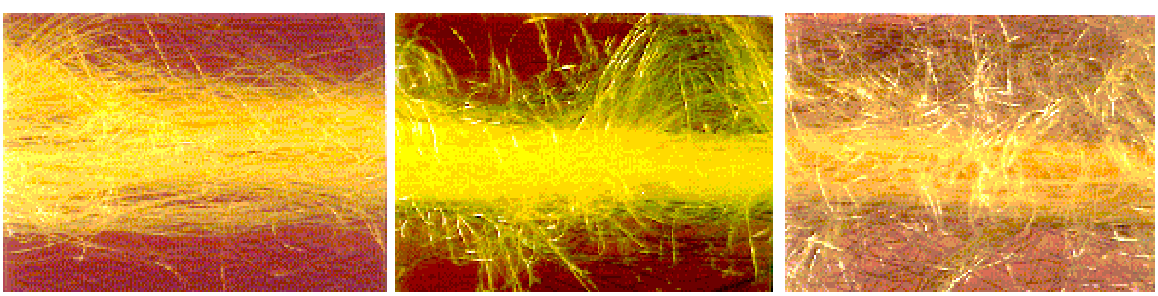


Figure 3.2: Relative loop sizes at overfeed of (a) 30% (b) 70 % (c) 100 %

3.4.1.2 Experiment 2

It was observed that a overfeed of 5 % resulted in a high degree of tension fluctuation in the yarn. This periodic tension fluctuation was more pronounced at lower speeds than at higher speeds. This tension fluctuations are attributed to stick slip that occurs because the stretch and winding tension are not compatible with the core overfeed for the given air pressure and speed. Increasing the core overfeed, or speed, or reducing the winding tension as appropriate achieves stability in the post-texturing zone.

It was also observed that at a high level of overfeed and speed the yarn formation is unstable due to poor texturing. The loop formation at high speeds is not adequate to take up the entire volume of overfeed thus tension is very low and the yarn is unstable.

3.4.2 TENSILE BEHAVIOUR OF SHEATH-CORE YARNS

The most interesting feature of Sheath-Core yarns is its characteristic "dual break". The tensile behavior of the sheath core yarn is described in figure 3.3 below.

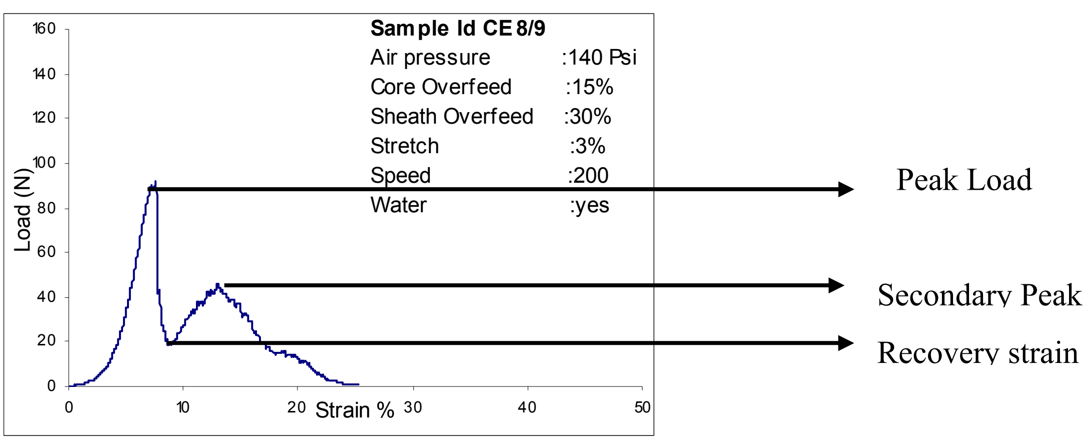


Figure 3.3: Tensile Behavior of Sheath-Core Yarns

The initial loading is almost entirely taken by the parallel core filaments, due to their low extension, however at peak load there is a catastrophic break of the core filaments this is followed by a steep decline in the stress. This is followed by a period of extension where the stress is almost constant, the stress in this region is due to the slippage of the effect yarns from the core. Once the yarn has extended sufficiently the sheath yarns then begin to take up the load and there is a slight increase in the stress. Ultimately the effect filaments break.

Based on the tensile behavior the structure of the sheath-Core yarns can be described as follows.

3.4.3 EFFECT OF PROCESSING PARAMETERS

3.4.3.1 Effect of Speed and Overfeed on the Tensile Strength

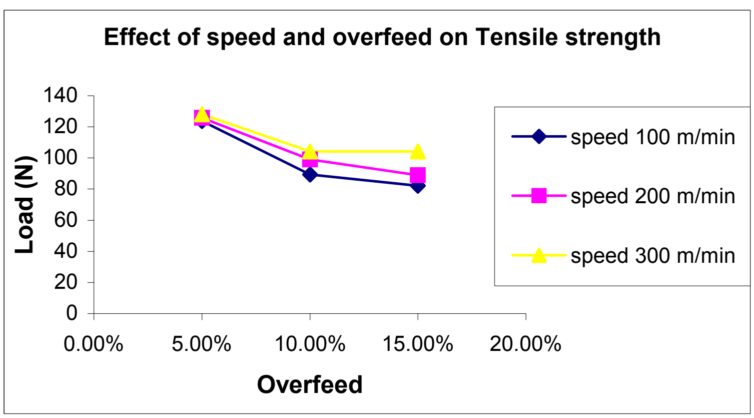


Figure 3.4: Effect of speed and overfeed on Tensile Strength

As shown in the graph above there is a reduction in strength due to the increase in overfeed. This holds for any speed that is used in the processing of the yarn. At higher levels of overfeed the effect of speed is more significant. At lower levels of overfeed there are fewer entanglements in the yarn and a increase in speed does not effectively decrease this minimum. The above graph also shows that at very low levels of overfeed, the variation in the resultant yarn properties is low for the same reason. At higher levels of overfeed there is more variation due to speed. Yarns textured at higher speeds at the same overfeed have higher tenacity due to fewer entanglements in them. Statistical analysis revealed that speed and overfeed have a significant effect on the resultant tensile strength with a p value less than 0.05.

3.4.3.2 Effect of Speed and Overfeed on the Tensile Strain

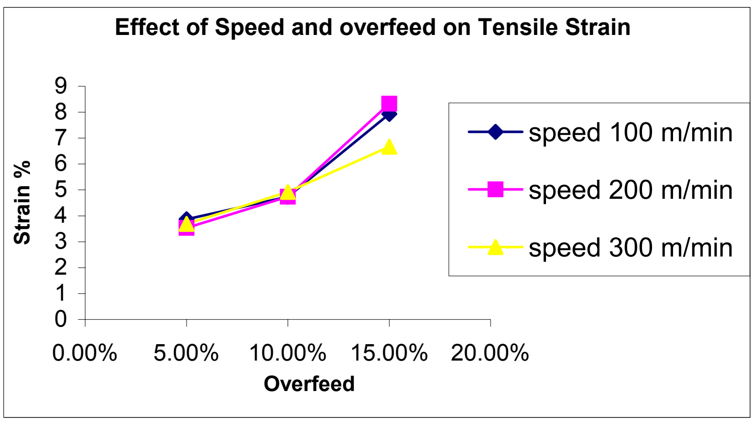


Figure 3.5: Effect of Speed and overfeed on the Tensile Strain

The above graph shows that the stains at peak load increase at higher levels of overfeed, this is due to the greater degree of entanglements at higher overfeed. The greater the speed the lesser the entanglements in the yarn this results a reduction in the strain at high speeds. Statistical analysis revealed that speed did not have a significant effect on the resultant tensile strain with p value of more than 0.05.

The strain is dependent on the number and the intensity of loops in the structure of the yarn. At higher overfeed opportunity for loop formation is greater. At higher speed the intensity of loop formation is low, due to the short duration of exposure to the air jet. For this reason, it might be possible that, at 300 m/min there is a significant reduction in the failure strain at peak that is seen when overfeed is 15%. Statistical analysis revealed that overfeed has a significant effect on the tensile strain at peak load while the effect of speed is not statistically significant.

In the experiment the stretch at all levels of overfeeds was kept at a constant 5%.

3.4.3.3 Effect of Speed and Overfeed on the Tensile Modulus

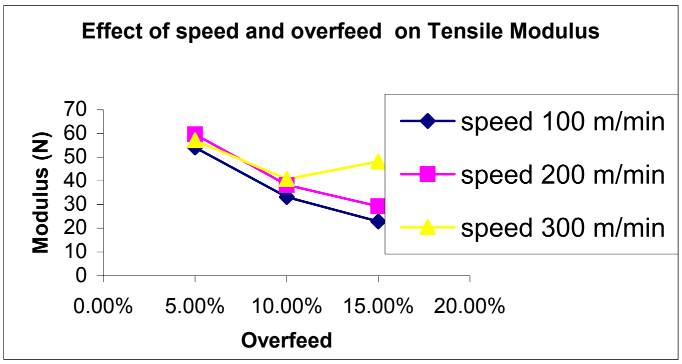


Figure 3.6: Effect on the Tensile Modulus

There is a increase in the modulus with an increase in the speed. This effect is more pronounced at higher levels of overfeed. The modulus is directly dependant on the intensity of loop formation. Good loop formation reduces the modulus. Therefore at high speeds there is a significant reduction in the entanglements resulting in a higher modulus. The effect of speed and overfeed are statistically significant with a p value of less than 0.05. (see appendix).

3.4.3.4 Effect of Overfeed on the Tensile Strength

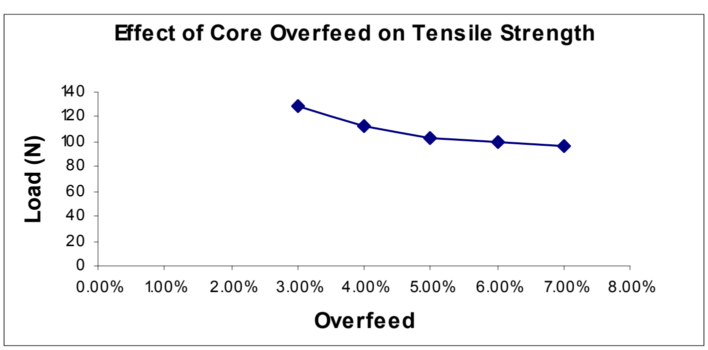


Figure 3.7: Effect of Overfeed on the Tensile Strength

Figure 3.7 is a summary of the findings in experiment 3. As shown in the graph above there is a decline in the strength due to the increase in overfeeds. The decrease in the strength is attributed to an increase in the entanglements among the core filaments in the yarn. The effect of Core overfeed on the resultant tensile strength is significant with a p value of less than 0.05.

3.4.3.5 Effect of Overfeed on the Tensile Strain

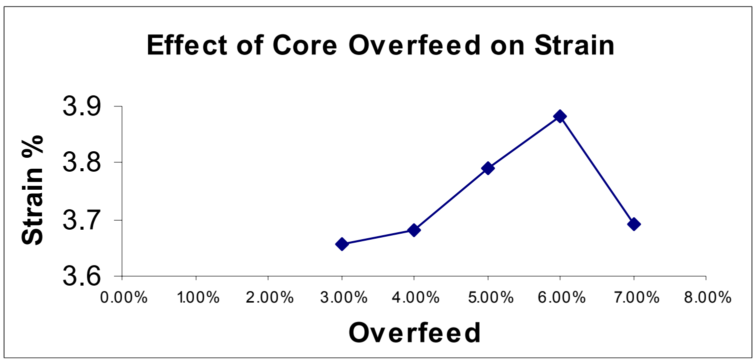


Figure 3.8: Effect of Core Overfeed on the Strain

The above graph shows that there is a increase in the stretch at higher levels of overfeed. However this trend is not consistent and the change is not significant. The trend in the given range of core overfeed was not statistically significant.

3.4.3.6 Effect of Overfeed on the Tensile Modulus

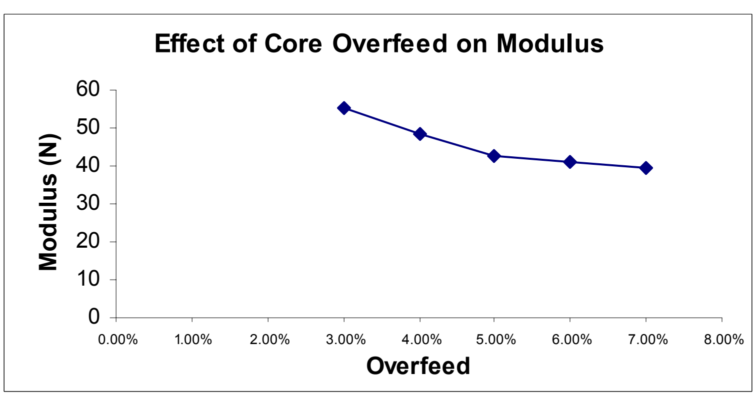


Figure 3.9: Effect of Overfeed on the Tensile Modulus

The modulus decreases as the overfeed increases due to the increase of core filament entanglement, as shown in figure 3.9. The trend is statistically significant with a p value of less than 0.05. (see appendix)

3.5 CONCLUSIONS

The findings of the investigation are enumerated below as follows:

1. Tensile strength of the yarns decreases as the overfeed increases due to more entanglements developed among the core filaments.

2. The tensile strength of the yarns increases with the increase of speed and decrease of overfeed due to the entanglements of the core filaments.

3. The modulus decreases as the overfeed increases due to the increase of core filament entanglement.

Anisotropy and delimitation are two major flaws in unidirectional continuous fiber reinforced composites. Non-woven composites are basically isotropic in mechanical properties and are less likely to delaminate, however they show poor mechanical properties especially tensile strength and modulus.

The Sheath-Core yarns described here are composed of sheath filaments that form surface loops while the core filaments retain their orientation and thus the high tenacity. The surface loops make the composite resistant to delimitation. The sheath filaments bind the parallel core filaments together. In effect, composites made using sheath-core yarns might combine the advantages of both non-woven based composites and continuous fiber reinforced composites. It is also likely that they will have properties that distinguish them from the parent yarn, as the sheath filaments are more likely to make a significant contribution to the strength of the composite and the composite will tend to be more ductile.

4 AIR JET DRAW TEXTURING MACHINE, INSTALLATION & TRIALS

4.1 INSTALLATION

The machine was shipped in separate components that had to be assembled together taking into consideration the space availability and the civil works required for the operation of the machine.

The components that had to be assembled were

1. Tube Heater
2. Water reservoir on a height adjustable rail
3. Microprocessor control unit
4. Creel Assembly
5. Link up to the computer control

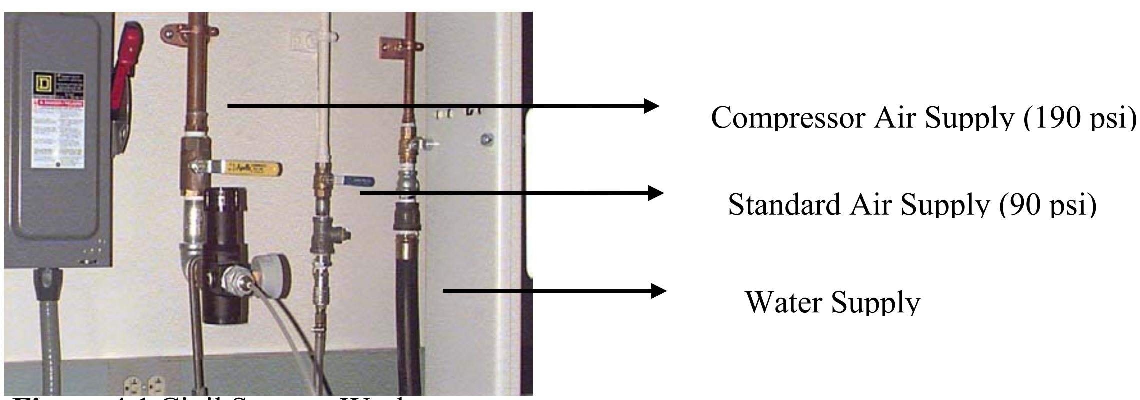


Figure 4.1 Civil Support Works

Civil works that are needed to support the operation of the machine are shown in figure 4.1.

1.Water connection, for constant water supply

2. Compressor -maximum air pressure 190 psi

Work done During the Installation

Water Reservoir

The water reservoir was mounted on the rail on the left-hand side of the machine. Raising or lowering the water reservoir can regulate the pressure of water or the amount of water flow through the wetting head.

Air inlet

The air inlet at the back wall was connected to the m/c. Care was taken to ensure that the connecting pipe did not result in the loss of air pressure. This inlet does not supply air at the required pressure. The compressor that will supply air at the required pressure has been procured and installed with a separate connection to the machine in addition to the existing air supply as shown in figure 4.1.

Microprocessor Control unit

This unit was mounted on a frame that is mounted on the machine.

Tube Heater

It is mounted on the frame that was previously fitted onto the machine. The heating unit fits on the right side of the frame. An air gun is used to thread the yarn through the tube heater.

Creel

The creel had 16 positions. It was necessary to cut down its size as it occupied too much floor space , the creel was cut to accommodate only 8 positions. The yarn detectors were then fitted on the creel and on the m/c.

The creel had to centered with respect to the spinning position. The feed tubes that guide the yarn from the creel to the m/c were fitted below the platform. It is important to align the tube correctly failing, which there will be lapping of yarn on the bottom draw rollers. The tube should be so aligned such that the yarn path does not drift towards the groove on the draw roller. If the yarn gets to the groove lapping will result.

Computer Interface

The computer was then interfaced with the machine. The computer during the set up detects if all the functional components have been fitted properly. All speed and temperature settings on the machine are done through the computer control unit.

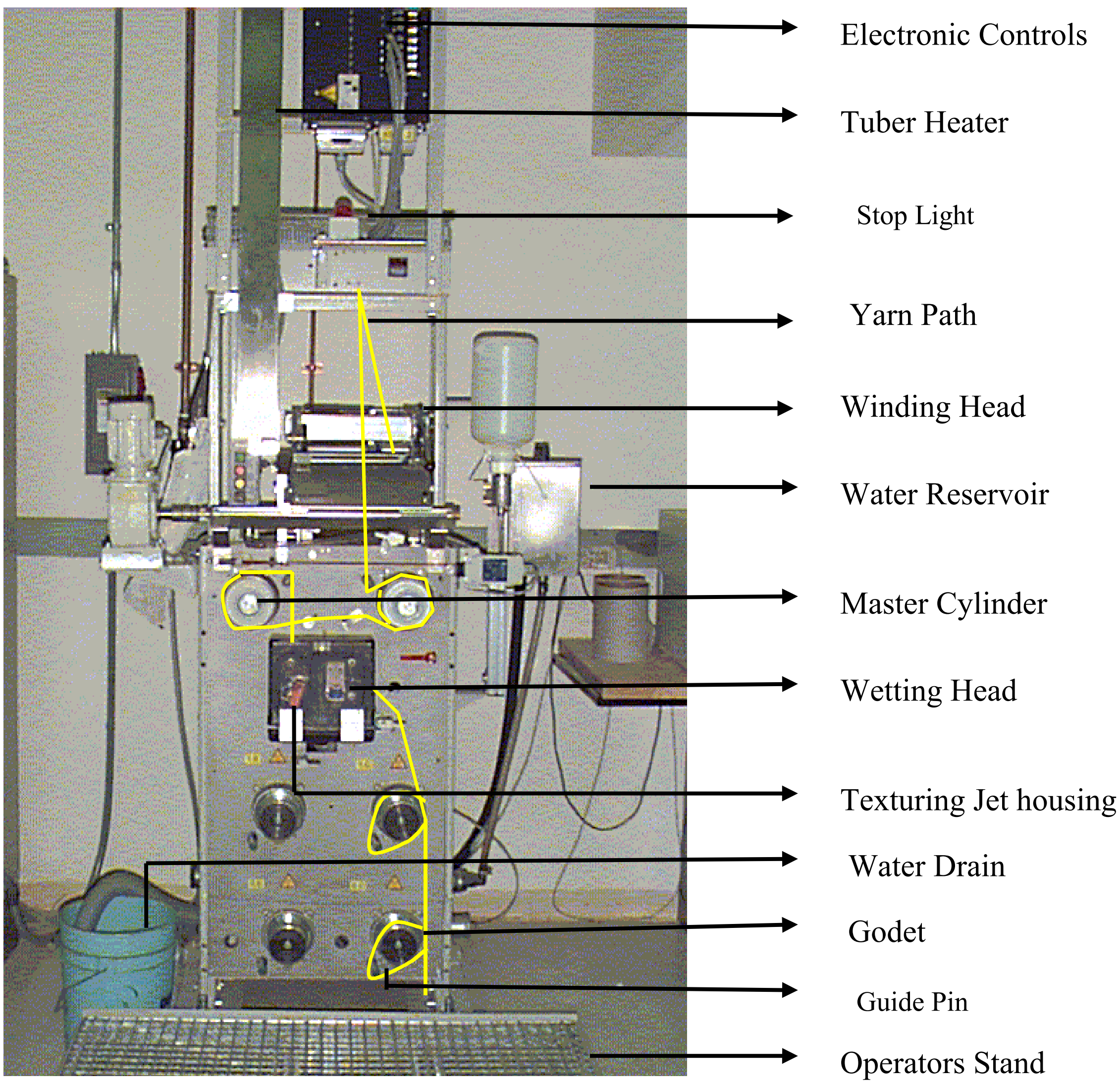


Figure 4.2: Complete Assembled Machine

4.1.1 CALIBRATION

It is important to calibrate the temperature on the heated rollers in both running and stopped condition. This calibration is done to compensate for errors that result from heat loss this varies in both the running and the stopped condition. Before arriving at the final values of the correction factors calibration is done thrice for both the running and the stopped condition. This is essential, as there can be variation due to error that has to be compensated along with the compensation for heat loss.

Once the calibration is done it is important to ensure that the settings are not changed again. For this reason it is important to not operate the machine in the third condition that will allow the operator to change the calibrated settings.

The machine is fully computer controlled and all setting are done from the central computer.

4.1.2 MACHINE SETTINGS

4.1.2.1 Modes of Operation

There are three modes of operation of the machine run, enter and configure. To use an existing recipe the machine is operated in the run mode. This mode of operation is intended for everyday running at a shop floor where all the recipes that are to be used have already stored.The “enter” mode is used when there is a need to modify an existing recipe or to enter a new recipe. When the machine is operated through this mode the options that will allow the necessary changes will be activated. The third mode of operation is the configure mode. When the machine is operated in this mode all the options are activated. When the machine is operated in this mode it will allow all operations including the calibration of the godets and the tube heater. It also allows the user to change the correction factors and tolerance limits.

4.1.2.2 Mechanical Settings

This setting is done on the screen marked as drives on the save and edit option. The speed of the operation is determined by the speed set on the master cylinder. The speed of the master cylinder is the reference speed for all other calculations made by the machine. The draw ratios for the respective core and effect yarns are specified. These values are entered into the text boxes provided for them on the screen.

The overfeed or stretch for the heat stabilization is specified as a percentage. The winding tension is also expressed as a percentage usually around 1% -3%. The m/c then calculates all speeds of the other roller and these speeds are set on the m/c once the operator saves his settings. To update the machine to the new parameters it is important to load parameters on the machine. Settings for the individual heads are set on the computer.

4.1.2.3 Threading

The thread path is described in figure 4.2. Approximately 8 loops made generally on each of the draw rollers. For very coarse yarns fewer loops may suffice. The polished surface of the draw rollers facilitates good heat transfer.

The yarn makes about four loops (wraps) on the master roller and the post heater roller. As these surfaces are rubber covered the gripping is good. The wraps are for control of the yarn. As can be inferred the more the number of warps the better is the gripping. This will vary depending on the type of yarn and the linear density of the yarn.

The thread path is very critical. On numerous trials it was observed that any offset from the straight path or incline to the vertical lead to increased lapping on the godets. This is true especially in the region where the filament yarn exists the tube and is wound on the lower godet. The end of the tube should be aligned with the heated godet otherwise lapping will occur.

It is also important to adjust the fixed pin so that the warp is distributed evenly over the surface of the godet. If there is repeated bunching up of the yarn or slippage of the yarn from the godet the angle of the pin requires to be adjusted.

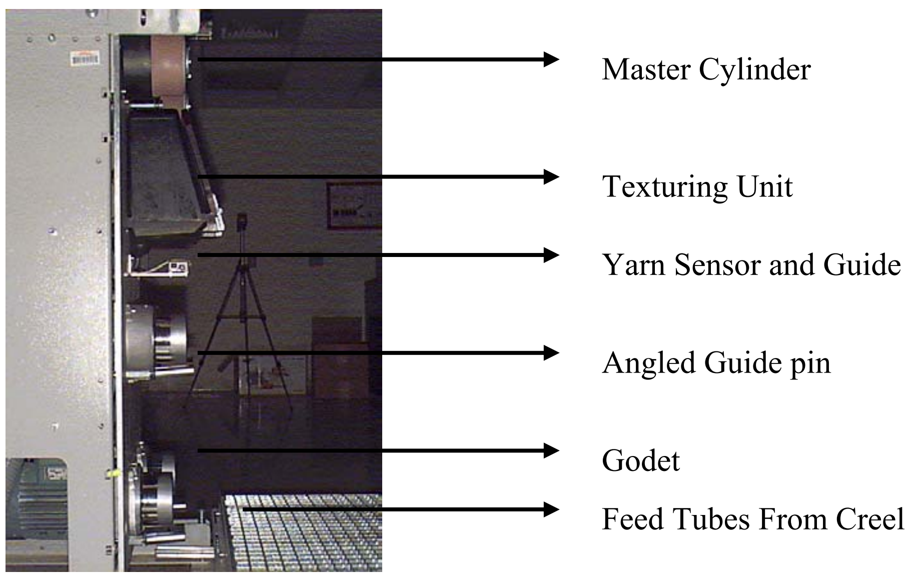


Figure 4.3: Machine Profile

4.1.2.4 Winding

There should always be a tension in the yarn between the post heating roller and the winding head. The yarn is stretched by a minimum of 1 to 3% to provide the tension to keep the yarn on the godet. After the tail is in the bobbin the operator must press the lever on the winding head initially to provide gripping and tension required during the start up. During the startup period it is noticed that the wraps on the rubber-coated roller are loosened. This is because the winding head is set to have a three-second duration in which it has to accelerate to the required winding speed set by the operator. If this leads to repeated lapping then it is suggested that the time for the winding head to accelerate to the required speed be reduced. This delay is set in the computer control.

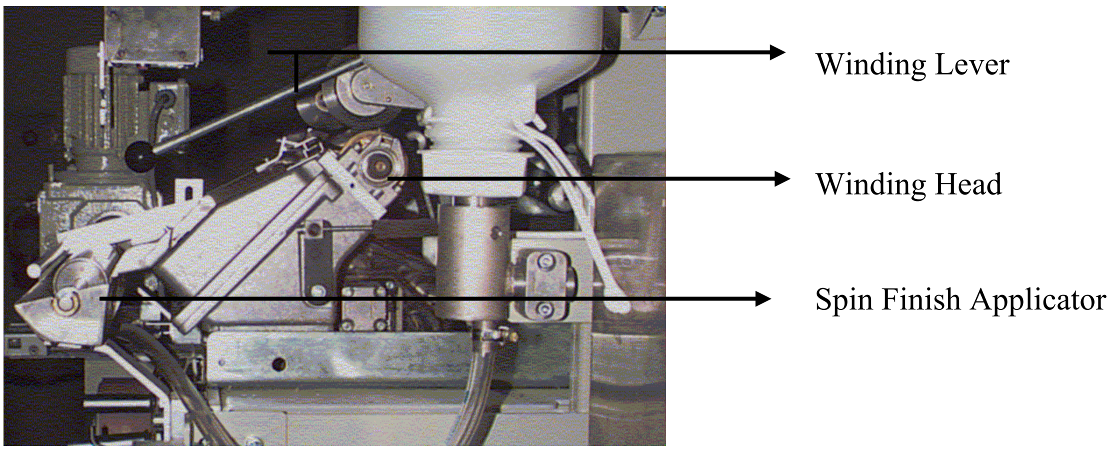


Figure 4.4: Winding unit profile

It is possible to set the space between the lay on the package. The setting is done at the main electronics control board. The range is 1 to 12.

1 is for the greatest spacing between the winding ends and this is called as wild winding.

1-4 the spacing is relatively high and the package has an open structure. This range of setting can be used for relatively coarse yarns and for packages that are intended for dyeing.

A setting of 5 is meant for semi-precision winding. The layers are close together and there is little gap between the adjacent layers.

4.1.2.5 Draw Roller (Godet) Setting

The yarn path should always be smooth. Any scratch on the roller surface will result in roller lapping, especially at higher speeds. The rollers should never be cleaned with a sharp surface. The greater the draw ratio the lower is the elongation in the yarn. Higher draw ratios improve the tensile strength of the yarn at the expense of elongation. Nylon is very sensitive to the draw ratio setting, which is generally about 1.3. Polyester is more flexible in this regard. Higher draw ratio than permissible will lead to broken filaments. Broken filaments show up as fluff on the yarn as it winding onto the package. The package itself appears to be hairy. Broken filaments are likely to cause a end break at the texturing nozzle.

4.1.2.6 Running of the Machine

The required speed is set at the master cylinder. Then the draw ratio required for the core and effect yarns is specified. These values are fed into the respective input fields as seen on the screen. Setting for individual spinning heads can be controlled from the computer.

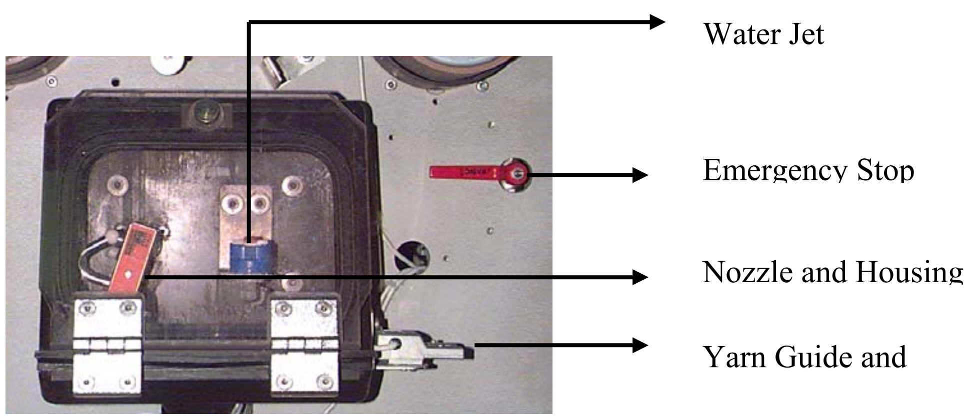


Figure 4.5: Texturing box , with jet and wetting head

The selection of the jet depends on the denier of the yarn that is to be textured.

4.2 MACHINE TRIALS

4.2.1 OBJECTIVES OF INITIAL TRIALS

The objectives of the initial trials are enumerated below.

1. To give the operator a better insight into the texturing processes.

2. To be able to visually distinguish between well-textured and partially textured yarns

3. To familiarize the operator with the Machine

4. To establish basic process parameters that are to be investigated further

5. To evaluate the changes in aesthetic properties of textured high tenacity yarns

6. To explore new possibilities and yarn configurations that can be produced with the given set up.

4.2.2 TEXTURING HIGH TENACITY YARN

The yarns used in all of the trials are fully drawn. In most of the trials there is a very low draw ratio of 1.05 - 1.02. This is done to prevent slippage of the yarns and ensure adequate grip between the lower and the upper godet. As there is no drawing operation the godets were kept at room temperature. There is no need to post heat the yarns and therefore the temperature on the tube heater was set to room temperature. The tolerance of the tube heater was increased to prevent interruption of the process. Water is essential in the texturing process. There is a minimal flow below which texturing is not complete. There are many reasons attributed to the influence of water on the texturing process. From previous research at North Carolina State University it was established that a overfeed of about 20% was taken up by well-textured yarn. As part of initial trials texturing of Kevlar, Spectra and Glass filaments was attempted. A brief summary of findings from these trials is given below.

4.2.3 TEXTURING OF KEVLAR

To understand the texturing of Kevlar a total of six different Kevlar/ Twaron multifilament yarns were used in trail. A brief overview of the objectives, trails and the results is given in the discussion below.

Table 4.1: Processing Parameters of Trials on Kevlar

Sample no	Trail number	Yarn count	Jet insert	Speed (mts/min)	Overfeed	Stretch	Draw Ratio	Winding Tension	Air Pressure (psi/kPa)	Comment
Kevlar 1										
	1	1000/666	T341	250	20%	6%	1.05	1%	110/758.4	Poor texturing/ unstable yarn path
	2	1000/666	T341	250	20%	6%	1.05	1%	120/827.3	‘’
	3	1000/666	T341	250	25%	6%	1.05	1%	130/896.3	‘’
	4	1000/666	T341	250	30%	6%	1.05	1%	140/965.2	Unstable yarn path
	5	1000/666	T341	100	20%	6%	1.05	1%	130/896.3	‘’
	6	1000/666	T341	100	30%	6%	1.05	1%	140/965.2	‘’
	7	1000/666	T341	250	25%	6%	1.05	1%	150/1034.2	‘’
	8	1000/666	T341	250	25%	6%	1.05	1%	160/1103.1	‘’
2	1(dry)	1000/'666	T341	50	40%	7%	1.02	2%	140/965.2	stable yarn path
	2(wet)	1000/666	T341	50	40%	7%	1.02	2%	140/965.2	Good texturing/ stable yarn path
3	1	1100/110	T341	500	35%	15%	1.02	1%	140/965.2	Poor texturing
	2	1100/110	Te371	500	35%	15%	1.02	1%	170/1172.1	Poor texturing
4	1	1100/100	T341	100	35%	7%	1.02	1%	140/965.2	Good texturing/ stable yarn path
5	1	1100/1000	T341	100	40%	13%	1.02	1%	140/965.2	‘’
	2	1100/1000	T341	250	40%	13%	1.02	1%	140/965.2	‘’
6	1	2600	T370	100	35%	13%	1.02	1%	140/965.2	‘’
	2	1000/666	T341	100	40%	15%	1.02	1%	140/965.2	‘’
7	1	600/670	T341	100	35%	11%	1.02	1%	140/965.2	‘’

The yarn to be textured was a Dupont Kevlar K-29 package, with a linear density of 1000 denier and 666 filaments.

Objectives of texturing this sample were as follows:

1. To observe the effect of Air pressure on the quality of texture
2. To understand the impact of different levels of overfeed and stretch on the process stability.

The air pressure was varied from 110 to 140 psi (758.4-965.2 kPa) and the initial speed was set at 250 m/min. At these conditions texturing observed was not very intense.

There was tension fluctuation in the post-texturing zone that resulted in repeated lapping. The speed was reduced to 100 m/min this stopped the lapping of the yarn on the godets. It is inferred that at the lower speed the intensity of texturing increased thus the amount of yarn overfeed was taken up resulting in constant tension in the stabilizing zone.

At 130 Psi / 896.3 kPa the texturing was not very intense. However there was good loop formation. At 140 Psi/ 965.2 kPa there was improvement in the quality of the textured yarn, the yarn path in the post-texturing zone was more stable. At 150 Psi/ 1034.1 kPa further improvement in the tension in the post texturing zone was observed.

To understand the effect of overfeed three levels were selected. It is observed that for higher overfeed it is essential to use higher air pressure to maintain similar intensity of texture. This is essential, as more energy is needed to cause the required lateral displacement of the increased volume of the filaments that are in the jet at any given moment in time.

4.2.4 TEXTURING OF SPECTRA

As compared to Kevlar, Spectra is very difficult to texture. The application of water shows a marked improved improvement in the texturing of Kevlar. This is however not the case with Spectra. Water seems to have a very minimal effect in the texturing of Spectra.

Process Parameters

Air pressure 140 psi/ 965.2 kPa

Speed 10 m/min

Draw ratio 1.02

Winding tension 2 %

Post stabilizing 11.5 %

Over feed 30 %

Intermittent texturing the sample produced shows regions of intense texturing where there is a formation of loops and a region where the filament are more or less un-textured.. At extremely low speed the rollers stop and start intermittently. This leads to the intermittent texturing. However such low speeds are not feasible. The trial demonstrates that extremely high pressures will be needed to texture spectra.

4.2.5 TEXTURING OF GLASS

The objective of the trials was to understand the texturing of glass filament. Texturing was first attempted at 40 psi/ 275.7 kPa, it was observed that the tension in the post texturing zone was too low . There was minimal loop formation in the yarn. Pressure was increased to 60 psi/ 413.5 kPa , it was observed that the intensity of loop formation was higher and the tension in the post texturing zone increased. The pressure was further increased to 80 psi / 551.5 kPa, it was observed that the texturing was good and there was even loop formation.

A stretch of 5% was found to be satisfactory. The overfeed was increased from 10 % to 20 % and the pressure was increased to 100 psi/ 689 kPa. Texturing was good. Further trials were conducted that showed that it is possible to increase speed along with appropriate increase in the air pressure.

Table 4.2: Processing Parameters of Trials on Textured Glass

Sample no	Trail number	Yarn count	Jet insert	Speed (mts/min)	Overfeed	Stretch	Draw Ratio	Winding Tension	Air Pressure (psi/ kPa)	Comment
1	1		T341	100	10%	5%	1.01	2%	40/275.7	Pressure inadequate
	2			100	10%	3%	1.01	2%	60/413.7	"
	3			100	10%	5%	1.01	2%	80/551.5	Good texturing
	4			100	20%	5%	1.01	2%	100/689.5	"
	5			100	25%	5%	1.01	2%	100/689.5	"
	6			50	30%	5%	1.01	2%	100/689.5	"
	7			100	25%	5%	1.01	2%	120/827.3	"
	8			200	25%	5%	1.01	2%	140/965.2	"

5 RECOMMENDATIONS

Air texturing is a very flexible process, the samples produced in this research show that other high modulus could also be air textured. The sheath-core Kevlar/ Kevlar yarns can be air textured. Using other filaments as a sheath might help to further increase the bonding between the epoxy matrix and the fiber. The Spectra multi filament yarns are by far the most difficult to texture. This makes it an ideal core, as it will retain a very high degree of orientation. The strength loss due to texturing should be more than compensated when these fibers are embedded in a epoxy matrix resin. It will there fore be of interest to make composite samples using the single yarns and sheath core yarns. Based on this there are three recommendations for future work.

1. Air texturing sheath –core structures using different filaments as sheath with Kevlar as core.
2. Air texturing Sheath-core structures using spectra filament as core.
3. Study the tensile properties of composites made with textured yarn structures including sheath core structures and relate the resulting composite properties to the yarn structure.

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APPENDIX

TABLE OF RESULTS

Sample Id	Linear Density Tex	Denier	Tenacity cN/Tex	St Dev	Strain @ Peak Load Strain %	St dev
s1	75.2	676.8	56.50	5.84	7.58	1.22
s2	75	675	53.01	1.67	9.15	0.71
s3	74.6	671.4	49.60	2.53	8.10	0.87
s4	74.6	671.4	48.63	3.75	8.68	1.08
s5	76	684	52.04	2.02	8.87	0.79
s6	70.6	635.4	56.40	5.16	7.01	2.16
s7	66.4	597.6	94.89	17.15	2.61	0.63
s8	74	666	54.70	5.71	8.27	1.23
s9	74.2	667.8	75.84	5.81	5.10	0.35
s10	75.4	678.6	51.55	2.46	8.26	1.02
s11	74.6	671.4	52.08	2.71	8.32	0.55
s12	74.2	667.8	52.42	3.34	8.40	1.50
s13	75	675	54.58	3.29	9.34	0.99
s14	73.8	664.2	52.84	2.79	9.88	1.09
s15	74.4	669.6	53.91	2.32	9.79	0.84
s16	74.4	669.6	56.21	2.55	9.38	1.00
s17	73	657	59.43	4.19	8.38	2.12
s18	78	702	62.60	5.50	4.03	1.07
s19	76	684	50.00	2.75	8.29	0.78
s20	75.6	680.4	50.16	1.86	8.43	0.63
s21	74	666	52.61	3.54	8.65	0.75
s22	76	684	48.99	3.79	8.37	1.17
s23	75.2	676.8	44.54	13.76	8.83	0.86
s24	74	666	53.89	2.33	8.48	0.65
s25	74.6	671.4	50.95	3.95	9.74	0.69
s26	74	666	52.23	3.27	8.84	0.96
s27	73.8	664.2	50.45	3.29	8.35	0.93

Single Textured yarn tensile strength statistical analysis

1. Regression Analysis: strength versus air pressure, speed, overfeed

The regression equation is

Strength (N) = 42.1 - 0.0725 air pressure + 0.0179 speed + 0.0894 overfeed

Predictor	Coef	SE Coef	T	P
Constant	42.069	2.842	14.80	0.000
air pres	-0.07249	0.01716	-4.23	0.000
speed	0.017883	0.003431	5.21	0.000
overfeed	0.08945	0.03431	2.61	0.010

S = 4.603 R-Sq = 16.1% R-Sq(adj) = 15.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	1082.48	360.83	17.03	0.000
Residual Error	266	5634.75	21.18		
Total	269	6717.23			

Source	DF	Seq SS
air pres	1	362.95
speed	1	575.52
overfeed	1	144.01

The regression equation that describes the relation between the processing parameters and the tensile strength is as follows.

Strength (N) = 42.1 - 0.0725 air pressure + 0.0179 speed + 0.0894 overfeed

Regression Analysis: strain versus air pressure, speed, overfeed

The regression equation is
strain = 12.9 + 0.0136 air pressure - 0.00619 speed - 0.114 overfeed

Predictor	Coef	SE Coef	T	P
Constant	12.909	1.167	11.06	0.000
air pres	0.013616	0.007043	1.93	0.054
speed	-0.006195	0.001409	-4.40	0.000
overfeed	-0.11389	0.01409	-8.09	0.000

S = 1.890 R-Sq = 24.8% R-Sq(adj) = 24.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	313.98	104.66	29.31	0.000
Residual Error	266	949.79	3.57		
Total	269	1263.77			

Source	DF	Seq SS
air pres	1	11.50
speed	1	69.04
overfeed	1	233.44

Conclusion
The strain is not affected by air pressure.

Regression Analysis: strain versus speed, overfeed

The regression equation is
strain = 14.8 - 0.00616 speed - 0.114 overfeed

Predictor	Coef	SE Coef	T	P
Constant	14.7949	0.6436	22.99	0.000
speed	-0.006165	0.001416	-4.35	0.000
overfeed	-0.11359	0.01416	-8.02	0.000

S = 1.899   R-Sq = 23.8%   R-Sq(adj) = 23.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	300.63	150.32	41.67	0.000
Residual Error	267	963.14	3.61		
Total	269	1263.77			

Source	DF	Seq SS
speed	1	68.40
overfeed	1	232.23

Regression Analysis: Initial Modulus versus air pressure, speed, overfeed

The regression equation is
E1 = - 0.795 - 0.00008 air pressure + 0.00149 speed + 0.0535 overfeed

Predictor	Coef	SE Coef	T	P
Constant	-0.7945	0.5481	-1.45	0.148
air pres	-0.000077	0.003308	-0.02	0.981
speed	0.0014857	0.0006616	2.25	0.026
overfeed	0.053525	0.006616	8.09	0.000

S = 0.8875 R-Sq = 21.0% R-Sq(adj) = 20.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	55.538	18.513	23.50	0.000
Residual Error	266	209.536	0.788		
Total	269	265.074			

Source	DF	Seq SS
air pres	1	0.007
speed	1	3.969
overfeed	1	51.562

Regression Analysis: Initial Modulus versus overfeed

The regression equation is
E1 = - 0.199 + 0.0442 overfeed

267 cases used 3 cases contain missing values

Predictor	Coef	SE Coef	T	P
Constant	-0.1986	0.1972	-1.01	0.315
overfeed	0.044239	0.004843	9.13	0.000

S = 0.6443   R-Sq = 23.9%   R-Sq(adj) = 23.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	34.634	34.634	83.43	0.000
Residual Error	265	110.010	0.415		
Total	266	144.645			

Regression Analysis: Final Modulus versus air pressure, speed, overfeed

The regression equation is

E2 = 5.93 - 0.0526 air pressure + 0.0190 speed + 0.130 overfeed

Predictor	Coef	SE Coef	T	P
Constant	5.934	2.234	2.66	0.008
air pres	-0.05264	0.01348	-3.90	0.000
speed	0.018968	0.002696	7.03	0.000
overfeed	0.12968	0.02696	4.81	0.000

S = 3.617   R-Sq = 24.6%   R-Sq(adj) = 23.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	1136.31	378.77	28.95	0.000
Residual Error	266	3480.75	13.09		
Total	269	4617.06			

Source	DF	Seq SS
air pressure	1	186.27
speed	1	647.39
overfeed	1	302.65

Detailed Investigation of the effect of speed and overfeed on sheath-core yarn tensile properties(from experiment 2)

Tabulated Statistics: Effect of speed and overfeed on Tensile Strength

Rows: speed2   Columns: overfeed

	0.05	0.10	0.15	All
100	123.80	89.31	82.23	98.45
	19.45	6.39	5.51	21.92
200	125.88	99.12	88.98	104.66
	20.22	6.09	8.78	20.32
300	128.11	104.10	104.14	112.12
	15.60	9.70	15.96	17.78
All	125.93	97.51	91.78	105.07
	17.97	9.61	14.12	20.63

Cell Contents --
strength:Mean
StDev

Tabulated Statistics: Effect of Speed and Overfeed on Tensile Strain

Rows: speed2   Columns: overfeed

	0.05	0.10	0.15	All
100	3.8650	4.7400	7.9300	5.5117
	0.6968	0.7027	0.9226	1.9301
200	3.5350	4.7400	8.3300	5.5350
	0.1944	0.5441	1.2356	2.2065
300	3.6900	4.9200	6.6700	5.0933
	0.3247	0.5412	1.4930	1.5369
All	3.6967	4.8000	7.6433	5.3800
	0.4626	0.5860	1.3955	1.9004

Cell Contents --
strain2:Mean
StDev

Tabulated Statistics: Effect of Speed and Overfeed on Tensile Modulus

Rows: speed2 Columns: overfeed

	0.05	0.10	0.15	All
100	54.089	33.191	22.837	36.706
	7.175	3.593	4.495	14.179
200	59.647	38.322	29.266	42.412
	9.283	4.431	5.029	14.439
300	57.110	40.739	48.180	48.676
	6.197	3.824	15.251	11.618
All	56.949	37.417	33.428	42.598
	7.745	4.988	14.353	14.198

Cell Contents --
modulus: Mean
StDev

Effect of Processing Parameters on resultant yarn properties

Regression Analysis: strength versus speed, overfeed

```
The regression equation is
strength = 126 + 0.0683 speed - 341 overfeed

Predictor        Coef     SE Coef          T        P
Constant      125.551       5.406      23.23    0.000
speed2        0.06835     0.01836       3.72    0.000
overfeed      -341.47       36.73      -9.30    0.000

S = 14.22       R-Sq = 53.6%     R-Sq(adj) = 52.5%

Analysis of Variance

Source            DF          SS          MS         F        P
Regression         2       20293       10146     50.15    0.000
Residual Error    87       17601         202
Total             89       37894

Source       DF      Seq SS
speed2        1        2803
overfeed      1       17490
```

Conclusion

The tensile strength of the yarns increases with the increase of speed and decrease of overfeed due to the entanglements of the core filaments.

Regression Analysis: Strain at Peak Load versus Speed, Overfeed

The regression equation is
strain at Peak Load = 1.85 - 0.00209 speed2 + 39.5 overfeed2

Predictor	Coef	SE Coef	T	P
Constant	1.8517	0.3760	4.92	0.000
speed2	-0.002092	0.001277	-1.64	0.105
overfeed	39.467	2.554	15.45	0.000

S = 0.9893 R-Sq = 73.5% R-Sq(adj) = 72.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	236.27	118.13	120.70	0.000
Residual Error	87	85.15	0.98		
Total	89	321.42			

Source	DF	Seq SS
speed2	1	2.63
overfeed	1	233.64

One-way ANOVA: Strain at Peak Load versus Overfeed

```
Analysis of Variance for strain2
Source     DF        SS        MS        F        P
overfeed    2   248.781   124.390   148.98    0.000
Error      87    72.638     0.835
Total      89   321.419
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  --------+---------+---------+--------
0.05       30    3.6967    0.4626  (--*-)
0.10       30    4.8000    0.5860          (-*-)
0.15       30    7.6433    1.3955                              (-*-)
                                   --------+---------+---------+--------
Pooled StDev =   0.9137                  4.5       6.0       7.5
```

Regression Analysis: Tensile Modulus versus speed, overfeed

The regression equation is

modulus22 = 54.1 + 0.0599 speed2 - 235 overfeed2

Predictor	Coef	SE Coef	T	P
Constant	54.149	3.527	15.35	0.000
speed2	0.05985	0.01198	5.00	0.000
overfeed	-235.21	23.96	-9.82	0.000

S = 9.281 R-Sq = 58.2% R-Sq(adj) = 57.3%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	10448.1	5224.1	60.65	0.000
Residual Error	87	7493.4	86.1		
Total	89	17941.5			

Source	DF	Seq SS
speed2	1	2149.3
overfeed	1	8298.8

Detailed Investigation of the effect of overfeed on sheath-core yarn tensile properties (from experiment 3).

Tabulated Statistics: overfeed

Rows: overfeed

	strength Mean	strain Mean	final mo Mean	strength StDev	strain StDev	final mo StDev
0.03	128.68	3.6550	55.194	13.47	0.2980	4.320
0.04	111.94	3.6800	48.584	7.71	0.2530	4.543
0.05	103.26	3.7900	42.586	9.30	0.3510	4.718
0.06	99.85	3.8830	41.217	6.78	0.4062	5.673
0.07	96.53	3.6906	39.488	7.63	0.3555	5.259
All	108.05	3.7397	45.414	14.65	0.3341	7.501

One-way ANOVA: Tensile Strength versus Overfeed

```
Analysis of Variance for strength
Source     DF        SS        MS        F        P
overfeed    4    6636.6    1659.1    19.22    0.000
Error      45    3883.9      86.3
Total      49   10520.5
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  -----+---------+---------+---------+-
0.03       10    128.68     13.47                              (----*----)
0.04       10    111.94      7.71               (----*----)
0.05       10    103.26      9.30        (----*----)
0.06       10     99.85      6.78     (----*----)
0.07       10     96.53      7.63   (---*----)
                                   -----+---------+---------+---------+-
Pooled StDev =     9.29                 96       108       120       132
```

Conclusion:

Tensile strength of the yarns decreases as the overfeed increases due to more entanglements developed among the core filaments.

One-way ANOVA: Strain at Peak Load versus Overfeed

```
Analysis of Variance for strain
Source     DF        SS        MS        F        P
overfeed    4     0.362     0.091     0.80    0.533
Error      45     5.107     0.113
Total      49     5.469
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  --------+---------+---------+--------
0.03       10    3.6550    0.2980  (----------*---------)
0.04       10    3.6800    0.2530   (----------*----------)
0.05       10    3.7900    0.3510        (---------*----------)
0.06       10    3.8830    0.4062            (----------*----------)
0.07       10    3.6906    0.3555    (----------*---------)
                                   --------+---------+---------+--------
Pooled StDev =   0.3369                  3.60      3.80      4.00
```

Conclusion

Failure strain of the yarns did not change significantly in the given range of the overfeed, although it tends to increase as observed in the previous study.

One-way ANOVA: Tensile Modulus versus Overfeed

```
Analysis of Variance for final mo
Source     DF        SS        MS        F        P
overfeed    4    1664.3     416.1    17.14    0.000
Error      45    1092.5      24.3
Total      49    2756.8
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ----------+---------+---------+------
0.03       10    55.194     4.320                           (----*----)
0.04       10    48.584     4.543                (----*----)
0.05       10    42.586     4.718      (----*----)
0.06       10    41.217     5.673   (-----*----)
0.07       10    39.488     5.259 (----*----)
                                   ----------+---------+---------+------
Pooled StDev =    4.927                   42.0      48.0      54.0
```

Conclusion

The modulus decreases as the overfeed increases due to the increase of core filament entanglement.