THE EFFECT of INTERMINGLING TECHNIQUES and NUMBER of ENTANGLEMENT POINTS to THE YARN STRENGTH

MASTER of SCIENCE THESIS

İSMAİL ÖZTANIR

SUPERVISOR

ASSOC. PROF. DR. M. EMİN YÜKSEKKAYA

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T.C.
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DEPARTMENT OF TEXTILE ENGINEERING

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We have read the thesis entitled **"THE EFFECT of INTERMINGLING TECHNIQUES and NUMBER of ENTANGLEMENT POINTS to THE YARN STRENGTH"** completed by **İSMAİL ÖZTANIR** under supervision of **ASSOC. PROF. DR. M. EMİN YÜKSEKKAYA** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

ASSOC. PROF. DR. M. EMİN YÜKSEKKAYA **………………………………………..**

Supervisor, Department of Textile Engineering

This study was certified with unanimity by committee member as Master of Science Thesis at Department of Textile Engineering.

PROF. DR. MEVLÜT TERCAN **………………………………………..**

Department of Textile Engineering, Uşak University

ASSOC. PROF. DR. MUHAMMET AKAYDIN **………………………………………..**

Denizli Vocational School of Technical Sciences, Pamukkale University

Date: 28/03/2014

This thesis was certified as Master Science Thesis by board of director Uşak University Graduate School of Natural and Applied Sciences.

ASSOC. PROF. DR. MEHMET AKTAŞ **………………………………………..**

Director, Graduate School of Natural and Applied Sciences

THESIS PRONOUNCEMENT

I certify that this thesis is a presentation of my original research work. Wherever contributions of others are involved, every endeavor is made to indicate this clearly, with due reference to the literature, and acknowledgement of collaborative research and discussions. This master thesis was completed under the guidance of Assoc. Prof. Dr. M. Emin YÜKSEKKAYA, at the Graduate School of Natural and Applied Sciences of Uşak University.

İsmail ÖZTANIR

THE EFFECT of INTERMINGLING TECHNIQUES and NUMBER of ENTANGLEMENT POINTS to THE YARN STRENGTH

(M.Sc. Thesis)

İsmail ÖZTANIR

UŞAK UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
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ABSTRACT

Intermingling is one of the best alternative methods to make the filament yarns more resistant against high volume stress. This technique has started to replace conventional methods such as sizing and twisting in terms of gaining strength. The intermingling process mixes multifilament yarns along with entanglement points and open parts by turns throughout the length of the yarns. This process makes tensile value of multifilament yarns entirely different from the component of separate filaments.

This study tries to define the effect of commingling on the filament yarn strength. Two matters are generally mentioned to describe the intermingling quality in a multifilament yarn. These are entanglement point numbers in a meter of the yarn and knot stability. Yarn speed in an intermingling process is one of the most influential factors on knot numbers and knot quality. This study also describes the yarn speed effect to the intermingling uniformity with various synthetic filament yarn samples.

In this study, PES and PA6 synthetic filament yarns with various linear densities were used to find out the effect of yarn count and yarn speed to the strength of intermingled yarns and intermingling uniformity. All of the yarn samples were tested in a tensile test device and also analyzed in terms of their entanglement point numbers. Furthermore, the results were evaluated statistically to find out the relationship among the intermingling parameters.

The aim of this study is to give an idea about intermingled yarn strength and compound to synthetic yarn manufacturers in especially hosiery and weaving sectors. In this way, the manufacturers may prevent yarn breakages and also machine stops choosing the best alternative yarn type according to the machine speeds.

Keywords: Intermingling, knot, tensile values, air jet, air cover, filament yarn, air pressure**.**

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PUNTALAMA TEKNİĞİ ve PUNTA SAYISININ İPLİK MUKAVEMETİNE ETKİSİ

(Yüksek Lisans Tezi)

İsmail ÖZTANIR

UŞAK ÜNİVERSİTESİ

FEN BİLİMLERİ ENSTİTÜSÜ

Mart 2014

ÖZET

Yüksek miktarlı gerilmelere karşı filament iplikleri daha dayanıklı hale getirmek amacıyla kullanılan en iyi yöntemlerden birisi puntalama işlemidir. Bu işlem ipliklere mukavemet kazandırma açısından haşıllama ve büküm gibi konvansiyonel metotların yerini almaya başlamıştır. Puntalama işlemi ipliklerin uzunluğu boyunca punta noktaları ve açık bölgeler şeklinde multifilament iplikleri birbirine dolamaktadır. Bu da multifilament ipliklerin mukavemet değerinin tek tek filament ipliklerin mukavemetlerinden tamamen farklılaşmasına neden olmaktadır.

Bu çalışma filament iplik mukavemeti üzerindeki puntalama etkisini tanımlamaya çalışmaktadır. Bir multifilament ipliğin punta kalitesini ölçmek için genellikle iki parametreden bahsedilmektedir. Bu parametreler bir metre uzunluğundaki iplikte olan punta sayısı ve oluşan puntaların kararlılığıdır. Punta sayısı ve kalitesi üzerinde en çok etkili olan faktörlerden bir tanesi de puntalama işlemindeki iplik hızıdır. Bu çalışma ayrıca çeşitli sentetik filament ipliklerde iplik hızının puntalama düzgünlüğü üzerindeki etkisini tartışmaktadır.

Çalışmamızda puntalanmış ipliklerin mukavemeti ve punta düzgünlüğü üzerinde iplik numarası ve makine hızının etkisini bulmak için çeşitli iplik numaralarında PES ve PA6 sentetik filament iplikler kullanılmıştır. Tüm iplik numuneleri bir mukavemet cihazında test edilmiş ve punta sayısı bakımından incelenmiştir. Ayrıca, test sonuçları puntalama parametreleri arasındaki ilişki istatistiksel olarak değerlendirilmiştir.

Bu çalışma ile özellikle de çorap ve dokuma sektörlerindeki sentetik iplik üreticilerine puntalanmış ipliğin sağlamlık özelliği ve iplik karışımının nasıl olması gerektiği konusunda bir fikir vermek amaçlanmıştır. Bu yolla iplik üreticileri, makine hızlarına göre en iyi iplik tipini seçerek iplik kopuşlarını ve makine duruşlarını önleme imkânı bulabileceklerdir.

Anahtar Kelimeler: Puntalama, punta, mukavemet değerleri, hava jeti, havayla kaplama, filament iplik, hava basıncı.

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İsmail ÖZTANIR

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Ayrıca mukavemet testlerinin gerçekleştirilmesinde verdikleri katkılardan dolayı Türk Standartları Enstitüsü Denizli Tekstil Laboratuar'ına teşekkür ederim.

Geçtiğimiz yıllar boyunca yetişmem için çok çaba harcayan ve anlayışları, destekleri ve sevgilerini esirgemeyen anne, baba ve kardeşlerime teşekkür ederim.

Son olarak eşime ve oğluma da teşekkür etmek isterim. Onların yardımı ve sevgisi olmadan bu tezi tamamlamam mümkün olmazdı. Dolayısıyla, bu yüksek lisans tezi eşime ve oğluma adanmıştır.

İsmail ÖZTANIR

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CHAPTER 1: INTRODUCTION

1.1. Introduction

Friction force among the fibers is the only force holding the fibers together in staple fiber spun yarns. This friction force provides the staple fiber yarns to withstand tensions in the process of manufacturing yarns and fabrics. Fibers which have different length values exist randomly in the yarn body. This random placement and twisting process make the friction force stronger and so staple fiber yarns can withstand different kinds of tensions in the production [1]. However, filament yarns do not have any important cohesion force like friction because of parallel settlement of fibers that can be seen in figure 1.1.

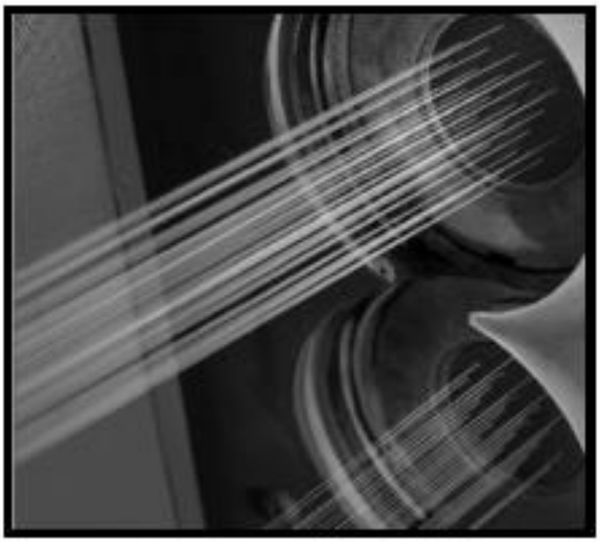

Figure 1.1 Flow of parallel filaments from nozzles [2]

Due to the lack of enough cohesion force between the filaments, many problems come out during the processes of yarn winding, unwinding, knitting, weaving, tufting, and similar fabric manufacturing processes. For example, in the weaving process, yarns are subjected to high amount of tension because of high machine speeds. Filament yarns could not withstand these tensions because of the parallel settlement of fibers. This settlement causes tension irregularities in the yarn structure. Depending on high textile manufacturing speeds, tension differences cause the yarn break and malfunction in the process.

In order to prevent yarn breakages, it is necessary to have a cohesion force among the synthetic filaments. In order to overcome this problem, intermingling is one of the best way make the filament yarns more resistant against high volume tensions. It is also accepted one of the best alternative techniques in comparison with the conventional techniques such as sizing or twisting [1].

1.1.1. Definition of Intermingling

When turbulent a jet of cold air suddenly hits in a perpendicular way to plain or texturized group of filaments which are stable or in motion, the filaments will separate from each other as much as possible. These dispersed filaments are wound and mixed together, and eventually a complex whole structure occurs in partially reduced air flow areas. The filament yarn is mobile in direction of its axis. On the other hand, air jet is stable and perpendicular to the yarn. The air jet could not achieve to open the mixed areas of the yarn, so opened and mixed regions of the yarn follow each other. In this way, filaments of the yarn are joined together. There is no physical or chemical change in the basic structure of the filament. The position of the filament is the only difference. Therefore, any appreciable change does not exist in the parameters of the yarn. That means, plain yarn is still plain, elastic yarn is still stretchable. It can be seen mixed space regions created by cold air flow along the fiber; here this process is called intermingling or interlacing. It is observed periodic mixed parts on the yarn; these parts are called knot, entanglement point, fixed point, or interlacing point [1, 3, and 4].

Two criteria are commonly used to define the type of intermingling present in a yarn. These are the number of knots per meter of yarn (kpm) and the strength (stability) of these knots (% retention). Sometimes the number of knots is entitled as nip intensity or nip density. As the name suggests, the knots per meter is simply a physical count of the numbers of interlace points inserted in a meter of textured yarn. The percentage retention is a measure of the strength of the inserted knots, i.e. their resistance to removal, assessed by counting knots before and after the application of a known load or extension to the yarn. This value gives an indication of the ability of the intermingling to survive subsequent yarn processing and to provide the required protection from the damaging of yarns. Of equal importance when talking of intermingling is to consider the open length of yarn between the intermingled knots. Indeed some would discuss that intermingling is the most important criteria, since it is the open length and the consistency of the intermingling that can directly affect how a yarn will process during fabric construction [5].

1.2.Review of Past Works

Alagirusamy et al. (2005) reported a study on effect of jet design to the intermingling and also described improvements of commingling nozzle design in the commingling process. This study found that knot frequency and interlacing degree of composite commingled yarns depend on the nozzle design. Air inlet number and inlet angle have an important effect on the structure of intermingled yarns. This study also mentioned about importance of air pressure so that air pressure enhancement causes an increase in the interlacing degree of the filament yarns [6, 7, and 8].

Ogale and Alagirusamy (2005) reported a study about tensile properties of commingled composites with a compound of glass fiber and filament yarns. This study indicated that composite modulus is ruled by glass compound while tenacity value is ruled by thermoplastic filament yarn compound. It is declared that a significant modulus decrease exists with an increase of air pressure in glass polyester and glass nylon commingled yarns. However, the air pressure does not affect the modulus to a large extent in the glass polypropylene commingled yarns. There is a decrease in tenacity value of all types of intermingled yarns as the volume fraction of thermoplastic fibres increases. It is also found that commingled yarns in knotted form would preserve almost 55% – 60% of the axial tensile strength [9, 10, and 11].

Another work done by Webb et al. (2007) was carried out to optimize splicing parameters for splice uniformity in continuous filament yarns. This work demonstrated that the strongest splice does not in general comply with the best aesthetic appearance. Therefore, this work indicated that an overall optimum splicer configure is necessary which makes contact between splice strength and splice appearance. It is also described that due to the different chamber design and reduced blast duration, an optimum splice appearance can be obtained, but these modifications create a negative effect on the splice strength [12, 13, and 14].

Shiu-Wu Chau and Wen-Lin Liao (2008) studied on interlacing nozzle geometry to determine yarn interlacing frequency. They used a numerical approach to predict the yarn interlacing frequency of triangular interlacing nozzle. This study described that for air nozzles only differing in their inlet diameter, an optimal size of inlet diameter (i.e. critical inlet diameter) can be obtained for a given pressure, which delivers the largest yarn interlacing frequency. Insufficient or extreme size of inlet opening leads to a weak interaction of shock surface inside the expansion chamber, and results in less number of fixed points per unit length. An optimal inlet pressure ensures the largest yarn interlacing frequency per unit pressure. It is also mentioned that the critical inlet pressure is dependent on the nozzle geometry. When the inlet pressure is larger than the critical inlet pressure, only a small increase in the yarn interlacing frequency is expected because the upper-lower shock surface has been completely developed. It is concluded that both inlet angle and pressure affect the intermingling uniformity whereas no noticeable connection exists between these factors [15, 16, and 17].

Özkan and Baykal (2012) performed a study on intermingling parameters and filament properties effect to the stability of knots. In order to achieve this aim, partially oriented yarn filaments were used as raw materials. Linear densities of POY, number of filaments in cross section, intermingling speed and intermingling pressure were taken as independent variables; and stability of the nips of intermingled yarns was evaluated as dependent variable. They found that a positive linear correlation exists between air pressure and knot stability. This correlation was also found statistically significant. This study also described that less yarn linear density values has positive linear relationship with knot stability and this relationship is statistically significant as well [18, 19, and 20].

Kravaev *et al.* (2013) presented a new method to analyze the blending quality along the length of commingled yarns. It is claimed that this new method can be applied for the manufacturing process of thermoplastic composites. For yarn analyses, five different commingled yarn structures were specified which are twist, braid, wrap, entangle and non-interlaced. The blending quality and filament distribution in the cross section of GF/PA hybrid yarn used to manufacture thermoplastic composites were investigated. Due to the combination of the yarn analysis along the yarn axis and in its cross section, the new method allows for the first time a reliable comparison of the blending quality in commingled yarns used for the manufacturing of thermoplastic composites [21, 22, and 23].

Boubaker *et al.* (2009) studied on a descriptive model for the longitudinal structure of wet pneumatic spliced yarn. It is found that elastic spliced yarns stand two more asymmetrical twisted zones in microscopic analysis although classical spliced yarns contain a symmetrical twisting zone. The study demonstrated that the wet pneumatic splice can be defined by six parameters which are zones of splice, length of each zone, splice length, number of twist turns on each zone, two elasthane filament ends, and center x coordinates. It is claimed that the established model shows the main reason of the irregularity of the spliced elastic yarn appearance is yarn end coming from the cop [24, 25, and 26].

Golzar *et al.* (2007) reported a study about intermingled hybrid yarn ratio in continuous fiber reinforced thermoplastic composites. The study investigated fiber volume fraction and diameter of reinforced filaments and thermoplastic filaments in hybrid yarn. This study also explained that for improving the homogeneity in commingled hybrid yarn, combining the reinforcement and thermoplastic filaments during the production line is one of the best methods. It is claimed the method can decrease the fiber damage caused by air texturing and enhance the homogeneity of PP/GF composite [27, 28, and 29].

Webb *et al.* (2009) performed a work about relationship between splicing performance and yarn count. The study reported that as yarn count was varied, industry-standard and experimental splicers with various configurations changed in performance. This study concluded that when yarn counts increase sufficiently, it is needed to enhance three variables to acquire optimum splicing. These three variables are cross section of the splicing chamber, airflow, and the knife separation [30, 31, and 32].

To describe the aesthetics of a splice, the retained yarn appearance (RYA) scale was devised and validated through the inspection and grading of hundreds of splices [33]. A subjective scale from 1 to 10 was finally used, based upon the appearance of each spliced joint. If a splice scored 10, it has no visible filamentation and has a well-ordered structure in the main section of the splice. All of the fibres are bound into the structure. There are no 'tails'. If a splice scored 5, it has a medium level of filamentation with a less-ordered structure in the main section of the splice. The splice is still acceptable in terms of appearance and processability. If a splice scored 1, it has extreme filamentation and the characteristic appearance of a splice is disrupted. The splice is completely unacceptable in terms of appearance and processability [12].

The use of PU/PA core-spun yarns in the manufacture of seamless garments will bring some problems. The most important problems are the size control and the ageing of PU elastic yarn. Because of the divergence in elasticity of PU/PA core-spun yarn, the size control becomes very difficult during the knitting process. Even for the PU/PA core-spun yarns from the same batch number but with different colors, their shrinkage can be different from each other. This makes the knitting process very difficult to control. In addition, the ageing of PU elastic yarn can result in the reduction of elasticity of the garment during use. In order to solve these problems, various solutions such as the polytrimethylene terephthalate (PTT)/polyester (PET) bi-component filaments was proposed to replace PU/PA core-spun yarn for producing seamless garments [34].

1.3. Thesis Outline

The main purpose of this study is to define the effect of commingling on the filament yarn strength. This study also describes yarn speed effect to the intermingling uniformity with various synthetic filament yarn samples. In this context, PES texturized intermingled filament synthetic yarns with the linear densities of 50, 70, 100,150 denier and PA6 texturized intermingled filament synthetic yarns with the linear densities of 40, 70, 100, 140 denier were used. We also used air covered elastic PES guipe (elastic yarn blended samples) yarns with the compound of 50/20, 70/20, 100/20, 150/20 and air covered elastic PA6 guipe yarns with the compound of 40/20, 70/20, 100/20, 140/20. In these compounds, first parts symbolize PES and PA6 yarn counts, second part (20) symbolize elasthane yarn count in all samples. The elasthane yarn draft value is 2.8 which mean the elasthane yarn stretch to the 280% value of its initial length. All samples were produced in an air cover machine which has approximately

5 bars air pressure value. Three different machine speeds were used to separate the samples in three different groups which are low intermingled; medium intermingled, and high intermingled. All samples were tested in a tensile test device which is called Uster Tensorapid 3. These tests were repeated twice and mean values were taken as the final tensile value. Test speed is 500 mm/min and pre tension value is 4.3 cN in this test device. Tensile test unit was taken as cN/tex in the test device. Before the tensile test, all yarn samples were unwinded about 300 meters to prevent yarn unevenness in upper parts of the yarns. All yarns were acclimatized in the standard atmosphere conditions during 72 hours before testing. In order to better understand the effect of intermingling on the yarn strength, experimental and numerical results of test specimens were compared in terms of yarn speed and entanglement point numbers.

To supported result of experimental tests, statistical analysis has been performed using SPSS software. The statistical tests were performed at 95% confidence interval to evaluate the relevance between the intermingling parameters.

This thesis is organized into five chapters. Chapter two has included issue of synthetic filament yarns, information about intermingling and effect of intermingling on the yarn strength behavior. Chapter three is about manufacturing method of intermingled yarns with different systems. Also determination of mechanical properties for commingled yarns and achieving of optimum intermingling process characteristics were given in this chapter. ANOVA statistical analysis is presented in chapter four. To find out the best intended results, parameters effect on each other was evaluated. Chapter five contains conclusions of numerical and experimental results and recommendations for further investigations.

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This thesis is sponsored by Uşak University Scientific Research Coordination Agency (BAP), (Project Number: 2013 TP/004). The tensile tests of the yarns were performed in Denizli Textile Laboratory of Turkish Standards Institution.

CHAPTER 2: INTERMINGLING and FILAMENT YARNS

2.1. Introduction to Intermingling

The principle of the intermingling process can be explained as follows: a continuous yarn, running under a defined tension through an air jet, can be interlaced if a perpendicular or nearly perpendicular high pressure air stream is applied to the yarn. The air stream creates a turbulence, splitting the yarn bundle and then forcing individual filaments together, which creates a kind of braiding effect on the yarn. Thereby the cohesion among the filaments is increased by a large magnitude. Such DTY yarn can now be used without any further twisting in weaving and knitting. The schematic below shows the principle of how an air stream can produce an interlaced yarn:

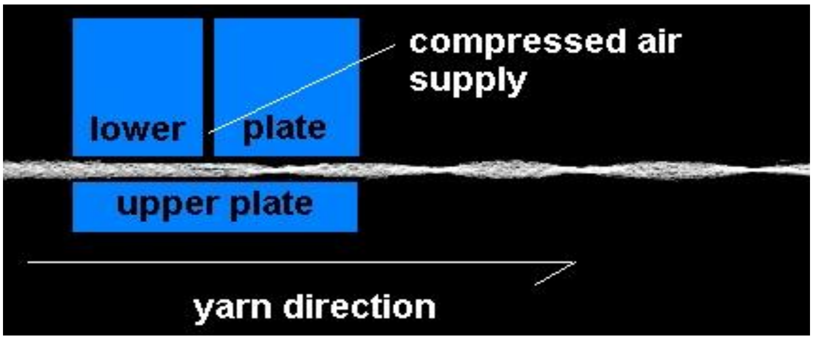


Figure 2.1 Air jet configuration which includes yarn and air supply meet [35]

A multifilament yarn is fed through the tangling jet. The perpendicular compressed air stream will split the filament bundle. Due to a very high dynamic force, the filaments collapse again into the filament bundle where they now entangle [35]. The principle of commingling is shown in the following figure [6].

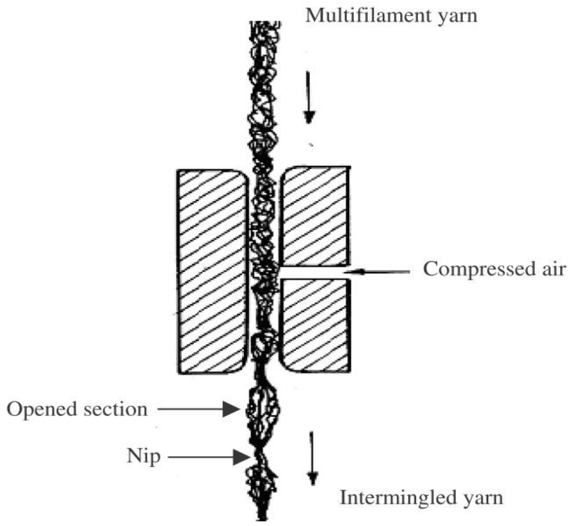


Figure 2.2 Principle of commingling [6]

The entangled yarn is characterized by having tangle knots at very regular intervals. This evenness is for subsequent processes most important. The density of the tangle knot is controlled by air pressure and the yarn tension. The evenness of knots is a result of the evenness of the yarn tension and the compressed air pressure. The design of the air jet and the angle of the yarn path in and out of the jet are mainly responsible for frequency of the knots and the actual air consumption. The shape of the yarn channel and the size of the orifices of the compressed air channel vary between the manufacturers of interlacing air jets [35].

Du Pont Company secured air jet intermingling by a patent in the United States in 1961. Six years ago from this date, the same company was the first company that patented air jet texturing. This case means that air jet intermingling is by-product of air jet texturing process. Air jets used for intermingling have simpler configuration than texturing air jets. They are produced and enveloped in the yarn plants and false twist texturing mills with the aim of specific manufacturing. Today, intermingling process provides a wider field of application than air jet texturing process [1, 36, and 37].

2.1.1. Operation and Feeding Yarn Parameters

Leading parameters which effect intermingling process are as in the following:
Air Jet Parameters: Type of jet (open, closed), jet dimensions (number of air holes, air hole diameter, yarn channel diameter, yarn channel length, position of air hole on the yarn channel,

meeting angle, and direction of air hole with yarn channel), jet geometry (sectional shape of air hole and yarn channel, longitudinal shape of yarn channel, positions of yarn guides)

Operation Parameters: Air pressure, yarn speed and yarn tension, total linear density of the yarn, each filament's linear density, cross sectional profile of the filaments (see Fig. 2.3), raw material of the yarn, surface characteristics of the yarn (plain, texturized and spun with staple fibers), spin finish grease on the filament.

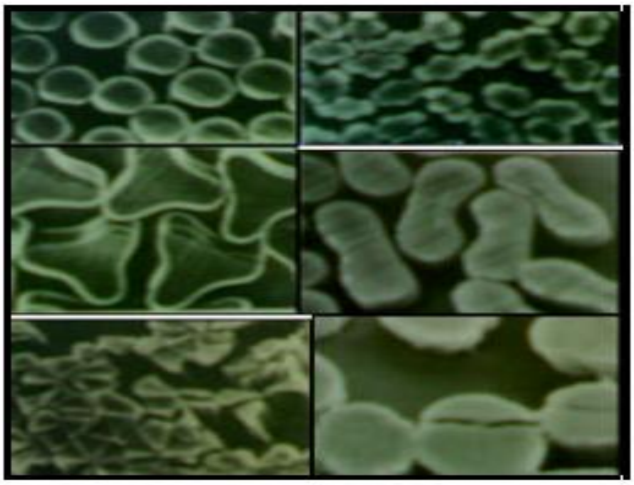


Figure 2.3 several filament yarn cross section profiles [2]

All above parameters have effects on intermingling process to varying degrees. Entanglement point number on the yarn (intermingling density), regularity of intermingling (entanglement uniformity) and endurance of entanglement are affected by these parameters. Air pressure effect on intermingling process is examined in details due to economic aspect of the process. Operating pressure of intermingling air jets usually changes between 0.5 - 5 bars. Many researchers arrive at a consensus that intermingling density is directly proportional with air pressure to the value of 3 bars. However, if the air pressure increases more, productivity of air jet comes to a saturation point; even it is getting worse as it is clear with intermingling density of the yarn.

It is almost impossible to determine an optimum intermingling speed due to wide application area of intermingling. Disorder of entanglement point frequency and difficulties in intermingling may be existed in high process speeds. Relation between entanglement frequency and operation speed can change with lots of variables like air jet configuration and yarn features. In addition, yarn tension is also very important to make a uniform intermingling. An example relation between mingle number per meter with yarn speed can be seen in the following graphic [1].

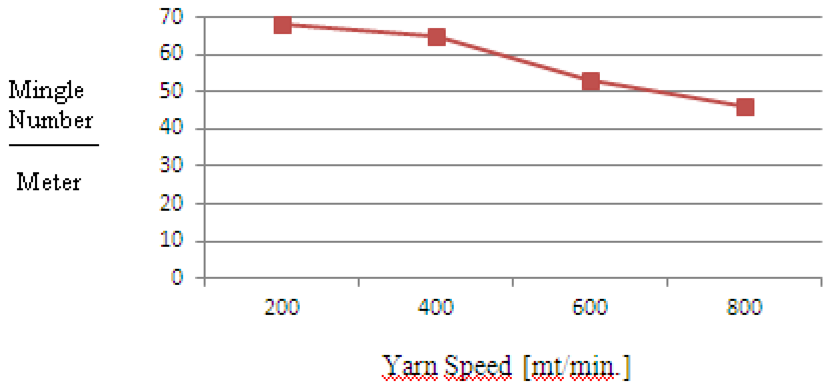


Figure 2.4 Entanglement point variation according to the yarn speed (PET 78 dtex 24 filaments; yarn duct diameter 2.1 mm; air hole diameter 1.3 mm; air gap 5 bars) [1, 38]

2.1.2. Quality of Intermingling Process

The aim of intermingling is to enwrap filaments each other at certain points, so a compact yarn structure can be obtained with this technique. When an interlaced yarn is kept with hand, it can be seen separated filament zones and fixed point zones side by side.

Three factors are more effective on the interlaced yarn quality. These factors are entanglement point number, uniform distribution of entanglement points along the yarn, and resistance of the entanglement point. The intermingled zones are the only criterion in lab tests. Entanglement point numbers in one meter length yarn is mostly used to measure the intermingling quality. There are three criteria to determine the quality of the interlacing process [1]:

- Entanglement point frequency (interlacing density),
- Uniform intermingling process, and
- Stability of entanglement point

2.1.3. Affecting Factors to the Level of Intermingling

The level of interlacing exist in a yarn is definitely not only dependent on the type of jets but also on the processing conditions, location of the jet on the machine and the operating pressure of the jet. The two main factors by which interlacing level is observed, i.e. knot count and knot strength are both affected by these factors. General rules that can be applied to the level of interlacing in false twist textured yarns are as follows:

- Increasing the air pressure will increase the number of entanglement points inserted into the yarn. This is correct to a degree; depend on which type of jet is being used. There is a point at which increasing the air pressure has no effect, since there is a limit to the rate at which interlacing can take place as well as a lack of sheer physical space to add more entanglement points. Should the air pressure be increased upwards, the level of intermingling may in fact decrease. This is because so much air is being forced through the jet that the air stream causes too much turbulence within the yarn chamber and instead of interlace the filaments, it blows them away.

- Increasing the size of the air orifice in the jet increases the knot strength but decreases the overall number of knots added per meter. This holds true for jets made by every manufacturer and is due to the physical law that the strength comes from the length(as well as the tightness) of the knot. Longer knots mean that it exists less in each meter of yarn. A precise disadvantage of having too large an air orifice is that the air consumption, at any given pressure, is increased, making the jets more expensive to operate. Also the increase in volume of air at high pressure can cause filament breaks with sensitive products such as cationic dye able or microfilament yarns.

- The overfeed of the yarn through the jet determines the yarn tension, which will also influence the number of entanglement points inserted per meter of the yarn. The yarn tension has an optimum value and can be high enough to have a negative effect by preventing the filaments from being interlaced at all. Otherwise, if the tension on the yarn is low enough within the jet, due to a very high overfeed, and then the air stream can just disrupt the filaments rather than intermingle them.

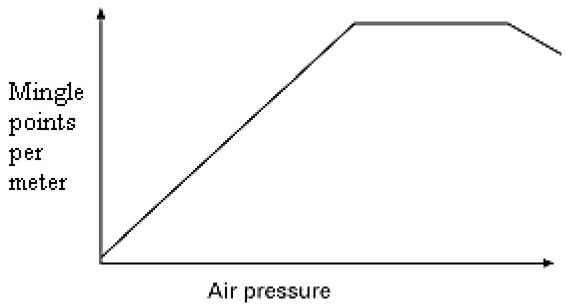
- Jet geometry is taken to mean the input and output angles of the yarn at the jet. This is most relevant when using forwarding jets of the type manufactured by Heberlein and Fibreguide among others. The ideal input and output angles of the yarn to the jet will vary according to the design of the jet but angles in the region of 20-32º are not extraordinary with this type of jets. These angles before and after the jet help to balance the yarn path by holding the yarn against the side of the air inlet let the air stream to flow at its maximum performance. Owing to this, a great deal of consideration has to be put into designing a suitable bracket for mounting the jet on the machine, whether the intermingling jet is situated above or below the second heater, so that the jet can work at its maximum efficiency. Some producers supply their jets with input and output guides fixed to the body of the jet such that they are fixed in the optimum position. Even in this case, care must still be exercised in fitting them to the machine.

- Intermingling jets located in the center of the machine, i.e. above the second heater, give a product with a higher degree of knot strength, than if the same jet is at the bottom of the machine at the same air pressure and overfeed. The reason for this is that as the yarn shrinks in the second heater, the shrinkage effect occurs preferably in the open yarn lengths between the intermingle points, due to a better heat penetration in these areas. This has the effect of giving each singular entanglement point more strength, as yarn shrinkage in the open lengths tends to shorten them locking the entanglement points more confident into the yarn.

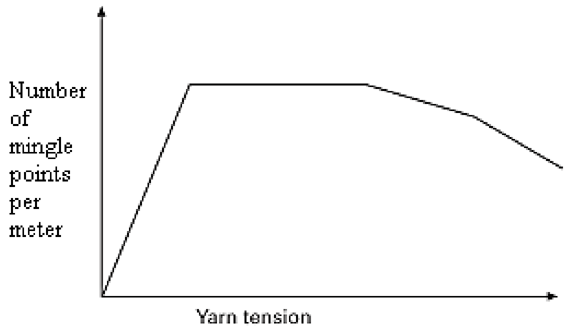
- The accurate choice of jet is exceptionally important. The overall intermingling characteristics required the denier of the product and manufacturing speed will all affect the choice of jet type for the process. These factors will also help to define what type of jet is required with respect to air orifice size and yarn channel diameter [5].

2.1.4. Effect of Intermingling on Yarn Characteristics

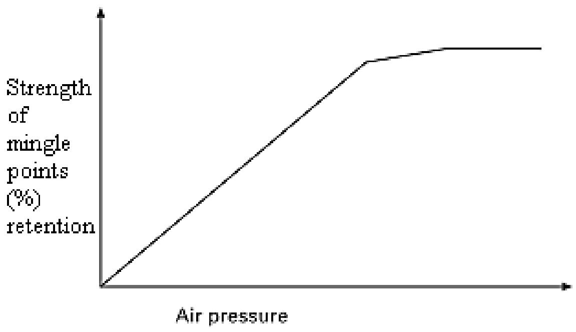
As the yarn is intermingled the action of inserting the mingle points in the yarn has a small but discernible effect upon the physical properties of the yarn. The effects on the different physical properties are shown in Figure 2.5. As seen in the figure, the type of empirical relationships to be expected as the air pressure (bar) supplied to the intermingling jet and the yarn tension within the jet are increased [5].



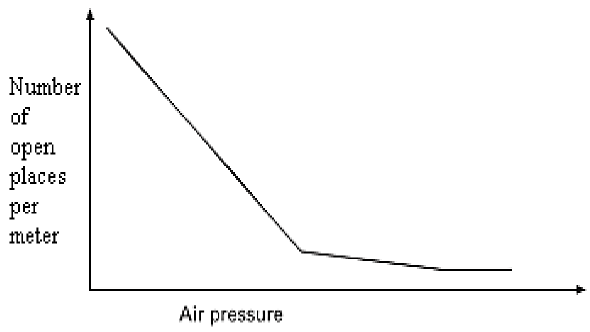
Mingle points per meter vs. air pressure



Mingle points per meter vs. yarn tension



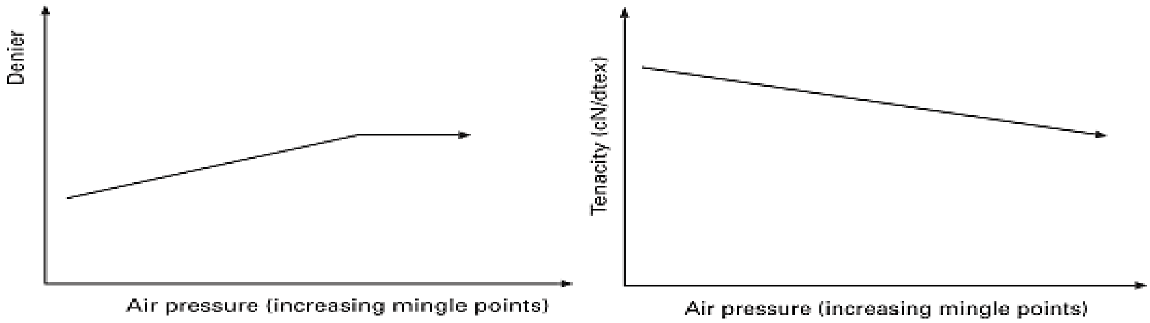
Strength of mingle points vs. air pressure



Number of open places per meter vs. air pressure

Figure 2.5 Relation between intermingling and physical properties [5]

Loss in tenacity: Tenacity is a relative value calculated by the breaking load of the yarn and its denier. The denier of the yarn increases with the number of intermingling points per meter of the yarn inserted due to the yarn compaction. This increase in denier has the effect of lowering the calculated values of yarn tenacity. Figure 2.6 shows relation between air pressure with linear density and tenacity [5].



Air pressure (increasing mingle points) Air pressure (increasing mingle points)

Denier (decitex) vs. air pressure Tenacity vs. air pressure

Figure 2.6 Relation between intermingling and physical properties [5]

Loss in percentage elongation at break: Loss in elongation can also be related to yarn compaction and, in particular, to the degree to which the individual filaments are bound to each other by the intermingling action. The tighter the degree of intermingling the more difficult it is for the individual filaments to move relative to each other when subjected to stretching action. Figure 2.7 shows relation between air pressure and % elongation [5].

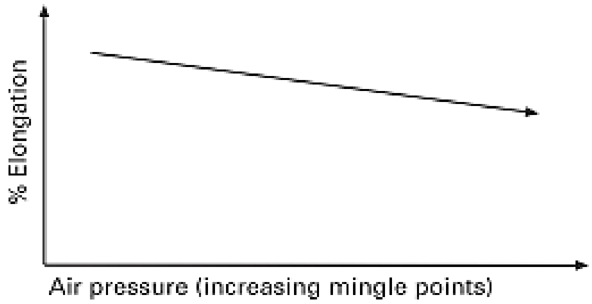


Figure 2.7 Relation between elongations vs. air pressure [5]

Loss in yarn skein shrinkage: Here again yarn compaction is the cause of the resulting loss in yarn skein shrinkage. The intermingling point effectively acts to restrict the shrinkage or crimp in the yarn, the open lengths of yarn being much more susceptible to the effects of heat than the dense mass of the actual knot. Figure 2.8 shows relation between air pressure and yarn shrinkage. As seen in the figure, as the air pressure increases, the percentage of yarn shrinkage decreases. This is happening due to the fact that yarn compaction enhancement occurs via increase in the air pressure. So, this enhancement in the yarn compaction causes a decrease in the yarn shrinkage. Figure 2.9 shows shrinkage effect on the yarn structure [5].

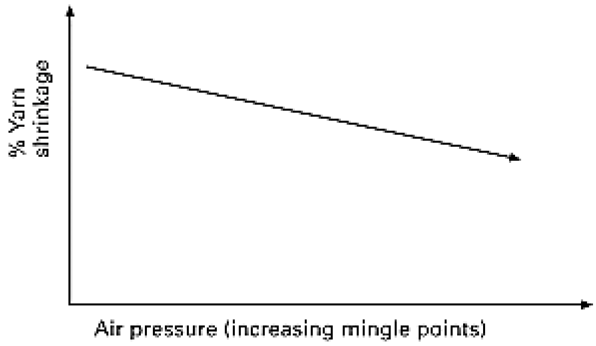


Figure 2.8 Relation between yarn shrinkage vs. air pressure [5]

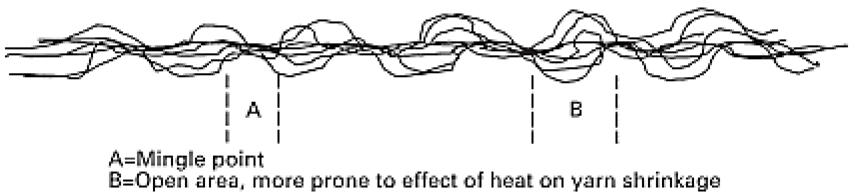


Figure 2.9 Mingle yarn structure [5]

Coefficient of friction: There will be a small decline in the overall diameter or thickness of the yarn bundle, with the overall cross-section of the filament bundle assuming a more circular form. This is also due to the yarn compaction. Correspondingly, a small reduction in the coefficients of friction of the yarn is observed due to this reduced surface area. Figure 2.10 shows relation between air pressure with yarn diameter and coefficient of friction [5].

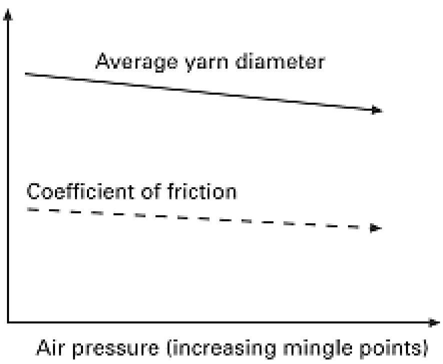


Figure 2.10 Relation between air pressure with yarn diameter and coefficient of friction [5]

2.2. Application Types of Intermingling

As mentioned before, the intermingling is an intermediate process usually used in filament yarns. A temporary cohesion force is given to the filaments of yarns and this cohesion effect is expected to eliminate with the tensions of finished fabric. It can be applied for both plain and texturized yarns as mentioned before. After producing and drawing plain yarns, a light intermingling is applied to a plain yarn to make winding and unwinding easier. Resulting intermingling process in plain filament yarns, existing fixed points or knots are so small that they are barely noticeable. The distances between fixed points are also so small. This process is called continuous intermingling and it is maintained with simple structured air jets in the reduced pressure values. This type of intermingling is applied to the yarn during producing, drawing or warp preparation.

When texturized yarns are intermingled, easily visible large knots and open sections will appear. This is directly depending on flexible characteristic and naturally bulkiness of the texturized yarns. When the yarn tension is low, filaments show tendency remaining in the minimum energy level, therefore they get a curved state. So, open areas in the yarn are bulkier than fixed point areas. If a very minor tension applies to the intermingled yarn, it will stretch and so it will be difficult to distinguish open sections and fixed point areas. Cohesion among the filaments, as a result of mixing filaments, provides more proper yarn winding and unwinding processes. Additionally, it does not create any problem during the fabric formation. Intermingling air jet can be used in false twist texturing machines to maintain interlacing in different positions of machines.

Air jet intermingling has also two different usage areas as combining filament yarns with discontinuous yarns called blending and binding filament yarns with each other and also elastic yarns called splicing. Today, instead of conventional knotting process, splicing process is widely used. It is known that in the weaving process, knots result big problems because of tensions on the adjacent warp wires that result negative effect on finished fabric. It is claimed that splicing method in which is used intermingling air jet, is the best method ever known between whole yarn combining methods. The conjunction in the yarn is barely noticeable in the splicing method, but knots in conventional process make a thicker structure. It is clear that this thicker area results machine stops and also loses allure of the fabric [1, 39].

2.2.1. Commingling in the Field of Composite

In commingling, reinforcing and matrix-forming filaments are intimately mixed in a nozzle by means of compressed air. Commingling involves purely mechanical interaction of rapidly moving air with filaments of the yarn that generates entanglements in and between filaments. Therefore, it is also applicable to most nonthermoplastic filament yarns including glass and carbon. This process is very versatile and gives very soft, flexible, and drapeable yarn. This has made commingling technology suitable for textile pre forming process to develop composite structures for high-performance applications. A sample commingled yarn can be seen in the Figure 2.11 [6].

Commingled yarns for composite applications consist of combination of high-performance filaments and matrix-forming thermoplastic filaments that have quite different tensile characteristics. The commingling process mixes these filaments along with introduction of nips and open sections alternately along the length of commingled yarns. This makes the tensile behavior of commingled yarns to be quite different from that of constituent individual filaments [9].

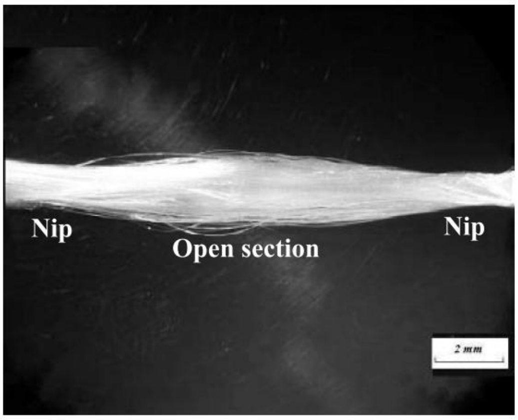


Figure 2.11 Glass/Nylon commingled yarn for high-performance thermoplastic composites [6]

In Figure 2.12, red-colored PP yarn and glass rovings are placed side by side and knot is formed and load is applied. It is observed that the glass filaments breaking at very low stress as low as 7cN/tex. Figure 2.13 shows a series (a–d) of pictures showing the knot formation on well-commingled section of the same colored PP yarn and glass roving. It can be seen that minimum breakage of the glass filaments in commingled yarns is as high as 12 cN/tex [9].

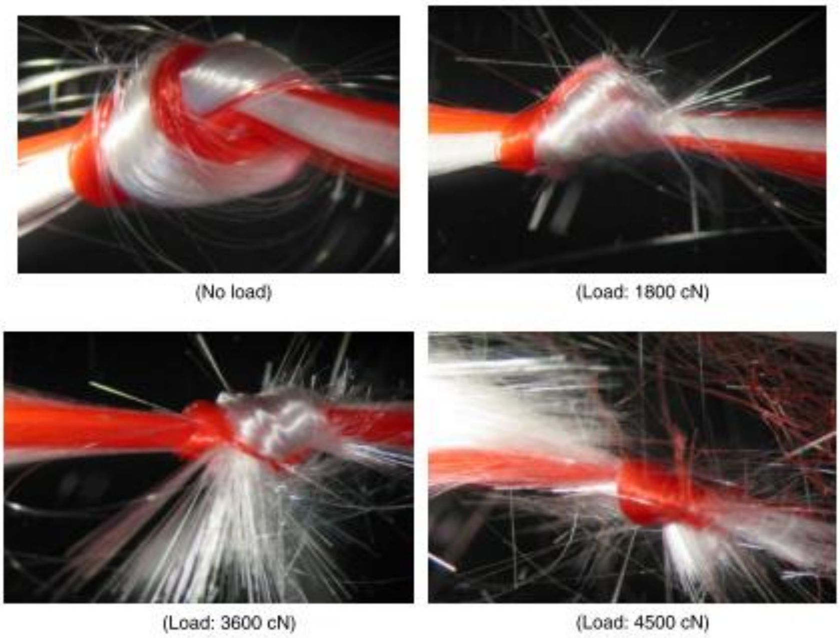


Figure 2.12 Knot tensile characteristics of side by side GF-PP yarns [**9**]

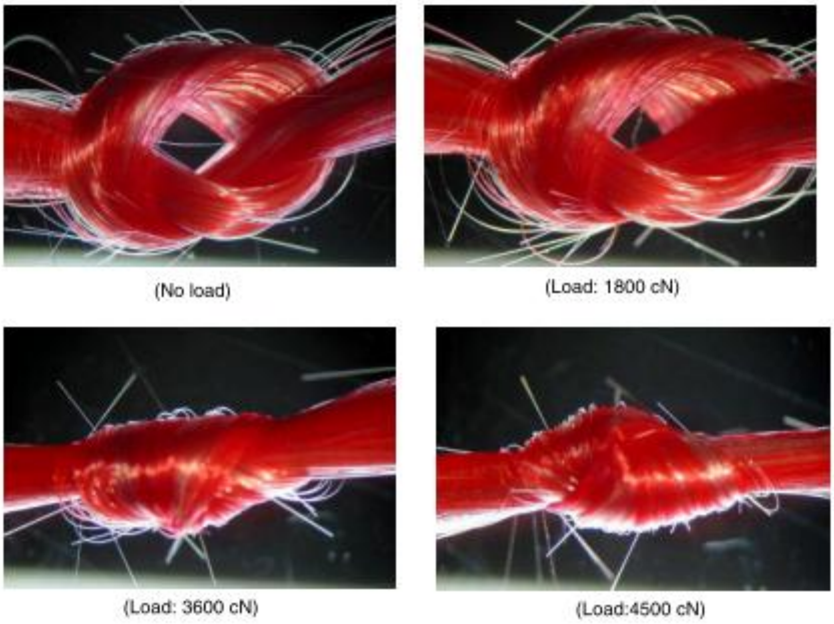


Figure 2.13 Knot characteristics of well-mixed portion GF-PP commingled yarns (white fibres: glass, red fibres: PP, magnification: × 40) [**9**]

2.3. Intermingling Air Jets

In simple terms, intermingling air jet is consisted of a yarn channel and air intake hole which feeds air to meet air and yarn in its channel. A short cylindrical pipe and in the middle of the pipe an air intake hole vertical to the pipe are the basis structures. After air jets are patented in the early 1960s, different configurations have been experienced to improve the productivity of air jets [1, 36, and 37].

The simplest jet comprises no more than a block of metal in which two holes or channels are drilled to meet at right angles (see figure 2.1). One channel spreads the complete length of the block to transport the yarn and the second meets it at right angles for the air supply. There are jets of this type still being produced but over the years there have been huge advances in the design of jets. Many complex designs now exist with wide variations in the cross-sectional shape of both the yarn and air channels. These changes have been intended at developing the efficiency of the air jet both by increasing the frequency and strength of the knots and also by reducing the air consumption, so making the jets more cost effective to operate [1, 36, and 37].

Yarn channels are commonly available in circular, triangular, semicircular and rectangular cross-sections, though other cross sections are available. The shape of the actual air orifice, where it enters the yarn channel, is usually of circular or elliptical cross section though some jets have been manufactured with rectangular or trapezoidal air holes. In a forwarding jet, as the name suggests, the air stream is angled in the direction of the yarn movement such that it imparts a forwarding action to the yarn. This means that this type of jet can operate at a much higher yarn overfeed through the jet than one where the air stream intersects the yarn path at right angles. In this case the tension on the yarn within the jet is reduced. The air inlet channel is usually set at an angle of 8-12º from the perpendicular, in the direction of the yarn travel [5].

As with all aspects of texturing machines, the design of intermingling jets has become more specialized over the years. The very earliest designs were crude in both engineering design and manufacturing. Nowadays, they are much more specialized with designs of both yarn and air channels being tailored towards specific processes and end use. Although this has the advantage of allowing the yarn manufacturer to choose the optimum intermingling jet for the process, it has the converse effect of forcing the purchase of a wide range of jet sizes to meet all requirements. It is no longer possible to buy a multipurpose intermingling jet, one that can contain a wide range of products simply by modifying machine parameters such as yarn speed, yarn tension (overfeed through the jet) and jet pressure operated. This has become luxury that is no longer available. The result of greater expertise by intermingling jet manufacturers has been to force the yarn producer to spend more time in the search for the optimum process. As a result of this developed specialization by the jet manufacturers, it has become increasingly important for the technologists to specify the production parameters carefully to enable a viable return on investment in both time and equipment to be made. Some intermingling jets, especially those designed for use on high-speed processes, are now offered as dual or tandem jets which have two distinct and separate intermingling nozzles mounted upon a common body. A different type also presents which have two air inlets into a single body [5].

Not only have the design of the yarn and air channels been advanced over the years but also the materials and methods of construction have been improved. From the early use of mild or hardened steel, jets are now available made from ceramic or tungsten carbide materials in which the shape of the air orifice, in the case of the latter, may have been formed by spark or wire erosion. The earlier jets manufactured were of the closed type, i.e. the yarn had to be threaded through the jet before the thread line could be started to run. It soon became apparent that jets of this type were impractical in a manufacturing environment. At the end, jets of the open type were developed. These jets differed by having a narrow slot cut into the yarn channel into which a running thread could be inserted. There was a little false to pay when using jets of this type in that their intermingling efficiency dropped slightly. But, this was tolerated due to the speed and ease with which the running thread could be put into productions [5].

Jets are now available which offer the best of both sides. The most common is that can be opened for ease of threading but can then be closed to make certain optimum process efficiency. One example of this type is the Heberlein Slide jet. This jet, along with others of this type, also has an advantage that, when opened to let threading, the air supply to the jet is automatically cut off so further aiding threading and avoiding the waste of compressed air [5].

2.3.1. Development of Air Jets

The basic configuration of an intermingling air jet is simple as a short steel pipe with a hole in the middle of it which compressed air is given. Therefore, most of texturing machine manufacturer and texturing plants have developed specific air jets in accordance with their objective of usage.

Figure 2.14 A novel air jet configuration [40]

From the first patent secured by DuPont in 1960, many industrial organizations like Eastman, Celanese, Burlington, Toray, Murata, Barmag, Fibreguide, Rieter-Scragg, Heberlein etc., have developed and patented several configured air jets [1, 36, and 37].

Today's high speed textile processes like manufacturing, texturing, and winding need open air jets which have yarn feeding slot inside the yarn channel. Instead of conventional round cross sectioned yarn channels, profile yarn channels have been preferred nowadays. For example, semi-circle and triangle cross sectioned yarn channels are preferred for their simple production method. In order to expose the yarn to the jet air effectively, longitudinal profile of the yarn channel can be modified. Different designs like to create an expanding entering point for yarn to meet with air jet and shortly after exposing filaments with compressed air; making holes on both sides of the channel to remove compressed air from the media can be applied. Air entering is usually seated upright with yarn channel in the air jet. A slight deviation of air entering from 90º angles provides a driving force to the yarn and this case is very useful for specific conditions [1, 41].

In addition to these common body designs, there are yarn guides on both sides of most novel intermingling air jets. These guides are designed to direct the yarn to the most efficient zone of the yarn channel and keep the yarn in this state. Air jet manufacturers take into account yarn density, process of yarn production, entanglement point numbers, intermingling stability and etc. when they fabricate air jet designs [1, 41].

2.3.2. Air jet Configuration

Frequency and regularity of intermingling are the basis aim of designing an air jet. Therefore, many researchers use frequency and distribution regularity of intermingling to evaluate the effects of air jet parameters. In addition, entering air should fill all the cross section of main yarn channel in an optimum configured air jet. Following parameters are found effective on the process of intermingling:

- Cross sectional area of the air inlet,
- Cross sectional area of the yarn channel,
- Angle between air inlet and yarn channel,
- The length of yarn channel,
- Surface characteristics of yarn channel,
- Longitudinal shape of yarn channel, and
- The positions of yarn guides located in front of and behind the air jet [1, 36]

Since the introduction of an air-jet texturing process into the yarn texturing practice, air-jet nozzles have been widely developed for various texturing purposes. The first application of air texturing technology can be traced back to the development of the Mirlan Jet in Czechoslovakia and the air-jet patents of DuPont around 1952. The first air-jet nozzles allowed only very slow texturing speeds and required compressed air at very high pressure. In the past decades, more efficient nozzles have been developed which could be operated at higher texturing speeds but with lower consumption of compressed air. Interlacing is one of the important features of the air-jet texturing process, where the yarn cohesion among filaments through intermingling mechanism is achieved without sizing them. Since the yarn cohesion plays an important role in the warping, weaving, and knitting process, various methods have been developed to generate yarn cohesion. Compared with other methods, air-jet interlacing is the easiest and economical way of generating the required cohesion among filaments. The first patented air-jet interlacing nozzle was later introduced in 1961 by DuPont, which was a coincidental invention accompanied by a related research on air-jet texturing nozzles. Since the invention of air nozzles, there have been plenty of researches focused on air-jet texturing nozzles, e.g. references represented an extensive study on air-jet texturing nozzles (i.e. HEMAJET), while the related investigations focused on air-jet interlacing nozzle are quite limited. As discussed by Rwei et al., an interlacing jet is different from a typical air-texturing jet by several aspects, such as nozzle geometry, imposed pressure and working temperature. There are still many issues in the air-jet interlacing processes that are far from being comprehensively understood, such as qualitative prediction of interlacing properties that deserve proper and extensive studies [15].

2.4. Formation of Entanglement Point

In order to establish an entanglement point formation mechanism, the movement of filaments inside the yarn channel should be displayed. Only in this way, the interaction between air flow and filament may be explained successfully. Transparent jets like mica and glass are the mostly used equipment in the experimental studies. The fixed point formation frequency is about 800 – 1200 Hz depending on yarn speed 600 meter/minute and 80-120 fixed point numbers in a meter of yarn. It is not possible to watch such a high frequency operation with naked eyes. For this reason, a high-speed imaging technique is a must. Intermittent laser illumination and high-speed imaging techniques have been so useful about searching filament movement in the air flow. These techniques allow observing effects of various process parameters like air pressure, yarn speed, and yarn tension [1, 42]. In general, all splices have a characteristic and broadly reproducible form as indicated in the following figure [12].

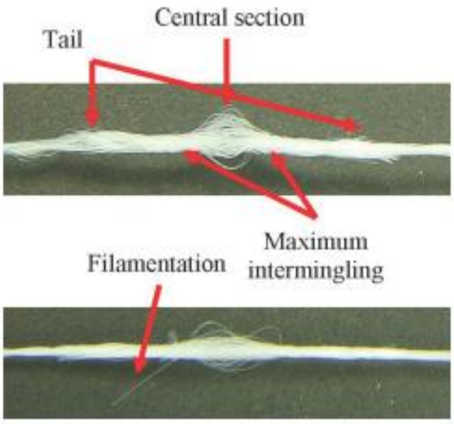


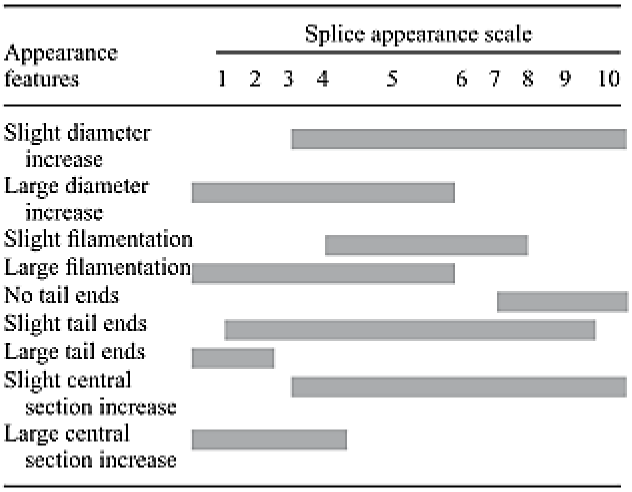
Figure 2.15 Characteristic form of a splice [12]

The operation pressure of intermingling air jets is usually lower than air jet texturing process. Pressure in intermingling changes between 1-6 bars, pressure in air jet texturing is about 8-10 bar. Many researchers have a consensus about intermingling density raises up directly proportional with air pressure up to 3 bar value. However, when air pressure is more raised than 3 bars, the productivity of the air jet come to a point of saturation and also it is getting worse. According to the other search, with rising up air pressure 4 bar value, frequency of entanglement also raises up. On the other hand, if the air pressure increases more, the quality of entanglement will enhance even though entanglement point number does not change. For instance, entanglement points seem more distinctive and they are distributed more regular along the yarn. Due to the existing wide application area of entanglement processes, yarn speed inside the air jet largely changes from zero (yarn knotting) to 4500 met per minute (filament manufacturing process) [1, 36, and 43].

It may be considered that formation of entanglement is existed from random mixing of filaments. Therefore, yarn tension is a very important factor during intermingling. If a very high tension which does not allow filaments vibrate freely is applied, entanglement process will not occur. On the other hand, if the tension is kept very low, all filaments can easily shift from the impact zone of entering air jet. In other words, intermingling process will not exist again. Then, optimum tension value in intermingling process is determined by air jet and yarn features and also process conditions. Intermingling process is not distanced from the other manufacturing methods like filament yarn producing, texturing, and drawing. So, intermingling and air jet parameters are selected according to the yarns which are treated before [1, 42].

To describe the aesthetics of a splice, the retained yarn appearance (RYA) scale was devised and validated through the inspection and grading of hundreds of splices (Cheng& Lam, 2000). A subjective scale from 1 to 10 was finally used, based upon the appearance of each spliced joint as summarized in Table 2.1 [12].

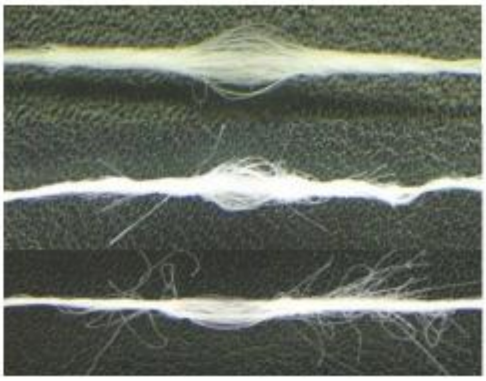
Table 2.1 Splice appearance scale [12]



If a splice scored 10, it has no visible filamentation and has a well-ordered structure in the main section of the splice. All of the fibres are bound into the structure. There are no ‘tails’. If a splice scored 5, it has a medium level of filamentation with a less-ordered structure in the main section of the splice. The splice is still acceptable in terms of appearance and processability. If a splice scored 1, it has extreme filamentation and the characteristic appearance of a splice is disrupted. The splice is completely unacceptable in terms of appearance and processability [12].

Obviously there is going to be a diameter increase when splicing because there are two yarn ends joining together. The difference between a slight and large diameter increase is that in some splices, the filaments are not bound in a tight structure and, therefore, cover a greater volume. A slight diameter increase is equal to or less than three times the diameter of a single yarn end while a large diameter increase is anything above this. If the yarn ends are not fully bound into the splice, then we get tail ends and filamentation. The protrusion of tail ends is assessed by the following criteria: a slight tail end is equal to or less than the diameter of the splice and greater than that for a large tail end. Filamentation is assessed by the number of filaments that are protruding from the splice either by stray filaments not being bound into the splice or through filaments close to the blast hole being damaged through excessive air velocity. Slight filamentation is equal to or less than 10% of the total filaments protruding from the splice [12].

Figure 2.16 shows three examples A, B and C with each obtaining a RYA of 9, 6, and 1 respectively. In greater detail, the splice example B was obtained by placing the sample under controlled tension and assessing the yarn diameter, tail ends, breakage and filamentation. Splice B had a diameter of 2.5 mm (4.2 mm at the center) with a tail end of 1.7 mm which obtains a score of 3 out of 4. Also, there was only a slight diameter increase and therefore obtains a score of 1 out of 2. There were four damaged/broken filaments and six loose filaments that remained unbound into the splice and therefore when pooled together equates to 7%filamentation and a resulting score of 2 out of 4. Therefore, the splice sample B has an overall RYA score of 6 [12].



(A)

(B)

(C)

Figure 2.16 Splice appearance grade: (A) 9, (B) 6 and (C) 1 [12]

CHAPTER 3: DIFFERENT DURABLE YARN MANUFACTURING METHODS

3.1. Air Covering

Air covering is the process of merging multiple yarns to make up yarns with new characteristics. In the course of the process, the yarns are fed into an intermingling jet to meet yarns with the air stream. Air covered yarns can be separated into groups of the elastic and the inelastic yarns. These yarns can be used in various fields of outwear, underwear, hosiery, sportswear, narrow fabrics, and bicomponent yarns. Stretchable fabrics including air covered yarns are extremely demanded for their wearing comfort not only physiological aspect but also psychological aspect. Elastic yarns in consolidation with other yarns are the basis of all tensible fabrics. Elastic yarns are directly added with restricted amounts same as in hosiery sector. On the other hand, elastic yarns are consolidated with other yarns (multi-component yarn) for all other fabric forms. Although lots of covering processes exist for producing multicomponent yarn, the air covering technology is known as the most productive way of covering to date due to its continuous technology [44].

Figure 3.1 Air cover systems [44]

Air covering is one of the methods to form core spun yarns. Compared to standard yarns, core spun yarns have become more and more used in the textile industry due to the contribution of the elastic filament in the improvement of their properties. In fact, the elasthane filament improves yarns' elasticity. The elasthane filament is chemically polyurethane elasthomer based and it offers a very good stretch elasticity that can reach over the value of 500% and its important elastic recovery that can reach up to 90%. On the other hand, it has a poor tenacity value that cannot exceed 0.9 cN/tex. For these reasons, the elasthane filament are covered by other fibres such as cotton and synthetic fibres [45, 46, and 47].

In addition, the elasthane draft has an important effect on the mechanical behavior of the core spun yarns. It is found that there is an increase in elasticity modulus and a decrease in the viscosity coefficients with the increase in the elasthane draft during the tensile test. It is also noticed that it exists an increase in nonlinearity coefficient when the elasthane drafts increase [45, 46, and 47].

In intermingling process, multifilament yarns are placed into an interlacing chamber and exposed them to a high pressure turbulent flow of compressed air or water. As a result of this process, multifilament yarns become intermingled, two yarn ends are emerged into one or one multifilament yarn has more strength value. In practice, although it may change depending on the end use area, the intermingling is maintained as 25-30 entanglement points in each meter of the yarn. The process is carried out by using compressed air flow and entanglement density can be adjusted by the pressure of the air entering the interlacing air jet center [1, 39].

In spite of tensible fabrics raisingly diffusing the textile market, the conventional inelastic fabrics still generate more than half of the whole market. Here is, the intermingling technology offer to the textile manufacturers to produce unique yarns, and give them an opportunity to move away from standard products. For example, by adapting this process, it is possible that flat and textured yarns with different colors and raw materials e.g. PES and PA can be manufactured [44].

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3.1.1. Air Cover Based Seamless Garments

Seamless garments are a special kind of knitted product produced without sewing stitches along the neck, waist or hip lines. As ‘‘one-step-molding garments’’, seamless garments are widely used as power stretchable underwear, outerwear and sportswear. Fully fashionable seamless garments are full of comfort and softness and give wearers a sense of fitting, vigor, grace, fashion and diversity. As high-end knitted products, seamless garments have entered the mainstream knitwear market. Till now, special weft and warp knitting technologies have been developed to produce seamless garments that can meet different consumers' requirements [34, 48, and 49].

Among many requirements by consumers, comfort, fitness and extensibility are the most important properties for seamless garments, particularly for seamless underwear and sportswear. In order to meet these requirements, the use of extremely elastic yarns is necessary. For seamless garments knitted with circular seamless machines, polyurethane (PU)/polyamide (PA) core-spun yarn is commonly used as a base yarn in the plating structure to enhance the elasticity of the garment. However, the use of PU/PA core-spun yarns in the manufacture of seamless garments will bring some problems. The most important problems are the size control and the ageing of PU elastic yarn. Because of the divergence in elasticity of PU/PA core-spun yarn, the size control becomes very difficult during the knitting process. Even for the PU/PA core-spun yarns from the same batch number but with different colors, their shrinkage can be different from each other. This makes the knitting process very difficult to control. In addition, the ageing of PU elastic yarn can result in the reduction of elasticity of the garment during use. In order to solve these problems, various solutions such as the polytrimethylene terephthalate (PTT)/polyester (PET) bi-component filaments was proposed to replace PU/PA core-spun yarn for producing seamless garments [34, 48, and 49].

3.2. Hydroentangling technique

Hydroentangling technique is becoming the most widely accepted system for the production of nonwovens because it is advantageous for the quality of product. In order to reduce the high cost of air consumption in the intermingling technique, experimental hydroentangling studies are performed recently. However, specific machine equipments are required to have the stable mingled yarns in the hydroentangling technique.

In hydroentangling process, extremely fine nozzles are used to discharge high-pressure water in water reservoir into ambient stagnant air to form high-velocity water-jets. These water-jets impact a loose fiber web to make the fibers in the web entangled with each other at a certain point far from the jet exit of the nozzles. In order to utilize the energy in the water reservoir adequately, the hydroentangling process requires that the energy consumed for nozzle resistance should be reduced to the limit when water goes through hydroentangling nozzles and the water-jets produced by these nozzles maintain their kinetic energy until they reach the fiber web [50, 51, and 52].

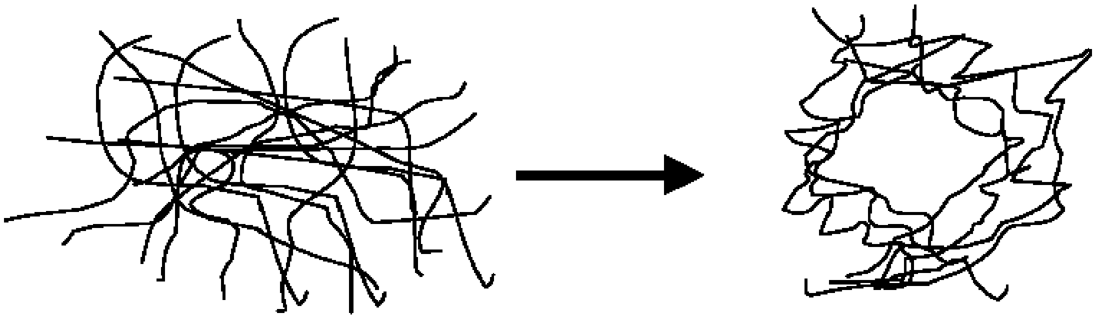

Figure 3.2 Fiber transformations during hydro entanglement [53]

The geometry of these fine nozzles plays a crucial role in the hydrodynamic behavior of the water-jets. Flow dynamic parameters of water-jets include velocity coefficient and intact length. The velocity coefficient is defined as the actual axial velocity of the flow to that obtained by inviscid one-dimensional theory. The intact length refers to the jet length that remains collimated and coherent. Some researchers have proved that the nozzles with various geometries had different velocity coefficients and the water-jets produced by them have different intact lengths because of internal flow effects resulting from their nozzle geometries [50].

3.3. Other Conventional Methods

In the textile area, conventional knotting techniques were used to unify yarn ends jointly. However, knotting was not enough in the aspect of quality due to variables in environmental conditions and employee factors. These variables cause to come out inadmissible finished textile products for consumers [54].

In addition, several methods such as sizing and twisting are performed to bring strength to the yarns basically. At the same time, these methods have disadvantages in terms of production costs according to the intermingling technique in the process of emerging fibers and yarns [1].

Here is, intermingling techniques were developed to cope with problems related knotting, sizing, and twisting. Intermingling technology will be more effective in the future of textile industry with developments in the following subjects [1]:

- Economy in high pressure air consumption,
- Positive control of entanglement point frequency,
- Quality differences between the air jets, and
- Noise

3.4. Intermingling Faults

Faults with intermingling can be broadly classified into two groups, those that involve with the properties such as the frequency or strength of the intermingling knot and those that are concerned with an irregularity or unevenness of intermingling along the length of the textured yarn [1].

3.4.1. Knot frequency and strength

If problems with the knot frequency and strength are noted, the first question that must be asked concerns the selection of intermingling jet for the particular process being employed. Factors such as the overall denier of the textured yarn, its filament denier and the speed of the process must be taken into account when choosing a jet in combination with a specific product. If these questions have been answered in the affirmative, the process conditions at which the jet is operated must be examined. Trial work is usually necessary to determine the optimum condition of air pressure, yarn tension, speed, and jet location for each individual process [1].

3.4.2. Irregularity of intermingling

By irregularity of intermingling is meant the presence of short or long gaps in the textured yarn where no interlace is present. One of the irregularity factors is general housekeeping on the machine. Are the intermingling jets dirty and becoming blocked so that their efficiency is impaired? Secondly is the age of the intermingling jet a factor. Yarn is abrasive and over a period of time wear can be become apparent in the yarn chamber of the jet to such an extent that its efficiency becomes impaired [5].

3.5. Intermingle or Interlace Testing

The level of intermingling applied to a yarn can have a profound effect on how the yarn will perform during both knitting and weaving but, of these two, the behavior in weaving is more important. This is because intermingling has largely replaced the twisting and sizing of warp yarns [5].

Intermingling of a yarn can be quantized in a variety of ways, various attributes of the quality of the intermingling being measured to quantify its characteristics. The number of entanglement points inserted, the regularity of these insertions and the strength (or resistance to removal) of the entanglements can all be used to quantify and qualify intermingling [5].

Several specialized pieces of test equipment are now in use, which are designed for quantifying the degree of intermingling present in a yarn. Though they operate by different principles of measurement they have the following in common:

1.Initial count (count 1) of the number of interlace points per unit length;

2. Subjection of the yarn to a small and constant draw between two rolls:

This draw, or extension, can be programmed for a series of stepped increases so that a profile of the strength of the intermingling points can be found over a range of values;

3. Second count of the interlace points (count 2). This enables the strength of the intermingling points to be calculated as a percentage of these points remaining after the yarn have been subjected to the drawing action (see Equation 3.1):

$$\text{Percentage knot retention or knot strength} = \frac{\text{count 2}}{\text{count 1}} \times 100\% \qquad (3.1)$$

Instruments that enable this double count to be made include those by Enka Tecnica (Itemat) and by Fibreguide (Fibrevision). The Itemat works by scanning the variation in thickness of the yarn bundle under test. The yarn is subjected to small constant pressure which will tend to flatten the areas of non-interlaced yarn. When an interlace point is detected, the more compact circular form of the yarn at the actual intermingling point prevents the pressure applied from flattening the yarn bundle and hence the movement of the pressure plate is restricted. It is this variation in movement of the pressure plate which is used to determine the number of intermingling points present in the yarn (see Figure 3.3).

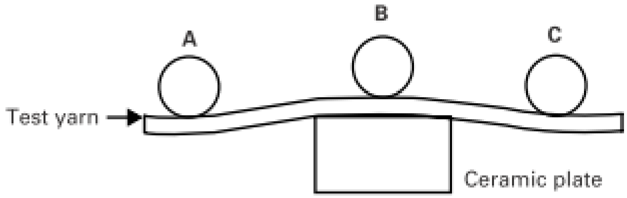

Figure 3.3 The Itemat instrument. A and C are the thread guides and B is the measuring pressure plate [5]

The Fibreguide instrument works on a different principle. This instrument uses a laser to scan the yarn as it passes through the measuring head, detecting interlace points as the variation in the degree of light received by the detector which is placed opposite the light source (see Figure 3.4). Other information such as the distance between the interlace points and the length of the interlace points themselves can be presented both statistically and graphically if required [5].

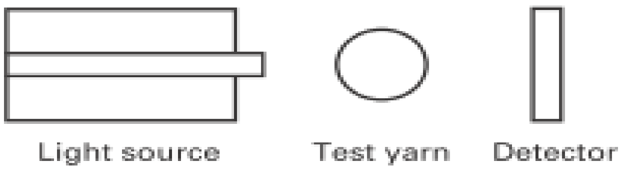

Figure 3.4 The Fibreguide instruments [5]

The instruments that are used today either ‘feel’ the yarn or use optical methods including lasers to count the number of intermingled knots. An older technique inserts a short needle between the filaments of the yarn. Each time a knot passes the needle it is deflected and a knot is counted. This technique is still in use but mainly for counting knots in yarns that have not been textured [5].

For the day-to-day checking of the level of intermingling in the textile laboratory, it is quite feasible to quantify the interlacing present in the textured yarn by the simple expedient of counting the number of interlace points present in a measured length of yarns. This should be carried out with the yarn placed upon a suitable dark background. It is somewhat laborious and depends to a certain extent on the operator, since the tensioning of the yarn before counting and the decision as to what comprises a knot cannot be precise. The method chosen will depend to a large degree upon the criticality of the end-use yarn and on economic considerations [5].

Some yarns do not exhibit visible interlacing points. Laying the yarn on the surface of a water bath, where the water is replenished continuously, can still assess them. The surface tension causes the filaments to separate as far as possible, thus revealing the degree of entanglement. Again, it helps if the water bath is dark in color, at least when assessing an undyed yarn [5]. (This method is commonly used for assessing intermingling in POY.)

3.6. Intermingling Density and Uniformity

To determine intermingling quality, mostly used method is to find average number of entanglement points in a meter of the yarn. However, this method cannot notify about unequal spacing between the entanglement points. It will be enough to calculate the minimum and maximum values of entanglement spacing. For example, if a test result is 0.6 cm and 1.3 cm, it means that spacing between entanglement points change between these length values. When two yarns are compared with same commingling frequency values, intermingling quality will be better which has more uniform spacing between entanglement points. For instance, two yarns which have 10 cm length and same commingling frequency were compared below. All samples have the same commingling number which is 100 per meter. However, intermingling quality would be different owing to diverse spaces between knots. Sample 2 has better intermingling quality value because of similar space length between knots [1, 55].

Sample 1: x--x-----x-----x---x--------x---x----x---x------x---- 10 knots / 10 cm

Sample 2: x----x----x----x----x----x----x----x----x----x---- 10 knots / 10 cm

Figure 3.5 Settlement of gaps and knots along filament yarn

Entanglement point counting operation is performed in four different ways [1]:

- Visual counting,
- Counting with passing the needle through the yarn,
- Measuring the thickness of the yarn, and
- Optical imaging

3.6.1. Visual Counting

Intermingled yarn is placed on a dark surface to count entanglement points at a certain length in this primitive method. This kind of method is inconvenient and subjective. Simple tensioners can be used to provide a stable tension. Although this method largely contains human error, it is still most widely used method in industry. An approximate idea can be obtained with a glance to the yarn. In an untwisted plain yarn which interlaced with a continuous process, entanglement points can be hardly distinguished. If this yarn is located on the surface of stagnant water, filaments will spread, so entanglement points will be selected easier [1].

3.6.2. Needle Passing

In an intermingled yarn, filaments are parallel to each other in open zones. This character is used to determine the length of open zones and hence interlacing frequency. Two methods exist for measure: sampling technique and continuous needle passing technique [1].

3.6.3. Thickness Measuring

If intermingled yarn is pressed with the tip of finger on a flat surface, whilst discrete regions of filaments is felt smooth, entanglement points are felt round and thicker. Reutlingen Interlace Counter controls thickness of the yarn mechanically at any moment thanks to the spring pressure of the moving head. This head consists of a block of hard metal. The head acts as a moving latch under the yarn guide and also under the spring pressure. Parallel filaments are suppressed by spring pressure in the form of strips with chosen yarn guide. Due to knots can't be compressed, when the determined limit value is exceeded, it will be treated as thick point. If a suitable measuring head and accurate limit value are chosen for the test yarn, Reutlingen Interlace Counter will give correct and reliable results [1, 56].

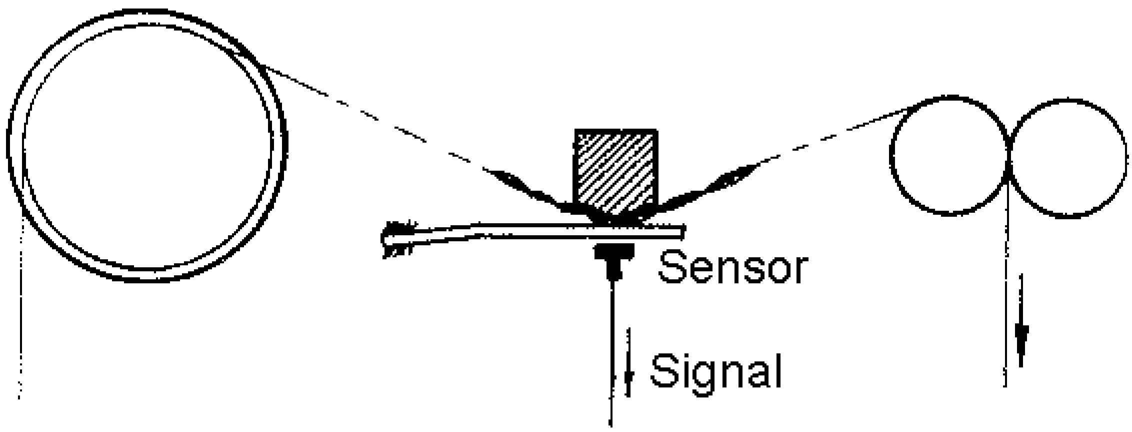

Figure 3.6 The measuring principle of Reutlingen Interlace Counter [1, 56]

3.6.4. Optical Imaging Technique

The yarn and measuring head are in contact in both methods of needle passing and thickness measuring. This contact disrupts structure of the yarn without doubt. Therefore, measuring results cannot always demonstrate real yarn structure which means entanglement point number in a meter of the yarn. Different optical imaging techniques are improved to eliminate disadvantages of contact between yarn and head. For example, Obestat test device is an optical imaging option which works with principle of electrostatic charges. Firstly, yarn sample is charged with high voltage direct current about 50 kV. The yarn is also moistened in order to facilitate conductivity. Charged filaments dispersed as soon as they enter electrostatic field. Intermingled yarn structure appears as self-evident in this method. The width of this range is determined with optical scanning in mingled state of filaments with the aid of a light barrier. The shadow differences in open sections of the yarn and knots are saved by photo sensor and these differences are transformed to impulses which can be adjusted and counted electronically [1, 55].

Another optical imaging technique is Charge Coupled Device which enables mingled yarns easily scanned and also intermingling frequency and uniformity are instantly determined. During this practice, yarn is pushed forward in a constant speed with a yarn transport device. CCD sensor is located vertically to the yarn axis. Yarn shadow is transmitted to the sensor with a light source. When the yarn shifts from the point of the sensor, sensor will finish scanning of yarn shadow. This system can be operated with an improved microcomputer technology. After scanning, microcomputers also calculate intermingling frequency and uniformity. Although CCD based yarn devices are very proper for intermingled yarns' quality control, device cost is very high. So, it is rarely used in industry and research studies [1, 57, and 58].

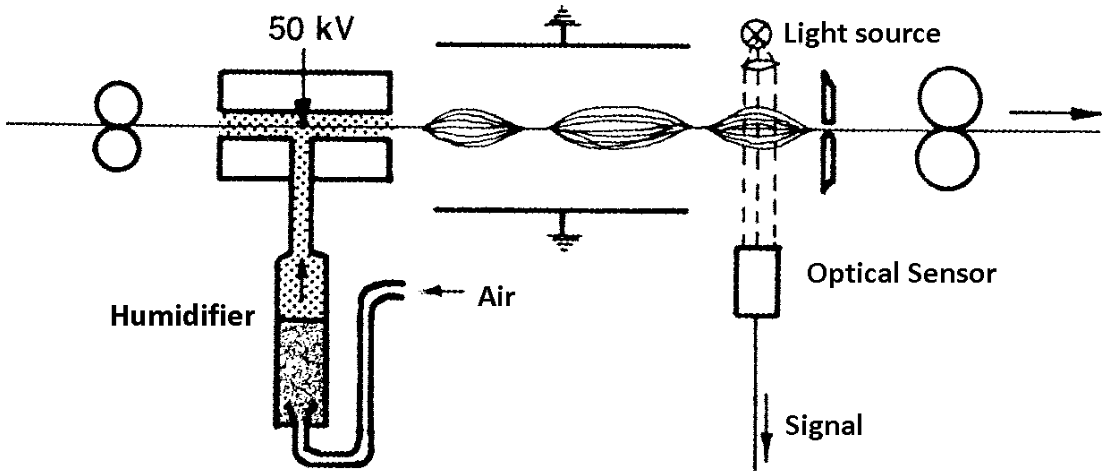

Figure 3.7 The working principle of Obestat test device [1, 55]

3.7. Interlacing Stability

Interlacing stability is one of the important quality standards. When an intermingled yarn is pulled from both sides and examined closely, fluffy areas will come in line with entanglement points (see figure 3.8). So, knots cannot be picked out in the yarn. When the applied tension is removed, some of temporarily lost knots will not exist anymore. So, some of knots will disappear and the yarn will elongate a little. If the tension is increased more, the yarn will break off. When the broken yarn is examined closely, some of knots will exist in the yarn cross section. Here is, these remaining knots are a measure of interlacing stability. Like interlacing uniformity, also interlacing stability is affected by yarn raw material, each filament linear density, and filament number in the yarn cross section, cross-sectional profile of the filaments, air jet type, air pressure amount, and intermingling speed [1, 59].

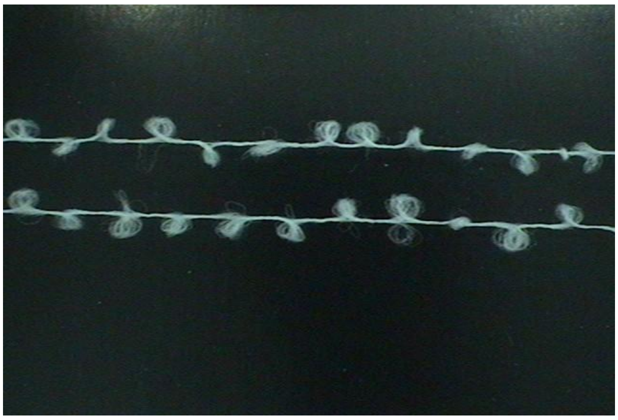

Figure 3.8 Knots and fluffy areas [59]

Easy disappearance of knots under tension causes decrease in yarn bulk and on account of this, irregularities and faults exist during fabric weaving stages. This is a huge disadvantage for the fabric quality. A quality control test is required to determine yarn interlacing stability. However, a common test technique does not exist yet [1].

Interlacing stability is commonly determined by stretching interlaced yarn several times and by comparing first number of knots and remaining number of knots. Filaments which coupled to each other should be durable to tensions and on account of this; knots should not disappear easily in the stretched yarn. From hence, it could be concluded that tight knots are more pronounced compared to soft knots. Thus, knots can be made tighter considering interlacing stability [1, 60].

To ensure a good harmony between interlacing stability and usage area of the product, a certain load is applied once and it is compared with values which are obtained in basic load level [1, 60].

First load level 0.1 cN/dtex basic load level

Second load level 0.3 cN/dtex weft knitting, warp knitting, weft

Third load level 0.5 cN/dtex standard warp tension

Fourth load level 0.7 cN/dtex high warp tension and composite yarns including elasthane

Maximum 20 percent loss of knot number is acceptable according to the yarn usage area in load stage. This means 80 percent of interlacing stability is suitable. Interlacing stability is calculated with the following Equation 3.2 which is:

$$\%STAB=\frac{\text{average knot frequency}\times(\text{knot numbers under appropriate load}\div m)}{\text{knot numbers under basic load}\div m}x100 \qquad (3.2)$$

Interlacing stability results clearly show that air jet pressure changes interlacing stability significantly, but it has less effect on intermingling intensity. As a result of all these studies, it can be said that intermingling industry does not have a standard, efficient and economical quality research technique. Improvements in micro computer technology are expected to decrease costs in optical imaging techniques [1, 60].

CHAPTER 4: EXPERIMENTAL INVESTIGATION and STATISTICAL ANALYSIS

4.1. Materials and Methods

In this study, PES texturized intermingled filament yarns with the linear densities of 50, 70, 100,150 denier and PA6 texturized intermingled filament yarns with the linear densities of 40, 70, 100, 140 denier were used. Air covered elastic PES guipe (elastic yarn blended samples) yarns also used with the compound of 50/20, 70/20, 100/20, 150/20 and air covered elastic PA6 guipe yarns with the compound of 40/20, 70/20, 100/20, 140/20. In these compounds, first parts symbolize PES and PA6 yarn counts, second part (20) symbolize elasthane yarn count in all samples. In this experiment, Creora® brand elasthane was used as elastic yarn inside of air covered guipe yarns. In this way, sixteen different yarns were used in the experimental part of this thesis. The elasthane yarn draft value is 2.8 which mean the elasthane yarn stretch to the 280% value of its first length.

All samples were produced in an air cover machine which has approximately 5 bars air pressure value. This SSM® branded air cover machine was manufactured in the year of 2000. In order to acquire antistatic property to the synthetic yarns and also providing more proper and fast moving manufacturing, 0.9% lubrication were made. The lubricant brand was Promar®. In the experimental studies, upward air jets which have circular cross sections were used. These air jets' air outlet direction was the same with the yarns' flow direction. Three different machine speeds were used to separate the samples in three different groups namely low intermingled, medium intermingled, and high intermingled. The machine speed values were 500, 600 and 700 meters per minute which are commonly used in commercial manufacturing processes. It is claimed that while the yarn speed value increases, entanglement point number which determines intermingling level will decrease theoretically. In practice, however, it is stated that there are 70 to 90 knots in a meter of the yarn depending on air pressure value and yarn speed. But, there were more than 100 knots in a meter of the yarn in our experimental study. These knots are visually counted under a certain tension. It is thought that these extra knots were a result of excessive air pressure application, upward air jets, and variation of materials. In addition, experimental results generally demonstrated us that high level intermingled yarns were produced in the speed of 500 mt/min, medium level intermingled yarns were produced in the speed of 600 mt/min and lastly low level intermingled yarns were produced in the speed of 700 mt/min according to number of knots per meter.

All samples were tested in a tensile test device which is called Uster Tensorapid 3. These tests were repeated twice and mean values were taken as the final tensile value. Test speed was 500 mm/min and pre tension value was 4.3 cN. Tensile test unit was taken as cN/tex in the test device. Before the tensile test, upper portion of the yarn bobbins were unwinded about 300 meters in order to prevent yarn unevenness. All yarns were acclimatized in the standard atmosphere conditions for 72 hours before testing as a standard testing procedure.

Figure 4.1 shows picture of the automatic tensile tester Uster Tensorapid 3 used in the experiment. Tensile tests can be soundly achieved in all types of filament yarns from 20 denier to 300 denier counts with this device.

Figure 4.1 Automatic multiple tensile tester

Figure 4.2 shows test device’s automatic control mechanism that can adjust test values and also device screen which test results can be obtained from. The device has also a printer which ensures to take outputs of test values.

Figure 4.2 Test device screen and printer

Table 4.1 shows the average tenacity values of intermingled PA6 composition yarns. There are some pointless tensile results in the examined PA6 yarns. It is considered that existing meaningless results could come out due to using different raw materials in the tensile tests. For instance, in 40/1 PA6 samples, meaningless tenacity results could occur owing to short linear density value and raw material based low strength value. In 40/20 PA6 guipe samples, the tenacity results increase from the yarn speed of 700 m/min to 500 m/min as expected. Although there are exceptions, same expected results can be seen in 70/1 PA6 samples and 70/20 PA6 guipe yarns. Even though the values are close to each other, similar tenacity increases with yarn speed decreases can be observed in the other 100 and 140 denier PA6 samples. The interesting point is all tenacity results are around 40 cN/tex except 140/20 PA6 guipe yarns. These yarns have twofold strength value which is about 80 cN/tex compared to the other samples. It is thought that 20 denier elasthane yarns can enhance compact structure of the guipe yarn after a certain linear density threshold value. Thus, the strength value of the 140/20 PA6 guipe yarn could be higher. However, any tenacity increase cannot be identified with increase in yarn count from 40 to 140 deniers as expected. This means that the tenacity values don’t vary linearly with the increase in thickness of the yarns.

Table 4.2 shows average tenacity values of intermingled PES composition yarns. In these yarns, 50/1 and 50/20 guipe samples’ color are white, all the other samples are black. PES yarns have more pointless tenacity results compared to PA6 yarns. It is thought that these pointless results exist because of raw material variety and color difference. There is no tenacity increase in 150/20 PES guipe yarns as in the 140/20 PA6 guipe yarns. Insomuch that, 150/20 PES guipe samples include almost the lowest tenacity values.

Table 4.1 Mean tenacity and knot number values of PA6 yarns after intermingling process

Yarn Compound	Sample 1(cN/tex)	Sample 2 (cN/tex)	Average Tensile Strength (cN/tex)	Average Knot Numbers
40/1 PA6 (700 mt/min)	33.15	38.36	35.755	95
40/20 PA6 guipe (700 mt/min)	33.96	33.50	33.73	110
40/1 PA6 (600 mt/min)	30.64	34.85	32.745	130
40/20 PA6 guipe (600 mt/min)	32.69	34.40	33.545	150
40/1 PA6 (500 mt/min)	34.82	33.84	34.33	110
40/20 PA6 guipe (500 mt/min)	37.99	36.17	37.08	170
70/1 PA6 (700 mt/min)	41.60	34.05	37.825	85
70/20 PA6 guipe(700 mt/min)	41.69	37.44	39.565	130
70/1 PA6 (600 mt/min)	41.86	41.32	41.59	95
70/20 PA6 guipe(600 mt/min)	39.46	39.11	39.285	135
70/1 PA6 (500 mt/min)	23.88	41.86	32.87	105
70/20 PA6 guipe(500 mt/min)	43.09	41.78	42.435	150
100/1 PA6 (700 mt/min)	33.56	36.88	35.22	75
100/20 PA6 guipe (700 mt/min)	38.66	37.69	38.175	135
100/1 PA6 (600 mt/min)	40.42	39.12	39.77	80
100/20 PA6 guipe (600 mt/min)	38,41	37.72	38.065	125
100/1 PA6 (500 mt/min)	39.63	40.72	40.175	90
100/20 PA6 guipe (500 mt/min)	37.42	34.69	36.055	120
140/1 PA6 (700 mt/min)	42.94	39.97	41.455	110
140/20 PA6 guipe (700 mt/min)	79.07	81.34	80.205	110
140/1 PA6 (600 mt/min)	44.76	44.43	44.595	100
140/20 PA6 guipe (600 mt/min)	77.86	79.91	78.885	110
140/1 PA6 (500 mt/min)	44.42	44.78	44.6	100
140/20 PA6 guipe (500 mt/min)	81.28	81.06	81.17	122

Table 4.2 Mean tenacity and knot number values of PES yarns after intermingling process

Yarn Compound	Sample 1(cN/tex)	Sample 2 (cN/tex)	Average Tensile Strength (cN/tex)	Average Knot Numbers
50/1 PES (700 mt/min)	32.98	35.19	34.085	100
50/20 PES guipe (700 mt/min)	34.39	30.97	32.68	135
50/1 PES (600 mt/min)	32.75	33.02	32.885	110
50/20 PES guipe (600 mt/min)	29.56	28.86	29.21	160
50/1 PES (500 mt/min)	30.51	31.94	31.225	115
50/20 PES guipe (500 mt/min)	32.96	30.16	31.56	155
70/1 PES (700 mt/min)	35.96	34.91	35.435	90
70/20 PES guipe(700 mt/min)	34.44	36.01	35.225	105
70/1 PES (600 mt/min)	41.36	33.31	37.335	100
70/20 PES guipe(600 mt/min)	31.38	33.72	32.55	110
70/1 PES (500 mt/min)	32.84	32.22	32.53	115
70/20 PES guipe(500 mt/min)	34.43	34.24	34.335	115
100/1 PES (700 mt/min)	33.53	32.30	32.915	100
100/20 PES guipe (700 mt/min)	31.36	30.99	31.175	105
100/1 PES (600 mt/min)	34.15	33.89	34.02	105
100/20 PES guipe (600 mt/min)	32.11	33.23	32.67	105
100/1 PES (500 mt/min)	31.37	31.97	31.67	100
100/20 PES guipe (500 mt/min)	32.74	31.85	32.295	120
150/1 PES (700 mt/min)	30.84	30.33	30.585	100
150/20 PES guipe (700 mt/min)	29.91	30.08	29.995	110
150/1 PES (600 mt/min)	29.25	30.28	29.765	100
150/20 PES guipe (600 mt/min)	30.51	43.76	37.135	115
150/1 PES (500 mt/min)	30.68	30.63	30.655	110
150/20 PES guipe (500 mt/min)	30.48	29.06	29.77	120

4.2. Statistical Data

After completing the experimental part, the data were evaluated statistically for variance analysis. While the machine speed and yarn type values were selected as independent variables, tensile strength and knot number values were selected as dependent variables in the analysis of variance tests.

4.2.1. Machine Speed vs. Knot Number

Analysis of variation of the results demonstrated that machine speed value had a significant effect on knot number value (at 95% significance level, $F = 3.644$, $p = 0.030$, see Table 4.3). Post Hoc test also showed that a significant difference existed between only 700 m/min and 500 m/min although there wasn't any statistical meaningful result between the machine speed values of 500 m/min, 600 m/min and 600 m/min, 700 m/min (see Table 4.4). It is thought that lack of statistical significant Post Hoc results is derived from speed values which are closer to each other.

Table 4.3 Machine Speed Effect on Knot Number

Unit: number/meter	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3189.062	2	1594.531	3.644	.030
Within Groups	40696.094	93	437.592		
Total	43885.156	95			

Table 4.4 Multiple Comparisons of Knot Number Test Results (Post Hoc Test)

Unit: Number/meter

Tukey HSD

(I) (machine speed)	(J) (machine speed)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
700 m/min	600 m/min	-9.06250	5.22968	.198	-21.5186	3.3936
	500 m/min	-13.90625*	5.22968	.025	-26.3624	-1.4501
600 m/min	700 m/min	9.06250	5.22968	.198	-3.3936	21.5186
	500 m/min	-4.84375	5.22968	.625	-17.2999	7.6124
500 m/min	700 m/min	13.90625*	5.22968	.025	1.4501	26.3624
	600 m/min	4.84375	5.22968	.625	-7.6124	17.2999

*. The mean difference is significant at the 0.05 level.

4.2.2. Machine Speed vs. Tensile Strength

The statistic results showed that machine speed value had not a statistically significant effect on tensile strength value (95% significance level F = 0.034, p = 0.967, see Table 4.5 and Table 4.6).

Table 4.5 Machine Speed Effect on Tensile Strength

Unit : cN/tex	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	9.570	2	4.785	.034	.967
Within Groups	13186.719	93	141.793		
Total	13196.289	95			

Table 4.6 Multiple Comparisons of Tensile Strength Test Results (Post Hoc Test)

cN/tex
Tukey HSD

(I) (machine speed)	(J) (machine speed)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
700 m/min	600 m/min	-.62656	2.97692	.976	-7.7170	6.4639
	500 m/min	.07937	2.97692	1.000	-7.0111	7.1698
600 m/min	700 m/min	.62656	2.97692	.976	-6.4639	7.7170
	500 m/min	.70594	2.97692	.969	-6.3845	7.7964
500 m/min	700 m/min	-.07937	2.97692	1.000	-7.1698	7.0111
	600 m/min	-.70594	2.97692	.969	-7.7964	6.3845

*. The mean difference is significant at the 0.05 level.

4.2.3. Yarn Type vs. Knot Number

The ANOVA evaluation results indicated that yarn type had a statistically substantial influence on knot number value (95% significance level F = 9.650, p = 0.000, see Table 4.7). Post Hoc test also showed that there was a statistically significant difference between the yarn types of 40/1 PA6 and 40/20 PA6, 40/1 PA6 and 50/20 PES, 40/20 PA6 and 70/1 PA6, 40/20 PA6 and 100/1 PA6, 40/20 PA6 and 150/1 PES, 70/20 PA6 and 150/1 PES, 50/20 PES and 150/20 PES. An example Post Hoc test for the yarn type of 40/1 PA6 can be seen in Table 4.8.

Table 4.7 Yarn Type Effect on Knot Number

unit: number/meter	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	28264.323	15	1884.288	9.650	.000
Within Groups	15620.833	80	195.260		
Total	43885.156	95			

Table 4.8 Multiple Comparisons of Yarn Type & Knot Number Test Results (Post Hoc Test)

unit: number/meter
Tukey HSD

(I) intermingled	(J) intermingled	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
40/1PA6	40/20 PA6	-31.66667*	8.06764	.016	-60.2050	-3.1283
	70/1PA6	16.66667	8.06764	.780	-11.8717	45.2050
	70/20 PA6	-26.66667	8.06764	.093	-55.2050	1.8717
	100/1PA6	26.66667	8.06764	.093	-1.8717	55.2050
	100/20 PA6	-15.00000	8.06764	.886	-43.5384	13.5384
	140/1PA6	8.33333	8.06764	1.000	-20.2050	36.8717
	140/20 PA6	-2.50000	8.06764	1.000	-31.0384	26.0384
	50/1 PES	3.33333	8.06764	1.000	-25.2050	31.8717
	50/20 PES	-38.33333*	8.06764	.001	-66.8717	-9.7950
	70/1 PES	10.00000	8.06764	.997	-18.5384	38.5384
	70/20 PES	1.66667	8.06764	1.000	-26.8717	30.2050
	100/1 PES	10.00000	8.06764	.997	-18.5384	38.5384
	100/20 PES	1.66667	8.06764	1.000	-26.8717	30.2050
	150/1 PES	8.33333	8.06764	1.000	-20.2050	36.8717
	150/20 PES	-3.33333	8.06764	1.000	-31.8717	25.2050

*. The mean difference is significant at the 0.05 level.

4.2.4. Yarn Type vs. Tensile Strength

The ANOVA evaluation results demonstrated that yarn type had a statistically significant influence on tensile strength value (95% significance level F = 96.978, p = 0.000, see Table 4.9). Post Hoc test also showed that there was a statistically significant difference between the yarn types of 40/1 PA6 and 70/20 PA6, 140/1 PA6, 140/20 PA6; 40/20 PA6 and 140/1 PA6, 140/20 PA6; 70/1 PA6 and 140/1 PA6, 140/20 PA6, 150/1 PES; 100/1 PA6 and 140/20 PA6, 50/20 PES, 150/1 PES; 100/1 PES and 140/1 PA6, 140/20 PA6; 100/20 PES and 70/20 PA6. An example Post Hoc test for the yarn type of 100/1 PA6 can be seen in Table 4.10.

Table 4.9 Yarn Type Effect on Tensile Strength

Unit: cN/tex	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	12508.388	15	833.893	96.978	.000
Within Groups	687.901	80	8.599		
Total	13196.289	95			

Table 4.10 Multiple Comparisons of Yarn Type & Tensile Strength Test Results (Post Hoc Test)

cN/tex
Tukey HSD

(I) intermingled	(J) intermingled	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
100/1PA6	40/1PA6	4.11167	1.69300	.533	-1.8771	10.1005
	40/20 PA6	3.60333	1.69300	.742	-2.3855	9.5921
	70/1PA6	.96000	1.69300	1.000	-5.0288	6.9488
	70/20 PA6	-2.04000	1.69300	.998	-8.0288	3.9488
	100/20 PA6	.95667	1.69300	1.000	-5.0321	6.9455
	140/1PA6	-5.16167	1.69300	.173	-11.1505	.8271
	140/20 PA6	-41.69833*	1.69300	.000	-47.6871	-35.7095
	50/1 PES	5.65667	1.69300	.085	-.3321	11.6455
	50/20 PES	7.23833*	1.69300	.005	1.2495	13.2271
	70/1 PES	3.28833	1.69300	.848	-2.7005	9.2771
	70/20 PES	4.35167	1.69300	.433	-1.6371	10.3405
	100/1 PES	5.52000	1.69300	.105	-.4688	11.5088
	100/20 PES	6.34167*	1.69300	.027	.3529	12.3305
	150/1 PES	8.05333*	1.69300	.001	2.0645	14.0421
	150/20 PES	6.08833*	1.69300	.042	.0995	12.0771

*. The mean difference is significant at the 0.05 level.

4.2.5. Test Result Graphs

In order to have data about relationship between the variables, one way analysis was performed. Firstly, knot number was chosen as dependent variable while machine speed value was chosen as a factor of predictor. According to the first analysis, knot number and machine speed values were negatively correlated as shown in the following figure 4.3.

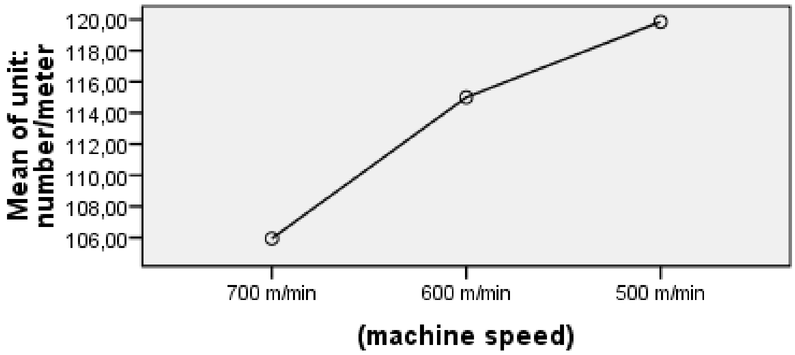

Figure 4.3 Machine speed impact to number of knots

Secondly, strength value was chosen as dependent variable while machine speed value was chosen as a factor of predictor. Although the strength values were very close to each other, maximum strength value emerged in the speed of 600 m/min with respect to this analysis as shown in the following figure 4.4.

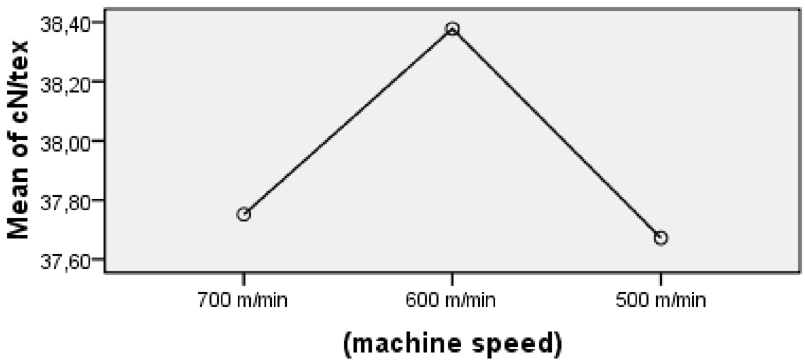

Figure 4.4 Machine speed impact to the strength value

After, knot number was chosen as dependent variable while yarn type value was chosen as a factor of predictor. While 50/20 PES elastic yarn has the maximum knot number value, 100/1 PA6 plain intermingled yarn has the minimum knot number value as shown in the following figure 4.5.

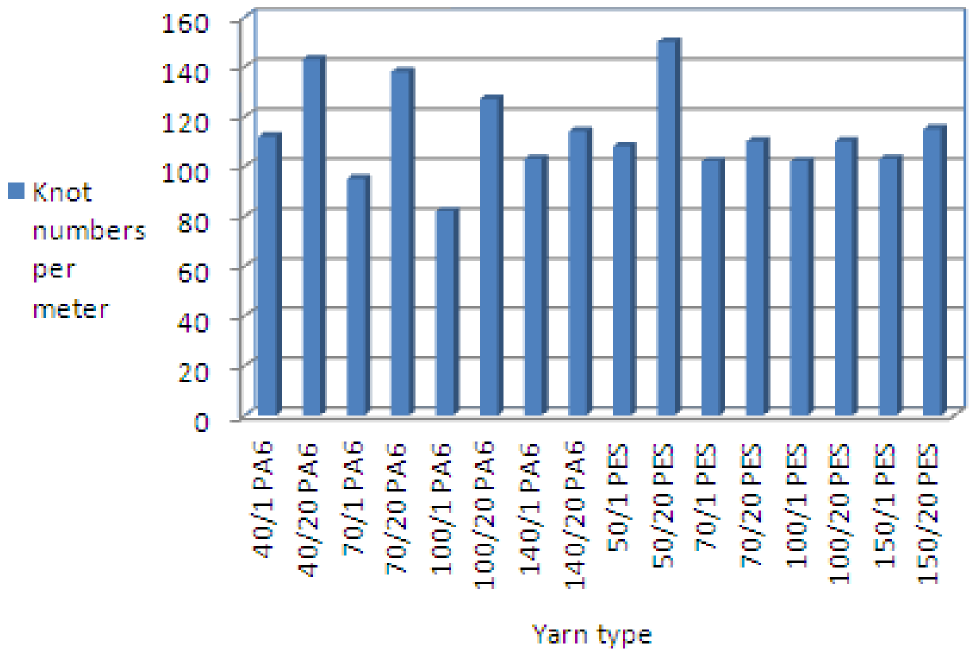

Figure 4.5 Yarn type impact to number of knots

Lastly, strength value was chosen as dependent variable while yarn type value was chosen as a factor of predictor. The noteworthy point is maximum strength value has come out in the elastic yarn type of 140/20 PA6 in accordance with the analysis as shown in the following figure 4.6.

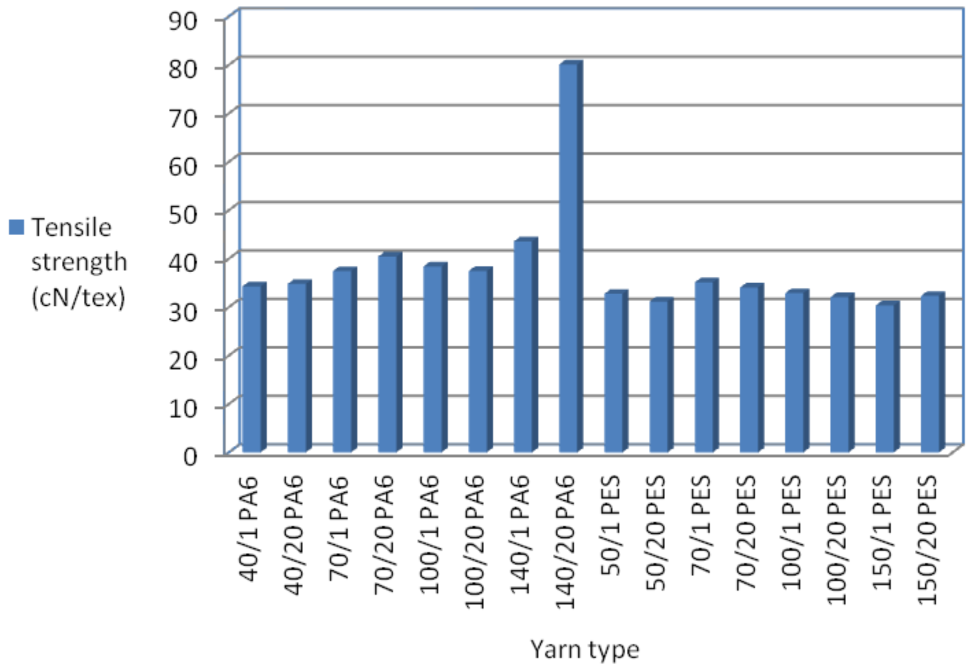

Figure 4.6 Yarn type impact to the strength value

CHAPTER 5: RESULTS and CONCLUSION

In this thesis, optimum intermingling conditions and durable yarn characteristics were investigated experimentally and statistically via using various types of synthetic filament yarns. PES and PA6 synthetic yarns were used in this study on account of extensive usage in industrial applications. These industrial applications were focused on especially weaving and hosiery sectors due to the fact that these sectors are manufacturing so many end use garments like socks and jeans for daily usage.

In order to find out the effect of intermingling on strength behavior of the filament yarns, machine speeds were classified in three different values and sixteen yarn types having diverse linear densities were selected. After completing the testing of samples, the statistical analyses were performed by using the strength and entanglement point numbers. Analysis of variance study let us understand deeply the relationship between physical parameters of yarns.

In the first experiment, the effect of machine speed was investigated with respect to the knot numbers. Statistical results demonstrated that machine speed had a statistically significant effect on the knot number that explained only significant difference exists between 500 m/min and 700 m/min. In the second experiment, relation between machine speed and tensile strength were analyzed. The statistical results showed that machine speed has no considerable effect on the tensile strength. The strength of yarns was almost same for every level of processing speeds. In the third experiment, the relationship between the yarn type and knot number was investigated. The ANOVA evaluation results indicated that the yarn type had a statistically expressive impact on the knot number. In the last experiment, the effect of yarn type was analyzed with respect to the tensile strength. Statistical results indicated that yarn type had a statistically remarkable effect on the tensile strength value.

Table 5.1 shows tenacity test results and average knot numbers of commingled PA6 and PES yarns. Average tenacity values of intermingled PA6 composition yarns concluded with meaningless results which could come out owing to using different raw materials in the tensile tests. In 40/1 PA6 samples, meaningless tenacity results could occur owing to short linear density value and raw material based on low strength value. In 40/20 PA6 guipe samples, the strength values were much higher in the processing speed of 500 m/min in comparison to the speeds of 600 m/min and 700 m/min as expected. Although linear density values of the PA6 yarn samples are different from each other, the interesting point is all tenacity results are around 40 cN/tex except 140/20 PA6 guipe yarns. These yarns have twofold strength value which is about 80 cN/tex compared to the other samples. The PA6 test results concluded that tenacity values don't vary linearly with the increase in thickness of the yarns. On the other hand, PES yarns have more pointless tenacity results compared to PA6 yarns. In order to give a brief explanation for this variation, it is thought that these pointless results exist because of the raw material variety and color difference. It is estimated that black colored yarns are more prone to wear owing to frictions between machine parts and yarn. There is no tenacity increase in 150/20 PES guipe yarns as in the 140/20 PA6 guipe yarns. Insomuch that, 150/20 PES guipe samples include almost the lowest tenacity values.

Table 5.1 Tenacity values and knot numbers

Yarn Compound	Tensile Strength of Sample 1(cN/tex)	Tensile Strength of Sample 2(cN/tex)	Average knot number /meter
40/1 PA6 (700 mt/min)	33.15	38.36	95
40/20 PA6 guipe (700 mt/min)	33.96	33.50	110
50/1 PES (700 mt/min)	32.98	35.19	100
50/20 PES guipe (700 mt/min)	34.39	30.97	135

Observed from experimental studies, commingling uniformity and stability can be affected from various factors like yarn counts, air pressures, machine speeds and raw materials. The experimental observations also revealed that strong relationships exist between the variables of yarn types and machine speeds with final yarn strength and knot numbers. It is known that increasing knot numbers directly affect the yarn strength in a positive way. Furthermore, it is also observed that as machine speed increases, knot number generally decreases due to less amount of air pressure exposure to the yarn.

In conclusion, it is accepted that the commingling is an innovative answer to make the filament yarns more durable against high volume tensions and yarn breakages in the manufacturing stages of multifilament yarns. With this method, it is possible to enwrap filaments at certain points. So, a unique compact yarn structure and durability feature can be obtained. Besides intermingling, air covering is also a distinctive process that merges multiple yarns to make up products with novel characteristics. These products can be used in various fields of outwear, underwear, hosiery, sportswear, narrow fabrics, and bicomponent yarns. Stretchable fabrics including air covered yarns are extremely demanded for their wearing comfort not only physiological aspect but also psychological aspect. Compared to standard yarns, core spun yarns produced by air cover method have become more and more used in the textile industry due to the contribution of the elastic filament to improve physical yarn properties. Despite stretchable fabrics raisingly diffusing the textile market, the conventional inelastic fabrics still constitute more than half of the whole market. Here is the intermingling technology offer to the textile manufacturers to produce unique yarns, and give them an opportunity to move away from standard products.

5.1. Recommendations for Prospective Studies

It is obvious that further work is required in this area to examine carefully the intermingling process with more parameters to reach the aim of uniform and stable intermingling. The following suggestions may be taken into consideration for guidance of prospective studies.

- Elongation values of the filament yarns may be added to the study in order to examine physical properties of the yarns in detail. In this way, more comprehensive and illuminating physical test results can be obtained with correlation between elongation and tensile test values.

- The other synthetic filament yarns like PAC, PP and PA66 may also be used to gain a broader perspective of filament yarn characteristics. So, useful and informative original knowledge may be notified to related textile industries like carpet, hosiery and automotive.

- To avoid pointless strength results in consequence of using diverse raw material, yarns may be provided from the same supplier that you have knowledge about their manufacturing process from the first stage. In other words, in order to avoid imperfections arising from production batch variety, it is required to obtain same synthetic raw material polymers like caprolactam, production methods and also climatic conditions.

- Closer yarn linear density and machine speed values may be picked out to associate and make sense of the relation between tensile strength and knot number values. Because, thickness variety of the yarns may cause different and unallied test results which is impossible to make inference. In addition, high machine speed values may give rise to damages and breakages along the filament yarn length.

- The other intermingling parameters like air pressure, elasthane draft, temperature and humidity may be strictly kept under control. For instance, air pressure difference may induce entanglement point disorder in a certain length of the yarn and so this case may be concluded with yarn strength decrement. It is also required to have detailed data about elasthane yarn’s physical properties like optimum draft, strength and recovery values. Although climatic conditions do not have critical importance as in natural fibers, remaining in unfavorable conditions during long periods may cause strength diversity.

- Besides intermingling, air cover technology needs to be examined in details owing to wide scope application areas especially in the field of health recently. Multiple yarn characteristics consisting combined elasticity and strength features may bring out novel physical yarn superiorities which may bring advantage and convenience to the manufacturing methods.

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