ABSTRACT

MUTHUSAMI, RAMAKRISHNA PRASAD. Impact of Process Parameters and Nozzle Design on the Tensile Properties of Air-jet Textured Yarns. (Under the direction of Dr.William Oxenham).

Air-jet texturing is one of the most versatile methods known to convert flat synthetic filament yarns to textured yarns. Over the years, developments in air jet texturing have been related to the developments in nozzle design. With this developement yarns from finer denier to extremely coarse denier can be textured. Researchs has been conducted in the past on various aspects of the air-jet texturing porcess. There have been a number of claims in the literature about various aspects of the process such as the impact of process variables on the strength and structure of the air-jet textured yarn, mechanism of loop formation, role of water in texturing etc. This current research is aimed to study one such aspect namely the effect of process variables and nozzle design on the tensile properties of the air-jet textured yarns.

This research provides a parametrical analysis of the effect of a single process parameter on the tenacity, modulus and elongation of the yarn. This type of analysis is carried out for five such parameters namely overfeed, air pressure, speed, draw zone temperature and post-texturing stretch. Two series of preliminary trials are reported and are aimed at understanding the various aspects of the process and the significance of process parameters on the tensile properties of the yarn. Subsequent experiments are conducted for studying the influence of each of the above mentioned parameters and nozzle type on the properties of the yarn. The research concludes by comparing the results of the various experiments with different nozzles to provide a broad base on the selection of jet nozzle for the desired quality of the textured yarn.

Impact of Process Parameters and Nozzle Design on the Tensile Properties of Air-jet Textured Yarns.

by
Ramakrishna Prasad Muthusami

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Textiles

Raleigh, North Carolina

2011

APPROVED BY:

Dr. Pamela Banks-Lee
Prof. Nancy Powell

Dr. William Oxenham
Chair of Advisory Committee

BIOGRAPHY

The author, Ramakrishna Prasad Muthusami, was born on 2nd July, 1985 in a town called Erode in Southern India to his parents Mr. Muthusami Sengodan and Mrs. Poongodi Muthusami. He graduated his high school from Bharathi Vidya Bhavan in his hometown. He graduated with his Bachelor degree in Textile Technology from the prestigious Anna University in Chennai. He then pursued his Master's degree in North Carolina State University, Raleigh, North Carolina. He wishes to take over and expand his family business of yarn manufacturing with the help of knowledge he acquired throught out his education.

ACKNOWLEDGEMENTS

First and foremost, I would like to offer my sincere thanks to my advisor Dr.William Oxenham for all his support and encouragement through out the course of the research. I would also like to extend my gratitude towards Prof. Nancy Powell and Dr. Pamela Banks-Lee for helping me complete my two and a half year education here at North Carolina State Universtity with wonderful experience and great knowledge.

I also take this opportunity to acknowledge the great support rendered to me through out the course of the research by Mr.Edmir Silva and Mr.Michael Whitaker of Unifi Inc, Yadkinville, North Carolina. Special thanks to both of them.

Also, I thank all my friends and fellow graduate students for being with me for the past two years sharing my experience and helping me in everyway possible when the situation demanded. Special thanks to Ms. Liu lu for helping me with SAS program.

Finally I would like to thank my parents and my family for their continuous support and care which encouraged me in doing this research.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.INTRODUCTION AND OVERVIEW

1.1 Introduction

Air jet texturing is one of the several process used to convert flat synthetic filament yarns to textured yarns and it is the most versatile of all known methods. This technique has been in practice for more than half century. The yarns produced using this method are used for applications such as car seat cover fabrics, sewing threads, sportswear, upholstery, automotive textiles, decorator fabrics etc but there is little use in apparel. Because of the limited range of applications of air-textured yarn in the apparel area there was restricted research and thus limited understanding of the process.

In recent years with extended uses for the products of this process, there has been an improvement in the study of air-jet texturing process and developments in the nozzle design. These studies and research have enabled yarns varying from very fine denier to extremely coarse denier to be textured using air-jet texturing process. Air-jet textured yarns are produced with characteristics resembling to those of the conventional staple-fiber product. At one time the yarns were referred to as “spun-like yarns”.

1.2 Overview of the project

According to Ali Demir and Hassan Mohamed Behery “The term ‘texture’ defines and describes those attributes of an object that can be recognized by the human sight or touch”. [1] The main texture properties desired in apparel and domestic textiles are warmth, opacity, flexibility, and good wearing properties, coupled with an attractive appearance and easy maintenance. Because of the growing world demand for textile goods and decreasing natural resources, synthetically produced yarns are a major raw material for the textile industry today. However, these synthetic yarns, such as polyamide and polyester continuous filament yarns as spun from the spinnerets lack the previously discussed human appeal (primarily aesthetics). These filament yarns either extruded, or indeed lightly twisted are often referred to as flat yarns. Textured filament yarns offer some superior properties, such as high strength, good elasticity, stretch, and abrasion resistance though the magnitudes of these parameters depend on the texturing technology.

Therefore, the primary objective of all synthetic filament yarn conversion processes, for yarns that are to be used in apparel industry, is to imitate the features of the natural fiber yarns while maintaining the desirable properties of synthetic fibers. One method of achieving this is to cut the continuous filaments into staple fibers and then process them into yarn form using conventional spinning methods as for cotton and wool. This is a time-consuming and therefore wasteful process, although it is useful for blends of man-made fibers with the natural fibers. Alternatively, continuous filaments can be converted into yarns by various texturing methods at lower costs but often these inadequately simulate spun yarns. Texturing, in general, is the modification process of regular structure of synthetic filaments into somewhat random structures.

This is achieved in many ways, such as thermal, mechanical, and chemical deformation of the individual filaments, and their spatial arrangement in the yarn bundle.

1.3 Purpose of texturing

The majority of filament yarns used today is synthetic fibers that need texturing although there are some that need no modification. The texturing process creates bulk, stretch and texture on the yarn surface. Bulk of yarn or fabric is generally the volume it occupies in free space. More bulky the yarn more air permeable the resultant fabric. Bulk is very important for breathability of a fabric, hence fabrics manufactured from bulkier yarns are comfortable to wear and handle. Stretch which is also referred to as comfort stretch, of a yarn attributes to the aesthetic and functional properties of the fabric manufactured from it. Texture of a yarn is defined as the quality of the yarn which can be recognized by touch or sight by the humans. The prime purpose of texturing filament yarn is to create a structure that is desirable for the following reasons [2]:

- The open structure cause the material to have good insulation properties
- Less organized structure of textured yarn gives a desirable matte appearance.
- Textured materials feel softer than the lean twisted flat yarn.
- The crimped filament structure gives a lower effective modulus of elasticity to the structure when compared with that of a flat yarn.

Whether a yarn is primarily given bulk, stretch or texture or combination of these three attributes is mainly governed by the fiber type, texturing technology and processing conditions.

1.4 Classifications in texturing

The three basic classifications of texturing techniques are

- Thermo-mechanical texturing
- Mechanical texturing
- Other texturing techniques like chemical treatment, bi-component forming and production of irregular-shaped individual filaments.

1.4.1 Thermo-mechanical texturing

Thermo-mechanical texturing method makes use of the thermoplastic property of most synthetic yarns and basically consists of mechanical deformation, i.e, twist or torque deformation, stuffing and bending, of the filaments while heating them to semi-plastic condition and setting this deformation by cooling to ambient conditions. Thus permanent crimps are imparted to the yarn, and these are due to the reforming of the molecular cross-links while the filaments are in their distorted shape. It is claimed that false-twist, stuffer box, knife-edge crimping, gear and knit-de knit texturing techniques are in this category of texturing with false-twist technique accounts for about 85% of all texturing process [1].

1.4.2 Mechanical texturing

The parallel arrangement of the filaments can also be changed by purely mechanical means to create spun-like yarns with an entangled core and surface loops imitating the protruding hairs of spun staple yarns. This is achieved by a unique method known as air-jet texturing. In this process, any filament yarn, not necessarily thermoplastic, is overfed through a specially designed nozzle that creates supersonic, highly turbulent air jet. The extra length of the filaments provided by the overfeed is taken up as entanglement in the yarn core, and loops and arcs at the surface of the yarn. In contrast to the yarns textured by other texturing techniques, air-jet textured yarns are uniquely not stretchable and with properties similar to spun-staple yarns.

1.4.3 Other Texturing Techniques

Regular arrangement of the synthetic filaments may also be changed by various other techniques, such as chemical treatment, differential heat treatment, bi-component forming and the production of irregular-shaped individual filaments, so as to give certain amount of texture. While these types of texturing are usually achieved by treating the yarn (for example with chemicals or heat), the ability to create the texture is inherent in the parent yarn (such as being composed of two components which act differently to extended effects [heat, chemical, etc]). This type of yarn is generally called producer- modified textured yarn.

1.4.3.1 Bi-component filament texturing

In the case of synthetic fibers, the bi-component fiber is such that the material on one side tends to shrink preferentially during either its manufacturing or on activation during texturing or some equivalent process. The principle is that two polymers differing in chemical structure, melting point, co-monomer content, molecular weight, or some other properties produce an oriented filament in which the two oriented components undergo differential shrinkage when subjected to some thermal or other relaxing treatment. This method is often called as self-crimping and is a man –made version of what occurs naturally in wool fibers.

1.4.3.2 Differential Shrinkage Texturing

This type of texturing process is often used in the production of high-bulk staple-spun yarns. These yarns can be produced with two types of fibers, one with a high potential shrinkage and one with little potential shrinkage blended together before the spinning process and the resultant yarn is heated under relaxed conditions. The differential shrinkage causes the low shrinkage components to buckle into crimps and loops in the yarn, causing it to become bulky. These kinds of yarns are mainly used in knitting industry.

1.4.3.3 Chemical Texturing

The thermo-mechanical texturing process involves weakening of the intermolecular links in the fiber causing a deformation and then retaining the deformation. The deformation process involves the dissipation of the internal strains induced by mechanical stressing. For this a high-thermal input is required and it constitutes a major cost in the operation. But in chemical texturing or chemo-mechanical texturing the strain dissipative environment need not, necessarily, be thermal in nature. Here a suitable solvent can be used as a medium to relax the fibers and hence the deformation could be retained.

1.5 False-Twist Texturing

False twist texturing is one of the most important types of yarn modification. False-twist process evolved from the conventional, twist-untwist texturing. The major breakthrough in false-twist texturing was achieved in the mid -1970s with the commercial introduction of friction false twisters [2]. False-twisting process helps in creating bulk without creating twists in the yarn. This is done by twisting and untwisting the yarn and heat setting it between these two processes. False-twist device has two sets of rollers through which the yarn continuously moves at a certain speed. A twisting device is placed between these two rollers to impart twist to the yarn on both sides of the twisting device. But the twists on both the sides are different in direction. Since the yarn is continuously moving the resultant twist in the yarn is zero as each twist on one side of the twisting device cancels out to the twist on the other side of the device as the yarn moves. The heating arrangements are placed between the twisting device and the feed rollers. With this the yarn twisted between the feed rollers and the twisting device is heat set before the untwisting process on the other side. The yarn is also cooled before reaching the false-twisting device thus producing bulk in the resultant yarn.

1.6 Air-Jet Texturing

The air-jet texturing process converts flat, continuous filament yarns into entangled, convoluted, bulky, spun-like structured yarns. This process is by far the most versatile of all yarn texturing methods in that it can blend filaments together during processing, and it, therefore, simulates a desirable attribute of spun fiber yarns. Air-jet textured yarns are produced from thermoplastic, cellulosic or inorganic filament yarns using a turbulent fluid, which is usually compressed air. Loops are formed on the surface of the filament yarn, giving it a voluminous character. Thus, in its simplest form, the air-jet texturing machine consists of no more than a supply of yarn, suitable winding unit and an air-jet interposed between the two.

1.6.1 Principle of air-jet texturing

The processes of air-jet texturing are illustrated schematically in figure 1; When overfed ($V_1 > V_2$) filaments enter the texturing nozzle, they are carried along through the nozzle, blown out from the texturing end, and are formed into loops which are mutually trapped in the yarn structure by the effect of the supersonic and turbulent air stream and forms a textured yarn structure. The supply yarn is normally wetted just before it is fed into the texturing nozzle by passing it through a wetting unit.

Wetting improves the quality of textured yarn produced. Textured yarn is taken up at right angles to the nozzle axis by the delivery rollers. The yarn is stretched slightly ($V_3 > V_2$) after taken up from the nozzle to stabilize the loops formed during the process. The textured yarn is then wound up by means of a high-speed winding unit. A heater can optionally be used between the stretch zone and winding unit to impart further desired properties to thermoplastic yarns, but this is not essential for the process.

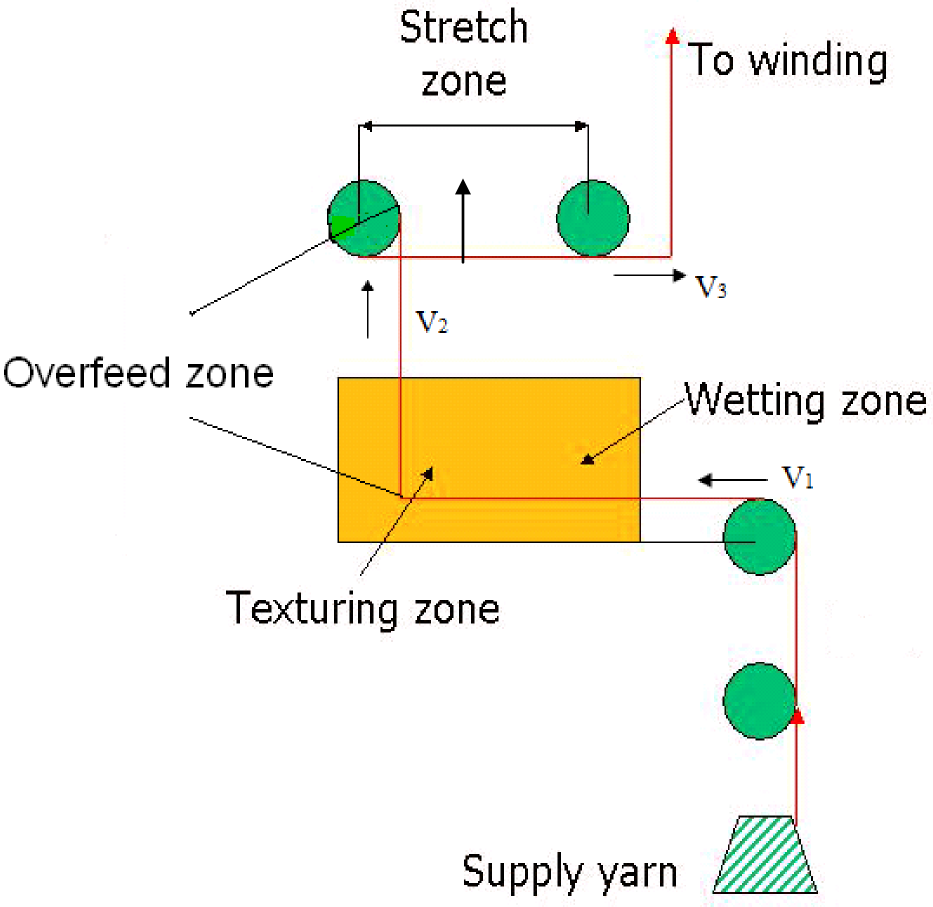


Figure 1.1: Process Flow of Air-Jet Texturing (fundamentals of air-jet texturing- Nikhil Dani)

1.6.2 Scope of present study

The current research attempts to find the effect of process parameters on the quality and structure of the textured yarn. This is of interest with the availability of finer feedstock coupled with newer jet designs which potentially enable a significant increase in production speed. These in turn could lead to yarns which could find greater application in the apparel sector. Partially oriented polyester yarn is used as the raw material for this research. The objectives of the research are as follows:

- To find the optimum process parameters that are suitable for manufacturing high quality textured yarns at high speed.
- To test the yarns for changes in the properties compared to feed yarn as well as to find any new properties the yarns may have acquired.

2. LITERATURE REVIEW

2.1 State of the Air-jet Texturing Process

Air-jet texturing process has seen a great deal of developments and improvements ever since the announcement of the first nozzle patent in 1952 [3]. Although the progress was slow in the initial period, due to the high energy consumption and related cost of operation, the market share of air-jet textured yarns steadily increased because of:

- The developments in nozzle design which offer low air consumption
- Provision of wider ranges of suitable supply yarns
- Increased awareness of its unique capabilities to economically simulate spun yarns and to blend different types of yarns during processing.

Today's air-jet texturing technology can process yarns ranging from fine polyester and polyamide yarns to heavy carbon filaments for aerospace technology and glass fibers. In contrast with early texturing machines equipped with only one type of nozzle, i.e. Taslan IX, a number of texturing machines come with many different profiles and configurations [4]. Such machines facilitate processes like drawing POY (partially oriented yarns) and heat setting after texturing.

2.2 Evolution of Air-jet texturing process

Although air-jet texturing machines come with different profiles and configurations, there are two main groups under which they can be classified. The first consists of machines with individual drives and the second is more traditional having a headstock with motors, drives and shafts at each position [5]. These were called lineshaft machines. Most air-jet texturing machines are equipped for two different feed yarns.

Machines with individual drives are very flexible in terms of the different range of products that can be produced. They allow the addition of different components to the machine so that different process technologies can be performed. Line shaft machines have winding unit similar to those used in a false-twist processing and are therefore commonly doffed in groups. These machines are now available with automatic doffing, which makes random doffing a feasible alternative. The simplest of air-jet texturing machine has three shafts and a winder and the most complex possesses seven shafts and a winder [5]. The machine used for this research work, Stähle RMT-D (SSM) has individual drives for the shafts.

2.2.1Nozzle development

The jet is the heart of the air-jet texturing process. Stähle RMT-D machine is capable of processing yarns from 50-5000 denier but individual jets are limited to a narrower range [5]. The choice of jet is also determined by the type of the materials to be processed, the end use and the characteristics of the yarn to be produced. The continuous evolution of texturing nozzles may be broadly divided into four major groupings [6]:

- Early stage and ‘false start’ with Taslan IX nozzle;
- Upsurge of improved nozzles, i.e. Taslan X and XI;
- Further improvements to the Taslan nozzles (Taslan XIV and XV) with impact elements, and interest from textile companies other than Du Pont;
- The contemporary stage with the Taslan XIV, XV and XX, and cylindrical type nozzles, e.g. Hemajets.

Nozzles developed during the first stage were inefficient in their utilization of the-compressed air. This kind of inadequate designs occupied the first ten years of development. Therefore this first stage of the development was called a 'false start' by researchers Phillips and Isaacs [7] [8].

Following the failure of the first development, the jet, designated as Taslan IX was developed with an axial air flow which was accelerated by well established converging-diverging geometry, while the highly overfed yarn was admitted to the main channel through a stepped hollow needle inclined at 45^o to the nozzle axis as shown in figure below. Despite the serious wear problems these nozzles were used in the industry for over a decade [6].

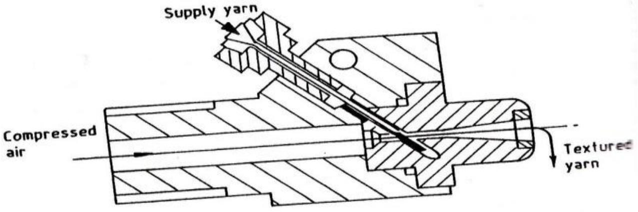


Figure 2.1 Taslan IX jet nozzle with axial air flow [17]

Dissatisfied with the poor performance of the Taslan IX nozzle, Du Pont decided to develop a new design with improved aerodynamics of the nozzle's inner surfaces. The long lasting breakthrough resulted in the emergence of Taslan X nozzle. Further suggestions from researchers Wray and Entwistle helped Du Pont to continue to improve the nozzle design through Taslan XI, XII [9]

The introduction of external impact elements (also known as baffles) such as plates, bars and spheres immediately after the nozzle exit was another development stage. The Taslan XIV and XV were introduced with impact plate and bar respectively. Despite the continuous developments and improvement attempts, there are still certain drawbacks such as high compressed air consumption and frequent contamination of the air vent in the nozzle with spin finish. This problem arose due to the spin finish being washed from the yarn surface and thus the jet needed frequent cleaning (usually ultrasonic) and maintenance. This is still somewhat a problem today.

The above discussed drawbacks thus have induced some other manufacturers to develop new nozzle jets. Most significant development in the nozzle design took place in 1970s. Heberlein took over the air-jet technology developed by Berliner Maschinenbau A.G. of Switzerland in 1977 and introduced its first Hemajet nozzle in 1978 [10]. Heberlein later introduced six other nozzles designated as T100, T311, T110, T140, and T350 with the first digit indicating the provision of either one or three inlet holes [4].

Recent developments from Heberlein offer jet nozzles capable of high texturing speeds at the rate of 1000 m/min. In addition to the T-series, Heberlein has developed two other series of jets called S-series and A-series which are compatible for high overfeed texturing to produce softer yarns and compact stable yarns at high texturing speed respectively [18].

2.2.2 Wetting of the supply yarn

Wetting of the supply yarn is an indispensable part of the air-jet texturing process today. There have been several methods of water application developed along with other developments in air jet texturing. In the early days of the process, the conventional way of wetting the yarn was by threading it through a water bath. Today a wetting head or a spray unit either integrated with texturing nozzle or as a separate unit is used. Several wetting agents have been tested for their effects on texturing in the past. But any improvement witnessed was too unsubstantial to draw positive conclusion. However, by reducing the surface tension of the water, its wetting properties could be improved so as to wet the individual filament surfaces more effectively and thereby further reduce the friction and this was claimed to result in better texturing [11].

2.2.2.1 Effects of wetting on the airflow

A substantial amount of water carried by the yarn from the wetting unit is blown away at the entrance of the nozzle by secondary air-flow of the texturing process. So only a small fraction of water is allowed into the nozzle which upon meeting the incoming air jet is blown away into fine particles of mist. These particles will presumably have an effect on the primary flow. In order study this effect researchers Acar, Turton and Wray calculated the flow velocity at the exit plane of the nozzle for only air flow and for air-water mixtures. This was repeated for various operating pressures. From the results of this study they concluded that wetting of the yarn has only a slight effect on the exit flow velocity [11].

2.2.2.2 Effects of wetting on friction in air-jet texturing process

It is claimed that for most of the materials, pre-wetting reduces the inter-filament friction and also friction between filaments and contacting surfaces [12]. This leads to an increase in the resultant forces acting on the individual filaments and easier longitudinal displacement of the filaments with respect to each other. This in turn encourages the formation of loops, which then become entangled as they emerge from the nozzle [12].

2.2.2.3 Effect of wetting on the physical properties of the yarn

According to W.E. Morton and J.W.S. Hearle "generally as the moisture regain increases, bending stiffness and torsional stiffness of the filaments reduces [13]. There is also an increase in diameter and some change in density of the fiber”. While this is claimed to represent the ‘general situation’ this is obviously only true for certain fibers which absorb water and furthermore increase in fiber diameter when wet- this is only true of a limited number of filament yarns. Furthermore, according to S.Chand [13], wet texturing was better due to reduced rigidity and increased diameter or change in specific volume of the filaments is highly unlikely due to short time span of the wetting process under normal conditions.

2.2.2.4 Significance of quantity of water

Earlier experiments by researchers Bock and Lunenschloss [14] show that beyond a certain small threshold there is no significant change in the properties of the textured yarn with respect to the quantity of water used in the wetting process. This is because, if more water is used, most of it gets blown away in the primary flow and the remaining amount (not absorbed by yarn) is thrown out of the nozzle through the secondary flow. Using more water is hence, a redundancy which could be easily avoided. With this it therefore appears that only a small amount of water is needed to have the desired effect on the texturing process, and hence on the resultant yarn properties.

2.2.2.5 Issue with the previous explanations for the role of water in texturing

According to Nikhil P.Dani, the explanations given for the role of water in texturing in the literature have not pointed out the specific property of the yarn which has been improved by the use of water. For example, the explanations in the literature were not specific if the improvement in the quality of the yarn is in terms of its overall diameter, stability or a uniform structure and strength of the yarn. According to him, the major roles of water in texturing were to impart cohesion between the filaments, forming filament groups which results in loop formation, and to remove spin finish from the yarn.

2.2.3 Loop formation mechanism

It is claimed that inside the air-jet nozzles, shock waves occur in the flow, the strength of which varies depending on the type of the nozzle [15]. These shocks are at least partially destroyed by the presence of the filaments in the nozzle during the texturing process; nozzles providing varying degrees of shock strength are equally effective in the texturing process. Therefore, the effect of shock waves on the filament motion is negligible [15] [2].

2.2.3.1 Mechanism according to Acar, Turton and Wray

Usually there are many filaments in a supply yarn, but to explain the loop formation mechanism, researchers like Acar considers only a few filaments emerging from the nozzle as shown

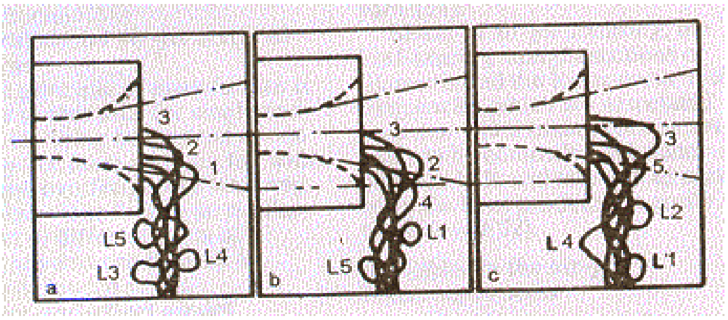


Figure 2.2: Mechanism of loop formation according to Acar et al [15]

According researchers Acar, Turton and Wray, some the filaments move at faster speed than the others. This may be due to the relatively greater fluid forces acting on them. Consequently these filaments slip and cause a longitudinal displacement aided by the overfeed. The longitudinal displacement of the faster moving filaments is also be affected by the frictional forces acting upon them. The difference in displacement causes loops and entanglements in the filaments. When the textured yarn is withdrawn at right angles to the axis of the nozzle these entanglements creates tension and the textured yarn is shortened from its original length.

Therefore on the one hand the emerging filaments are thrown out of the nozzle at much higher speed than the texturing speed and on the other hand the tension created in the yarns pulls the leading edge of the emerging filaments towards yarn delivery. Since the filaments are kept close to the core of the delivery yarn they are forced into bows and arc shapes by the fluid forces acting upon them from the inside of the nozzle. These are then entangled with other emerging filaments, which are formed into fixed stable loops within the textured yarn.

2.2.3.2 Mechanism according to Sengupta, Kothari and Srinivvasan

According to other researchers, like Sengupta, Kothari and Srinivasan, turbulent, asymmetric fluid forces in association with intermittent compression shock waves open up the filaments and blow the overfed lengths out of the texturing nozzle at speeds much greater than the delivery speed of the yarn. The difference in the speeds between the ‘leading’ and ‘trailing ends’ of the section of filaments under the action of fluid forces, causes the bending of the filaments in the form of loops and arcs.

2.2.4 Factors affecting loop formation

In order to analyze the effects of various parameters on the loop formation mechanism researchers Acar, Turton and Wray considered a single filament emerging out from the nozzle. The effects of any changes in the texturing conditions on that filament were analyzed in the light of the described mechanism of loop formation.

2.2.4.1 Effects of air pressure

When the air pressure is increased, the speed of the filament is also increased as a result of increased air velocity, and therefore, the ‘trailing end’ will move rapidly and the time taken to blow out the free length of the filament will also become shorter. High air pressure will also enhance the differences between the forces acting on the filaments and cause greater relative longitudinal displacements. The increased filament speed increase the frequency of the loop formation and the entanglement process could then become more effective in flows with high velocities and intensified turbulence. Therefore, more effective texturing is likely to be achieved by increasing the air pressure.

2.2.4.2 Effects of overfeed

When overfeed is increased, it gives a possibility of longer length of the filament to be blown out of the nozzle in a given time interval. If the texturing speed is not changed the ‘leading end’ of the filament will not move very far and hence the extra length of the overfed yarn will either form a larger loop or several loops in this unit time. Increasing the overfeed will therefore result in an increase in loop size and loop frequency. This in turn causes increase in the linear density. It also results in increase in the instability of the yarn because greater the number of entangled loops greater becomes the chance of these loops being pulled out when the yarn is tensioned. But when the overfeed is excessively high, the filaments and the textured yarn is allowed to be blown away from the nozzle causing no loop formation as shown in Figure 2.3.

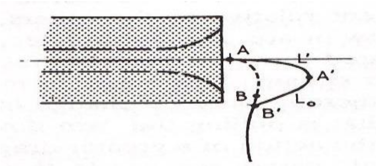


Figure 2.3: Effect of overfeed on loop formation [15]

2.2.4.3 Effects of texturing speed

Increasing the texturing speed will cause both the ‘leading’ and ‘trailing ends’ to move faster and a given length of filament will be exposed to the air-flow for a shorter time. Because of this, any loops that are formed will be less stable and may be removed easily under subsequent tensioning of the textured yarn. Consequently, the number of stable loops formed will be reduced, the tension in the yarn in the delivery zone will drop, and the filaments will be blown away from the nozzle, so that failures will be caused in the continuity of the texturing process.

In order to counteract the adverse effects of increased texturing speeds, at least partly, the air-flow velocity could be increased. This could cause the process to become more effective, but the very high operating pressures required could make it uneconomical. The scope for increasing productivity by further increases of production speed therefore appears to be very limited with existing jet technology.

2.2.4.4 Effects of other elements

Although it is claimed that the baffle arrangement (also known as impact element) at the nozzle exit is believed to improve the process stability and hence the yarn quality in the texturing of certain fibers, it is unlikely to have significant effects on the flow inside texturing nozzles, since any such element is usually situated at a distance of about one nozzle diameter from the exit. It is thus remote from the immediate nozzle-exit region, where loop formation actually takes place. One possible minor role of this impact element is to act as a physical barrier to those filaments that are blown well away from the nozzle.

2.2.5 Air jet textured yarns

Air –jet textured yarns are of different characteristics of their parent yarns. Textured yarns possess high physical bulk, high linear density and subdued luster.

Depending on the amount of overfeed and the effectiveness of the texturing conditions i.e nozzle type, air pressure, texturing speed, the physical bulk of the textured yarn is increased.[2]

From the consideration of yarn feed, air-jet textured yarns are divided into three categories [2]:

i. Single-end air-jet textured yarns;
ii. Parallel-end air-jet textured yarns;
    a. Single component yarns;
    b. Multi-component /blended yarns;
iii. Core and effect air-jet textured yarns;

2.2.5.1 Single-end air-jet textured yarns

Single-end texturing denotes the situation whereby a single end is overfed to the texturing nozzle, and the resultant textured yarn is withdrawn. However the number of filaments in the yarn should be high to produce a stable air-jet textured yarn structure.

2.2.5.2 Parallel-end air-jet texturing yarns

In parallel texturing, two or more ends are fed at the same overfeed into the nozzle so as to facilitate a blend of different types of supply material, or of the same material but with different filament linear densities or number of filaments, or different cross-sectional shapes.

2.2.5.3 Core and effect air-jet textured yarns

Multiple ends overfed into a texturing nozzle at different speeds constitute the core and effect textured yarns. Core component is usually fed at a slower speed than the effect yarn. The versatility of the air-jet texturing process is best observed by the core-effect operation.

2.2.6 Applications of air-jet textured yarns

End uses and applications of air-jet textured yarns are based on the properties of the yarn produced. Air-jet textured yarns are extensively used in the textile industry. Heberlein Fiber Technology Inc. tabulated a list of applications of air-jet textured yarns based on the properties of the yarn.

Table 1: Property and Applications of different air-textured yarns [5]

Property	**Application**	**Feeder Yarn**
Low friction character	Sewing thread	Polyester, Nylon
Spun yarn	Automotive furnishings, Sportswear, Leisure wear,	Polyester, Nylon,
High friction	Ski wear, table cloth, Bed sheeting	Nylon, Polyester
Dimensional Stability	Tarpaulin coated fabric	Nylon, Polyester-single,
Blended yarns	Heather effects, composite materials	
Structural effects	Curtains, wall coverings	Polypropylene, polyester
Functional wear	Rain and sportswear	Micro filament polyester, nylon

3. EXPERIMENTAL

3.1 Introduction

This section describes the experimental aspects of the research. It includes experimental components such as texturing machine and testing instruments along with supply yarns and techniques used for the analysis of textured yarn.

3.2 Material used

Yarn packages of 115 denier, 136 filaments, POY Dacron® polyester produced by UNIFI were used for this research.

3.3 Air-Jet Texturing machine

The experimental setup used in this research was Stähle-Eltex air texturing machine. The model of this machine is RMT-D single end unit. This is one of the popular and widely used modern day machine with a complete computer controlled accessibility. The main components of this machine are:

- Creel stand
- Yarn guides
- Four heated godet rollers, two for core yarn feed and two for the effect yarn feed.
- Texturing box
    - Water jet
    - Air-jet with air-jet nozzle
    - Yarn guides
- Two rubber covered stretch rollers
- Finish applicator
- Yarn traverse guide
- Secondary heating zone
- Precision winding unit
- Water draining system
- Computer

Figure 3.1: Stähle-Eltex air texturing machine

Figure 3.2: Creel stand

Threading of the yarn through the texturing machine is described as follows:

1. Supply yarn packages are loaded on to the creel shown in the Figure 3.2 and the leading end of the yarn are threaded through ceramic yarn guides and an electronic yarn break detector located on the creel.

Figure 3.3: Ceramic guide with an electronic yarn breakage detector

2. The ends are then guided through a guide tube (shown in the picture below) with the help of air suction.

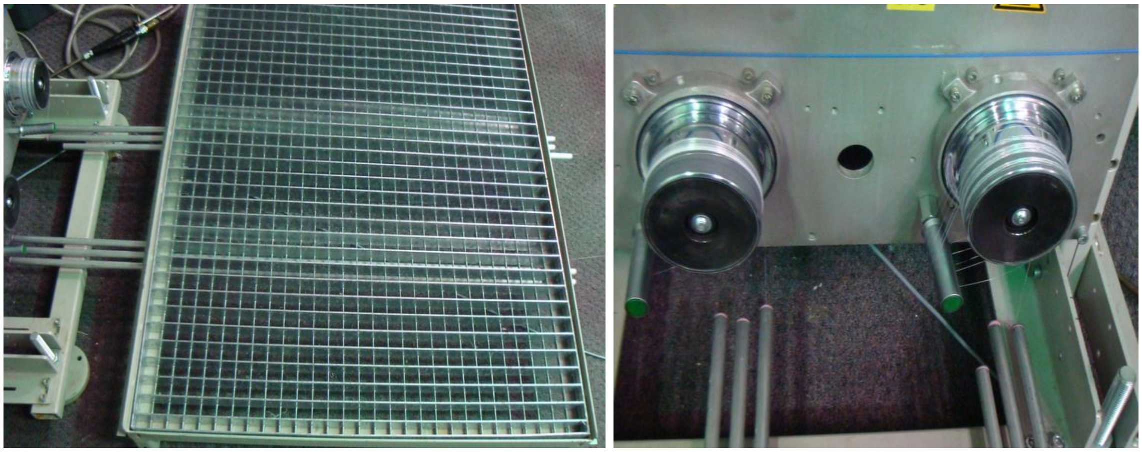


Figure 3.4: Guide tubes

These yarn guide tubes lead to the lower godet rollers shown in the Figure 3.5 which are marked as O.C and O.E representing one each for core and effect yarns respectively where the yarn is wrapped around for five to eight times to avoid slippage. It is then wrapped around the top godet rollers marked as 1.C and 1.E.

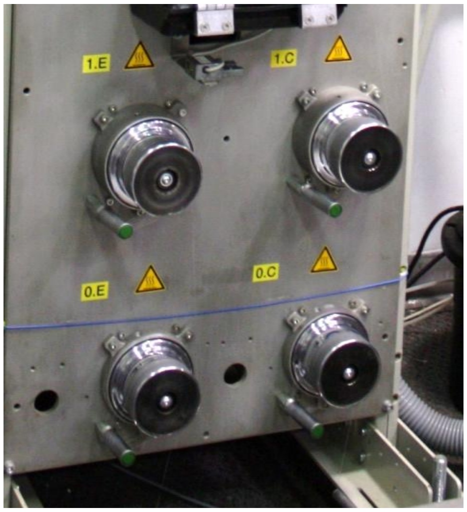


Figure 3.5: Godet rollers

3. The yarn then enters the jet box shown in Figure 3.6 consisting of water bath and air jet nozzles. The core yarn passes through the water bath and the effect yarn is threaded through the air-jet nozzle directly from the top godet roller 1.E.

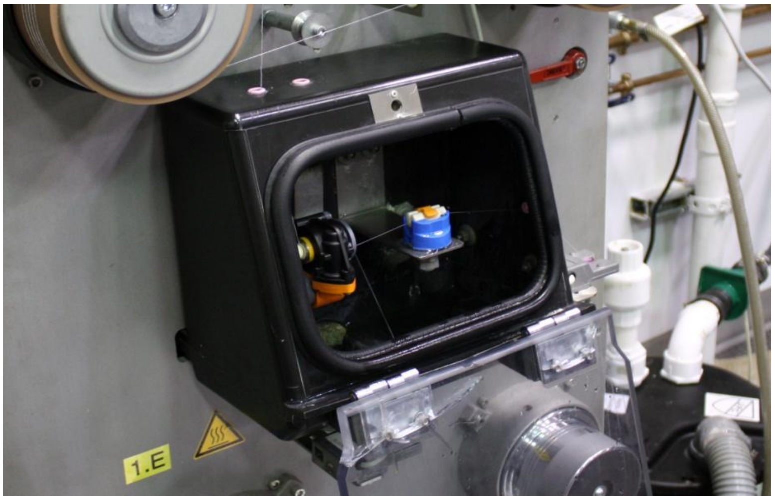


Figure 3.6: Texturing Box

4. Textured yarn withdrawn at right angle from the nozzle exit is wrapped around the rubber covered stretch rollers shown in Figure 3.7 before taken to the winding unit through a traverse guide shown in Figure 3.8.

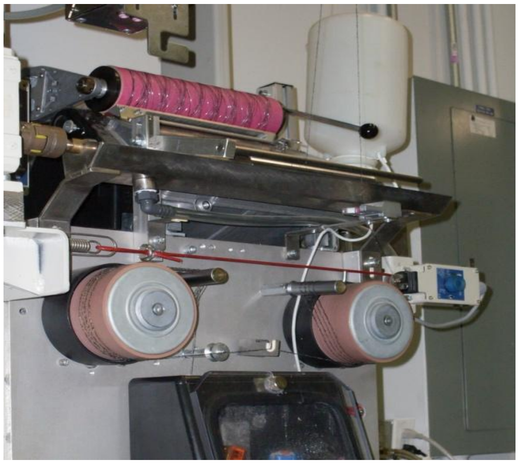


Figure 3.7: Stretch-zone

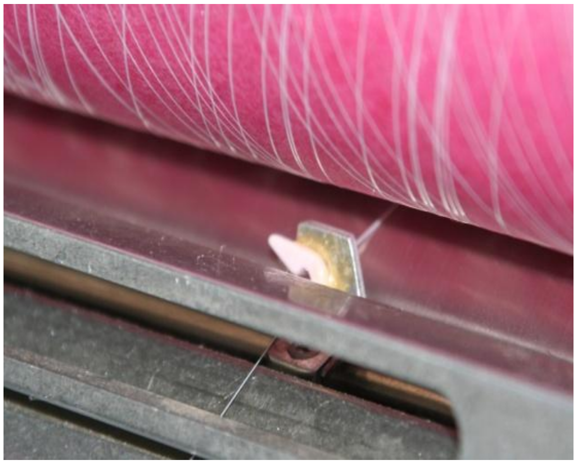


Figure 3.8: Traverse guide

All the rollers in the texturing machine are driven by separate motors and are controlled by the computer. The secondary heating system of the machine was not used as the partially oriented yarns were fully drawn before entering the texturing yarn.

3.4 Nozzles

The specifications of the nozzles (as claimed by Heberlein) used for this research is given Table 2. The nozzles are shown in Figure 3.9 (black-S325, grey-S315, yellow-A317)

Figure 3.9: Nozzles used in research

Figure 3.10: Nozzles used in preliminary trials

Table 2: Specifications of different jet nozzles (retrieved from Heberlein's pamphlet)

Type	Range of pressure (PSI)	Winding speed (m/min)	Total feed yarn count (denier)	Single filament count (denier)	Yarn overfeed up to
S315-2	116-203	1000	20-225	0.45-2.25	60%
S325-2	116-203	900	180-405	0.67-3.6	70%
A317-2	116-203	1000	40-225	0.45-2.25	45%

Apart from these three nozzles, two other old nozzles (shown in Figure 3.10, left- T100, right- T351) are also used in the preliminary trials of the research. The specifications of these nozzles are given in table 2a. The poor condition of these two nozzles (as shown in Figure 3.10) restricted us from using them beyond the preliminary trials in this research.

Table 2a: Specifications of T-series jet nozzles used in preliminary trials

Type	Range of pressure (PSI)	Winding speed (m/min)	Total feed yarn count (denier)	Single filament count (denier)	Yarn overfeed up to
T 100	58-203	650	45-630	1.4-2.3	30%
T 351	58-203	500	450-4500	Up to 19.8	80%

3.4.1 Nozzle maintenance

The removal of spin finish from the yarn during texturing process often clogs the air-inlets of the air-jet nozzles. Hence a periodic cleaning of the jets was carried out throughout the research. Ultrasonic cleaner (shown in Figure 3.11) was used with water to clean the jets after every batch of sample trials.

Figure 3.11 Ultrasonic cleaner

3.5 Operating Procedure

Operating the eltex air-texturing machine is very simple. The following procedure is carried out in order to run the machine.

- The main power supply for the machine is controlled by a 30 amp, 600V AC/DC switch. The power supply is turned on by pushing the lever to top position as shown in the Figure 3.12.

Figure 3.12: Power supply switch

- The next step in operating the machine is to turn electrical panel of the machine by turning the panel switch to the vertical position as shown in the Figure 3.13. Following which the red emergency switch is pulled off and the machine is turned on by pushing the green control voltage switch shown in the Figure 3.14

Figure 3.13: Electric panel switch

Figure 3.14: Control voltage switch

- The start button for the machine is located on the left side of the precision winder as shown in the Figure 3.15.

Figure 3.15: Start button panel

- The air supply to the texturing machine is turned on by turning on the air compressor, the auto-pressure control panel and the gate walls of the air pipe (Figure3.16) that runs into the texturing machine.

Figure 3.16: Air supply controls

- The SSM eltex air-texturing machine is computer controlled machine. The computer is logged on with the administration name and a password. The machine is run by a software namely, Staehle Texturing. This software is password protected. The screenshot of the software is shown below in Figure 3.17. The password is entered by choosing the ‘Enter’ option in order to unlock the software for use.

Figure 3.17: Stäehle texturing software.

- Every parametrical setting used in each experiment is saved as recipe in ‘Staehle Texturing’. The recipes can be loaded and edited as and when wished. The option ‘Load’ (Figure 3.18) helps to load a saved recipe onto the machine. The ‘Save and edit’ option let the user to make changes to the existing recipe. The ‘Create and edit’ helps to create new recipes for new experiments.

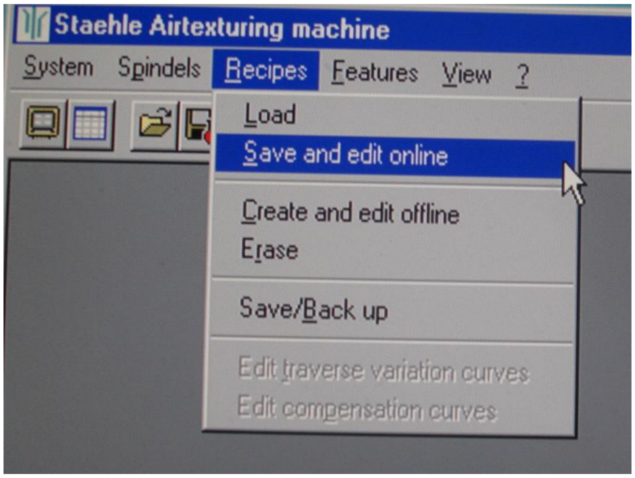
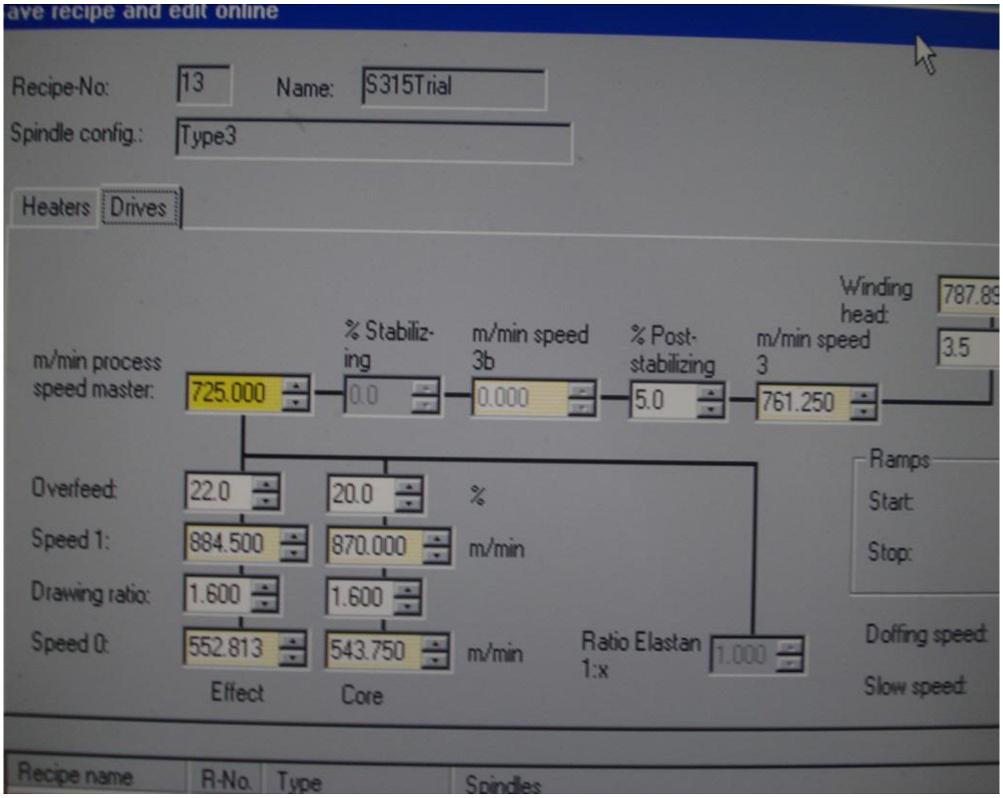


Figure 3.18: Saving and loading recipes on Stäehle Texturing

- Once a recipe is loaded and the machine is run, the system prohibits the user from changing any parameter. The screenshot of a recipe is shown in Figure 3.19. This allows the users to change any data they wish with respect to the experiment in progress.



Recipe-No: 13

Name: S315Trial

Spindle config.: Type3

Winding head: 787.8

3.5

m/min process speed master: 725.000

% Stabilizing: 0.0

m/min speed 3b: 0.000

% Post-stabilizing: 5.0

m/min speed 3: 761.250

	Effect	Core	
Overfeed:	22.0	20.0	%
Speed 1:	884.500	870.000	m/min
Drawing ratio:	1.600	1.600	
Speed 0:	552.813	543.750	m/min

Ratio Elastan 1:x: 1.000

Figure 3.19: Editing parameter for a recipe in Stäehle Texturing.

3.6 Testing

Yarn samples were tested for tensile strength using MTS® Q Test/5 Tensile Tester. As per ASTM standard D2256, 120 yards of yarn samples were taken using a wrap wreel and weighed in a balance. The weight in grams is then converted into denier by using the following formula

$$\text{Denier} = \frac{\text{weight of 120 yards of yarn in grams x 9000}}{120 \text{ x } 0.9144}$$

Three samples from each package were used to find the average denier. Yarn samples were then cut into ten inch length and suspended between the five pound load cells of MTS® tensile tester shown in Figure 3.20 to test for their tensile strength.

This was repeated for ten trials of each yarn sample.

Figure 3.20: MTS® tensile tester

4. RESULTS AND DISCUSSIONS

4.1 Introduction

Two series of preliminary trials were carried out in this research. The first set of experiments was carried out using the available T-series jet in the laboratory. These jets were used to texture the yarns at low speeds. Because these jets were not been used for a long time, most of the jets were corroded and have become inefficient. This led to the purchase of new set of hemajets from Heberlein. Thus new jets were used for the further study in this research.

4.2 Preliminary trials with old jets

This research was started with two old Heberlein jets T100 and T351. Owing to the poor condition of the jet cores, these jets were used only to get the basic understanding of the texturing process. Also the limitations of these jets with the speed at which they can be operated allowed very minimal number of samples to be obtained for the study.

4.2.1- T100 trials

After initial understanding of the texturing process by running number of trial runs by trial and error method, the first set of trials were taken using the jet T100. The parameters chosen for the trials are shown in table 3.

Table 3: Parameters for effect of overfeed with T100 jet

Value	Temperature (^oC)	Draw ratio	Pressure (kPa)	Overfeed (%)	Speed (m/min)	Post-texturing Stretch (%)
1	90	1.1	551.6	31	400	5
2	90	1.1	551.6	35	400	5
3	90	1.1	551.6	39	400	5
4	90	1.1	551.6	43	400	5
5	90	1.1	551.6	45	400	5

It is to be noted that this experiment with changing overfeed percentage was carried out to test the limits of the jet in terms of the percentage of overfeed yarn it can process and its influence on tensile properties of the resultant yarn.

The results of these samples (shown in table 4) were obtained and used to plot graphs to find the influence of overfeed on tenacity, modulus and elongation of the yarn.

Table 4: Effect of overfeed with T100 jet

Denier	Peak load(cN)	Elongation % at peak load	Modulus (cN/denier)	Tenacity (cN/denier)	Over feed (%)
214.43	441.98	82.64	18.27	2.07	31
218.83	345.28	66.73	17.80	1.58	35
225.43	322.87	63.05	15.23	1.43	39
228.73	325.96	58.76	21.85	1.42	43
231.98	319.65	55.23	14.89	1.39	45

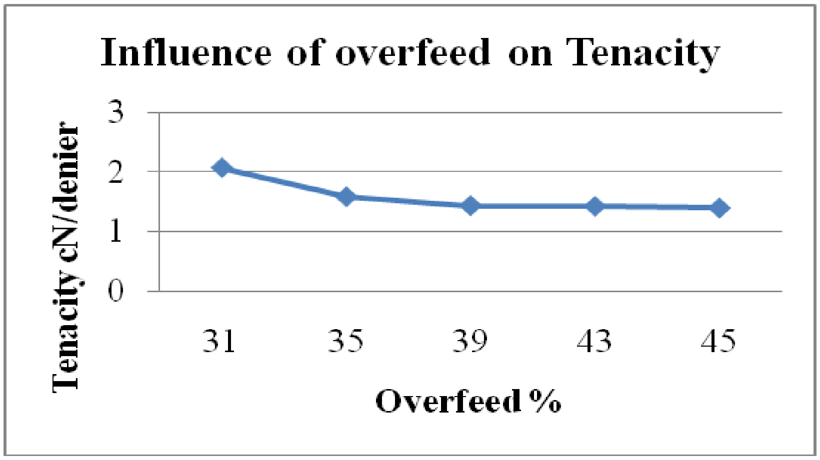


Figure 4.1: Influence of overfeed on tenacity of T100 yarns

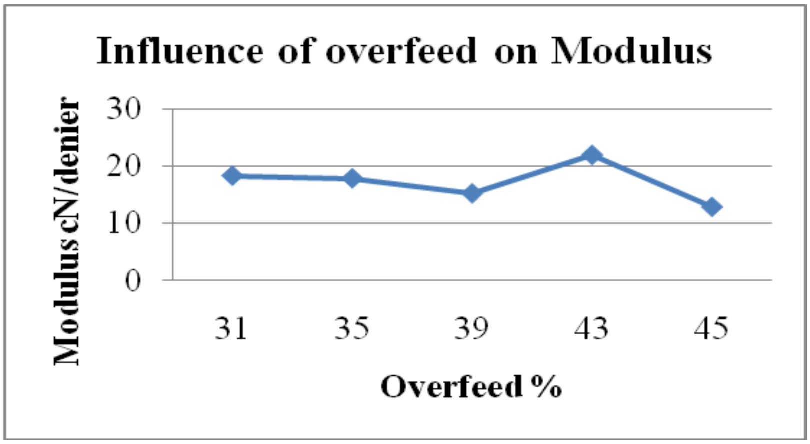


Figure 4.2: Influence of overfeed on modulus of T100 yarns

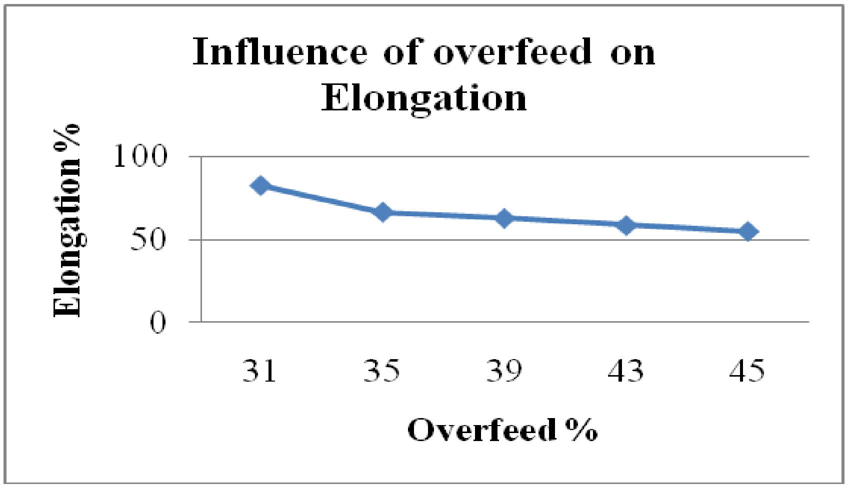


Figure 4.3: Influence of overfeed on elongation of T100 yarns.

From these results it was safe to assume that overfeed of the feed yarn into the nozzle influences the tensile strength of the resultant yarn and that it lowers more and more as it increases. It is to be noted that these yarns are not fully drawn and that it is reflected in low tenacity and high elongation values.

4.2.2- T351 trials

The second set of preliminary trials was carried out with T351 nozzle jet. The samples these trials were tested for the influence of pressure on the tensile properties of the yarn.

The parameters chosen and the results are shown in the table 5 and table 6 respectively.

Table 5: Parameters for effect of pressure with T351

Value	Temperature (°C)	Draw ratio	Pressure (kPa)	Overfeed (%)	Speed (m/min)	Post-texturing Stretch (%)
1	90	1.4	551.6	24	375	5
2	90	1.4	620.5	24	375	5
3	90	1.4	689.5	24	375	5
4	90	1.4	758.4	24	375	5
5	90	1.4	827.4	24	375	5

Table 6: Effect of pressure with T351 jet

Denier	Peak load(cN)	Elongation % at peak load	Modulus (cN/denier)	Tenacity (cN/denier)	Pressure kPa
174.69	550.49	74.58	31.5207	3.52	551.6
175.24	548.41	73.87	30.6617	3.49	620.5
175.78	549.65	74.08	28.8776	3.46	689.5
176.09	543.69	72.45	30.6128	3.29	758.4
177.05	540.92	71.08	32.757	3.34	827.4

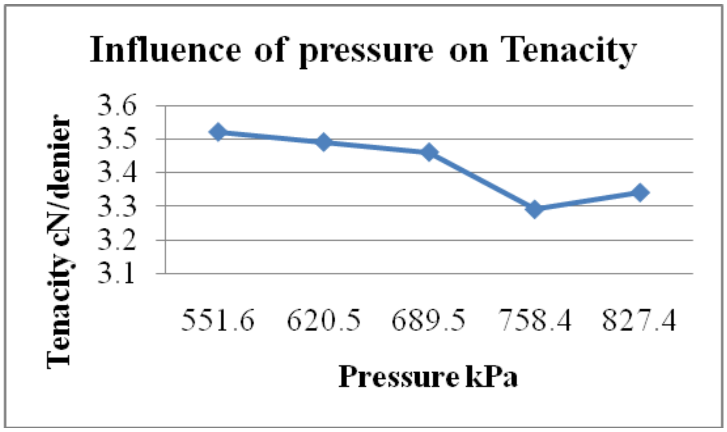


Figure 4.4 Influence of pressure on tenacity of T351 yarns

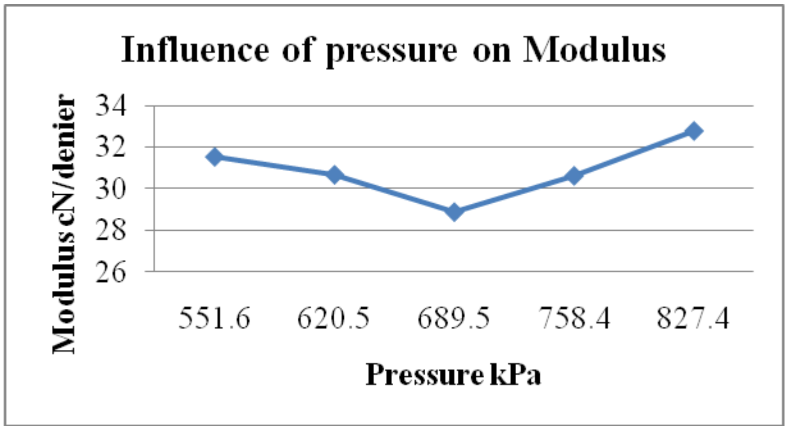


Figure 4.5 Influence of pressure on modulus of T351 yarns

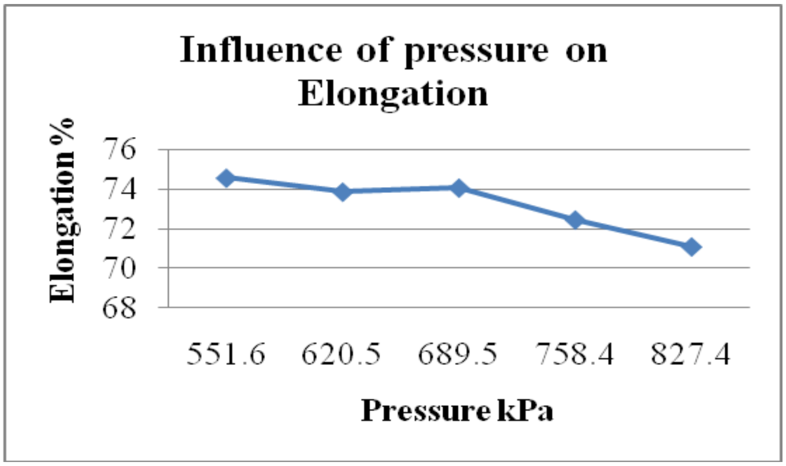


Figure 4.6 Influence of pressure on elongation of T351 yarns

We were able to understand the influence of pressure and overfeed on the tensile strength of the yarn from these two sets of preliminary trials. But the poor condition of the jets and limitations of the jet in terms of speed at which they can operate effectively were a cause of concern for the objective of the research. One of the main objectives of this research was to test the feasibility of texturing finer yarns at very high speed. So this demanded the need of new jets with high speed limitations. As earlier the samples for this trial were not fully drawn which resulted in low tenacity and high elongation. But when compared to the previous trial the tenacity was much higher because of the higher draft in the draw zone.

4.3 Preliminary trials with new jets

All the previous experiments conducted with the available Eltex RMT-D machine at North Carolina State University were only of coarse count yarns with the machine running at relatively low speeds using T-series jets. It was thus challenging to understand the behavior of yarns as fine as 115denier as they kept breaking often. Many different parametrical adjustments were tried to resolve the problem. One of the problems detected during the study was that the nozzles and the jet body that being used were all corroded. This resulted in improper air flow blowing the overfed yarn around the baffle ball and causing breakage.

All the breakage problems were solved by changing and correcting the tension in the creel and by changing the position of the yarn packages in the creel so that unwinding is smooth and unhindered, preliminary trials were conducted to find the influence of different process parameters on yarn tenacity, yarn modulus and elongation. This change also enabled the machine to operate at higher draft (1.6) and higher speed. The trials were conducted on two different jet nozzles one of each series (S and A) to find if there is any difference among the influence of parameters on properties of yarns produced from two different nozzles. Six parameters were considered for the parametrical study. Temperature of the godet rollers (used for drawing), draw ratio, air pressure, overfeed %, take-up speed and post-spinning stretch were the parameters taken into account. The experimental design considered for these preliminary trials was Taguchi method. This was determined after an interaction with experts from the industry (Mr.Edmir Silva, Unifi Inc, Yadkinville, NC). According to this method, orthogonal arrays were used to organize the parameters affecting the process and the levels at which they should be varied. In case of these preliminary trials, three levels of values for each parameter were considered. The orthogonal array, therefore, used for these trials is L18 array. Out of the eighteen possible samples, some samples were not available for the test as they were impossible to produce because of incompatibility in the combination of the parametric values. As a result 15 samples of A317 and 17 samples of S315 were obtained for testing. Upon testing the results were analyzed using SAS software. The results were obtained at 95% confidence level. The results are judged by the *p-value* calculated by the SAS program. The results of SAS analysis are included in appendix I.

Table 7: Design of experiment (L18 array)

Experiment	P1	P2	P3	P4	P5	P6
1	1	1	1	1	1	1
2	1	2	2	2	2	2
3	1	3	3	3	3	3
4	2	1	1	2	2	3
5	2	2	2	3	3	1
6	2	3	3	1	1	2
7	3	1	1	1	3	2
8	3	2	2	2	1	3
9	3	3	3	3	2	1
10	1	1	1	3	2	2
11	1	2	2	1	3	3
12	1	3	3	2	1	1
13	2	1	1	3	1	3
14	2	2	2	1	2	1
15	2	3	3	2	3	2
16	3	1	1	2	3	1
17	3	2	2	3	1	2
18	3	3	3	1	2	3

Table 8: Parameters used for preliminary trials with new jets.

Value	Temperature (^oC)	Draw ratio	Pressure (kPa)	Overfeed (%)	Speed (m/min)	Post-texturing Stretch (%)
1	90	1.56	551.6	20	475	5
2	120	1.60	689.5	22	500	7
3	130	1.64	827.4	27	525	8

Table 9: Influence of parameters on the yarn properties

Jet Designation	Properties	Temperature	Draw ratio	Pressure	Overfeed	Speed	Stretch
A317	Tenacity		●	●	●		●
	Elongation	●	●	●	●		●
	Modulus	●	●	●	●		●
S315	Tenacity		●	●	●		●
	Elongation	●	●	●	●		
	Modulus	●	●	●	●	●	●

- Indicates a significant influence of the parameter on the corresponding yarn property

4.4 High Speed Texturing

The work reported in this chapter was carried out to find optimum processing parameters that are suitable for manufacturing high quality textured yarns at high speed. The experiment was carried out on three different jet nozzles S325, S315 and A317. All the trials were carried out under the recommended jet nozzles' limitations. The samples were tested for their elongation, tenacity and modulus using the MTS® Q Test/5 Tensile Tester.

4.5 S325 Experiments

The first five set of experiments were carried out to find the optimum overfeed percentage for 160 denier Dacron core and effect yarn using the jet nozzle, S325. Each experiment was carried out by varying the values of one of the five paramaters while keeping the others constant.

4.5.1 Overfeed

In this first experiment with S325 jet nozzle, the overfeed percentage is varied while all other parameters are kept constant. The parameteric values chosen for this experiment and the results are given in table10 and table 11 respectively.

Table 10: Parameters for effect of overfeed with S325

Draw Ratio	Pressure (kPa)	Temperature (^{o}C)	Overfeed (%)	Stretch (%)	Speed (m/min)	Winding Speed (m/min)
1.6	689.5	90	22	5	725	780
1.6	689.5	90	24	5	725	780
1.6	689.5	90	26	5	725	780
1.6	689.5	90	28	5	725	780
1.6	689.5	90	30	5	725	780

The parameters were chosen based on the specifications of the jet nozzle, and our discussion with the experts from the industry. The samples were tested for their linear density and subsequently for their tensile strength.

Table 11: Effect of overfeed on S325 yarns

Denier	Peak load(cN)	Elongation % at peak load	Modulus (cN/denier)	Tenacity (cN/denier)	Over feed (%)
160.97	485.29	38.38	26.85	3.02	22
162.18	489.97	39.23	25.50	3.02	24
163	454.88	36.34	22.09	2.79	26
163.93	440.07	35.21	20.02	2.69	28
164.78	435.12	35.14	19.23	2.64	30

- With respect to Figure 4.7, yarn tenacity decreases as the overfeed of the effect yarn is increased from 22–30 %. With an increase in overfeed, there is also an increase in the percentage of fibers that are not aligned with the yarn axis. These misaligned fibers do not add to the strength of the yarn, but rather detract from it.
- As the overfeed of the effect yarn is increased, the yarn modulus (cN/den) also

- decreases, as displayed in Figure 4.8. Modulus is the ratio of stress to strain and it is a measure of stiffness. It can be used to determine how easily a yarn (and the resultant fabric) will deform.
- From the Figure 4.9, it is evident that changes in the overfeed percentage has a very little effect on the elongation of the textured yarn. This can be due to the fact that the loops formed during texturing are locked into places and they do not enhance the elongational properties of the textured yarn. The small amount of elongation that does exist comes from the non-textured, parallel fibers in the yarn

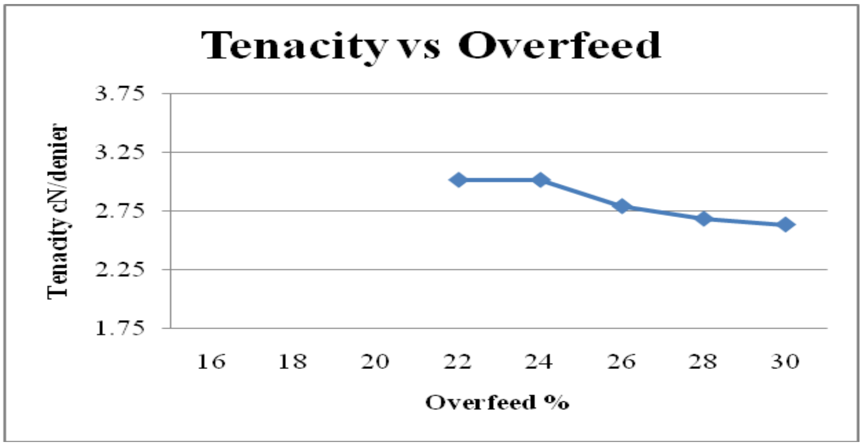


Figure 4.7: Tenacity of S325 yarns with different overfeed percentage

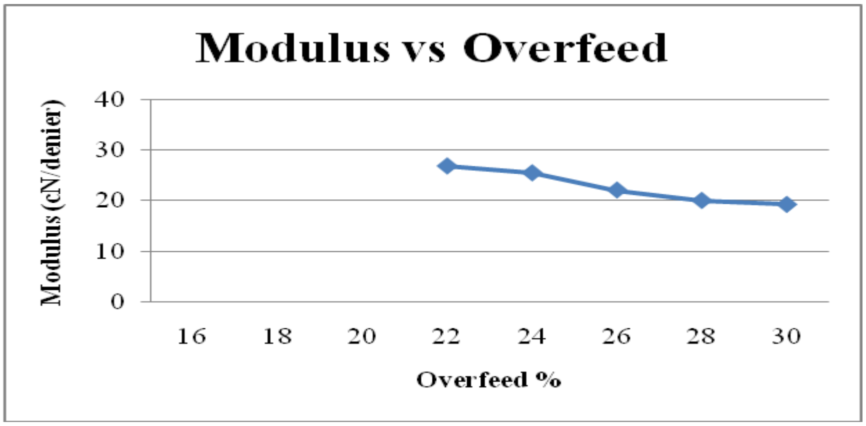


Figure 4.8: Modulus of S325 yarns with different overfeed percentage

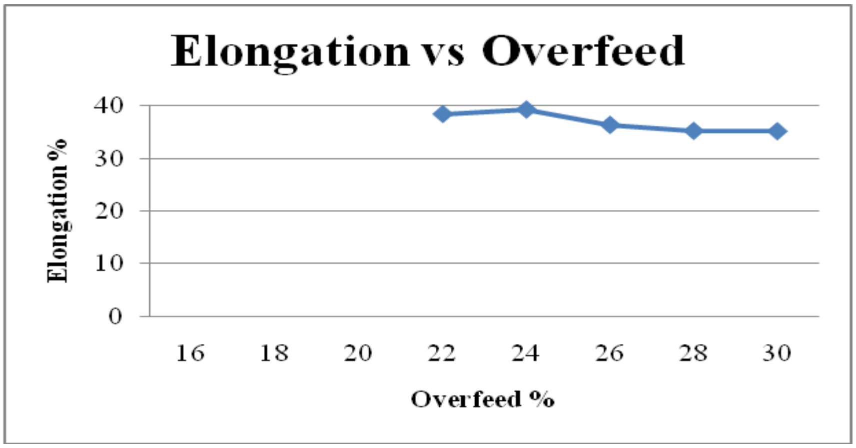


Figure 4.9: Elongation of S325 yarns with different overfeed percentage

4.5.2 Pressure

The second experiment is to find out the optimum pressure. Parameters considered for the experiment and the results are given in table 12 and table 13 respectively:

Table 12: Parameters for effect of pressure with S325

Draw Ratio	Pressure kPa	Temperature (^{o}C)	Overfeed (%)	Stretch (%)	Speed (m/min)	Winding Speed (m/min)
1.6	551.6	90	26	5	725	780
1.6	689.5	90	26	5	725	780
1.6	827.4	90	26	5	725	780
1.6	965.3	90	26	5	725	780
1.6	1103.2	90	26	5	725	780

Table 13: Effect of pressure on S325 yarns

Denier	Peak load (cN)	Elongation% at peak load	Modulus (cN/denier)	Tenacity (cN/denier)	Pressure (kPa)
161.99	470.55	37.68	21.77	2.90	551.6
163	454.88	36.34	22.09	2.79	689.5
163.08	429.15	33.42	22.79	2.64	827.4
163.46	395.39	28.92	29.52	2.42	965.3
163.27	389.04	28.36	31.71	2.38	1103.2

- From the Figure 4.10, it can be undestood that the effect of pressure on the tenacity of the textured yarns is same as the effect of overfeed percentage. The tenacity of the textured seems to decrease as the air pressure is increased inside the jet nozzle. This is due to the fact that the fibers are misaligned by the greater pressure inside the nozzle and hence they do not attribute to the strength of the textured yarn.
- With respect to Figure 4.11, the modulus of the textured yarn increases with increase in pressure inside the nozzle. The possible explanation for this phenomenon would be that the high pressure inside the nozzle wraps up the fibers towards the core of the yarn when a force is applied around the axis of the yarn and as a result the modulus strength of the whole yarn is increased.

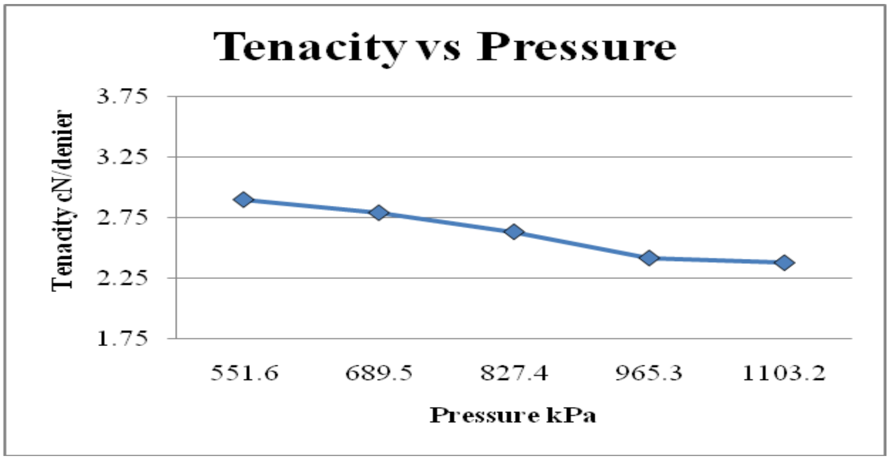


Figure 4.10: Tenacity of S325 yarns with different pressure setting

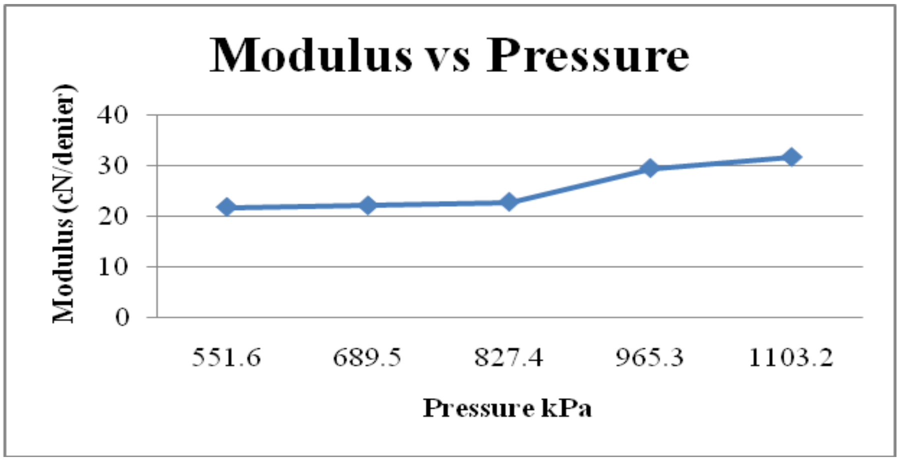


Figure 4.11: Modulus of S325 yarns with different pressure setting

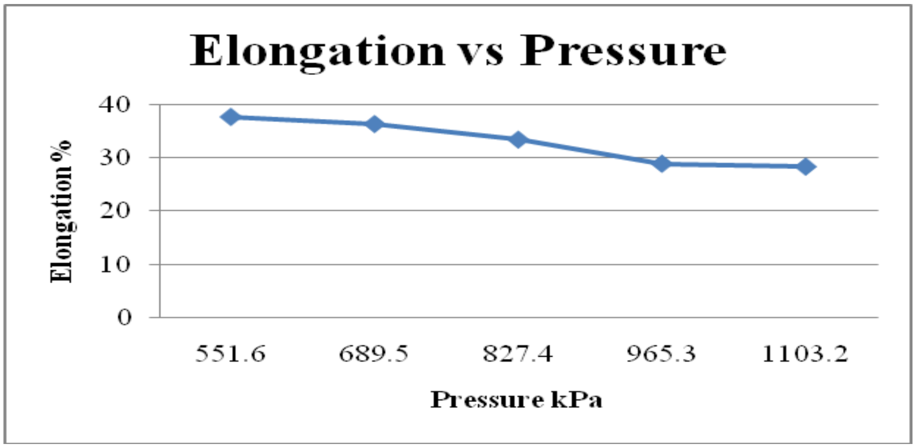


Figure 4.12: Elongation of S325 yarns with different pressure setting

- Figure 4.12 reveals the relation between the elongation of the textured yarn with respect to changing pressure inside the nozzle jet. As evidenced in the graph the elongation of the yarn decreases as the pressure is increased. This could be explained by more entanglement producing smaller, tighter loops which are responsible for the reduced elongational properties of the yarn.

4.5.3 Take up speed

The third expriment for the S325 nozzle was carried out with different take up speeds and the resultant yarns are tested for their tensile properties. Parameters for the experimentand its results are shown in table 14 and table 15 respectively.

Table 14: Parameters for effect of take up speed with S325

Draw Ratio	Pressure (kPa)	Temperature (^oC)	Overfeed (%)	Stretch (%)	Speed (m/min)	Winding Speed (m/min)
1.6	827.4	90	24	5	575	618
1.6	827.4	90	24	5	625	672
1.6	827.4	90	24	5	675	725
1.6	827.4	90	24	5	725	780
1.6	827.4	90	24	5	775	838

Table 15: Effect of take up speed on S325 yarns

Denier	Peak load (cN)	Elongation % at peak load	Modulus (cN/denier)	Tenacity (cN/denier)	Speed (m/min)
162.55	420.19	31.59	29.91	2.59	575
162.18	398.70	29.21	28.00	2.46	625
161.96	405.62	30.57	25.85	2.51	675
162.15	438.51	33.76	32.02	2.70	725
161.19	421.40	31.77	32.68	2.62	775

- It is evident from the Figure 4.14 that the modulus of the textured yarn is almost constant for all values of take-up speed only with minimum variation

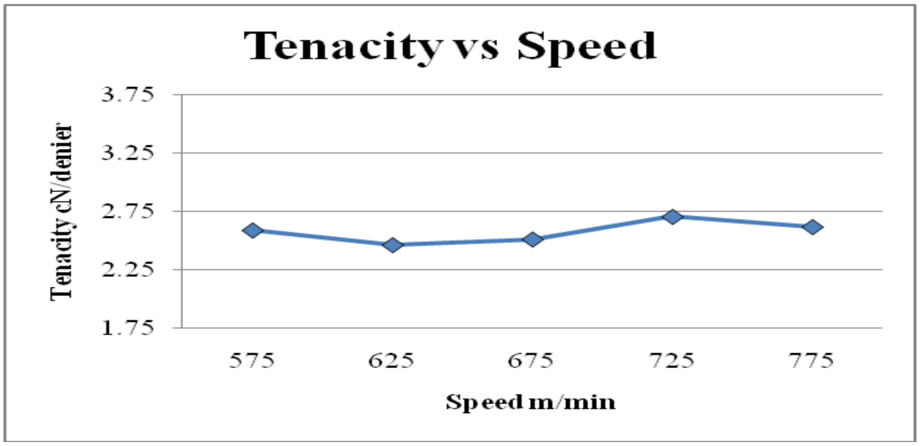


Figure 4.13: Tenacity of S325 yarns at different take up speeds

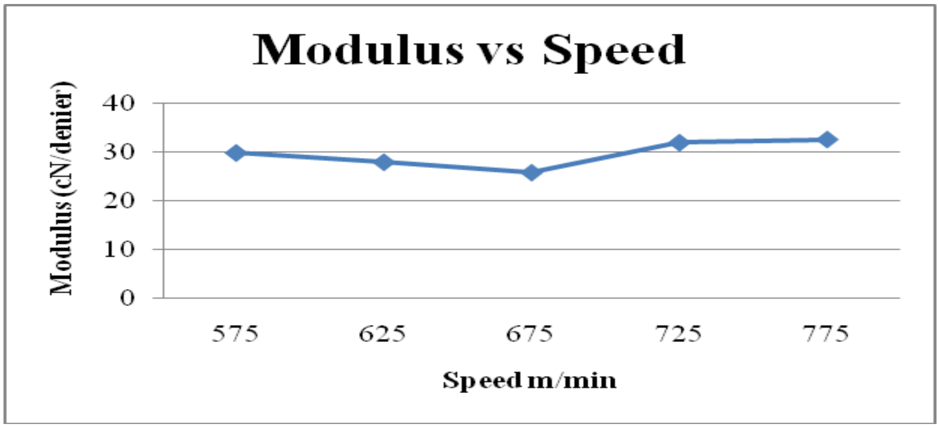


Figure 4.14: Modulus of S325 yarns at different take up speeds

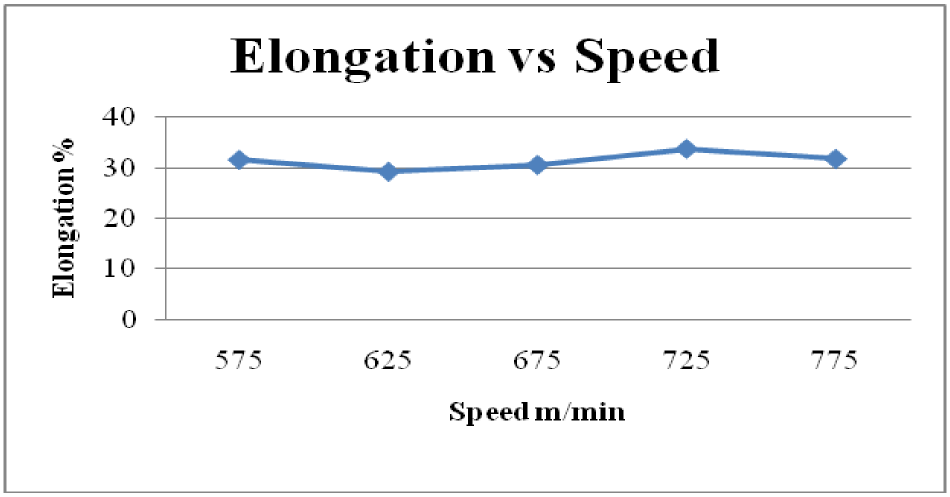


Figure 4.15: Elongations of S325 yarns at different take up speeds

- Figure 4.13 reveals that with the increase in the take up speed of the textured yarn, the tenacity appears to decrease upto a certain limit and increases further on. The tenacity achieved at 625 m/min is lower than tenacities achieved at other setting which shows the fact that the yarn is more textured at the speed of 625 m/min than at any other speed considered in the experiment.
- Elongation of the yarn marginally increases with increase in the take up speed. This may be due to the poor texturing at high speeds. The graph in Figure 4.15 is a testimony to the fact that the elongation of the yarn drawn at 625 m/min is much less and hence can be recognized as a well textured yarn

4.5.4 Temperature

The fourth experiment with S325 was carried out with different draw zone temperature settings. Draw zone temperatures are changed by changing the temperature of the godet rollers. Parameters selected for the experiment and the results are shown in table 16 and table 17 respectively.

Table 16: Parameters for effect of draw zone temperature with S325

Draw Ratio	Pressure (kPa)	Temperature (^oC)	Overfeed (%)	Stretch (%)	Speed (m/min)	Winding Speed (m/min)
1.6	689.5	90	28	5	750	807
1.6	689.5	100	28	5	750	807
1.6	689.5	110	28	5	750	807
1.6	689.5	120	28	5	750	807
1.6	689.5	130	28	5	750	807

Table 17: Effect of draw zone temperature on S325 yarns

Denier	Peak load (cN)	Elongation % at peak load	Modulus (cN/denier)	Tenacity (cN/denier)	Temperature (^oC)
163.96	439.36	36.71	18.76	2.68	90
163.85	435.31	35.24	19.69	2.66	100
163.6	443.23	34.62	18.49	2.70	110
163.9	452.94	35.23	18.69	2.76	120
163.33	447.03	32.85	18.65	2.73	130

- As seen in Figure 4.17, the modulus of the yarns textured at different temperatures are almost constant. This shows that temperature with which the yarns are pre-drawn has a very minimal effect on the modulus of the resultant textured yarn.

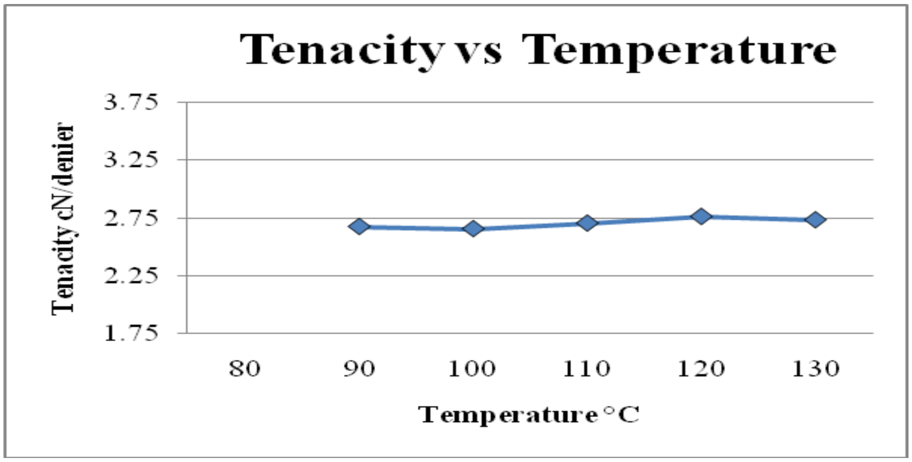


Figure 4.16: Tenacity of S325 yarns with different draw zone temperature setting

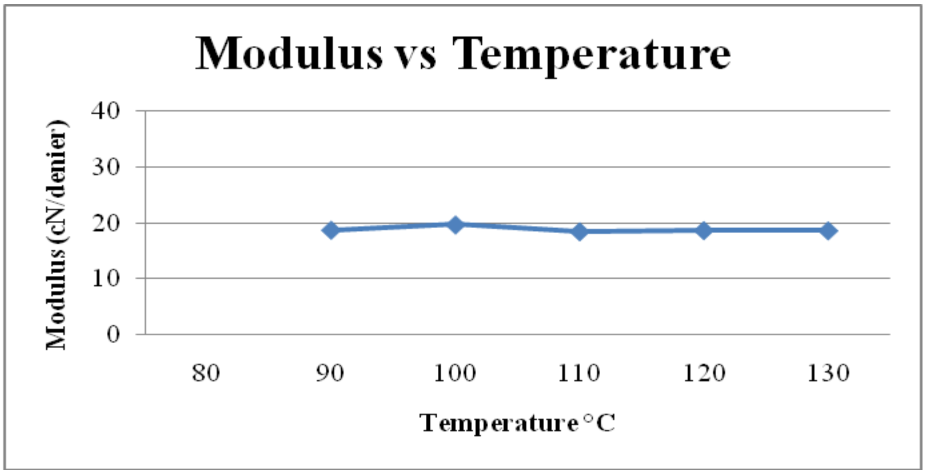


Figure 4.17: Modulus of S325 yarns with different draw zone temperature setting

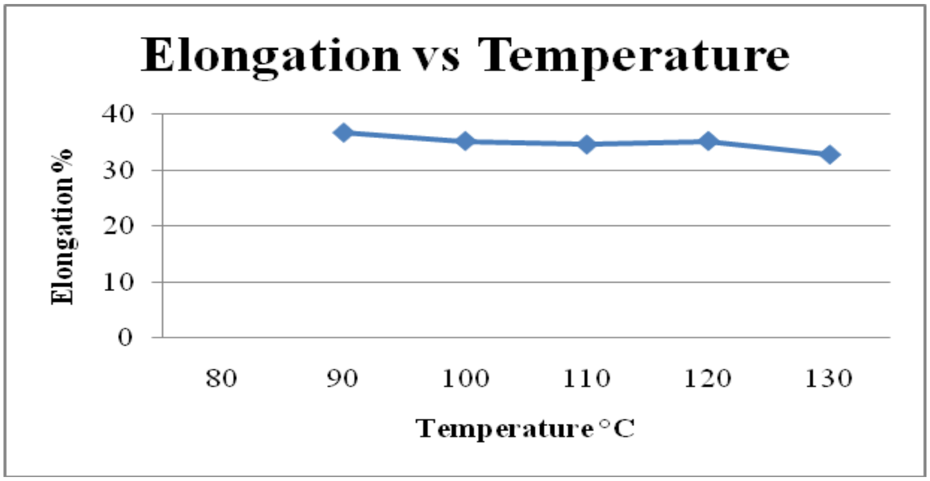


Figure 4.18: Elongation of S325 yarns with different draw zone temperature setting

- The graph in Figure 4.16 shows very little change in the tenacity of the yarn with respect to change in the temperature value.
- With respect to Figure 4.18 the elongation of the textured yarns decreases with increase in temperature.

4.5.5 Post- Texturing Stabilization

The fifth and final experiment for S325 was carried out with different post-texturing stablization (or stretch) settings. Parameters considered for the experiment and the results are shown in table 18 and table 19 respectively.

Table 18: Parameters for effect of post-texturing stretch with S325

Draw Ratio	Pressure (kPa)	Temperature (^oC)	Overfeed (%)	Stretch (%)	Speed (m/min)	Winding Speed (m/min)
1.6	827.4	90	26	3	775	822
1.6	827.4	90	26	5	775	838
1.6	827.4	90	26	7	775	849
1.6	827.4	90	26	9	775	865
1.6	827.4	90	26	11	775	881

Table 19: Effect of post-texturing stretch on S325 yarns

Denier	Peak load (cN)	Elongation % at peak load	Modulus (cN/denier)	Tenacity (cN/denier)	Stretch (%)
164.5	433.28	35.39	29.70	2.64	3
162.04	426.88	34.11	25.35	2.64	5
160.46	422.75	32.30	35.37	2.64	7
155.84	426.93	31.87	42.39	2.74	9
158.19	431.46	29.94	46.21	2.72	11

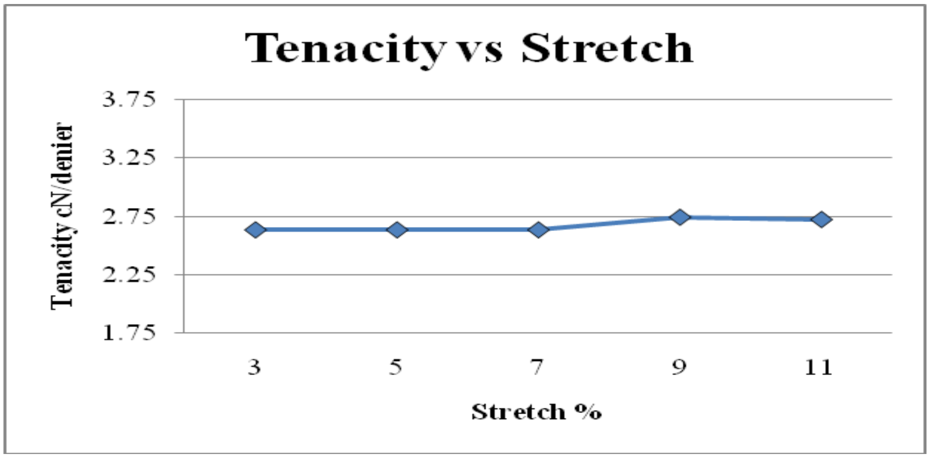


Figure 4.19: Tenacity of S325 yarns with different mechanical stretch

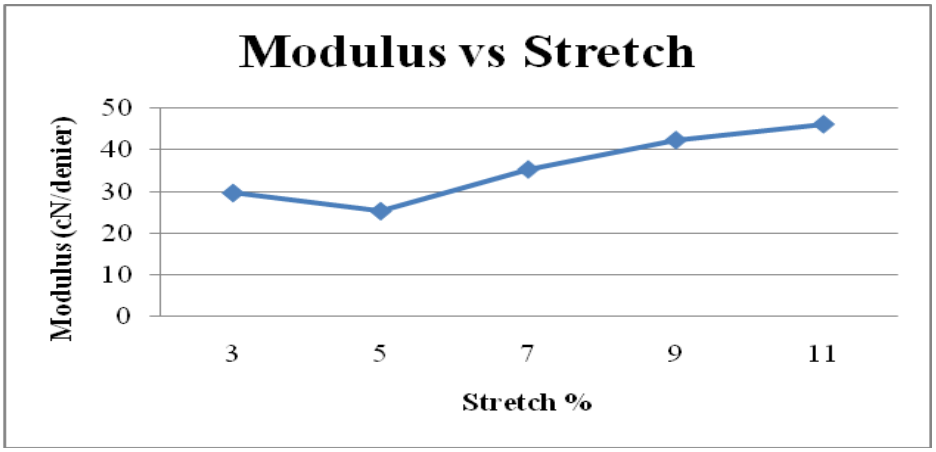


Figure 4.20: Modulus of S325 yarns with different mechanical stretch

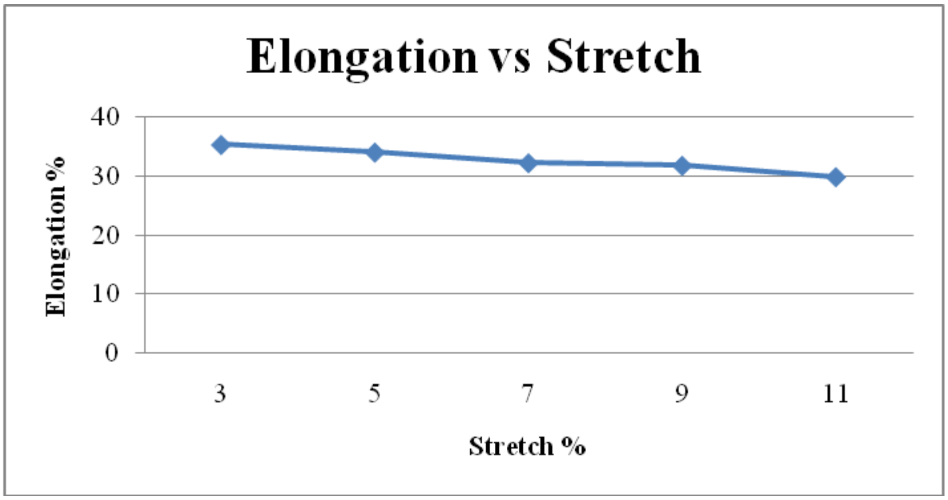


Figure 4.21: Elongation of S325 yarns with different mechanical stretch

- It is evident from the Figure 4.19 that the tenacity of the textured yarn slightle increases with the increase in the post-texturing stretch. The denier of the yarns decreases as the stretch is increased since the looser fiber loops are tightened and locked.
- The increasing trend in modulus is shown in Figure 4.20. Since the stretching locks the loops together there is less movement available during subsequent stretching (that is in testing) and thus the measured modulus is higher.
- With respect to Figure 4.21, the elongation of the yarn decreases with increase in post-

- texturing stretch and the reasoning is same as the change in modulus.

4.6 S315 Experiments

The next five experiments were carried out with the nozzle, S315. The parameters are chosen according to the specifications and limitations of S315. The experiments were carried in the same manner as that of S325 experiments.

4.6.1 Overfeed

The first of the five set of experiments was carried out to find an optimum overfeed percentage by varying the overfeed percentage while keeping the other parameters constant. The parameters chosen for the experiment and the results are shown in table 20 and table 21 respectively.

Table 20: Parameters for effect of overfeed with S315

Draw Ratio	Pressure (kPa)	Temperature (^oC)	Overfeed (%)	Stretch (%)	Speed (m/min)	Winding Speed (m/min)
1.6	689.5	90	16	5	725	787
1.6	689.5	90	18	5	725	787
1.6	689.5	90	20	5	725	787
1.6	689.5	90	22	5	725	787
1.6	689.5	90	24	5	725	787

Table 21: Effect of overfeed on S315 yarns

Denier	Peak load (cN)	Elongation % at Peak load	Modulus (cN/denier)	Tenacity (cN/denier)	Over feed (%)
155.34	503.21	38.07	39.46	3.24	16
156.39	528.60	41.79	34.44	3.38	18
157.86	537.91	42.14	35.32	3.41	20
157.54	515.39	42.09	29.07	3.27	22
159.12	520.51	43.17	27.64	3.27	24

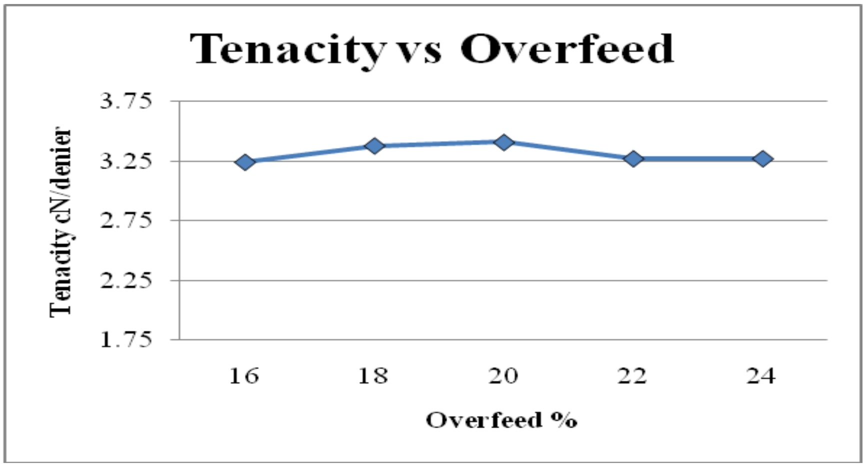


Figure 4.22: Tenacity of S315 yarns with different overfeed percentage

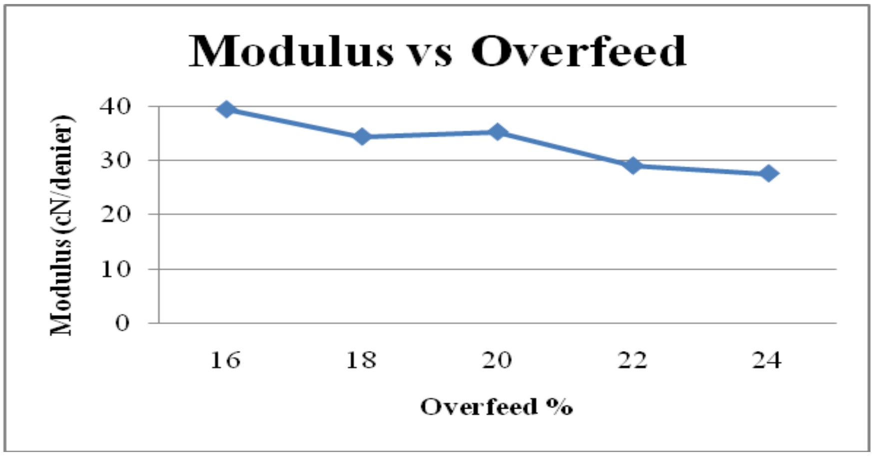


Figure 4.23: Modulus of S315 yarns with different overfeed percentage

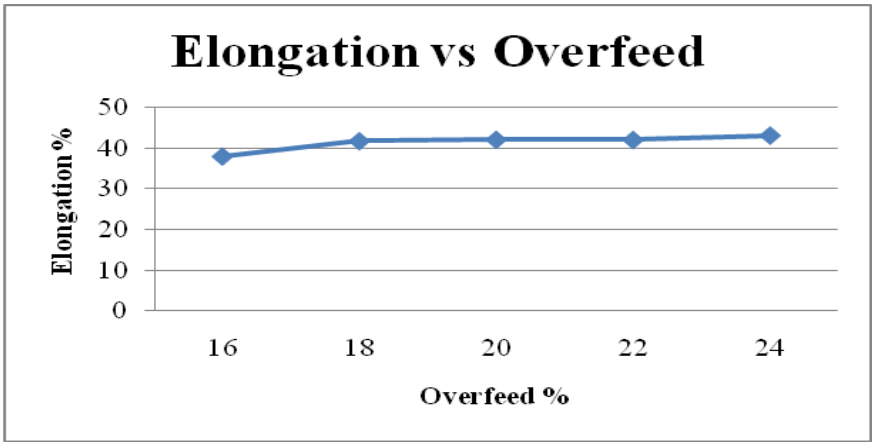


Figure 4.24: Elongation of S315 yarns with different overfeed percentage

- The tenacity of the yarn textured with S315 (Figure4.22) is almost constant with increasing the overfeed percentage.
- Just like the yarns textured with S325, the modulus of yarns textured with S315 also reduces as the overfeed percentage is increased. This is evident from the graph in Figure 4.23.
- With respect to Figure. 4.24, there seems to be a very little increase in the elongation of the yarn with increase in the overfeed percentage.

4.6.2 Pressure

This experiment was carried out for the study of effects of pressure on the properties of the yarn textured using S315. The parameters chosen for the experiment and the results are given in table 22 and table 23 respectively.

Table 22: Parameters for effect of pressure with S315

Draw Ratio	Pressure (kPa)	Temperature (^{o}C)	Overfeed (%)	Stretch (%)	Speed (m/min)	Winding Speed (m/min)
1.6	620.5	90	22	5	725	787
1.6	689.5	90	22	5	725	787
1.6	758.4	90	22	5	725	787
1.6	827.4	90	22	5	725	787
1.6	896.3	90	22	5	725	787

Table 23: Effect of pressure on S315 yarns

Denier	Peak load	Elongation % at Peak load	Modulus (cN/denier)	Tenacity (cN/denier)	Pressure (kPa)
158.77	525.00	46.79	29.91	3.30	620.5
157.54	515.39	42.09	29.07	3.27	689.5
157.99	512.66	46.32	27.32	3.24	758.4
158.82	488.80	42.01	29.02	3.08	827.4
159.61	498.28	42.89	31.12	3.13	896.3

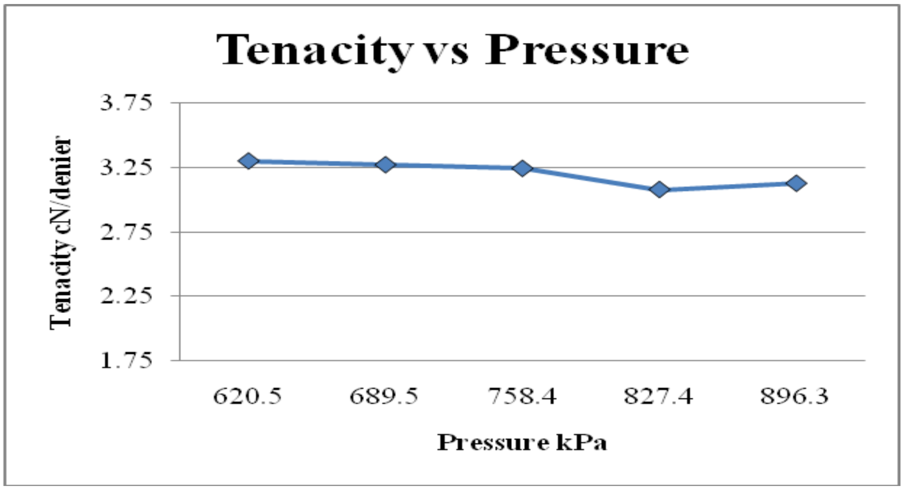


Figure 4.25: Tenacity of S315 yarns with different pressure setting

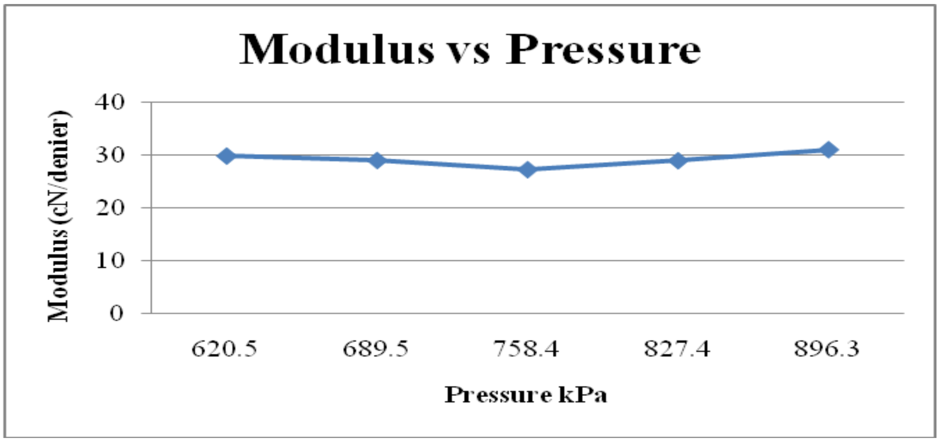


Figure 4.26: Modulus of S315 yarns with different pressure setting

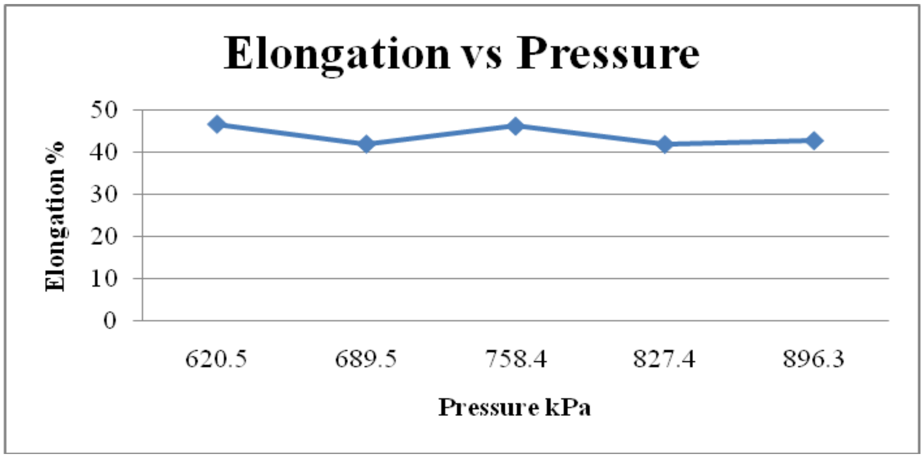


Figure 4.27: Elongation of S315 yarns with different pressure setting

- From figures 4.25, 4.26 and 4.27 it is evident that within the experimental conditions, pressure seems to play a minor role on yarn tensile properties. It is clear that jet S315 is less sensitive to pressure when compared S325 (Figure 4.10, Figure 4.11 and Figure 4.12)

4.6.3 Take-up speed

The next experiment involves changing the take-up speed of the textured yarn while all the other parameters are kept constant throught the experiment. Table 24 and table 25 shows the parameters and results of this experiment respectively.

Table 24: Parameters for effect of take up speed with S315

Draw Ratio	Pressure (kPa)	Temperature (^{o}C)	Overfeed (%)	Stretch (%)	Speed (m/min)	Winding Speed (m/min)
1.6	758.4	90	22	5	675	733
1.6	758.4	90	22	5	700	760
1.6	758.4	90	22	5	725	787
1.6	758.4	90	22	5	750	815
1.6	758.4	90	22	5	775	842

Table 25: Effect of take up speed on S315 yarns

Denier	Peak load (cN)	Elongation % at Peak load	Modulus (cN/denier)	Tenacity (cN/denier)	Speed (m/min)
159.69	497.91	43.23	28.09	3.12	675
159.97	508.12	44.21	28.06	3.18	700
157.99	512.66	46.32	27.32	3.24	725
158.57	516.15	46.46	29.32	3.25	750
159.56	521.12	46.51	29.13	3.26	775

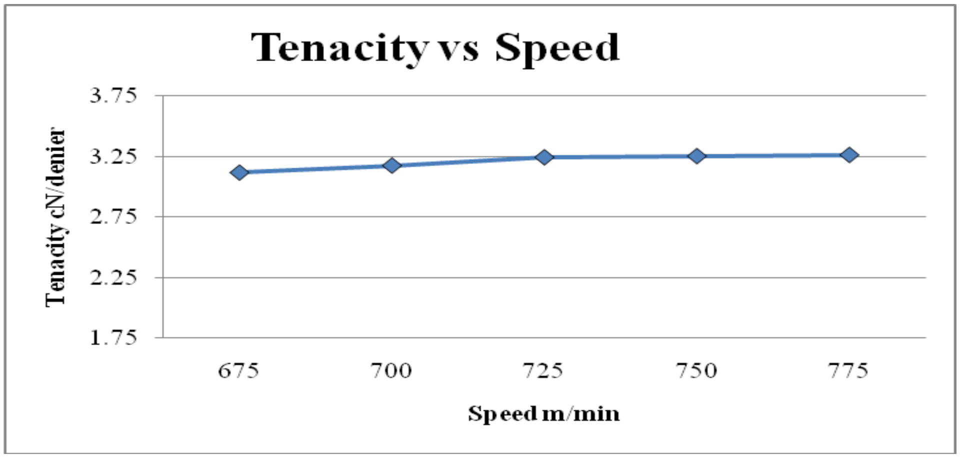


Figure 4.28: Tenacity of S315 yarns at different take up speeds

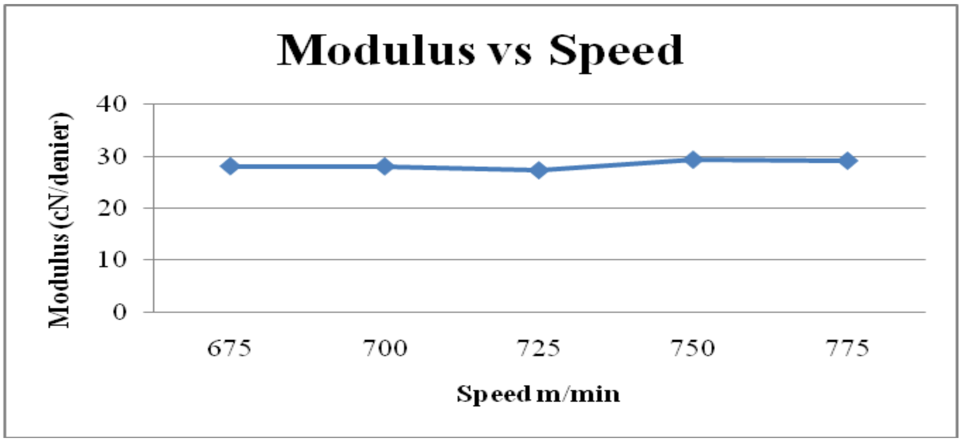


Figure 4.29: Modulus of S315 yarns at different take up speeds

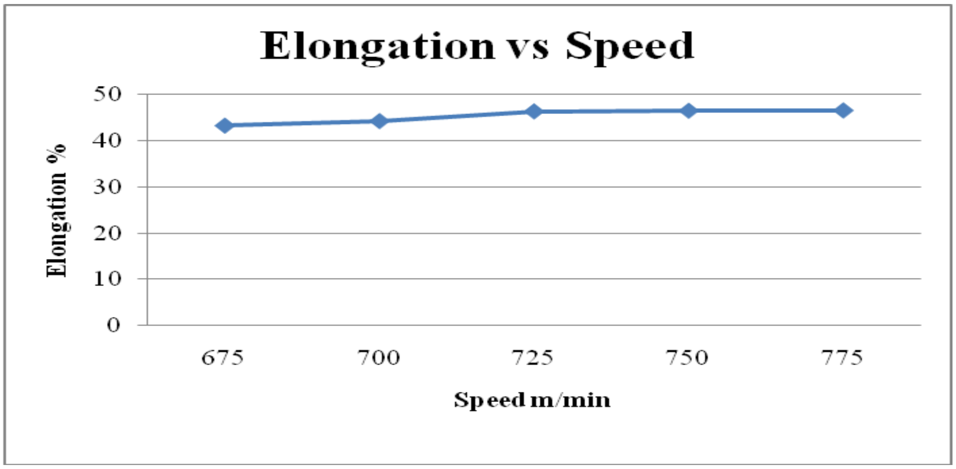


Figure 4.30: Elongation of S315 yarns at different take up speeds

- As evident from the Figure 4.28, the tenacity of yarns textured at high speeds using S315 nozzle jet is higher than those textured at low speeds. This means that at higher speeds the yarn tends to texture more at slow speed. This can be vouched by the results of elongation tests which are shown in Figure 4.30 for the same set of yarns. The fact that elongation increases with increase in speed suggests that more nuber of fibers are not textured and hence constitutes more elongation.The Figure 4.29 indicates that the modulus of the yarn is almost constant for all the speeds.

4.6.4 Temperature

This experiment is carried out with the parameters shown in table 26. Effect of temperature is observed in this experiment. The results are shown in table 27.

Table 26: Parameters for effect of draw zone temperature with S315

Draw Ratio	Pressure (kPa)	Temperature (^oC)	Overfeed (%)	Stretch (%)	Speed (m/min)	Winding Speed (m/min)
1.6	689.5	90	22	5	725	787
1.6	689.5	100	22	5	725	787
1.6	689.5	110	22	5	725	787
1.6	689.5	120	22	5	725	787
1.6	689.5	130	22	5	725	787

Table 27: Effect of draw zone temperature on S315 yarns

Denier	Peak load (cN)	Elongation % at peak load	Modulus (cN/denier)	Tenacity (cN/denier)	Temperature (^oC)
157.54	515.39	42.09	29.07	3.27	90
160.05	533.76	44.90	33.41	3.33	100
158.44	545.54	44.68	34.42	3.44	110
159.28	541.09	43.66	32.67	3.40	120
162.21	478.56	42.11	29.68	2.95	130

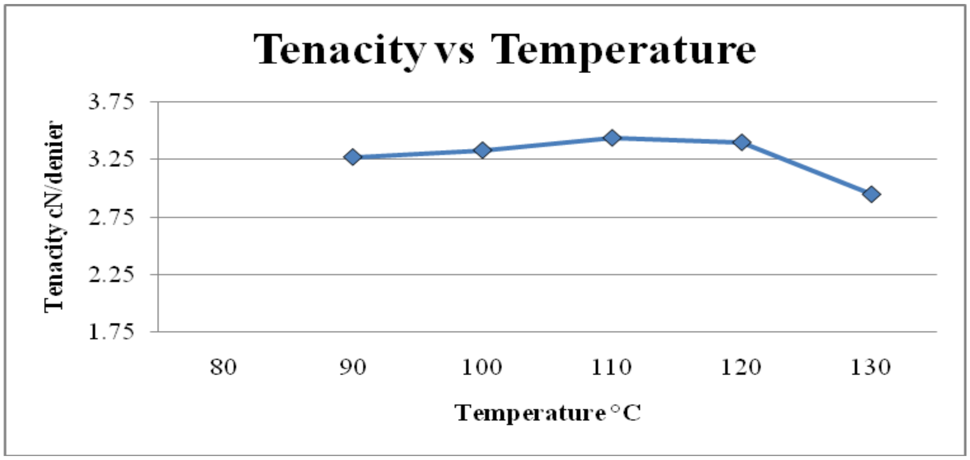


Figure 4.31: Tenacity of S315 yarns with different draw zone temperature setting

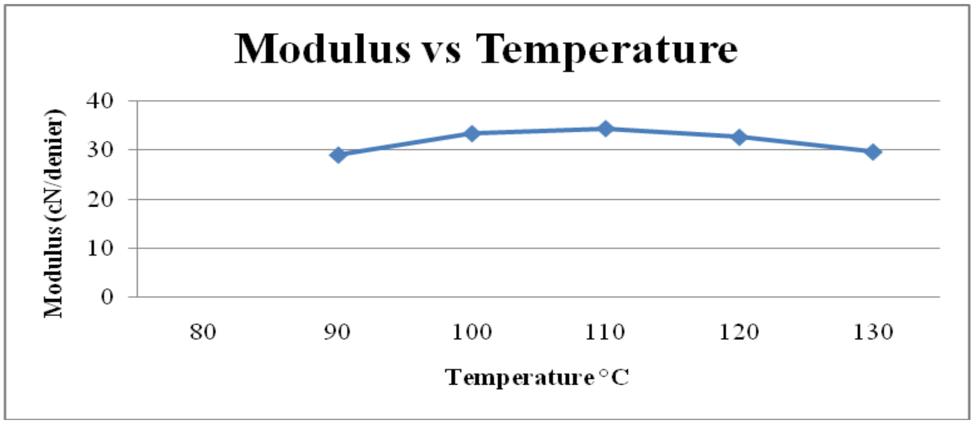


Figure 4.32: Modulus of S315 yarns with different draw zone temperature setting

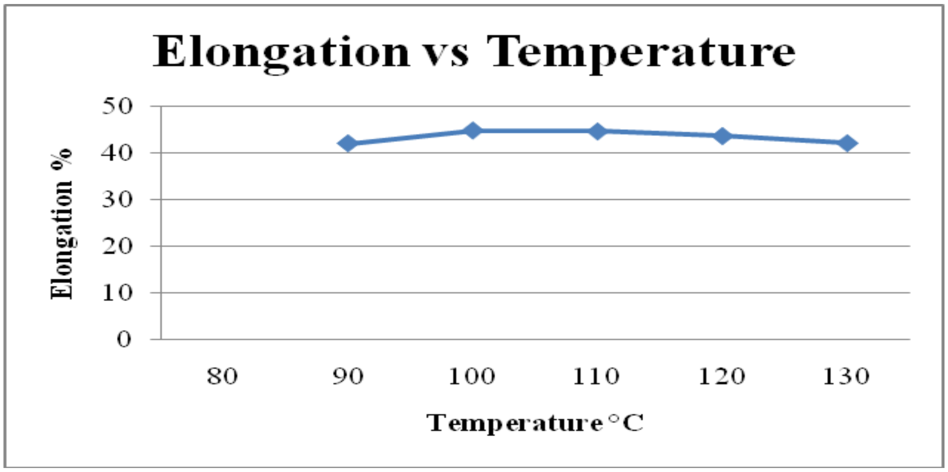


Figure 4.33: Elongation of S315 yarns with different draw zone temperature setting

- It is clear from Figure 4.31 to Figure 4.33 that the tensile properties of the yarn appear to reach through a maximum with increasing drawing temperature and the highest tenacity, modulus and elongation is achieved at about 110 ^{o}C.

4.6.5 Post-Texturing Stablization

Next experiment is done to analyse the effect of post-texturing stretch on the properties of the yarn. The parameters used in the texturing process and the results are shown in table 28 and table 29 respectively.

Table 28: Parameters for effect of pos-texturing stretch with S315

Draw Ratio	Pressure (kPa)	Temperature (^{o}C)	Overfeed (%)	Stretch (%)	Speed (m/min)	Winding Speed (m/min)
1.6	689.5	110	22	3.5	725	776
1.6	689.5	110	22	4	725	780
1.6	689.5	110	22	4.5	725	784
1.6	689.5	110	22	5	725	788
1.6	689.5	110	22	5.5	725	792

Table 29: Effect of post-texturing stretch on S315 yarns

Denier	Peak load (cN)	Elongation % at Peak load	Modulus (cN/denier)	Tenacity (cN/denier)	Stretch (%)
163.91	472.59	41.93	31.43	2.88	3.5
163.55	484.88	43.50	30.53	2.97	4
161.06	472.73	40.53	35.25	2.94	4.5
158.44	545.54	44.68	34.42	3.44	5
161.28	503.30	42.99	40.81	3.04	5.5

- The graph in Figure 4.34 and Figure 4.36 reveals that the amount stretch in post-texturing stage has a little effect on the tenacity of the yarn and elongation of the yarn. As observed in Figure 4.35, the modulus of the yarn increases with increase stablizing zone stretch.

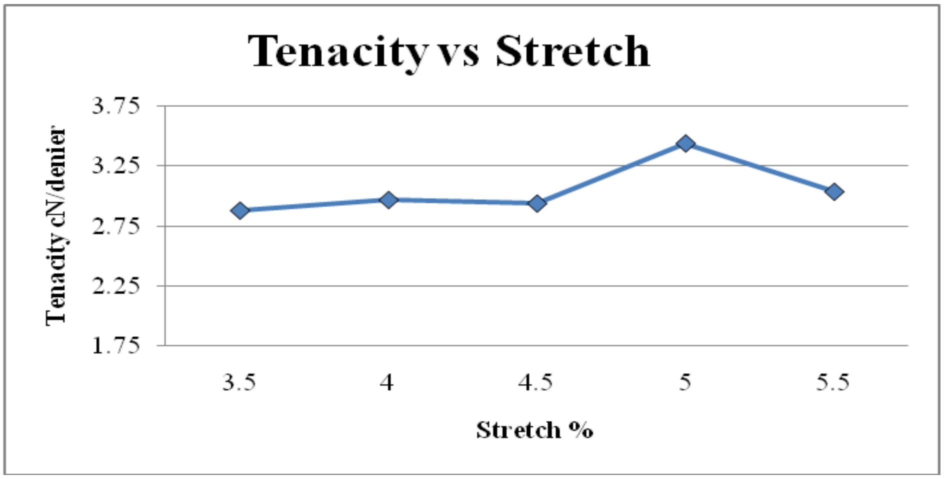


Figure 4.34: Tenacity of S315 yarns with different mechanical stretch

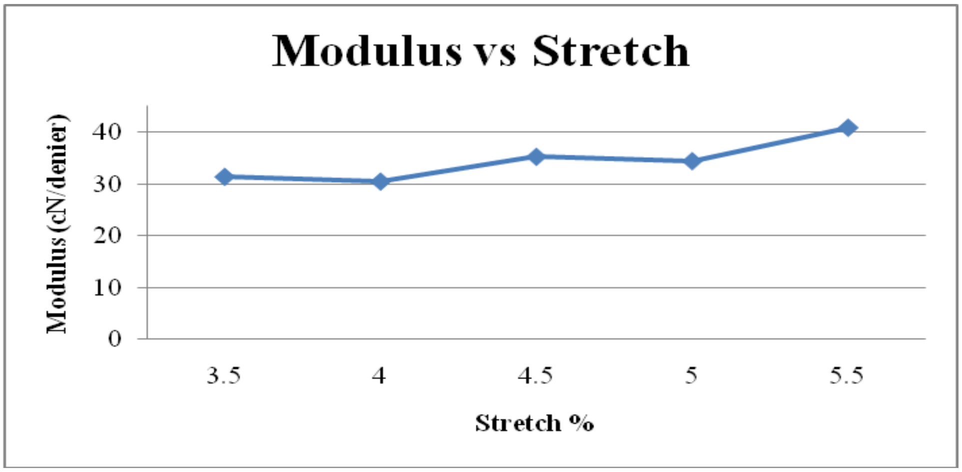


Figure 4.35: Modulus of S315 yarns with different mechanical stretch

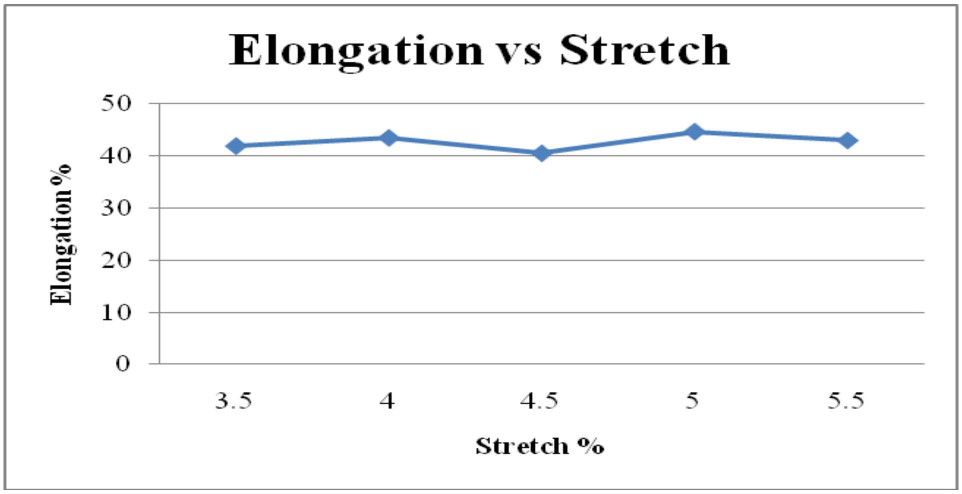


Figure 4.36: Elongation of S315 yarns with different mechanical stretch

4.7 A317 Experiments

The final set of experiments were carried out with A317 jet nozzle. The experimental parameters were changed only slightly from the previous set. The intentions of these experiments were same as the previous two experiments. It was carried out to study the effect of parametric variables on the properties of the textured yarn.

4.7.1 Overfeed

First of the five experiments was carried out to study the effect of overfeed percentage. The parameters considered for the experiment and the results are show in table 30 and table 31 respectively.

Table 30: Parameters for effect of overfeed with A317

Draw Ratio	Pressure (kPa)	Temperature (^{o}C)	Overfeed (%)	Stretch (%)	Speed (m/min)	Winding Speed (m/min)
1.6	758.4	90	16	5	725	787
1.6	758.4	90	18	5	725	787
1.6	758.4	90	20	5	725	787
1.6	758.4	90	22	5	725	787
1.6	758.4	90	24	5	725	787

Table 31: Effect of overfeed on A317 yarns

Denier	Peak load (cN)	Elongation % at Peak load	Modulus (cN/denier)	Tenacity (cN/denier)	Over feed (%)
157.97	514.54	39.74	41.17	3.25	16
158.44	522.48	41.28	41.31	3.29	18
159.23	518.24	42.50	35.74	3.25	20
160.41	515.05	42.77	32.68	3.21	22
162.02	502.90	42.24	29.61	3.11	24

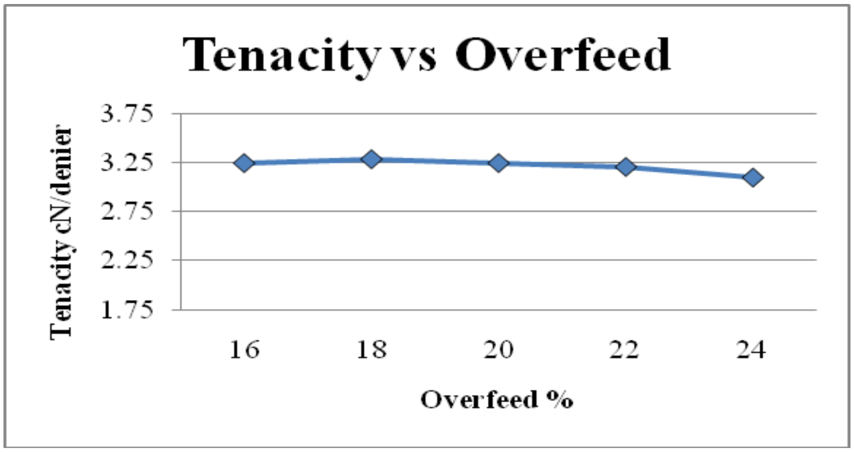


Figure 4.37: Tenacity of A317 yarns with different overfeed percentage

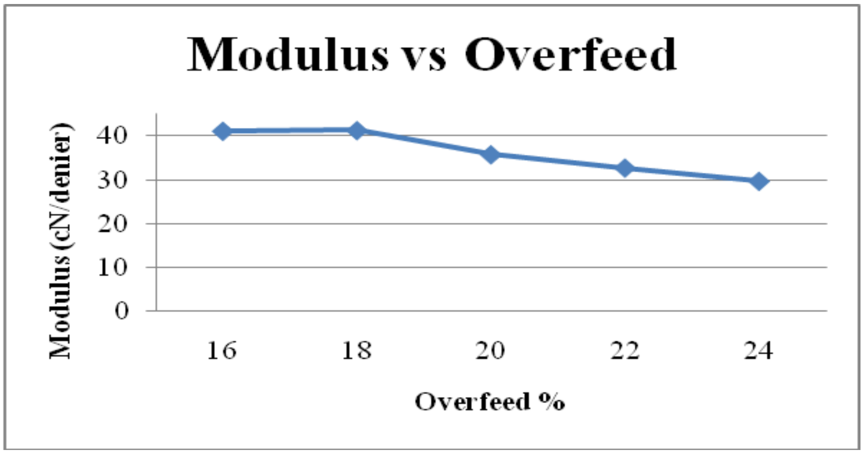


Figure 4.38: Modulus of A317 yarns with different overfeed percentage

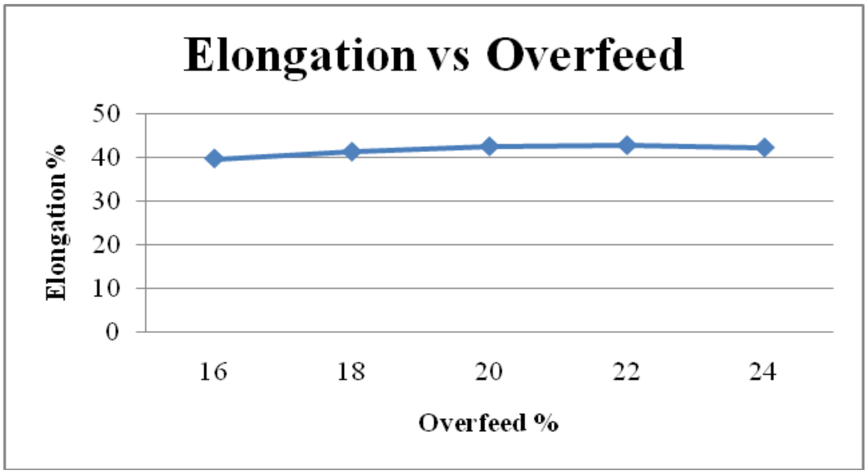


Figure 4.39: Elongation of A317 yarns with different overfeed percentage

- With respect to Figure 4.37, 4.38 and Figure 4.39 the tensile properties yarns textured by A317 jet are same as that of jet S315. This can be attributed to the close proximity of the specifications of the two jet cores and the parameteric values chosen for the experiments with two jets.

4.5.2 Pressure

The next experiment was carried out with the parameters shown in table 32.

Table 32: Parameters for effect of pressure with A317

Draw Ratio	Pressure (kPa)	Temperature (^{o}C)	Overfeed (%)	Stretch (%)	Speed (m/min)	Winding Speed (m/min)
1.6	620.5	90	24	5	725	787
1.6	689.5	90	24	5	725	787
1.6	758.4	90	24	5	725	787
1.6	827.4	90	24	5	725	787
1.6	896.3	90	24	5	725	787

Table 33: Effect of pressure on A317 yarns

Denier	Peak load (cN)	Elongation% at Peak load	Modulus (cN/denier)	Tenacity (cN/denier)	Pressure (kPa)
159.48	538.58	46.12	31.15	3.38	90
161.31	498.60	41.57	28.60	3.09	100
162.02	502.90	42.24	29.61	3.11	110
161.03	493.07	40.16	33.86	3.06	120
161.83	470.33	36.81	32.27	2.91	130

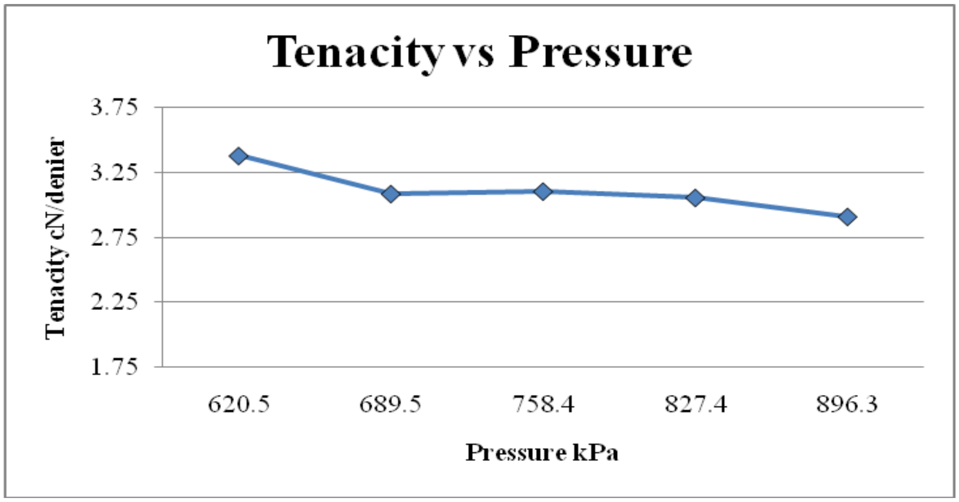


Figure 4.40: Tenacity of A317 yarns with different pressure setting

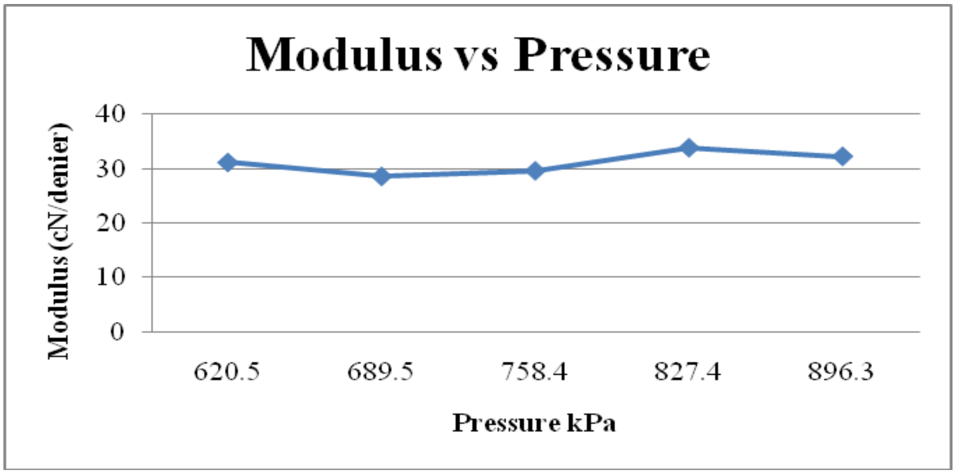


Figure 4.41: Modulus of A317 yarns with different pressure setting

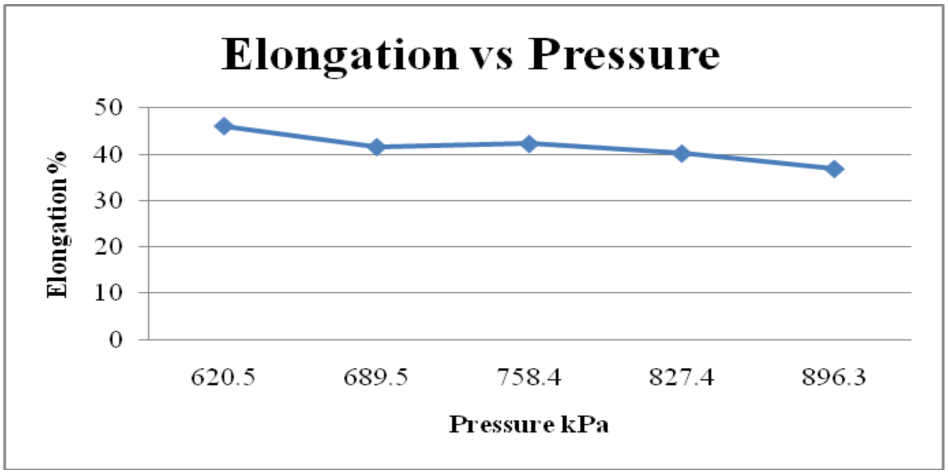


Figure 4.42: Elongation of A317 yarns with different pressure setting

- From all the graphs in Figure 4.40, Figure 4.41 and Figure 4.42, it is clearly evident that the quality of texturing increases with increase in pressure inside the jet nozzle. The Figure 4.40 where the tenacity decreases with increase in pressure indicates that fibers are textured well to have formed loops and locked together resulting in less tenacity in the yarn.

4.7.3 Take-up speed

The following experiment is carried out to study the effect of take-up speed on the properties of the yarn. The parameters considered for the experiment and the results are shown in table 34 and table 35 respectively.

Table 34: Parameters for effect of take up speed with A317

Draw Ratio	Pressure (kPa)	Temperature (^{o}C)	Overfeed (%)	Stretch (%)	Speed (m/min)	Winding Speed (m/min)
1.6	620.5	90	22	5	650	706
1.6	620.5	90	22	5	675	733
1.6	620.5	90	22	5	700	760
1.6	620.5	90	22	5	725	787
1.6	620.5	90	22	5	750	813

Table 35: Effect of take up speed on A317 yarns

Denier	Peak load (cN)	Elongation % at Peak load	Modulus (cN/denier)	Tenacity (cN/denier)	Speed (m/min)
159.67	522.62	43.11	28.92	3.27	650
159.94	527.62	44.01	27.64	3.30	675
160.57	521.43	42.36	33.19	3.24	700
159.48	538.58	46.12	31.15	3.38	725
160.02	533.05	45.18	34.93	3.33	750

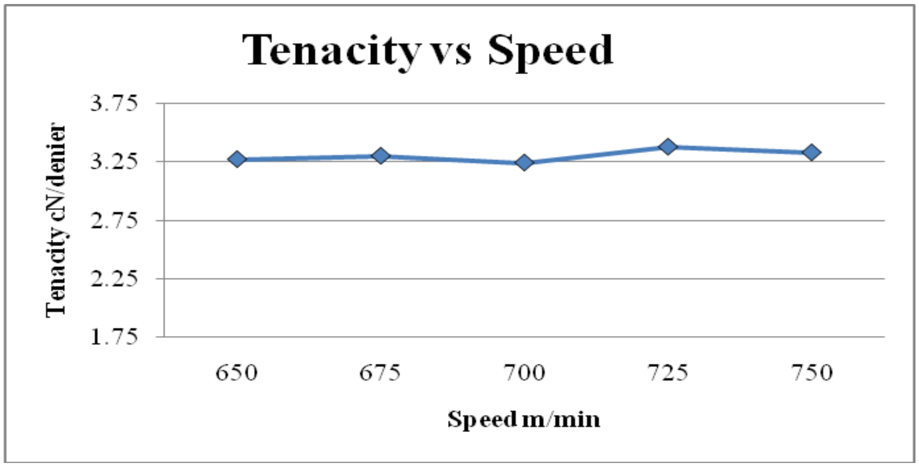


Figure 4.43: Tenacity of A317 yarns at different take up speeds

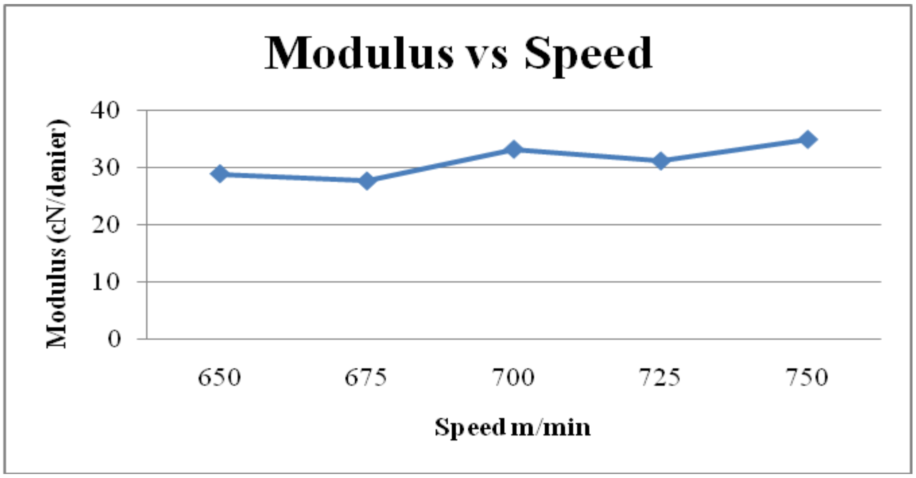


Figure 4.44: Modulus of A317 yarns at different take up speeds

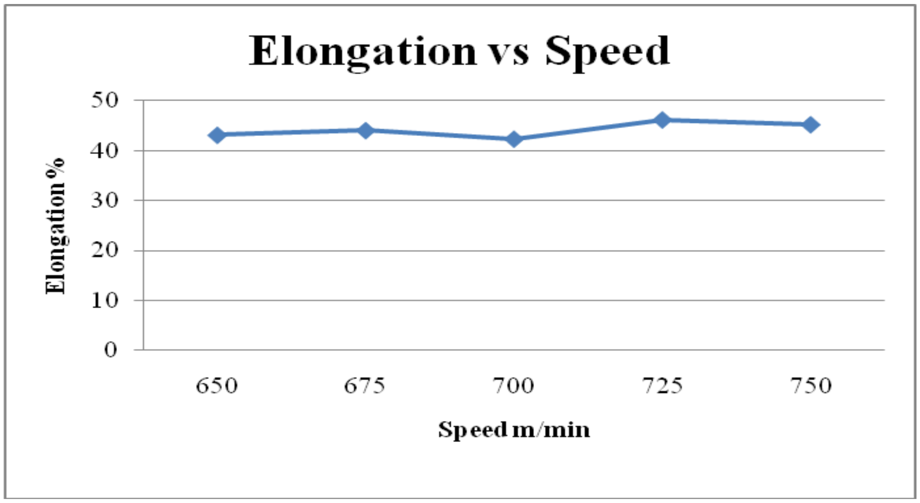


Figure 4.45: Elongation of A317 yarns at different take up speeds

- As suggested by the Figure 4.43- 4.45, the tensile properties of the yarns textured with A317 at different take-up speeds are same as that of yarns textured by S315 jet.

4.7.4 Temperature

The next set of samples are tested for the effect of draw zone temperature on the properties of the yarn. The parameters considered for the experiment and the results are shown in table 36 and table 37 respectively.

Table 36: Parameters for effect of draw zone temperature with A317

Draw Ratio	Pressure (kPa)	Temperature (^oC)	Overfeed (%)	Stretch (%)	Speed (m/min)	Winding Speed (m/min)
1.6	758.4	80	22	5	725	787
1.6	758.4	90	22	5	725	787
1.6	758.4	100	22	5	725	787
1.6	758.4	110	22	5	725	787
1.6	758.4	120	22	5	725	787

Table 37: Effect of draw zone temperature on A317 yarns

Denier	Peak load (cN)	Elongation % at Peak load	Modulus (cN/denier)	Tenacity (cN/denier)	Temperature (°C)
161.31	502.92	41.26	32.24	3.12	80
160.41	515.05	42.77	32.68	3.21	90
162.24	533.85	41.93	41.93	3.29	100
160.84	531.15	39.72	41.87	3.30	110
161.03	537.18	37.83	42.17	3.33	120

- Elongational properties of the yarn textured by A317 is same as that of yarns textured by S315.

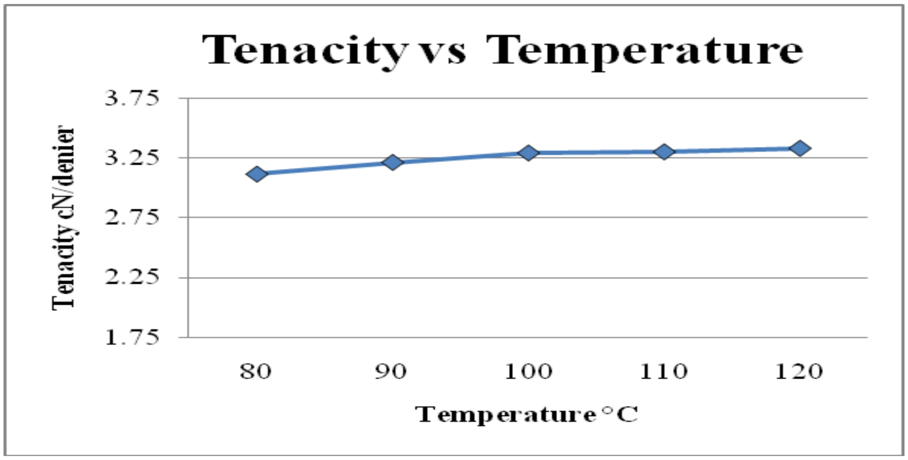


Figure 4.46: Tenacity of A317 yarns with different draw zone temperature setting

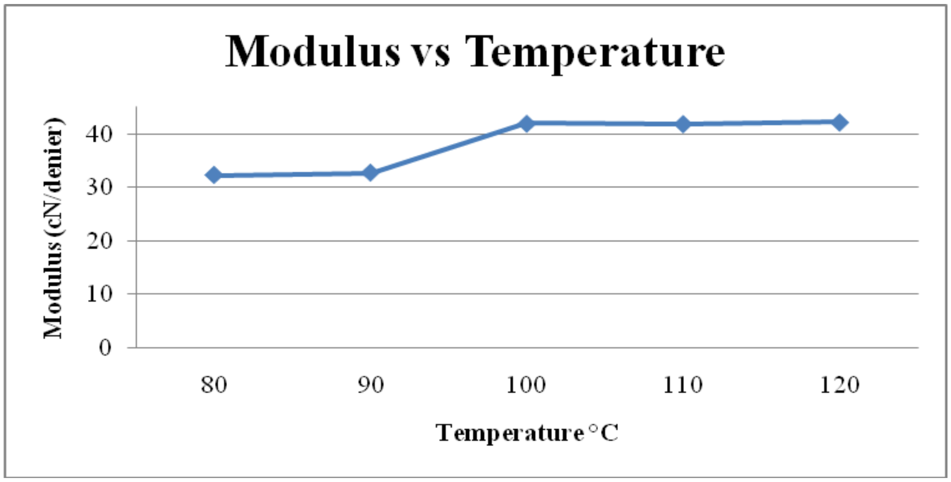


Figure 4.47: Modulus of A317 yarns with different draw zone temperature setting

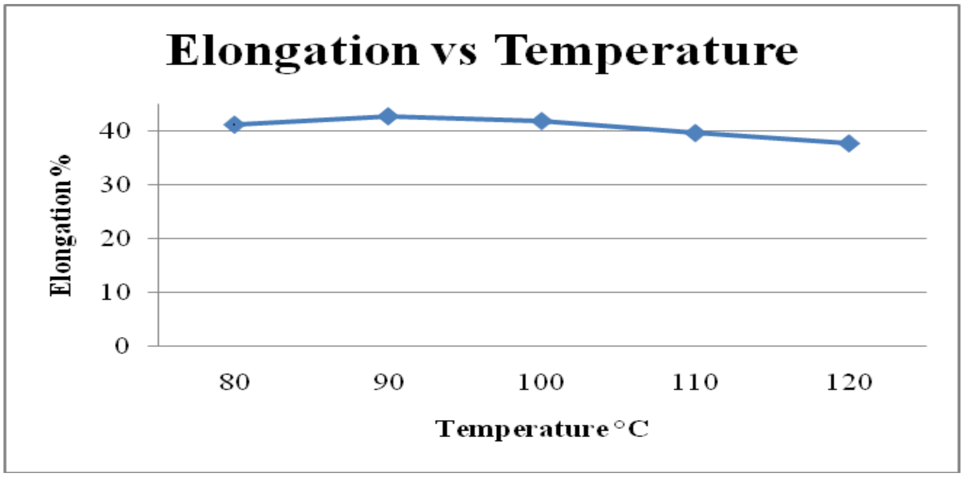


Figure 4.48: Elongtion of A317 yarns with different draw zone temperature setting

- Graphs from Figure 4.46 and 4.47 suggest that the tenacity and modulus of the yarns increases with increase in temperature. While the modulus of the yarn is slightly higher than that of yarns textured by S315, the tenacity of the yarns textured by the two jets are almost same.

4.7.5 Post-Texturing Stabilization

The final experiment of this study is done with the variable post-texturing stretch while all other parameters are kept constant. The parameters used and the results obtained are shown in table 38 and table 39 respectively:

Table 38: Parameters for effect of post-texturing stretch with A317

Draw Ratio	Pressure (kPa)	Temperature (^{o}C)	Overfeed (%)	Stretch (%)	Speed (m/min)	Winding Speed (m/min)
1.6	758.4	90	22	3.5	725	776
1.6	758.4	90	22	4	725	780
1.6	758.4	90	22	4.5	725	784
1.6	758.4	90	22	5	725	787
1.6	758.4	90	22	5.5	725	791

Table 39: Effect of post-texturing stretch on A317 yarns

Denier	Peak load (cN)	Elongation % at Peak load	Modulus (cN/denier)	Tenacity (cN/denier)	Stretch (%)
161.64	504.75	42.32	25.81	3.13	3.5
162.54	497.38	40.81	27.49	3.06	4
161.83	511.58	41.55	31.68	3.17	4.5
160.41	515.05	42.77	32.68	3.21	5
161.06	516.76	40.51	38.31	3.20	5.5

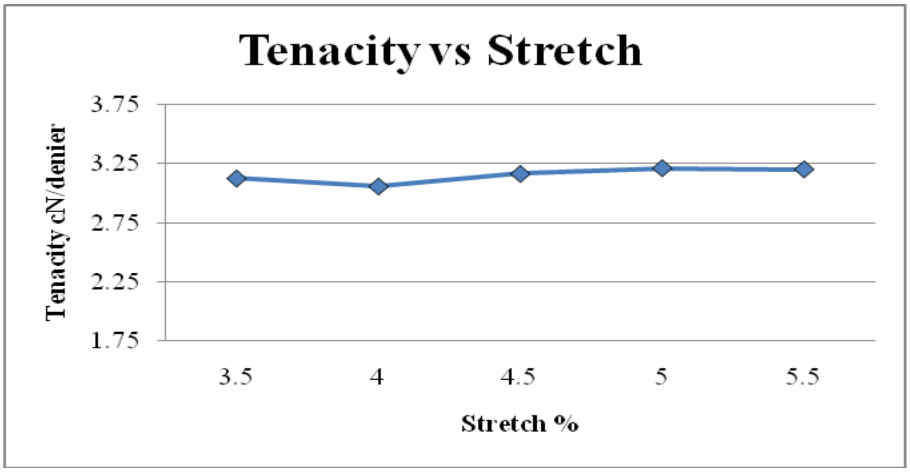


Figure 4.49: Tenacity of A317 yarns with different mechanical stretch

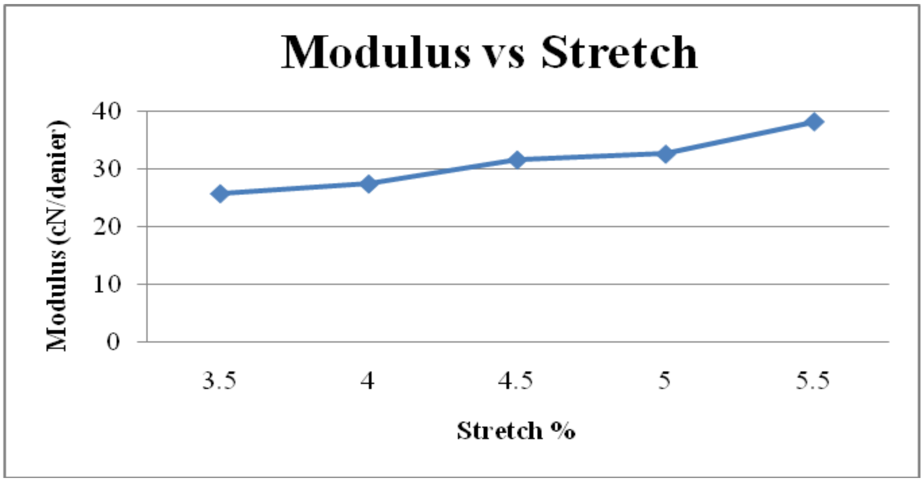


Figure 4.50: Modulus of A317 yarns with different mechanical stretch

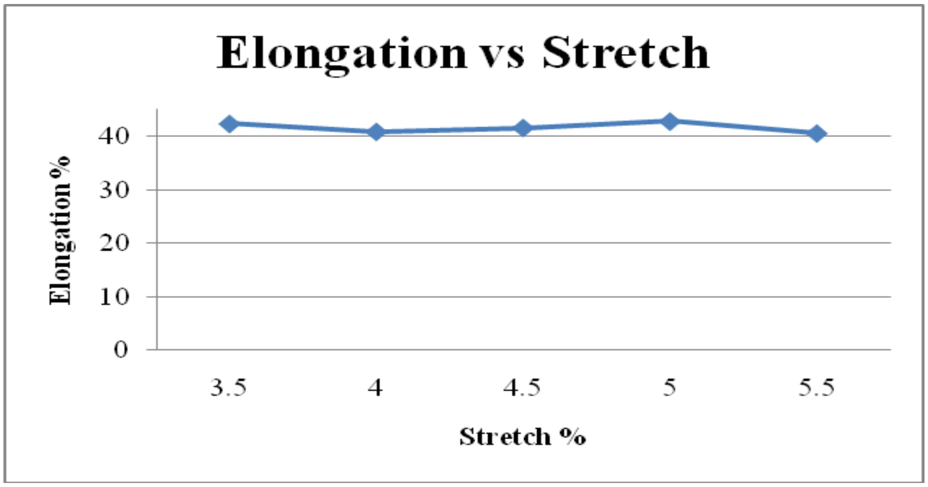


Figure 4.51: Elongation of A317 yarns with different mechanical stretch

- In comparison with the yarns textured by jets S325 and S315, the tensile properties of the yarns textured by A317 follows the same trend in the graph. This is evident from the graphs 4.49 and 4.50. The tensile strength of these yarns appear to slightly higher than of yarns textured by S325 and almost equal to that S315. Elongation of these yarns are almost same as that of textured by S315.

5.CONCLUSION AND RECOMMENDATIONS

From all the experiments conducted during this research, it became clearly evident that the fine yarns can be textured at high speeds very effectively. Although the recommended speeds from the industry are much slower, the experiments conducted in this study provides satisfactory results as to claim that high speed texturing is possible with suitable jet nozzles and air-jet texturing machine.

Based on the three sets of experiments using three different jets the following graphs are charted out. The graphs are drawn to compare the tensile properties and elongation of the yarn textured using these three different jets. The data used is from the earlier trails and it should be emphasized that these were carried out under a range of conditions, close to those recommended by the jet manufacturer (table 2). This means that while the charts which follow can be used as broad indicators of the effect of jet choice on yarn properties, they should not be viewed as a planned experimental comparison since other parameters may also be changing (for example in Figure 5.1 while the effect of overfeed is shown for the different jets other variables such as speed, pressure etc may also have an effect. However it is not possible to run all jets under exactly the same condition while only changing one variable).

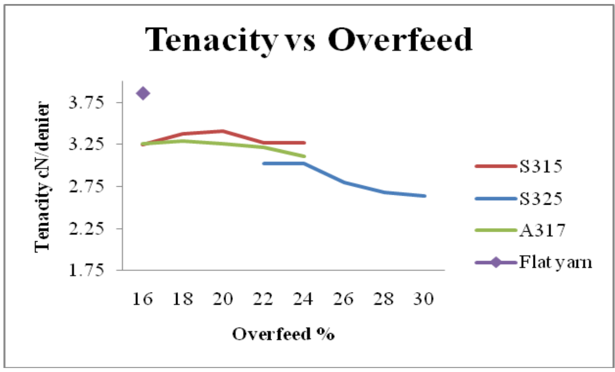


Figure 5.1: Comparison of tenacity vs overfee

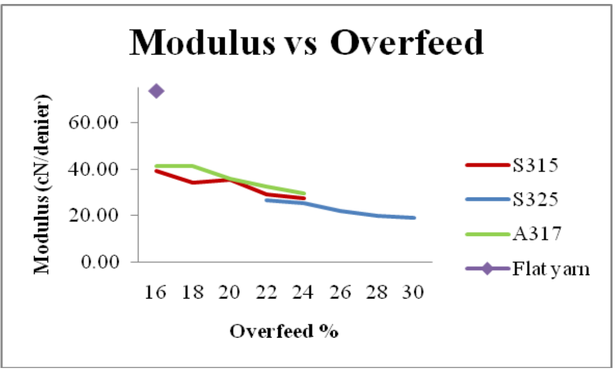
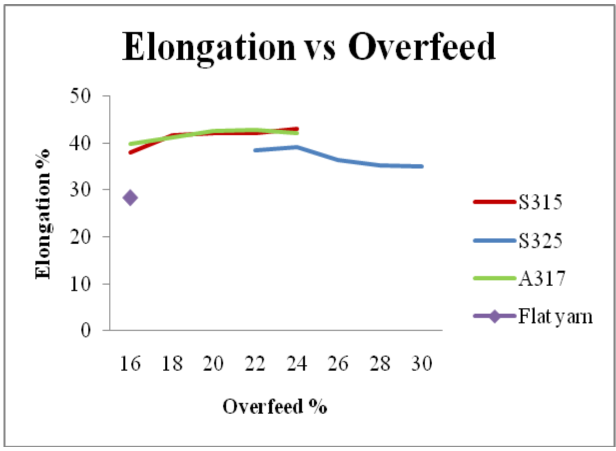


Figure 5.2: Comparison of modulus vs overfeed



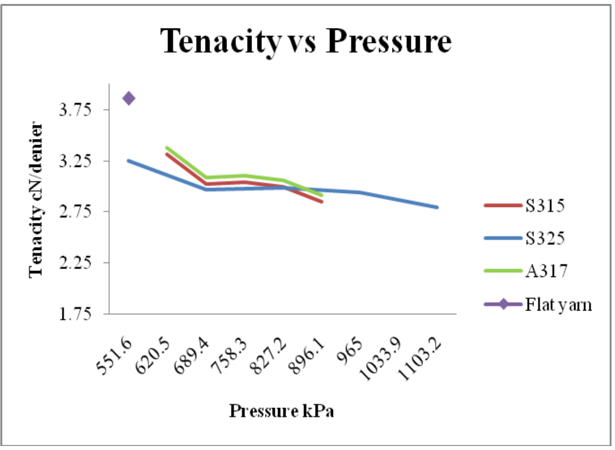
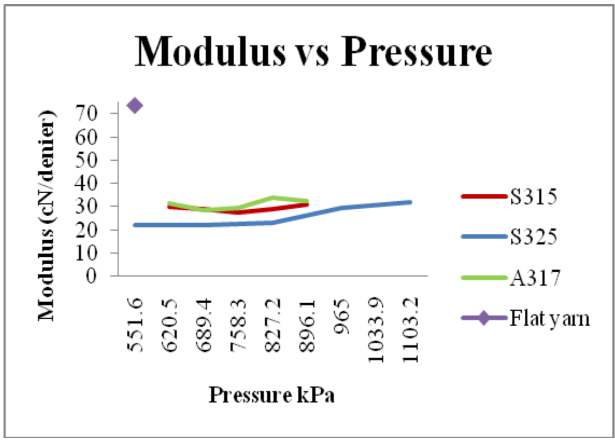


Figure 5.3: Comparison of elongation vs overfeed Figure5.4: Comparison of tenacity vs pressure



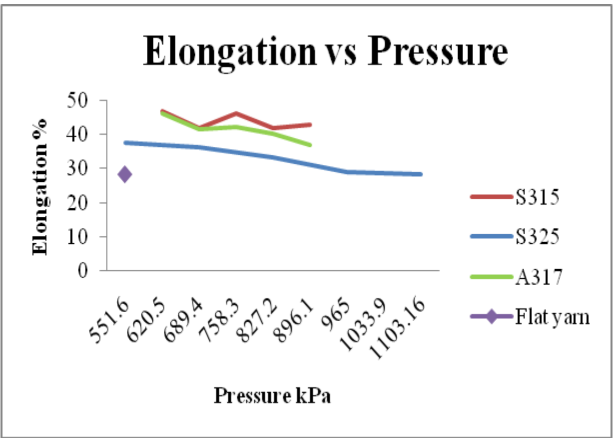


Figure 5.5:Comparison of modulus vs pressure Figure 5.6: Comparison of elongation vs pressure

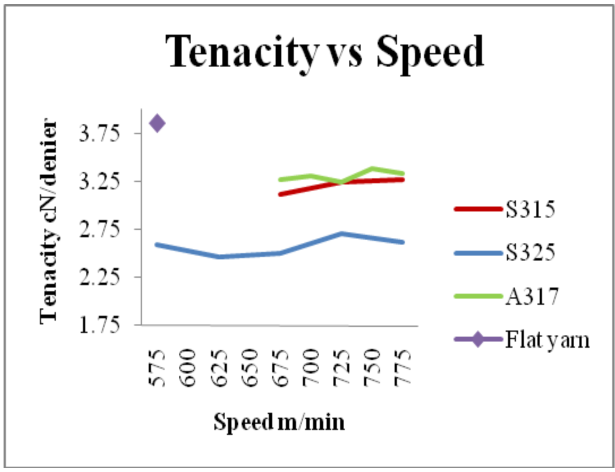


Figure 5.7: Comparison of tenacity vs speed

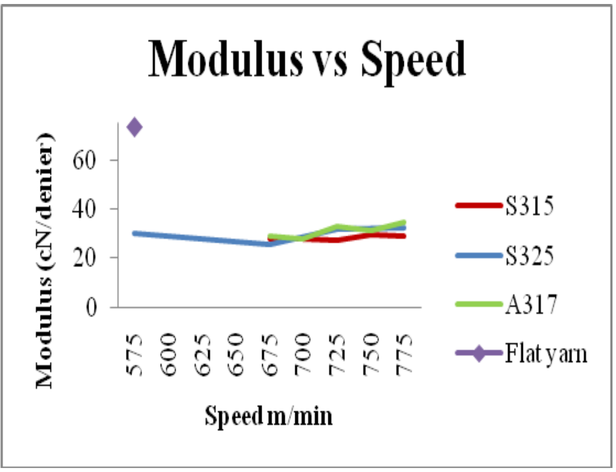
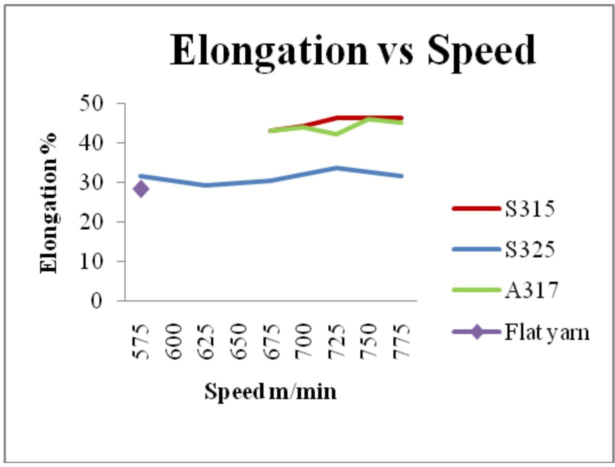


Figure 5.8 : Comparison of modulus vs speed



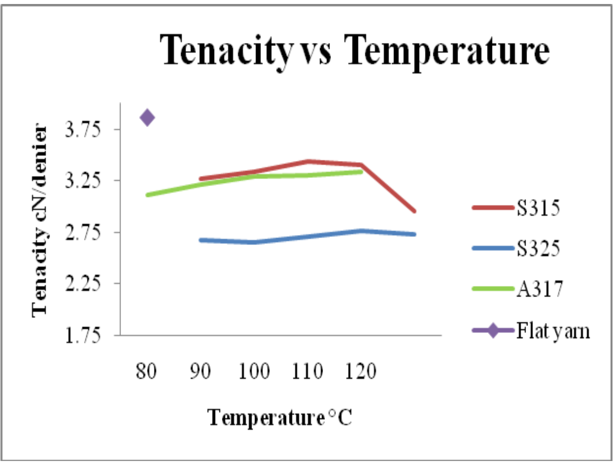
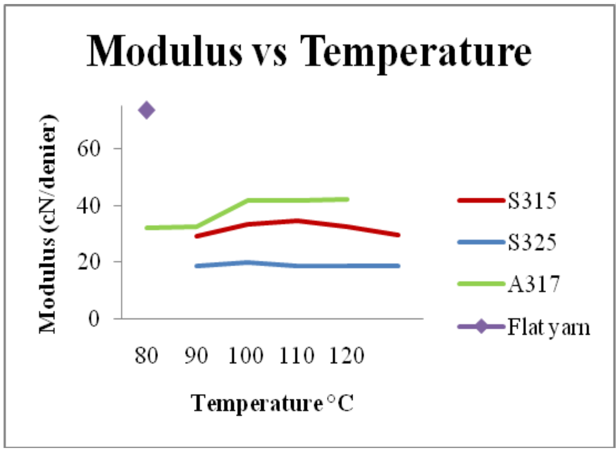


Figure 5.9:Comparison of elongation vs speed Figure5.10:Comparison of tenacity vs temperature



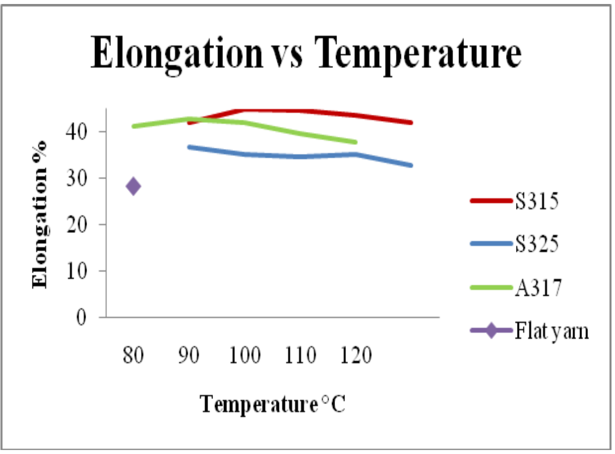
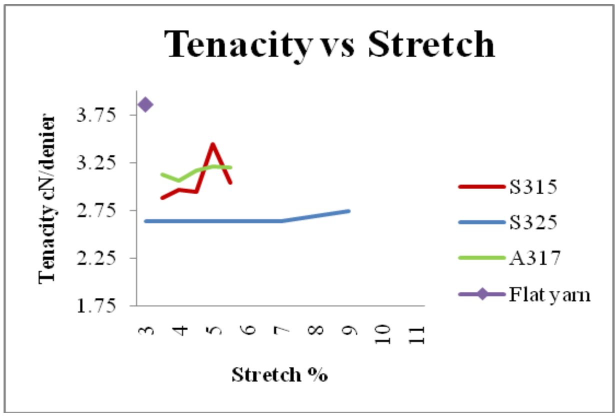


Figure5.11:Comparison of modulus vs temperature Figure5.12:Comparison of elongation vs temperature



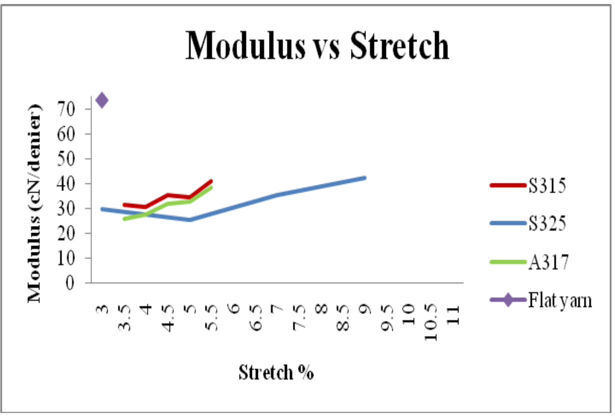


Figure 5.13: Comparison of tenacity vs stretch Figure 5.14: Comparison of modulus vs stretch

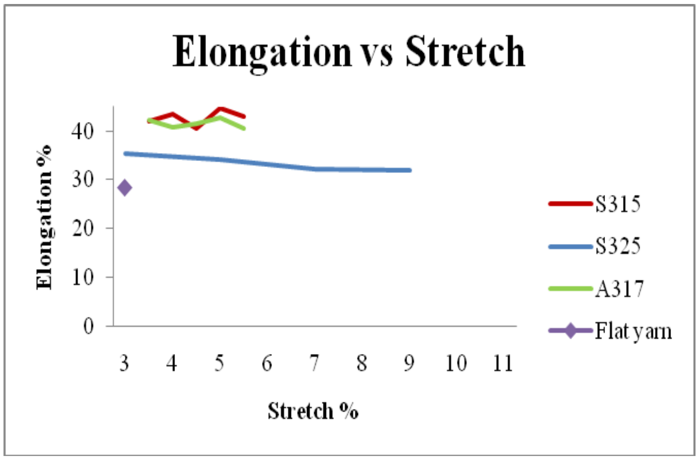


Figure 5.15: Comparison of elongation vs stretch

From all these graphs it is evident that the tenacity and modulus of textured yarn is much less than that of flat un-textured yarn. While the tensile strength of the textured yarn is less, the elongation is always higher than the flat un-textured yarn.

From Figures 5.1, 5.4, 5.7, 5.10, and 5.13 it is evident that nozzle A317 and S315 have produced yarns with high tenacity. As indicated earlier, although the comparison can be based on the common values of the paramameters (manufacturers suggested conditions) in discussion in each of the graphs, it is to be noted that it is not a direct comparison. For example in Figure 5.1 shows the influence of overfeed on the tenacity of yarns textured using different jets. But the jets were operated in different conditions (like pressure and speed).

Similarly from Figures 5.2, 5.5,5.8,5.11, and 5.14 it appears that yarns textured using nozzle A317 is superior in terms of modulus. The same can be concluded from the graphs charted out to analyse the influence of the parameters on the elongation of the yarns textured by different jets.

It is claimed that the tenacity of the yarn and the quality of texturing is inversely proportional. This was evident in the current research as well. As shown in Figure 5.16, the yarn with 24% overfeed appears to be more textured than the yarn with 16% overfeed. These are samples of the nozzle A317 taken to study the effect of overfeed. The overfeed of the samples is increased the tenacity of the yarn decreases. This can also be verified from the Figure 5.17 where the yarn with 24% is slightly coarser than the one with 16 % overfeed.

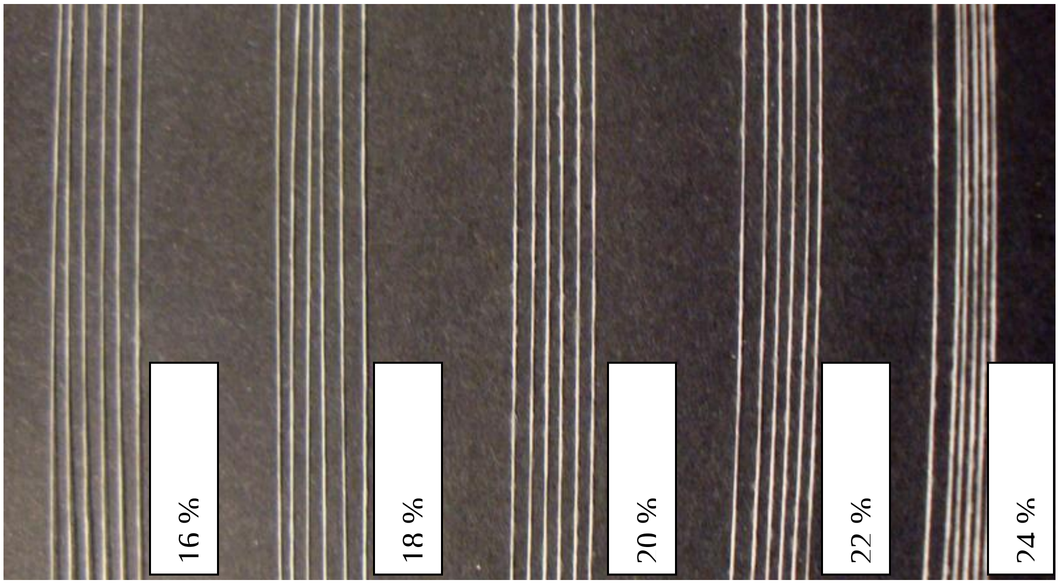


Figure 5.16 Apperance test for A317 yarns with different overfeed

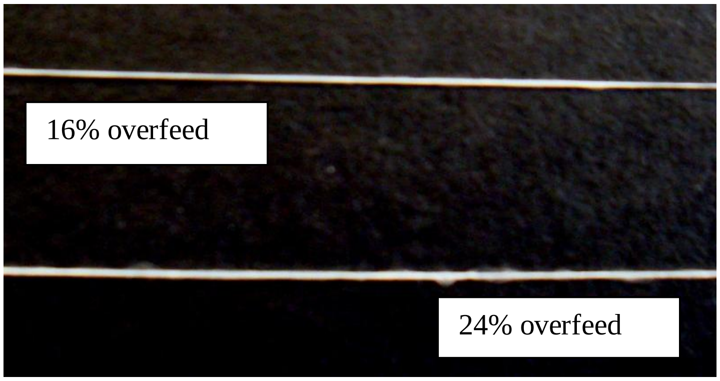


Figure 5.17 : Comparison of the appearance of A317 yarns of 16% and 24% overfeed

Although the claim mentioned earlier holds true for the A317 yarns, it can not be generalized for all the values of the tenacity. In other words, it may not be safe to assume that stronger yarns always give texturing because the tenacity of the yarn is influenced by a number of variables such as pressure, overfeed, temperature, jet type etc. Since there is no common set of experimental parametric values for all the three jets used in this current research it is impossible to draw a conclusion on the influence of jets on the appearance of the yarn. However a SAS program has been run on the samples of S325 yarns with the intention of finding any interaction between the parameters in influencing the tenacity of the yarn and it was found that there is an interaction between pressure and overfeed in influencing the tenacity of the yarn. The results of the SAS program is shown in appendix II. This was found to be true across all the jet nozzles used in the research. Based on the SAS results (*p*-value) the importance of each parameter in influencing the tenacity is given in table 40 where '1' correspondence to most important factor while '5' represents the least important factor. In all of the jet nozzles, pressure and overfeed appeared to be most important factors influencing the tenacity of the yarn.

Table 40: Importance of the parameter in influencing the tenacity of the yarn from different jet nozzles

Nozzle type	Draw zone temperature	Pressure	Overfeed	Speed	Post-texturing stretch
S315	4	1-2	1-2	5	3
S325	5	1	2	3	4
A317	5	1	2	4	3

In future, this study can be extended in efforts to find the influence of the process parameters on the tensile strength of yarns textured using different jets under similar conditions. With the knowledge of knowing that finer yarns can be textured at high speeds as core –sheath structure, future studies can be done on the feasiblity of producing specialty yarns containing spandex and other filament yarns and the influence of parameters on their strength and stability.

REFERENCES

1. Demir, Ali, and Hasan M Behery. *Synthetic Filament Yarn Texturing Technology*. 1. 1. upper saddle river: 1997. Print.
2. Lord, P. (2003). *Handbook of yarn production*. Woodhead Publishing Limited.
3. Demir, Ali and Prof. Wray G.R, “An overview of the Air-jet Texturing Process”, Loughborough University of Technology (LUT)
4. Steinman A J, *Air Jet Texturing,* Air Jet Texturing Conference, Clemson University, Greenville, S.C, 1985
5. Hearle, JWS, L Hollick, and DK Wilson. *Yarn Texturing Technology*. 1. 1. WashingtonDC: Woodhead Publishing Limited, 2001. Print.
6. Hoffsommer K P, *Air Texturing for the 1980’s: A look backward and forward,* Fiber producer, 1980, Vol.8, (6), 22-77
7. Phillips M, *Air Texturing: Where are the fabrics?,* America’s Textile, 1983, vol 12,(5), 17-20
8. Isaaca III A, *Air Texturing Prepares for Lift-off Again,* Textile World, 1984, (10), 48-55
9. Wray G R and Entwistle J H, *The modification of a Taslan jet to operate low air pressures,* Journal of Textile Institute,1969, vol 60, (10), 411-419
10. U.S Patent, 4 097 875. Heberlein Maschinenfabrik, July 19, 1977
11. Acar, M. , Turton, R. K. and Wray, G. R.(1986), ‘*An Analysis of the Air-jet Yarn Texturing process Part V: The Effect of Wetting the yarns’*,, Journal of the Textile Institute, 77: 6, 359 -370

12. M.J Schik, Textile Research Journal, 1973, 43,pages 103,342, 254
13. S.Chand, *The Role of Water in Air-jet Texturing (A critical review)*, Journal of Textile Institute, 1986, 3, pages 438-444
14. Bock G and Lunenschloss J, *An Analysis of the Mechanism of Air-jet Texturing*, Textile Machinery : Investing for the Future, The Textile Institute, Manchester, 1982
15. Acar, M. , Turton, R. K. and Wray, G. R.(1986) *'An Analysis of the Air-jet Yarn Texturing part IV: The Mechanism of Loop Formation*', Journal of the Textile Institute, 77: 6,371 — 376
16. Sengupta, Kothari, Srinivasan (1990). Man Made Fiber Year Book of Chemiefasern/Textile industries: 74
17. Acar, M. , Turton, R. K. and Wray, G. R.(1986) *'An Analysis of the Air-jet Yarn Texturing part I :* A brief history of developments in the process" Journal of textile institute No.1, 19-27
18. "Taslan™ Air Texturing Heberlein® Hemajet-Jet cores." *Oerlikon Textile components*. Oerlikon, n.d. Web. 16 Jun 2010. <http://www.components.oerlikontextile.com/Portaldata/1/Resources/otc/pl_heberlein/downloads/pdb/740371_03-HemaJet-Jet-Cores-Series-2-compr.pdf>.

APPENDICES

APPENDIX I

SAS program was used to determine the dependency level of the yarn properties on the process parameters. The results are given in two appendices. The results for preliminary trials are given in appendix I and the result for experimental trials are given in appendix II . The norms for the F-value in these results was taken at 95% accuracy level.

SAS results for the analysis of the influence of parameters on tenacity of yarn produced from A317

```
                                             The GLM Procedure

                                        Class Level Information

                                 Class         Levels    Values

                                 temp               3    90 120 130

                                 draw               3    1.56 1.6 1.64

                                 pressure           3    80 100 120

                                 overfeed           3    18 20 22

                                 Speed              3    475 500 525

                                 Stretch            3    5 7 8


                                Number of Observations Read          15
                                Number of Observations Used          15
The GLM Procedure

Dependent Variable: tenacity

                                             Sum of
      Source                      DF         Squares     Mean Square    F Value    Pr > F

      Model                       12      0.92972952      0.07747746       8.62    0.0009

      Error                       10      0.08985309      0.00898531

      Corrected Total             22      1.01958261


                     R-Square     Coeff Var      Root MSE    tenacity Mean

                     0.911873      3.000537      0.094791         3.159130


      Source                      DF       Type I SS     Mean Square    F Value    Pr > F

      temp                         2      0.06800939      0.03400470       0.78    0.5970
      draw                         2      0.17921523      0.08960762       9.97    0.0042
      pressure                     2      0.48944624      0.24472312      27.24    <.0001
      overfeed                     2      0.12932891      0.06466446       7.20    0.0116
```

```
      Speed                      2      0.03906949      0.01953475       2.17    0.1644
      Stretch                    2      0.02466025      0.01233012       1.37    0.2974

      Source                    DF     Type III SS     Mean Square    F Value    Pr > F

      temp                       2      0.03527958      0.01763979       1.96    0.1909
      draw                       2      0.13534047      0.06767024       7.53    0.0101
      pressure                   2      0.42681640      0.21340820      23.75    0.0002
      overfeed                   2      0.08637178      0.04318589       4.81    0.0345
      Speed                      2      0.02456691      0.01228346       1.37    0.2986
      Stretch                    2      0.02466025      0.01233012       1.37    0.2974
```

SAS results for the analysis of the influence of parameters on elongation of yarn produced from A317

```
                                          The GLM Procedure

                                     Class Level Information

                              Class         Levels    Values

                              temp               3    90 120 130

                              draw               3    1.56 1.6 1.64

                              pressure           3    80 100 120

                              overfeed           3    18 20 22

                              Speed              3    475 500 525

                              Stretch            3    5 7 8


                             Number of Observations Read          15
                             Number of Observations Used          15

                                          The SAS System

                                        The GLM Procedure

Dependent Variable: elongation

                                                  Sum of
      Source                    DF         Squares     Mean Square    F Value    Pr > F

      Model                     12     3147.109614      262.259134      30.65    <.0001

      Error                     10       85.567778        8.556778

      Corrected Total           22     3232.677391


                     R-Square     Coeff Var      Root MSE    elongation Mean

                     0.973530      2.920879      2.925197           100.1478


      Source                    DF       Type I SS     Mean Square    F Value    Pr > F

      temp                       2      759.980070      379.990035      44.41    <.0001
      draw                       2     1215.366167      607.683083      71.02    <.0001
      pressure                   2      992.934865      496.467433      58.02    <.0001
      overfeed                   2       19.889522        9.944761       1.16    0.3517
      Speed                      2       22.658101       11.329051       1.32    0.3090
      Stretch                    2      136.280889       68.140444       7.96    0.0085
```

```
      Source                      DF     Type III SS     Mean Square    F Value    Pr > F

      temp                         2      431.864241      215.932121      25.24    0.0001
      draw                         2     1273.253738      636.626869      74.40    <.0001
      pressure                     2      947.890116      473.945058      55.39    <.0001
      overfeed                     2       20.276825       10.138413       1.18    0.3453
      Speed                        2       66.035556       33.017778       3.86    0.0573
      Stretch                      2      136.280889       68.140444       7.96    0.0085
```

SAS results for the analysis of the influence of parameters on modulus of yarn produced from A317

```
                                         The GLM Procedure

                                      Class Level Information

                               Class         Levels    Values

                               temp               3    90 120 130

                               draw               3    1.56 1.6 1.64

                               pressure           3    80 100 120

                               overfeed           3    18 20 22

                               Speed              3    475 500 525

                               Stretch            3    5 7 8


                              Number of Observations Read          15
                              Number of Observations Used          15
                                         The SAS System
                                       The GLM Procedure
Dependent Variable: modulus

                                                  Sum of
      Source                      DF         Squares     Mean Square    F Value    Pr > F

      Model                       12     1420.382241      118.365187      29.90    <.0001

      Error                       10       39.584333        3.958433

      Corrected Total             22     1459.966574


                     R-Square     Coeff Var      Root MSE    modulus Mean

                     0.972887      7.132449      1.989581        27.89478


      Source                      DF       Type I SS     Mean Square    F Value    Pr > F

      temp                         2     174.8610864      87.4305432      22.09    0.0002
      draw                         2     165.6720006      82.8360003      20.93    0.0003
      pressure                     2     134.6278353      67.3139176      17.01    0.0006
      overfeed                     2     436.5992294     218.2996147      55.15    <.0001
      Speed                        2     136.6722889      68.3361444      17.26    0.0006
      Stretch                      2     371.9498000     185.9749000      46.98    <.0001
```

```
      Source                     DF     Type III SS     Mean Square    F Value    Pr > F

      temp                        2     150.4761521      75.2380761      19.01    0.0004
      draw                        2     173.7095139      86.8547569      21.94    0.0002
      pressure                    2     207.2503759     103.6251879      26.18    0.0001
      overfeed                    2     542.0758794     271.0379397      68.47    <.0001
      Speed                       2       2.7732533       1.3866267       0.35    0.7128
      Stretch                     2     371.9498000     185.9749000      46.98    <.0001
```

SAS results for the analysis of the influence of parameters on tenacity of yarn produced from S315

```
                                         The GLM Procedure
                                    Class Level Information
                             Class         Levels    Values

                             temp               3    90 120 130

                             draw               3    1.56 1.6 1.64

                             pressure           3    80 100 120

                             overfeed           3    18 20 22

                             Speed              3    475 500 525

                             Stretch            4    5 6 7 8


                            Number of Observations Read          17
                            Number of Observations Used          17

                                         The SAS System
                                       The GLM Procedure

Dependent Variable: tenacity
                                              Sum of
      Source                     DF          Squares     Mean Square    F Value    Pr > F

      Model                      13      0.96986426      0.07460494      30.95    <.0001

      Error                      11      0.02651174      0.00241016

      Corrected Total            24      0.99637600


                     R-Square     Coeff Var      Root MSE    tenacity Mean
                     0.973392      1.580394      0.049093         3.106400

      Source                     DF       Type I SS     Mean Square    F Value    Pr > F

      temp                        2      0.03618294      0.01809147       7.51    0.0088
      draw                        2      0.19051687      0.09525843      39.52    <.0001
      pressure                    2      0.31778947      0.15889474      65.93    <.0001
      overfeed                    2      0.30483719      0.15241860      63.24    <.0001
      Speed                       2      0.00378497      0.00189249       0.79    0.4800
      Stretch                     3      0.11675281      0.03891760      16.15    0.0002


      Source                     DF     Type III SS     Mean Square    F Value    Pr > F

      temp                        2      0.05640244      0.02820122      11.70    0.0019
      draw                        2      0.22079595      0.11039797      45.81    <.0001
      pressure                    2      0.16787928      0.08393964      34.83    <.0001
      overfeed                    2      0.28439883      0.14219942      59.00    <.0001
      Speed                       2      0.00036133      0.00018067       0.07    0.9282
```

```
    Stretch                      3      0.11675281      0.03891760      16.15    0.0002
```

SAS results for the analysis of the influence of parameters on elongation of yarn produced from S315

```
                                           The GLM Procedure
                                      Class Level Information
                               Class         Levels    Values

                               temp               3    90 120 130

                               draw               3    1.56 1.6 1.64

                               pressure           3    80 100 120

                               overfeed           3    18 20 22

                               Speed              3    475 500 525

                               Stretch            4    5 6 7 8


                              Number of Observations Read          17
                              Number of Observations Used          17

                                           The SAS System
                                         The GLM Procedure

Dependent Variable: elongation
                                                Sum of
      Source                      DF         Squares     Mean Square    F Value    Pr > F

      Model                       13     2370.468176      182.343706      23.30    <.0001

      Error                       11       86.097424        7.827039

      Corrected Total             24     2456.565600

                    R-Square     Coeff Var      Root MSE    elongation Mean
                    0.964952      2.828115      2.797685           98.92400

      Source                      DF       Type I SS     Mean Square    F Value    Pr > F

      temp                         2     860.1596278     430.0798139      54.95    <.0001
      draw                         2     933.5821213     466.7910606      59.64    <.0001
      pressure                     2     483.0450038     241.5225019      30.86    <.0001
      overfeed                     2      85.3952281      42.6976140       5.46    0.0226
      Speed                        2       0.7347831       0.3673915       0.05    0.9543
      Stretch                      3       7.5514117       2.5171372       0.32    0.8097


      Source                      DF     Type III SS     Mean Square    F Value    Pr > F

      temp                         2     551.6930966     275.8465483      35.24    <.0001
      draw                         2     805.7668065     402.8834033      51.47    <.0001
      pressure                     2     361.4780966     180.7390483      23.09    0.0001
      overfeed                     2      81.4316863      40.7158432       5.20    0.0257
      Speed                        2       0.1782488       0.0891244       0.01    0.9887
      Stretch                      3       7.5514117       2.5171372       0.32    0.8097
```

SAS results for the analysis of the influence of parameters on elongation of yarn produced from S315

```
                                           The GLM Procedure

                                      Class Level Information
```

```
                                Class         Levels    Values

                             temp               3    90 120 130

                             draw               3    1.56 1.6 1.64

                             pressure           3    80 100 120

                             overfeed           3    18 20 22

                             Speed              3    475 500 525

                             Stretch            4    5 6 7 8


                            Number of Observations Read          17
                            Number of Observations Used          17

                                         The SAS System

                                       The GLM Procedure
Dependent Variable: modulus
                                              Sum of
      Source                      DF         Squares     Mean Square    F Value    Pr > F

      Model                       13     1204.529565       92.656120      15.08    <.0001

      Error                       11       67.597851        6.145259

      Corrected Total             24     1272.127416


                      R-Square     Coeff Var      Root MSE    modulus Mean

                      0.946862      10.10403      2.478963        24.53440


      Source                      DF       Type I SS     Mean Square    F Value    Pr > F

      temp                         2      43.5932785      21.7966393       3.55    0.0648
      draw                         2      45.0065049      22.5032525       3.66    0.0604
      pressure                     2      49.3329469      24.6664734       4.01    0.0491
      overfeed                     2     465.7672000     232.8836000      37.90    <.0001
      Speed                        2      10.9277905       5.4638952       0.89    0.4386
      Stretch                      3     589.9018441     196.6339480      32.00    <.0001


      Source                      DF     Type III SS     Mean Square    F Value    Pr > F

      temp                         2      68.1109515      34.0554758       5.54    0.0216
      draw                         2     123.2588261      61.6294131      10.03    0.0033
      pressure                     2     142.9407296      71.4703648      11.63    0.0019
      overfeed                     2     526.0342441     263.0171220      42.80    <.0001
      Speed                        2       6.5863296       3.2931648       0.54    0.5997
      Stretch                      3     589.9018441     196.6339480      32.00    <.0001
```

APPENDIX II

SAS results for the analysis of the influence of parameters on tenacity of yarn produced using S325

```
                                   Class Level Information

                        Class         Levels    Values

                        temp               5    90 100 110 120 130

                        pressure           5    80 100 120 140 160

                        overfeed           5    22 24 26 28 30

                        Speed              6    575 625 675 725 750 775

                        Stretch            5    3 5 7 9 11


                            Number of Observations Read          25
                            Number of Observations Used          25

                                     The SAS System
                                    The GLM Procedure

Dependent Variable: tenacity

                                            Sum of
      Source                      DF         Squares     Mean Square    F Value    Pr > F

      Model                       21      0.57171543      0.02722454      44.67    0.0047

      Error                        3      0.00182857      0.00060952

      Corrected Total             24      0.57354400

                     R-Square     Coeff Var      Root MSE    tenacity Mean
                     0.996812      0.920115      0.024689         2.683200

      Source                      DF       Type I SS     Mean Square    F Value    Pr > F

      temp                         4      0.00956305      0.00239076       3.92    0.1453
      pressure                     4      0.34459134      0.08614784     141.34    0.0010
      overfeed                     4      0.11678247      0.02919562      47.90    0.0047
      pressure*overfeed            1      0.05623714      0.05623714      92.26    0.0024
      Speed                        5      0.03224500      0.00644900      10.58    0.0402
      Stretch                      3      0.01229643      0.00409881       6.72    0.0759

      Source                      DF     Type III SS     Mean Square    F Value    Pr > F

      temp                         3      0.00560000      0.00186667       3.06    0.1913
      pressure                     4      0.29096044      0.07274011     119.34    0.0012
      overfeed                     4      0.12403217      0.03100804      50.87    0.0043
      pressure*overfeed            1      0.01974113      0.01974113      32.39    0.0108
      Speed                        5      0.03354143      0.00670829      11.01    0.0381
      Stretch                      3      0.01229643      0.00409881       6.72    0.0759
```