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STRUCTURE AND PROPERTIES OF VORTEX YARN

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ABSTRACT

The goal of this dissertation was to investigate the influence of technological parameters including the spindle diameter, yarn delivery speed, main draft and yarn fineness on the structure and properties of Vortex yarn. The investigation was based on yarns comprising 100% viscose with different fineness (from coarser to finer yarns),delivery speed ,spindle diameter and main draft. Geometrical properties(ribbon length, ribbon diameter and ribbon angle) of the yarns were investigated using Image analysis, which was used to capture and process images of the yarns. Ribbon length was used to estimate the amount of twist and twist coefficient of the and ribbon angle was used to calculate twist intensity. The yarns mechanical properties(tensile strength, hairiness, evenness and yarn imperfections) were investigated on the investigated using Uster Tester 4 and yarn hairiness was also investigated using Zweigle G567.Statistical analysis was used to investigate the normal distribution,95% confidence interval(upper and lower limit) and mean values. The properties of the yarn were analyzed in relation to twist coefficient. The results shows that delivery speed and spindle diameter have influence on ribbon twist and twist coefficient. Twist has significant influence on the diameter and ribbon angle of the yarn. Higher speed and larger spindle diameter yield yarns with better evenness and strength compared to yarns produced at low speed and smaller diameter. However yarns High twist increases ribbon angle.

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Table 1: List of symbols

Name	Symbols	Units	Name	Symbol	unit
Fiber fineness	t	dtex	**Mass**	m	g
Fiber diameter	d	μm	**yarn substance diameter**	Ds	μm
Fiber cross-sectional area	s	m^2	**Yarn packing density**	μ	-
Yarn fineness	T	tex	**Yarn cross sectional area**	S	m^2
Yarn density	ρ	g/cm^3	**Yarn unevenness**	CV	%
Fiber volume	v	m^3	**Koechlin’s twist coefficient**	α	$ktex^{1/2}/m$
Yarn diameter	D	μm	**Phrix’s**	a_m	$ktex^{2/3}/m$
Yarn twist	Z	1/m	**Force**	F	N
Elongation to break	ε	-	**Radius**	r	m
Tensile strength	σ	cN/tex	**Height**	h	m
Yarn length	l	m			
Yarn volume	V	m^3			
Hairiness	H	-			

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1 INTRODUCTION

Currently there is no much information on machinery parameters that affect the structure and properties of vortex spun yarn. However Basal and Oxeham have investigated the parameters and properties of PES/Cotton vortex spun yarn and 100% polyester. [1] And effect of some variables on the properties of 100% cotton vortex spun yarn where also investigated by Huseyin. [6]

Thus the purpose of this study is to investigate the influence of machinery parameters on the structure and properties of 100% viscose vortex spun yarn at constant pressure.

In addition, in this study, the vortex yarn will be compared to other yarns spinning systems (rotor and ring spinning systems) and to air-jet. However, the yarns will be compared theoretically (i.e. Structure and properties of Vortex yarn and comparison with ring and rotor yarn. Advantage and disadvantage of Vortex yarn processing, influence on the fabric properties.

The mechanical properties or characteristics of the fabrics depend not only on the physical properties of the constituents' fibers, but also on the arrangement of the individual fibers in yarn cross section. Several fabric properties such as strength, handle, elongation, covering power,

Resistance to abrasion, ease of dyeing, and wearing comfort are affected by yarn properties to varying degrees. The arrangements of the fibers in yarn structure have significant influence on the quality of the end- product and the manufacturing process for example weaving and knitting. The yarn characteristics depend mainly on properties of the fiber and the yarn structure. Various yarn technological processes produce yarns of different structures. The technologies are being introduced in improving the yarn properties and production speed (however, some of the processes did not make it commercially or satisfy the customer's need and the required quality.

Murata vortex spinning is proclaimed more advantageous over ring, open-end (rotor), and air-jet spinning systems. The structure of vortex yarn is claimed to be similar to the ring yarn and unlike the air jet system, it is suitable for spinning 100%carded cotton. Several fabric properties such as strength, handle, elongation, covering power, resistance to abrasion, ease of dyeing, and wearing comfort are affected by yarn properties to varying degrees.

However there are still some limited researches about the main parameters that affect the properties of vortex spun yarns. Thus the purpose of this study is to investigate the influence of process parameters on the structure and properties of vortex yarn (i.e. the role of delivery speed, main draft, yarn fineness and spindle diameter on the properties of vortex yarn.

2 LITERATURE REVIEW

2.1 REAL TWIST AND FALSE TWIST MECHANISM

During yarn formation, constituent fibers or strand of fibers are bonded together mechanically by means of twist insertion. This process increases the frictional forces between the fibers and prevents fibers from slipping over one another by yielding radial forces to the interior of the yarn.[1].

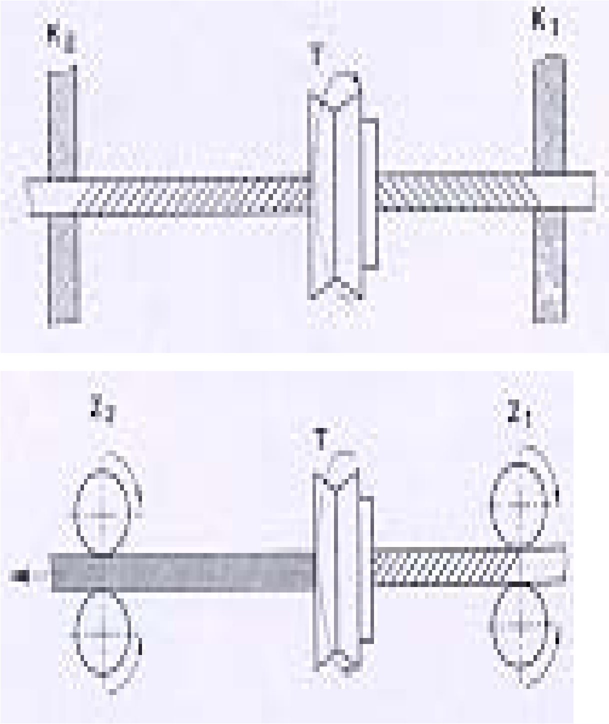
There are two terms that are associated with twist, which are real twist and false twist.

2.1.1 Insertion of real twist

The easiest way to insert twist into a strand of fibers (or filaments) is to hold one end (or part) of the strand while the strand length (or the length of the remaining part) is made to rotate on its axis or applying torgue movement on the other side of the fibre strand [2]. Consequently, the fibres are no longer parallel to the bundle axis, but are arranged in a helical path.[l].

2.1.2 Insertion of false twist

False twist is a results of applying twist to fibre strand, which is nipped on both sides, between the two nip points.[1,7].Both sides of the twisting device will experience twist in opposite direction(i.e. when viewed from K_1T it will appear to be turning clockwise and from K_2T it will appear counter clockwise. [2]Thus at the start of twisting Z twist will be inserted and on the other side of the twisting device will be S twist which results in zero net twist since the strand will have the same amount of twist from both sides of the device. This can be seen on **figure 1A.**If the clamps K_2 are replaced by rotating rollers then the strand will experience twist only between K1 and the twisting device(i.e. only Z twist) and the strand although being twisted has no twist as it depart the twisting device. It can be observed on **figure 1B**. [1].



A **B**

Figure 1: False twist mechanism [1, 7]

The mechanism is used to give the fiber strand a temporary twist. As suggested by Basal this mechanism can be used to generate spun yarns.Consequently, a substantial number of edge fibres do not obtain twist from the twisting element. Only the core part, which is the main part of the fiber bundle, enters the twisting element as the fully twisted form. The opposing turns imparting by the twisting element cancel the twist inserted to the core fibers earlier and give twist to the surface fibers which are originally untwisted. When the fiber strand departs from the twisting element, core fibers will no longer have any twist. “Surface fibers”, on the other hand obtain twist in the opposite direction and wrap around the parallel core fibers [1,7].This can be observed on figure 2 below:

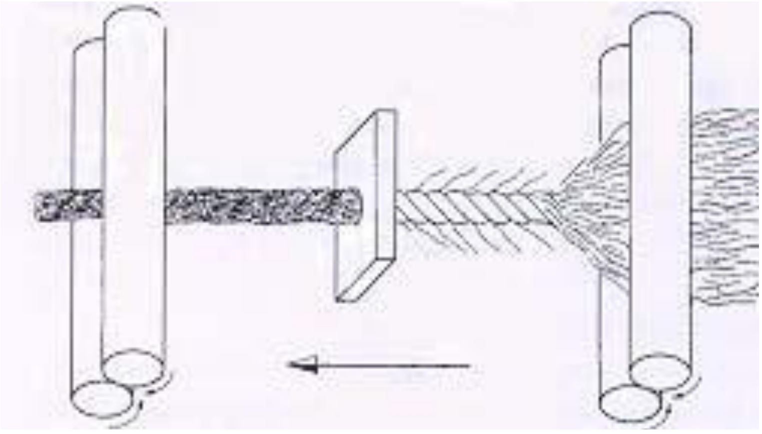


Figure 2: Yarn formation by means of false twist mechanism [1,7]

Several numbers of spinning technologies have used the false twist mechanism to produce yarns. Murata vortex spinning system (MVS) and Murata air-jet spinning system are the typical examples (I.e. vortex spinning system uses false twist mechanism).[1].Ring and rotor spinning systems uses real twist mechanism. Thus the structure of MVS is different from the two spinning systems. Some known processes operating on this principle (false twist) are Rotofil by Du Pont, Dref-3 by Dr. Ernst Fehrer.Linz, Murata Jet spinning and Murata Vortex spinning. [7]

2.2 VORTEX SPINNING SYSTEM

2.2.1 Introduction

The vortex spinning technology is one of the most promising new inventions in the spinning market. And it (vortex spinning technology) was developed by Japanese firm Murata (Muratec). Murata’s No. 851 Vortex Spinner made its first appearance at OTEMAS’97[1]. Vortex spinning is a false twist process, and the twist insertion in this system is achieved by means of air-jets. The main attraction of vortex spinning is that it is claimed to be capable of spinning 100% carded cotton fibers at very high speeds (400m/min), and the resulting yarn structure is more similar to ring yarn than to rotor yarn . Other claimed advantages of vortex spinning are a low maintenance cost due to fewer moving parts, elimination of the roving frame stage, and improved fully automatic piecing system. In addition to these, yarns produced by this method have low hairiness compared to normal ring yarns. This is claimed to be due to being “airsinged" and "air-combed," which in turn results in reduced fabric pilling; and fabrics made from vortex yarns have outstanding abrasion resistance, moisture absorption, color-fastness and fast drying characteristics. Murata suggests that MVS is best suited by far to the high volume production of medium cotton yarns from carded cotton. Thus, it seems that this spinning system presents more of a threat to rotor spinning [2].An entirely new technology "to spin yarn with the vortex flow of compressed air" created vortex; a quite new type of yarn. As in all other fasciated yarns, the structure of vortex yarn consists of a core of parallel fibers held together by wrapper fibers. [1].The idea of vortex spinning is to improve two features of air-jet system: (1) the number of wrapper fibers, (2) the length of wrapper fibres. The driving force of MVS development was to produce 100% cotton yarn on jet spinning. [8, 1].vortex spinning is a false twist process, and the twist insertion is by means of air-jets.

2.2.2 Principle of vortex spinning system

In MVS system, the sliver is fed directly to a 4-line drafting unit. The figure 3 below shows the principle of MVS spinning unit. [1] The drafted fibres are passed through an air jet nozzle and hollow spindle [3].

Figure 3-MVS spinning unit [1, 14]

The fibre bundle passage comprises nozzle blocker and needle holder. The needle holder has a substantially central, longitudinal axis and a guide surface that twists relative to the longitudinal axis a pin-like guide member associated with the needle holder protrudes toward the inlet of the spindle [1, 2]

Fibres exiting the nip of the front roller are sucked into a hollow spindle and they are held together more firmly as they move towards the tip of the needle protruding from the orifice [1]. The twist on the fibres is inserted by means of the forces of compressed air. The twisting motion tends to propagate (or move upwards) towards the front rollers. [1 The needle protruding from the inlet (orifice) of the spindle prevents the propagation (or the upwards movement) of the twist. [1].Therefore, the upper portion of some fibres is separated from the nip of front rollers but they are kept open. [3].When the fibres have left the orifice (guide members), the upper portion of the fibres begins to expand due to the whirling force of the jet air stream and they twine over the spindle. Since the leading ends of all fibers are moved forward around the guide member and drawn into the spindle by the preceding portion of fiber bundle being formed into a yarn, they present partial twist and are less affected by the air flow inside the spindle. On the other hand, when the trailing ends of the fibers which have left the front rollers move to a position where they receive the powerfully whirling force of the nozzle, they are separated from the fiber bundle, extend outwardly and twine over the spindle. Subsequently, these fibers are spirally wound around the fibre core and formed into vortex yarn as they are drawn into the spindle (figure 4 and 5 illustrate the formation of vortex yarn).

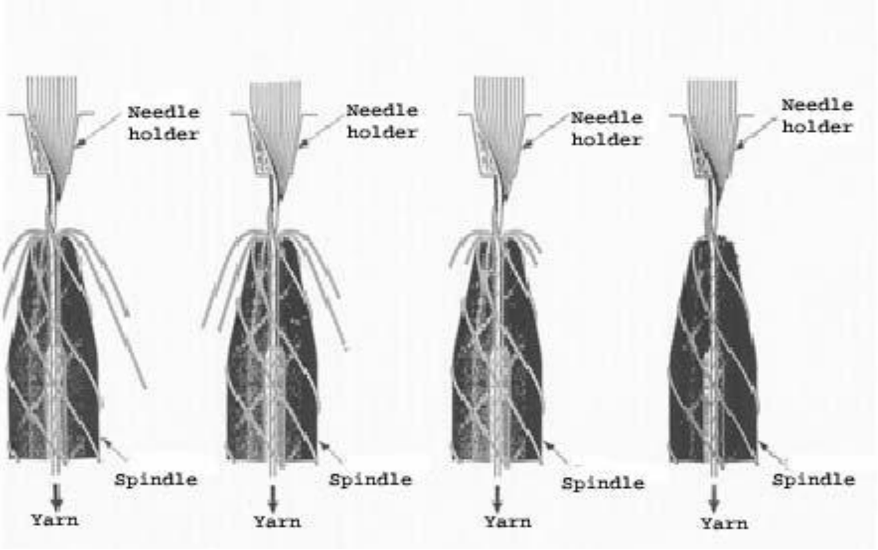


Figure 4: yarn formation in vortex spinning [1]

The diagram below (figure 5) is a single jet design of Murata Vortex system, which is a single air-jet spinning system. Compared to tandem jet system, it incorporates a modified jet inlet. The lower degree of wrapping that may be obtained from a single jet has the advantage of producing softly wrapped yarns [2]

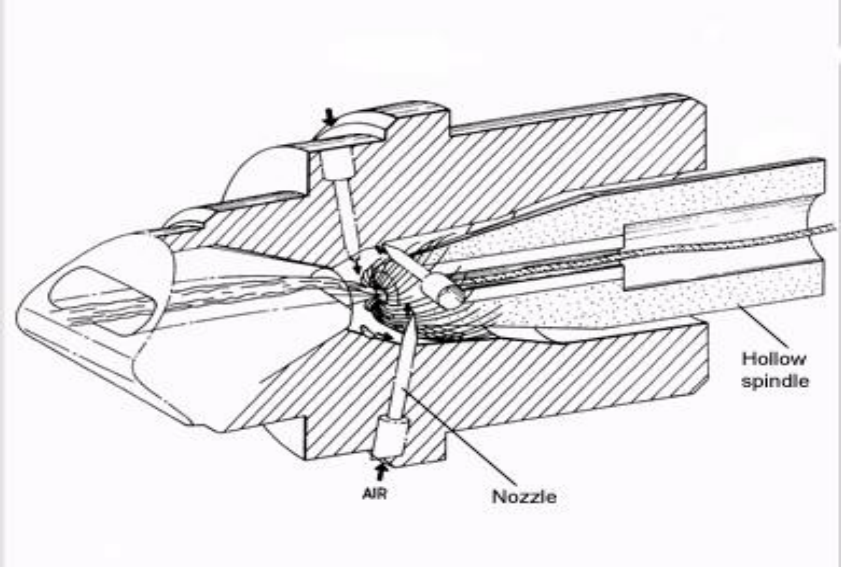


Figure 5: Murata Vortex single jet design (Principle of vortex spinning).[1,2]

The complete yarn is wound onto a package after it is cleared off defects.During the yarn formation, as the needle prevents the twist propagation. Thus, most of the fibers do not receive false twist. In addition, separation of the fibers occurs everywhere in the entire edge fibres. This results in higher number of wrapper fibers in the yarn. That is the reason why vortex spun yarn has more wrapper fibers than air-jet spun yarn and their yarn structure is similar or resembles that of ring spun yarn. [1].figure. 7

2.3 VORTEX SPUN YARN COMPARED TO AIR-JET SPUN YARN

2.3.1 Murata Air-jet spinning

2.3.1.1 Principle of air jet spinning system

In MJS, the air jet comprises two a nozzle (i.e. nozzle 1 and nozzle 2) of which nozzle 1 is placed between the nip of the front roller and nozzle 2. Nozzle 1 has air rotating in counter clockwise direction. Thus, the two nozzles apply air rotation in opposite directions. However, the air rotation in nozzle 2 has higher rotational speed than nozzle 1 to avoid absolute false twisting. The fibre strand form a spinning triangle similar to that of ring spinning .However, the fibres are under mush less tension than those in ring spinning(i.e. the fibres in the triangle are comparatively loose compare).the air rotation of fibre strand causes ballooning of fibre bundle between nozzle 1 and the front roller. This result in fibres being raised from fibre bundles and moves freely. This process is called “end-opening” action. [8]. Nozzles 1 prevents edge fibres from being twisted in or even twists them in opposite sense around core fibres (i.e. the edge fibres are left loose). Therefore, the core, which is the main part of the fibre bundle, passes through the nozzle two in full twist. The core fibres in nozzle 2 are untwisted and thus depart the nozzle in parallel form. In addition, the edge fibres are twisted around the parallel bundle of fibres in opposite direction and wrap around the bundle [1]. Figure 6 below illustrate the principle of air-jet.[1,3,4]

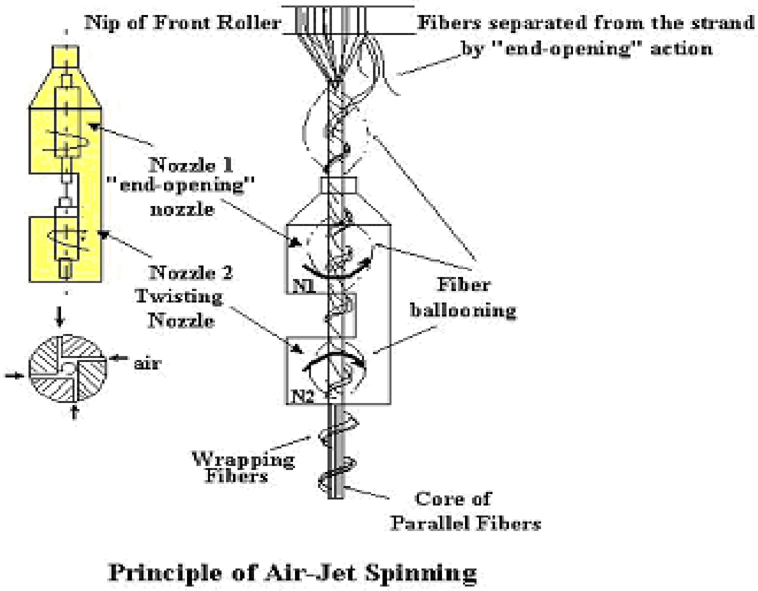
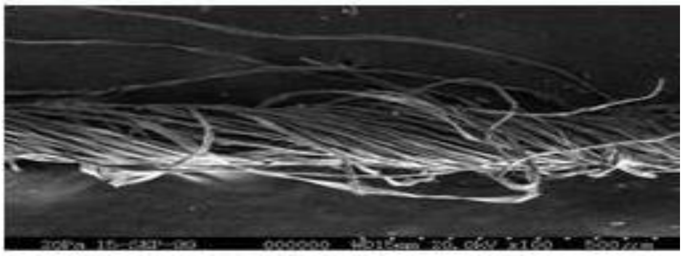


Figure 6: Principle of air-jet spinning [2]

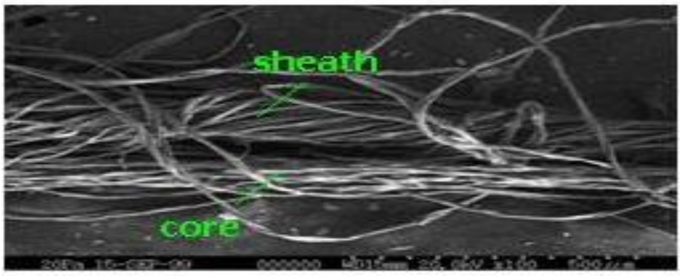
The main difference between the air jet and vortex yarn is the number of wrapper fibers, which is much higher in vortex yarns. In air jet spinning, only the edge fibers become wrapper fibers.

In vortex spinning, on the other hand, the fibre separation from the bundle occurs everywhere in the entire outer periphery of the bundle. It is very likely that during yarn formation the leading part of the fibers will not be able to escape from the false twist penetrating upwards and eventually become located in the core. The trailing parts, on the other hand, will not receive twist and become wrapper. [2]

In vortex spinning, the tip of the fibre is focused to the centre of the yarn by the vortex of compressed air so that the centre of the yarn is always made straight without twisted. The other tip forms the outer layer that twines another fibre. Figure 7 show the structure of vortex yarn (and untwisting the yarn revealed the core and the sheath that is formed by wrapper fibres).the image was taken under SEM.[1,27]



Vortex yarn



Untwisted vortex yarn

Figure 7: SEM images of Vortex yarn structure [1, 13]

This technology produces the vortex yarn with a unique structure through vortex spinning regardless of materials (it is claimed to process 100% cotton yarn).Vortex spinning has too many advantages, such as high production speed up to 400 m/min, better yarn properties like "ring-like" structure, low hairiness, reduced fabric pilling, better abrasion resistance, higher moisture absorption, better colour-fastness and fast drying. [2]

2.4 VORTEX SPUN YARN COMPARED TO RING AND ROTOR SPUN YARN

2.4.1 Ring spinning system

2.4.1.1 Introduction

Ring spinning system was invented in 1828 by American Thorp.. Many modifications have been done on the machine in order to increase its productivity but the basic principle has not changed. In order to increase spinning machine productivity, the speed of the traveler must also be increased. The speed could not be increased any further because of the heat produced by the traveler (.i.e. the traveler speed in thus limited). It is most widely used and prominent spinning method (compared to other spinning methods) by the industries today. Even though the productivity of ring spinning system is low, the ring spun yarn is still acceptable as the fundamental structure in spun yarn technology.[9,5].Ring spinning system is a real twist process.

2.4.1.2 Principle

Ring spinning is a continuous spinning system in which the twist is inserted into a yarn by circulation of a traveler around a ring. Twisting action and winding action take place simultaneously by means of rotating spindle.[5]

2.4.2 Rotor spinning system

2.4.2.1 Introduction

Open-end (OE or Rotor) spinning method is process whereby twisting and package building are separated by applying false twist principle. Real twist however is achieved in the yarn by forming a break in the attenuated mass at the point of twist insertion. The break is obtained by drafting the fiber mass to the point if individual fiber separation. An alternative description is that the free end of the yarn (i.e. the open end) is rotated while individual fibers are collected and twisted onto the end to increase the yarn length. Hence, it is referred to as open-end spinning. [2, 5.]

2.4.2.2 Principle

In Open-end spinning system, fibre bundle from the sliver stock are separated or drafted into individual fibres by creating a break in the continuum of the fibre mass. Opening of fibre bundle into individual fibres is achieved by the opening roller and an air stream. The drafted fibres are assembled in the rotor groove that is rotated to twist the fibres into a continuous strand of yarn. The length of yarn sound is then wound to form a package. Thus, twisting action occur simultaneously with the packaging but consecutively to winding. [2, 5]

2.4.3 Comparison of vortex spun yarn to ring and rotor spun yarn

Murata Vortex system can spun a yarn at up to 400m/min (i.e.it has high production rate).The structure resembles that of ring spun yarn and unlike air-jet system; it is suitable for spinning 100% carded cotton. Murata vortex spun yarn is claimed to have low hairiness compared to the normal ring spun yarn.and fabrics made from vortex yarns have outstanding abrasion resistance, moisture absorption, colour-fastness and fast drying characteristics[1].The figure 8 below show the structure of ring, OE and vortex spun yarn.

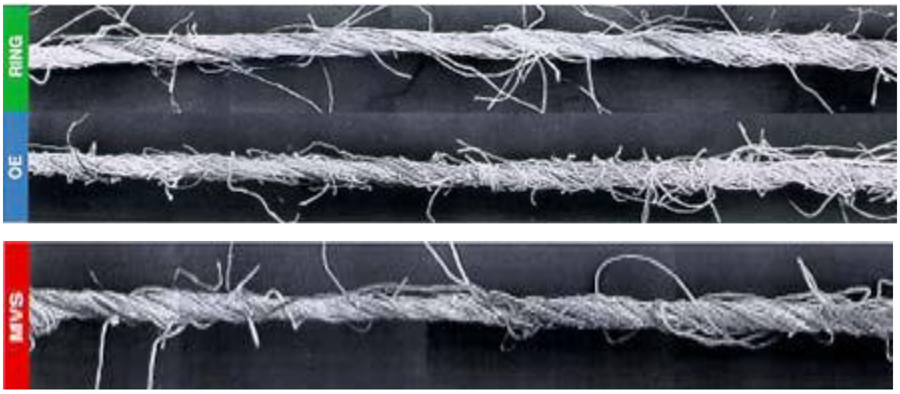


Figure 8: Ring, rotor and vortex spun yarns. [1]

2.5 PARAMETERS AFFECTING THE STRUCTURE AND PROPERTIES OF VORTEX YARN

2.5.1 Introduction

Several parameters that affect the structure of yarn (100% cotton and polyester-cotton blended yarn) were investigated by Basal and conducted by Dr.William Oxenham. They include nozzle angle, nozzle pressure, spindle diameter, yarn delivery speed and the distance between the front roller and the spindle. The effect of the parameters on the yarn structure, from their investigation, had them to conclude that short distance between the spindle and the front roller caused better yarn evenness, low imperfections and less hairiness. High nozzle angle, high nozzle pressure, low yarn delivery speed and small spindle diameter reduced yarn hairiness too. High nozzle angle, high nozzle pressure and low delivery speed causes high fiber migration. They also found that the parameters (nozzle angle, nozzle pressure and delivery speed) do not have any significant impact on the strength or tensile properties of the yarn. This is believed to be caused by the relatively small differences between the levels of these parameters used in the trials. [1]Some parameters (such as nozzle angle, nozzle pressure) are still investigated as there is insufficient information regarding those parameters).They also found that the parameters (nozzle angle, nozzle pressure, and delivery speed) do not have any significant impact on the strength or tensile properties of the yarn. [1]In analysis of structure of fiber, various methods have been discovered to study the path (migration) of fiber in yarn.

There is tracer fiber technique which was discovered by Morton and Yen and still a reliable method in determining the structure of yarn. [1,

Oxenham and Alagha adopted an image analysis processing for analyzing the structure of friction-spun yarn which is more effective than the traditional microscopic method [18]. However, the properties or parameters determined with this method cannot be done automatic. Thus require some improvement.[18,19]

And the other method is by Ishtiaque adopted using of soft cross-section analysis method (i.e. cutting cross-sections of the yarns) in charactering the orientation of fibers in the yarn. In this method, the samples (yarns) are embedded into a mixer of molten wax and paraffin before being cut. [19]

In analysis of MVS yarn, the yarn can be untwisted which reveals two sections of the yarn (the parallel core fibers and the wrapper fibers. And with the image analysis method, the parameters such as the wrapper ribbon diameter, angle of wrapper ribbon to the axis of yarn and length of the wrapper ribbon can be measured. The **figure 9** below show the structure of the yarn with measured parameters

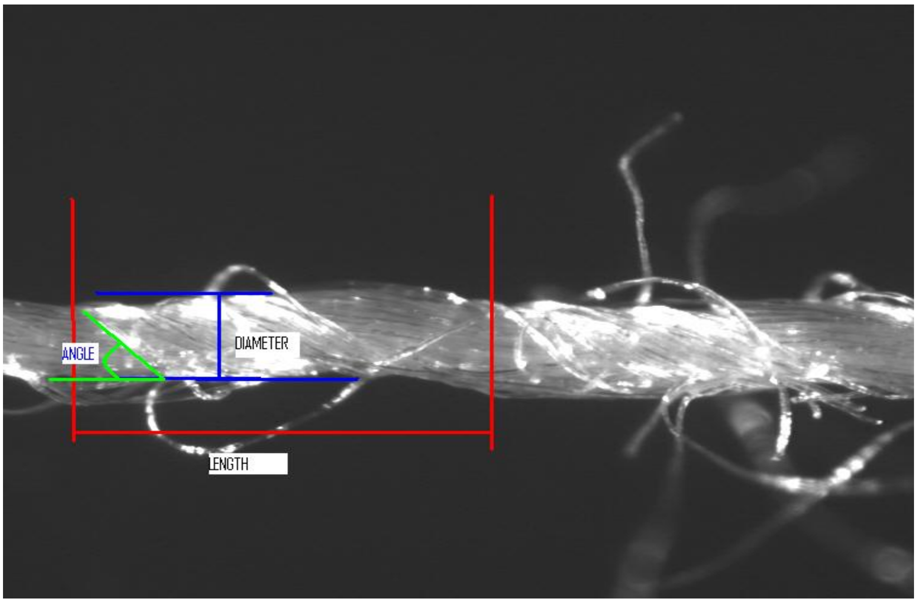


Figure 9: structure of MVS spun yarn [image analysis]

It has been proven that measured parameters can be influenced by the nozzle pressure, spindle diameter, thus influencing yarn properties such as twist and yarn fineness.

2.5.2 Basic fiber characteristics

2.5.2.1 Fiber fineness

Fibers are the fundamental elements or units of yarn. The textile fibers comes with various fiber cross section, some are circular (e.g. wool and some of synthetic fibers) and others are irregular. The fineness of the fiber, for circular cross-section shaped fiber, can be defined by its diameter and fiber density [12, 20]. It can be expresses as the ration between fiber mass and length of fiber. And mass of fiber is given by the product of fiber volume and fiber density. Volume of fiber is given by cross-sectional area of fiber and the length of fiber (equation 5.1b). It is defined by:

$$t = \frac{m}{l} = \frac{v\rho}{l} = \frac{sl}{l} = s\rho$$

(5.1a)

Where

$$v = sl$$

(5.1b)

Where t is fiber fineness in 1Mtex or dtex, m is mass of fiber in kg and l is length of fiber in [m],ρ is fiber density , V is volume of fiber and s is a fiber cross-sectional area.

2.5.2.2 Fiber diameter

Fineness and density define the cross sectional area. The cross sectional area enables to evaluate the equivalent diameter (equation 5.2 defines the cross-sectional area of fiber). The derivation is significant for non-cylindrical fibers (i.e.it describes the diameter of the ring having the same cross section).The diameter is referred to as an equivalent diameter.[20].From the equation 5.1a the diameter can be derived as:

$$s = \pi d^2 / 4 \tag{5.2}$$

$$d_e = \sqrt{4s/\pi} = \sqrt{4t/\pi\rho} \tag{5.3}$$

Where d_e is the diameter and s is a fiber cross-sectional area

2.5.2.3 Fiber strength and Deformation at break

Mechanical properties of fiber are realized during tensile testing process or experiment in which the load is applied to a specimen of single fiber or bundle of fiber. [12]The load is applied on a fiber or bundle in its axial direction. The load causes the tension and deformation to be developed and the specimen to be elongated or extended in length. The tension on the fiber continues until the specimen ruptures. [12] The stress at which the specimen ruptures provides the measure of fiber strength, which in the point, and the corresponding increase in specimen length provides the breaking elongation. Breaking elongation and can be determined by the equation 5.4 below:

$$\varepsilon = \frac{\Delta l}{l_o} 100 = \frac{l_o - l}{l_o} 100 \tag{5.4}$$

Where ε is elongation in [%], *lo* is the original length, *l* is the length beyond yield point (which is shown on the figure 10) and $\Delta\ell$ is change in length (i.e. ℓ_o-ℓ) in [m]

And breaking stress of the specimen is given by the equations 5.5 and 5.6. Where equation 5.6 and 5.7 are the equation used to determine mechanical stress in [cN/cm^2] and textile tenacity in [cN/tex] respectively. The equation 5.7 cannot be used to compare fibers of different densities (i.e. the ratio F/t cannot be use in comparing strength of fibers having different densities. Figure 10 shows that before yield point the stress is proportional to strain.[12] And below this point the specimen or material can completely recover to its original length and beyond this point the specimen will endure permanent deformation.[12].

$$\sigma^* = \frac{F}{s} \tag{5.5}$$

$$\sigma = \frac{F}{t} = \frac{F}{s\rho} \tag{5.6}$$

$$\sigma = \frac{\sigma^*}{\rho} \tag{5.7}$$

Where σ is stress or tenacity in [cN/cm^2 or cN/tex], F is force in [N] and σ^* is mechanical stress

This is illustrated in the graph (stress-strain curve) below in figure 10 below:

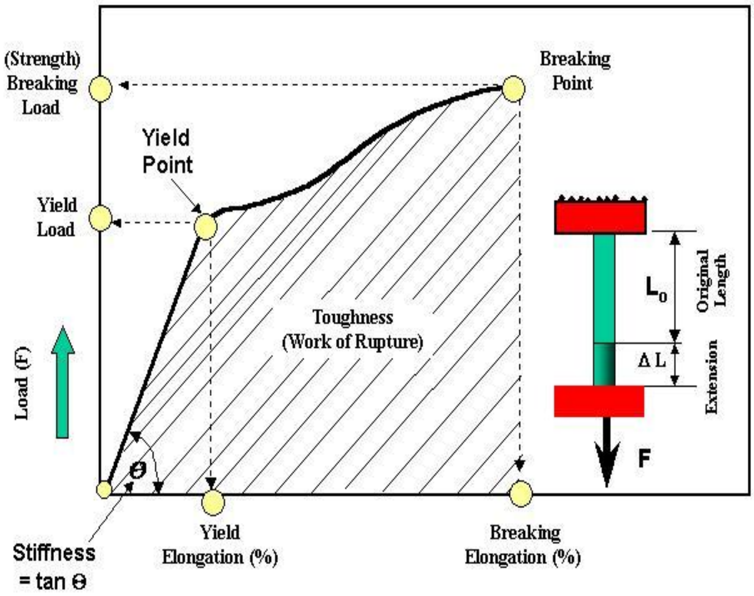


Figure 10: stress-strain curve,[12]

2.5.3 The basic yarn characteristics

2.5.3.1 Yarn fineness

The term yarn count is used to describe yarn fineness. The yarn fineness, which can be defined as mass per unit length and can be determined by the equation: [12]. By assumption, the equation 1 is applicable to all the types of yarns, thus we use it to describe the vortex yarn. But the yarn is influenced by the fiber mass density [20].The yarns are therefore compared to their fiber mass density but not yarn fineness or count (i.e. the yarn should be compared to the ration *t/ρ.* [20] From the equation 5.1 the fineness of the yarn in relation to mass of the fiber and length can be described as:

$$T = \frac{m}{l} = \frac{\rho V}{l} = \frac{\rho \pi D_s^{\ 2}}{4} \qquad (5.9)$$

Where T=yarn fineness [tex], m is mass [g] of 1km yarn,

2.5.3.2 Yarn diameter and Packing density

Yarn diameter is one of the important parameters of the structure of yarn. The relation between yarn diameter and yarn fineness (equation 5.9) can provide useful information in analyzing and comparing yarns [12]. If the value of packing density is known, it is then possible to evaluate real yarn diameter and limit or substance diameter by the following expressions:

$$D = \sqrt{\frac{4S}{\pi}} = \sqrt{\frac{4T}{\pi\rho}}$$

(5.10a)

$$D = \sqrt{\frac{4T}{\pi\mu\rho}}$$

(5.10b)

$$\mu = \frac{V}{V_T} = \frac{Sl}{\pi D^2 l/4} = \frac{4S}{\pi D^2} = \frac{4(\pi D_s{}^2/4)}{\pi D^2} = \left(\frac{D_s}{D}\right)^2$$

(5.11)

Where Ds is lowest possible yarn relation with only fibers(also known as substance diameter) which is defined by the equation 5.10, D is a diameter of a real yarn, S is yarn cross section area μ is packing density and V_T=total yarn volume,

The yarn diameter depends on the packing density (which is also influenced by amount of twist applied to the yarn) of the yarn and yarn count. [12.20]. This can be seen on the expression 5.8.1 The higher the cross sectional area the higher is the yarn diameter and the coarser the yarn. In contrast, the smaller the yarn diameter the finer will be the yarn. However, for other yarns, the size of the yarn diameter from different spinning systems can be described differently (e.g. the higher value of rotor spun yarn indicates that is bulkier than ring spun yarn)[12]. By assumption, the principle or the relation between yarn diameter and twist, fineness is applicable to estimate the yarn diameter of MVS yarn.

And for substance diameter, as the diameter of the yarn decreases thus the packing density of the yarn. The packing density is influenced by amount of twist. When the twist is high, more fibers are compact or compressed to the center of the yarn decreasing the diameter of the yarn. The packing density can be derived by the expressions (equations 5.11and 5.11):[20]

2.5.3.3 Yarn twist and twist intensity

The yarn twist can be determined from the measured length of the wrapper fiber. The amount of twist, Z, can be described as the number of turns per unit length [20] given by equation 5.13. To determine the relationship of twist to other parameters of yarn, ideal helical model (Hearle et al, 1969), from the figure 11 below can be used. [11, 12, 14,].In this model the fibers on the yarn surface are assumed to be circular and arranged in uniform helical path so that the distance from the center remains constant [25].A fiber at a center will follow the straight line of the yarn axis, but going out form the center, the helix angle gradually increases, since the number of turns is twist per unit length remains constant in all the layers. The density of packing of fibers in the yarn remains constant throughout the model.[25] Based on the model the yarn twist can be expressed as :

$$Z = \frac{1}{h} \qquad (5.13)$$

Where Z is twist, h is height of one turn of wrapper ribbon. For helical model describe only one turn of twist which is illustrated on the triangle on the right of figure 11.[12.22]

The product value of twist, yarn diameter, d, and pi (π) give us twist intensity (equation 5.14). This characteristic of yarn is dimensionless since the unit of twist (Z) is 1/m and yarn diameter is m. Hence there are no units. [20].If we assume that the fibers (for vortex, ribbon fibers) follows the helical path then twist intensity is also the tangent of angle α of this ribbon.

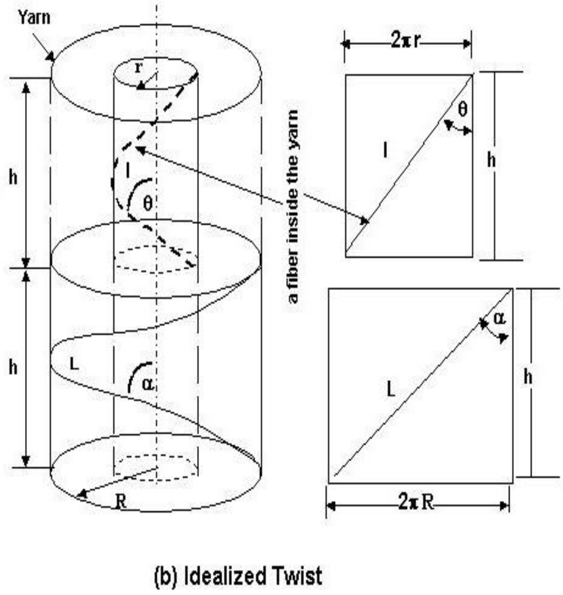


Figure 11: twist direction and twist factor of idealized yarn geometry. [12]

From the ideal yarn, the following relation for twist intensity can be derived

$$\tan\alpha = \frac{\pi 2R}{h} = \pi DZ$$

(5.14)

Where:

α is the twist angle

πDZ (2RπZ) is defined as twist intensity

R is radius of yarn

By assumption the model can be used to determine the geometrical parameters of the yarn.

2.5.3.4 Twist coefficient

Koechlin’s twist coefficient can be expressed as:

$$\alpha = \frac{Z \times \sqrt{T}}{31.623}$$

(5.15)

Where α is twist multiplier or twist factor which is measured in ***ktex$^{1/2}$m^{-1}***

And Phrix's formula can also be used to calculate twist factor. It is defined by the formula:

$$a_m = \frac{Z \times \sqrt[3]{T^2}}{100}$$

(5.16)

Where: a_m is Phrix's twist coefficient in ktex$^{3/2}$m^{-1}

2.5.3.5 Yarn tenacity and deformation at break

Yarns are also characterized to their strength (which is considered as one of the fundamentals characteristics of the yarn [12]. The yarn strength is realized during a tensile testing in its axial direction. The loads applied to the yields a tension which causes the yarn to extend in length. They continue to builds to until the yarn breaks. The load at which the yarn breaks provides the measure or amount of yarn strength and the corresponding increase in length provides a measure of breaking elongation. This principle has been described in 2.6.3.

Various principles from different spinning technologies produce yarns of different yarn mechanical properties. Fiber strength has influence on the tenacity of yarn.

2.5.3.6 Yarn Evenness and Imperfections

The evenness or regularity of a fiber strand (e.g. sliver, roving or yarn) is a measure of the extent of uniformity of a strand thickness (fiber mass) along its length. Imperfections represent abnormal incidents exceeding in their forms the expected variation in the thickness of a fiber strand (this include thin and thick places and neps) [12].Mass influences other properties of yarn (tenacity, twist) and flat textile (appearance on the final textile material). [21].Therefore, goals for each spinning system is to produce yarn with better or minimal unevenness. The yarn unevenness is expressed by Martindale's formula (which is represented by equation 5.17) below:

$$CV_{\lim}[\%] = \frac{100}{\sqrt{n}}$$

(5.17)

Where

$$n = \frac{T}{t}$$

(5.18)

C.V$_{\text{lim}}$ is limiting irregularity,

n is mean number of fiber in the cross-sectional of the longitudinal fibrous product,

t is fiber fineness

The equation 5.17 indicates that as the number of fibers per yarn increases, cross section increases, the limiting irregularity decreases. This may be explained on the bases that the increase in the number of fibers creates a compensating or a doubling effect that reduces the irregularity in yarn cross section.[12]The limit irregularity can be reached in case of an ideal distribution of fibers.

The main parameter use for characterizing yarn evenness is the coefficient of variation (C.V %). The parameter is base on “cut and weight” method. The Uster Tester uses a test length of 15mm.This means that CV% correspond to an electronic cut length of 8mm.[12].The periodic irregularities in the yarn can be revealed using a spectrogram chart. For spun yarns, Uster evenness’ tester produces the spectrogram that covers the range of wavelength from 2cm to 1280m.It assesses periodic mass variations. And these periodic variations are typically caused by mechanical defects. [12]

2.5.3.7 Yarn imperfections

The three major imperfections on that are exhibited on the yarn are thin places, thick places and neps. They can be classified as yarn faults which have influence on yarn quality. The Uster Tester 4 allows the following sensitivity thresholds for thin places -30%, -40%, -50% and -60%.So when the selected threshold is exceeded the thin place is counted. The standard setting is -50%. And for thick places, the following sensitivity thresholds are allowed +34% +50% +70% and +100%.When the limit is exceeded the thick place is counted. The standard setting for thick places is 50%.

A nep is a short thick place on the yarn. The nep can be either the fiber knot or a seed coat nep or a trash particle. Uster Tester allows the following thresholds for the nep: 140%, 200%, 280% and 400%.The standard threshold is 200%.

The imperfections are measured together with other properties of yarn such as hairiness, yarn diameter, mass evenness.

2.5.3.8 Yarn Hairiness

Yarn hairiness is one of the parameters which is related to other parameters of yarn such as technological operation or process (i.e. spinning process) and textile (appearance the fabric, comfort, aesthetic properties and hand).It can be influence by yarn count, fiber parameters and production technology. [23]. Hairiness may be defined as the extent of fibers protruding from the yarn body. There are various methods which can be used to determine yarn hairiness of a yarn by using Zweigle® hairiness measuring device, Uster tester and by NIS Image analysis. [22, 23, 24]

2.5.3.8.1 Determination of yarn hairiness using Image analysis

Image analysis NIS element is a system, which comprises light microscope, digital or analogue camera and computer installed with a special program or software. This method is based on scanning images of yarn longitudinal views.[24].And the processing of the images is done according to Internal Standard (IS 22-102-01/01) following Neckar’s theory. [24]

2.5.3.8.2 Determination of hairiness using Uster Tester 4

Testing of yarn hairiness in Uster Tester is based on the optical principle. The calibration with the yarn of the sensors is done at the start of the testing. The yarn is passed through the testing area or zone and the light flashes the protruding hairs or fibers. The scattered light by the protruding hairs is collected by the lens system and sent to the optical sensors. The electrical output of the optical sensors, which is proportional to the yarn hairiness, is converted to the digital values which are then evaluated by Uster Tester. [24].

2.5.3.8.3 Determination of hairiness by Zweigle G567

Determination of yarn hairiness on Zweigle G567 is based on optical principle. The calibration of the optical sensors is performed at the beginning of testing. The yarn is guided through testing zone and the monochrome light shines the protruding fibers. The scattered light by the yarn body and protruding hairs changes the intensity of the light which is detected by optical sensors (i.e. the optical sensors measures the change in intensity of light.[24].The observing of fiber occurrences is (length category,1mm.2mm.3mm.4mm.6mm.8mm.mm10,mm12mm and 15mm) correlate with the input information of the yarn. Data processing can be dome one the program of measuring device or any other program such as Microsoft excel and Matlab. The output data is the absolute occurrence of hairs in given length category. So when the measured fiber covers more than one category then only the last category will be counted.[24]

The occurrence of hairiness in given length category is determined by using sum criteria, S_{12} ,S_3 and S principle.S_{12} is defined as the sum of the absolute occurrence of hairs with length not more than first two categories. And S_3 gives information about occurrence of hairs that exceed more than 3mm length.S is the sum of the sum criterion. The sum criteria are expressed by the following equations:

$$S_{12} = \sum_{i=1}^{i=2} n_i \qquad (5.19a)$$

$$S_3 = \sum_{i=3}^{k} n_i \qquad (5.19b)$$

$$S = S_{12} + S_3 \qquad (5.19c)$$

Where: n_i is relative frequency of fibers, S_{12} and S_3 are sum criterions and S is sum of two criterion

2.5.3.8.4 Shape

It is the factor which indicates the average yarn roundness over the entire test length of yarn. The value correspond to the long main axis of an ellipse (e.g. circular shape=1 and ellipse 0.5).

3 EXPERIMENTAL PART

3.1 Material

3.1.1 Fiber and yarn properties

In order to determine the geometrical properties and the influence of draft, delivery speed and fineness of the Vortex yarn, 9 different yarns (i.e. 5 samples produced at different parameters with 5 bobbins in each sample) of 100% viscose fibers were produced using Muratec No. 861 Vortex. The yarns differ in number of counts, from fine yarns to coarser yarns (i.e. three levels of delivery speed, 325, 350 and 375 m/min and three levels of yarn counts, 16.5, 20 and 25 tex were selected. The yarns were produced at the same pressure of 0.5 MPa, spindle diameter of 1.1, 1.2 and 1.3 mm and 19.5 mm input rollers. The table below illustrates the data of the fibers used:

Table 2: Fiber material

Material	Type	fiber fineness [dtex]	Staple [mm]
100%VSs	carding machine	1,3	38
100%VSs	1st draw passage	4,1 ktex (sliver fineness)	
100%VSs	2nd draw passage	3,5 ktex	

The list of yarns and their corresponding test conditions (process parameters) are listed on the table 3 below:

Table 3 : Process Parameters

Technology Lot No.	material	Fineness [tex]	delivery speed [m/min]	Spindle diameter [mm]	Main draft	Nozzle pressure [mPa]
1	100% Viscose	16,5	350	1,2	45	0.5
2	100% Viscose	20	350	1,2	45	0.5
3	100% Viscose	25	350	1,2	45	0.5
4	100% Viscose	16,5	325	1,1	55	0.5
5	100% Viscose	20	325	1,1	55	0.5
6	100% Viscose	25	325	1,1	55	0.5
7	100% Viscose	16,5	375	1,3	35	0.5
8	100% Viscose	20	375	1,3	35	0.5
9	100% Viscose	25	375	1,3	35	0.5

Input roller distance =19.5mm

3.2 ASSUMPTIONS

For an ideal structure of MVS spun yarn, we assumed that the parallel fibers created yarn core with diameter D_c. The twisted fibers created the ribbon with helix contour around the core of the yarn with diameter D. Height of the ribbon is given by equation:

$$h = 1/Z_R \qquad (5.20)$$

And between angle β and the twist $Z_{R,}$ twist intensity can be evaluated using the expression:

$$\tan \beta_R = \pi D_C Z_R \qquad (5.21)$$

Where:

β_R is the ribbon angle, D_C is diameter of the core fibers and Z_R is the ribbon twist.

Since twist on of the ribbon is inserted by swirling of air, the ribbon twist was evaluated using the expression 5.20. We applied the expression 5.22 to evaluate ribbon twist coefficient. We also assumed that ribbon fibers form spiral cylinder *Dh* which correspond to the diameter of the yarn (i.e. ribbon fibers have the same diameter as the yarn and length *l* is negligible).

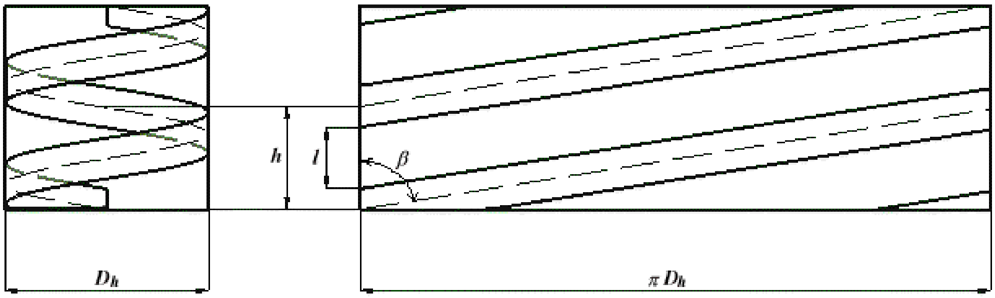


Figure 12: Model representation of ribbon fibers[27]

3.3 GEOMETRICAL PROPERTIES OF YARN

3.3.1 Methodology

In examination of geometrical parameters of the Vortex yarns, the yarns were observed under microscope (Nikon) with COHU (high performance CCD analogue camera) and NIS element software. The observation was done on the basis of capturing ribbon fibers on the yarn samples and 250 images were taken continuously for each kind of yarn samples. The arrangement or set up is shown on the Figure13 below. The captured images were stored in a computer and assisted in examining the influence of technological process parameters to the structure of Vortex yarn.

Figure 13: Experimental set up

3.3.2 Image processing

From the captured images, ribbon fiber helix angle (was measured to the inclination of the wrapper fiber to the core of the yarn), ribbon fiber diameter (the yarn diameter using Image Analysis software was measured from the edges of the yarn) and ribbon fiber length for one turn- twist were measured, manually. The boundaries of yarn and the path of ribbon fibers were marked using NIS element software. QC expert software was used to process the data from the measurements. Figure 9 demonstrate how the parameters were measured using Image Analysis software.

3.3.2.1 Statistical analysis

Normal distribution, 95% confidence interval (upper limit (*ul*) and lower limit (*ll*)) and mean values for all data were evaluated. Twist and twist coefficient were then calculated according to equations 5.11 and 5.13 respectively. And ribbon angle was evaluated using equation 5.12.

3.4 MECHANICAL PROPERTIES OF YARN

3.4.1 Methods

Properties of the yarns (i.e. evenness, imperfection (neps, thick and thin places) and hairiness were measured using Uster Tester 4 and Instron instruments and tensile properties were measured on Instron machine. The Figures 19 below shows the experimental set up of Uster Tester instruments and tensile properties experimental set up can be seen on Figure 20. The machine set to pull the yarn at the speed of 400m/min. In order to determine the properties of yarn 5 bobbins of each yarn sample were measured. The data was then collected on the computer.

And for tensile properties of the yarn, 20 measurement for each bobbin were measured resulting in 100 measurement for each yarn sample (each sample comprises 5 bobbins). The data was then collected on the computer installed with software. The statistical results from these tests are given on the table 7, 8 and 9(in the appendices).

Figure 14: Uster Tester 4 system setup.

Figure 15: Instron experimental setup

3.5 YARN HAIRINESS

In order to determine the hairiness of yarn sample, Zwigler G567 hairiness device was set to run speed of 50m/min for a length of 100m for each yarn sample. And the hairiness was also tested on Uster Tester 4.The setup is shown inFigure 16: Setup: Zweigle hairiness tester device Figure 16. The data as collected on the computer with installed software and the yarns were analyzed according to internal standard IS 22-102-01/01 Yarn diameter and hairiness.

Figure 16: Setup: Zweigle hairiness tester device

4 RESULTS AND DISCUSSION

The yarns were plotted according to the delivery speed, spindle diameter and main draft. The three digits (e.g. length 1.1 325 55) represents, spindle diameter, delivery speed and main draft respectively.

4.1 Geometrical properties

4.1.1 .1Microscopic observation

Statistical data of the measurement can be seen below on figures 15, 16, 17 and 18

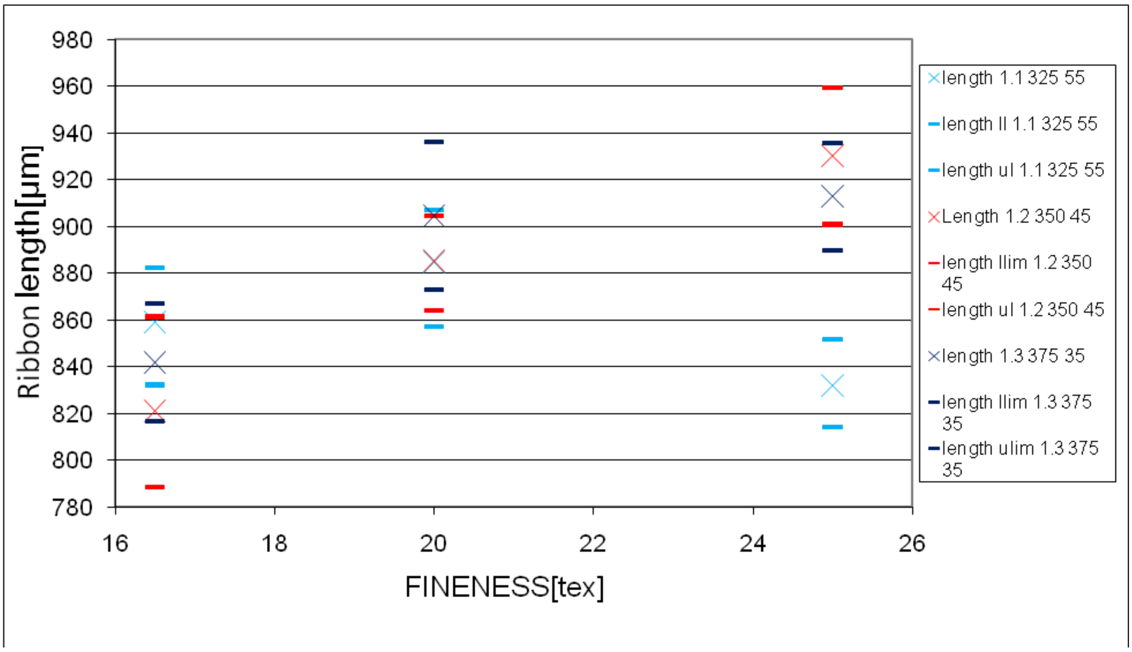


Figure 17: Ribbon length as function of fineness

Figure 17 shows that Ribbon length increases with increasing yarn tex (i.e. Coarser yarns have longer ribbon length compared to finer yarns) . Fineness has significant influence on the ribbon length. For coarser yarns, there is a significant difference between the yarns (i.e. high speed and larger spindle diameter have influence on ribbon length).

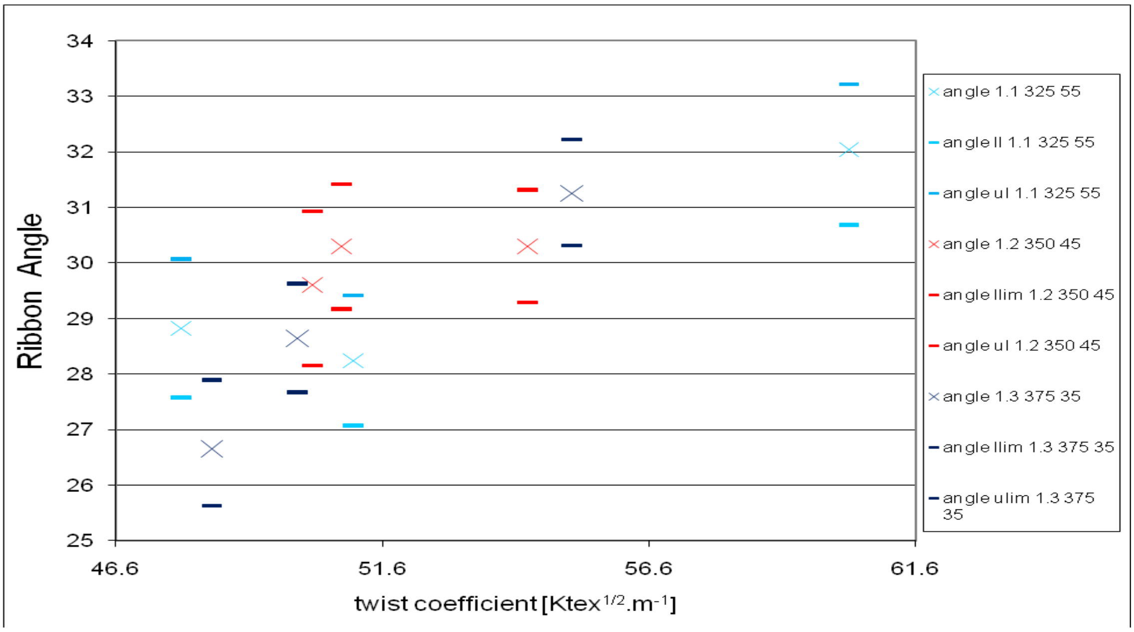


Figure 18: Ribbon angle as function of twist coefficient

Figure 15 shows that an increase in twist coefficient increases ribbon angle. Speed and spindle diameter do not show significant influence on the angle. When twist coefficient increases, the ribbons are tightly wrapped around the core of the yarn.

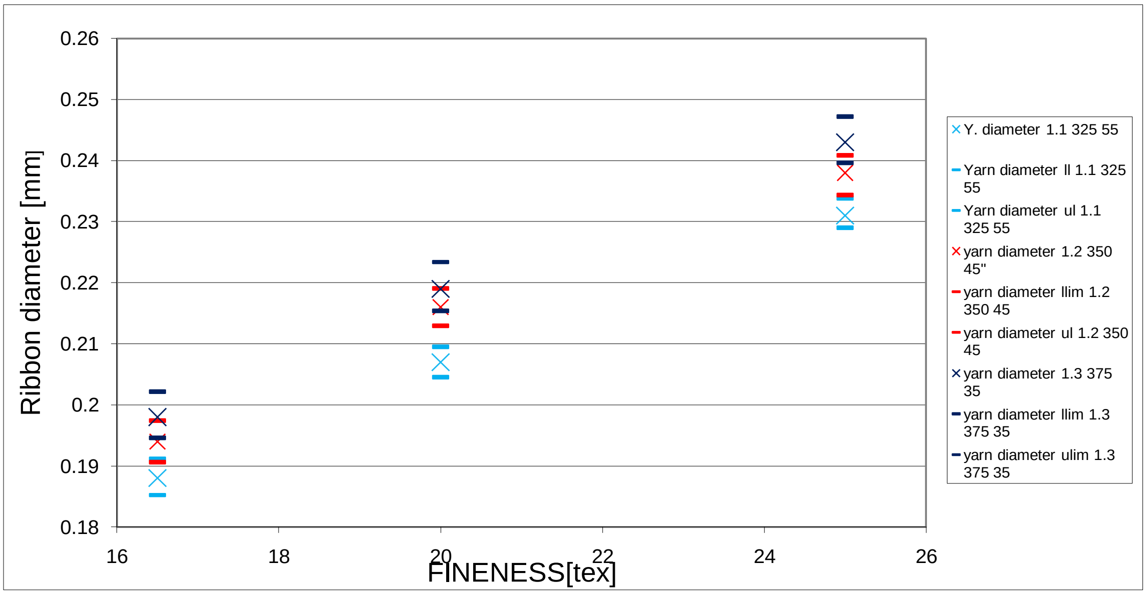


Figure 19: yarn diameter as function of twist coefficient (Uster Tester)

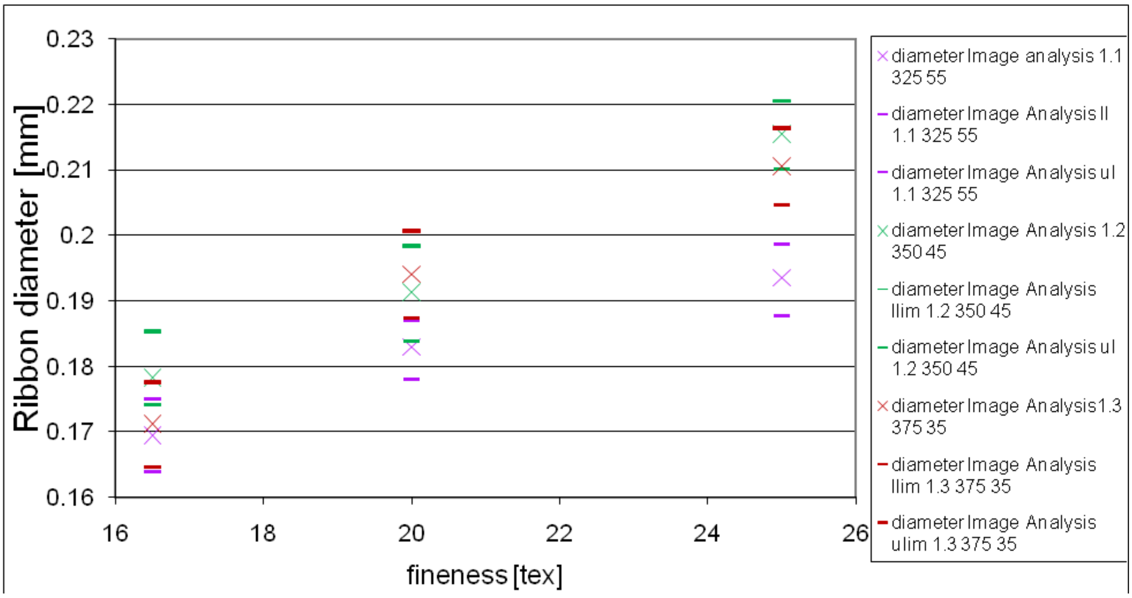


Figure 20: Ribbon diameter as a function of fineness [image analysis]

The influence on the diameter of the yarn was investigated using Uster Tester 4 and NIS Image analysis. Uster Tester measures the diameter of the yarn by measuring the higher distance (i.e.it also include hairiness) from the yarn core and for Image Analysis the diameter is measured directly from the yarn edges. Both results, from Figure 19 for Uster Tester 4 and Figure 20 for Image analysis, show that the diameter of the yarn increases with increase in fineness. For data refer to table 4 and 5. Speed and spindle diameter have influence on the diameter of the yarn. Smaller spindle diameter yield smaller diameter of yarn. Higher twist coefficient means finer yarns.

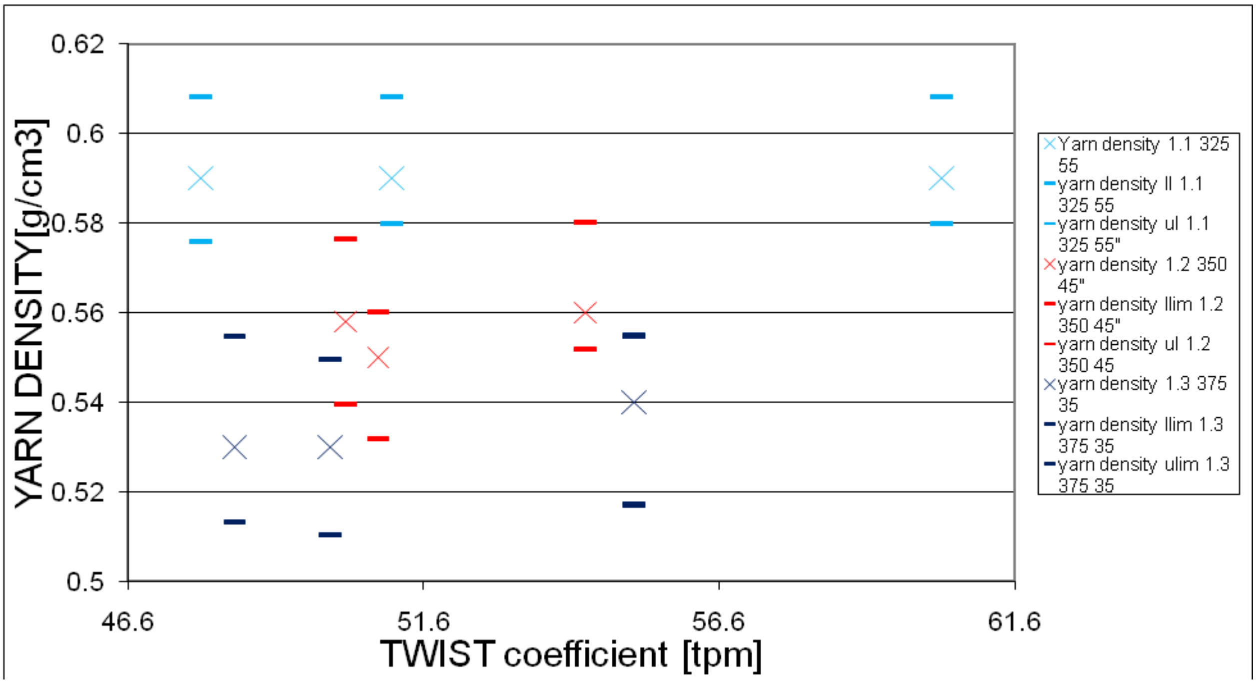


Figure 21: yarn density as function of twist coefficient

And the density of yarn is high for yarns produced at low speed and smaller spindle diameter (Figure 17).This due to tightness of the wrapper fibers around the core of the yarn (i.e. the core of the yarn is more compact than the yarn from high spindle diameter).Hence higher yarn density. The results also show that twist coefficient has no significant influence on the density of yarn.

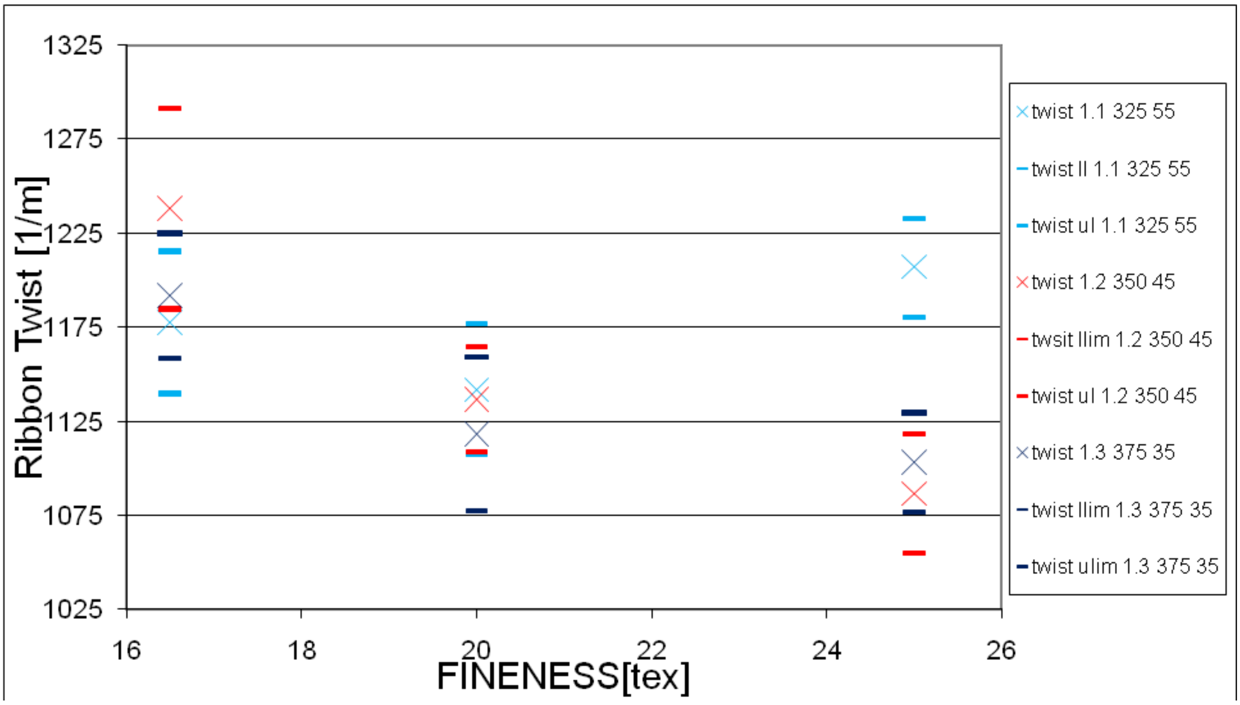


Figure 22: Ribbon twist as function of yarn fineness

For yarns with low twist and smaller spindle diameter will have higher twist (this is indicated by the 25 tex yarns) however, for 16.5 tex and 20 tex yarn yield non-significant results. Refer to Figure 22. The results show that the amount of twist decreases with increase in yarn fineness.

4.1.1.1 Yarn Evenness and Imperfections

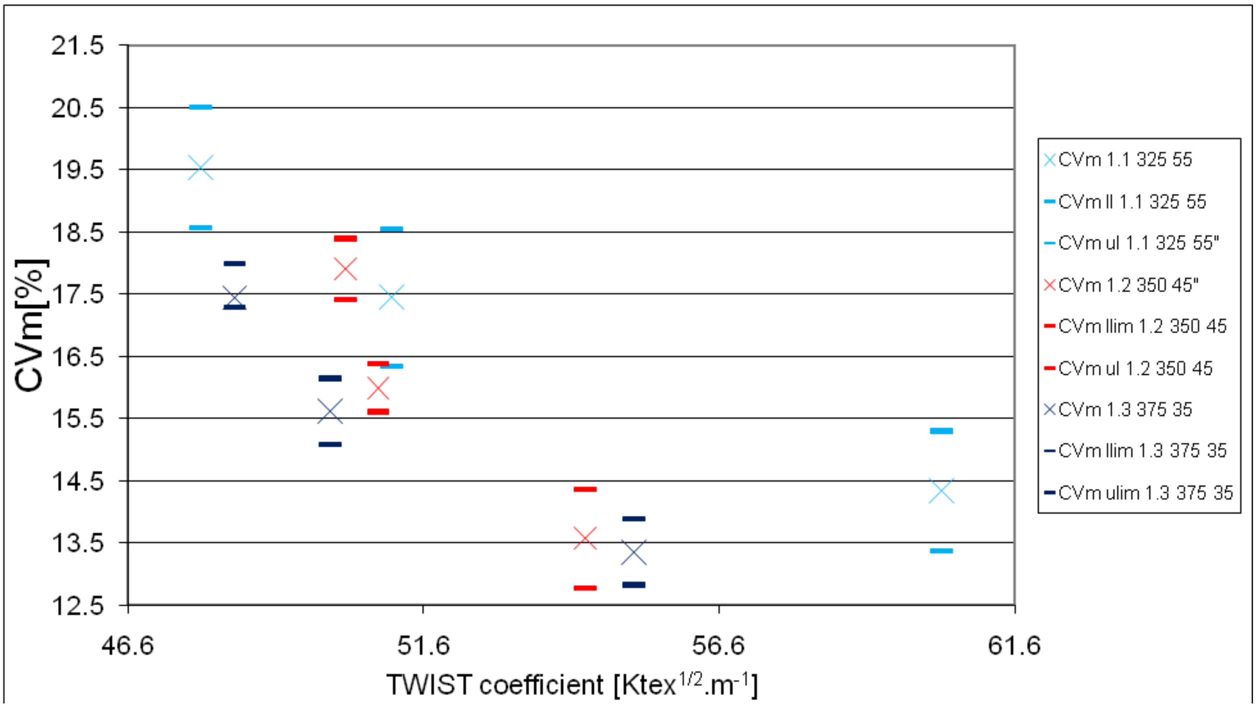


Figure 23: evenness as function of twist coefficient

The results shows that yarns produced at higher speed has better yarn evenness compared to the yarns produced at lower speed. This is because there is a better wrapping by the ribbon (i.e. more fibers are wrapped inside hence the yarn with better quality).Figure 23 shows that unevenness of the yarns decreases with the increase in number of fibers in the yarn cross-section. It can be seen that coarser yarns have better evenness compared to finer yarns.

Finer yarns have higher unevenness, more number of thick and thin places and neps in comparison to coarser yarns. This is illustrated on Figure 24, 25 and Figure 26 respectively. Yarn evenness decreases with increase in spindle diameter and increase in speed. That is, when spindle diameter and yarn speed increases the yarn evenness becomes better. The results also show that evenness decreases with increase in twist coefficient. This is due to better wrapping of the core fibres by the ribbons. The yarn imperfections (i.e. the number of neps, thick and thin places) decrease with the increase in twist coefficient. Fineness, speed and spindle diameter has significant influence on the thin and thick places

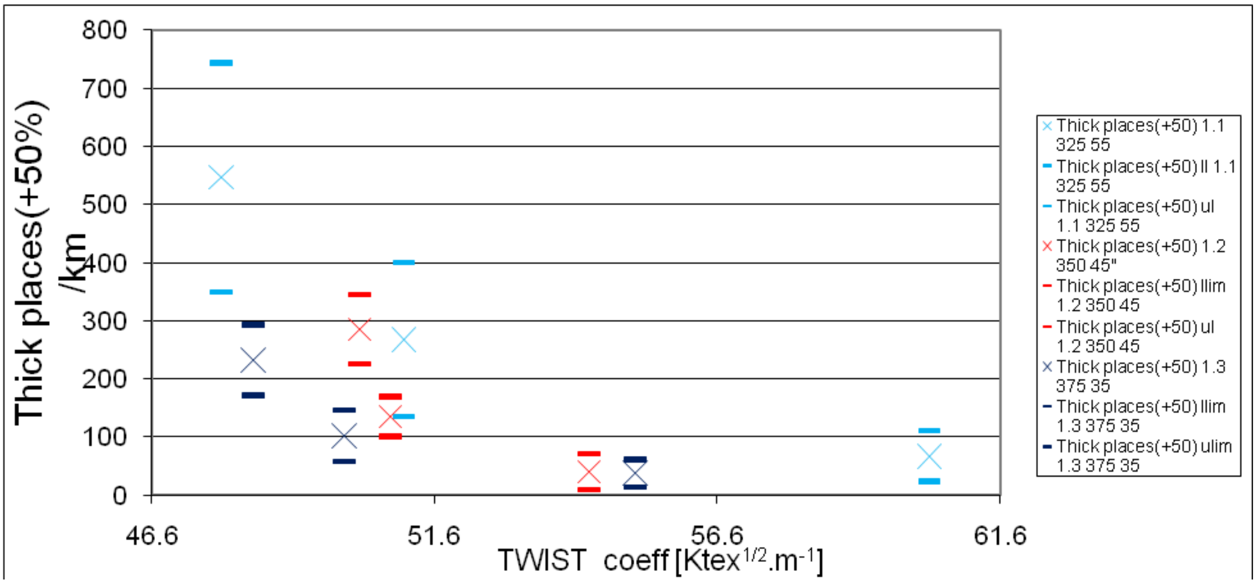


Figure 24: Thick places as function of twist coefficient

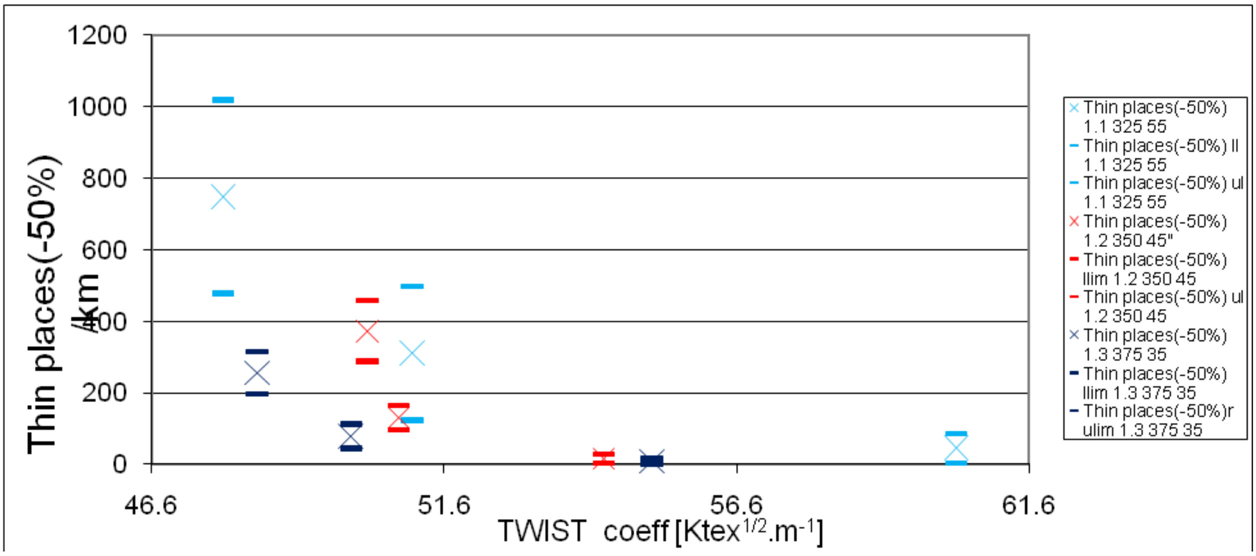


Figure 25: Thin places as function of twist coefficient

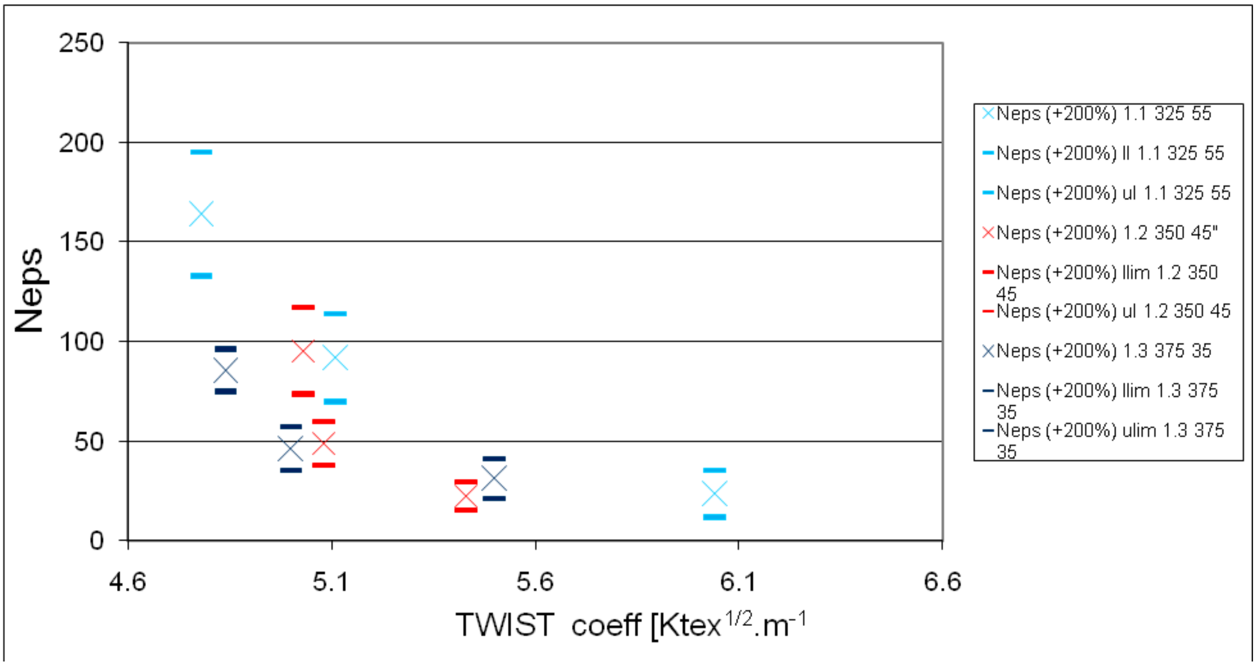


Figure 26: neps as function of twist coefficient

4.1.2 Hairiness

Figure 27 shows the hairiness results found using Uster Tester. Figure shows that yarns produced at low speed, small spindle diameter have low hairiness and the other hand high speed and high spindle diameter have higher hairiness. This due to tightness of the wrapper fibers around the core of the yarn (i.e. the core of the yarn is more compact than the yarn from high spindle diameter).Hence higher yarn density. And the low hairiness is because of a better wrapping. Hairiness increases due to increase number of loose fibers. When the spindle diameter is high there is less control of fibers. Consequently, the yarn will have more fibers protruding the core of the yarn, hence higher hairiness. The results of hairiness from Zweigle G567,Figures 28 and 29 also show that hairiness is higher for yarns produced at higher speed.

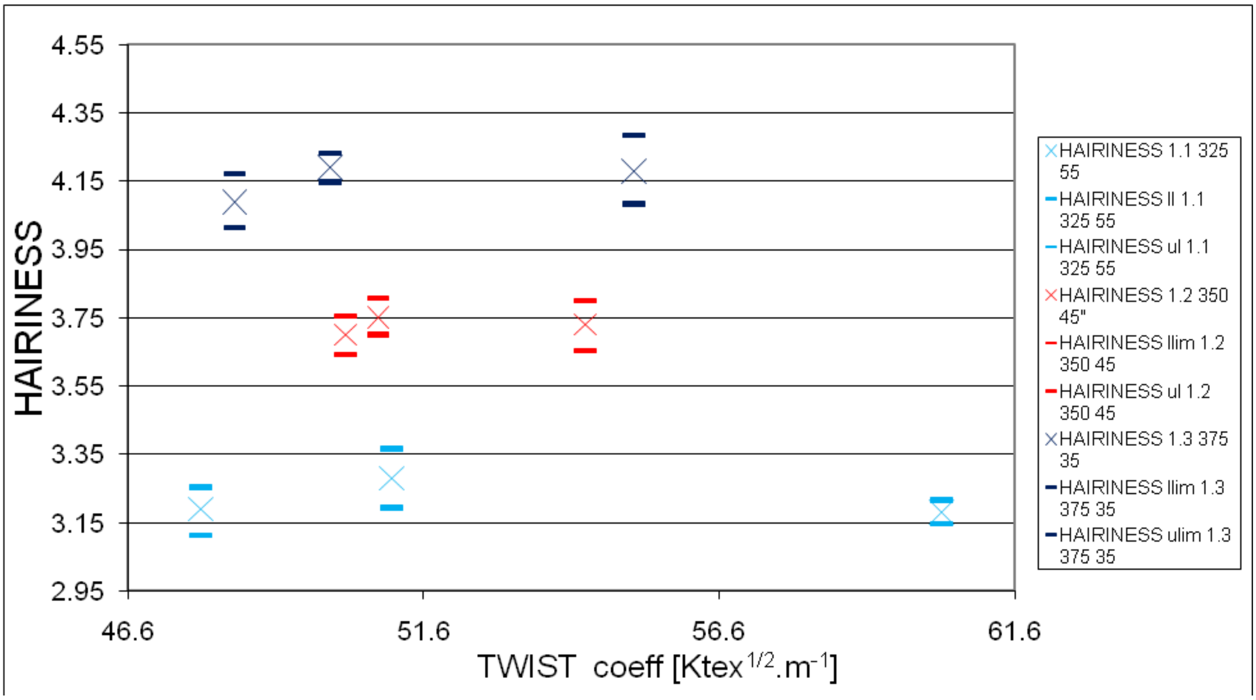


Figure 27: Hairiness as function of twist coefficient from Uster Tester 4

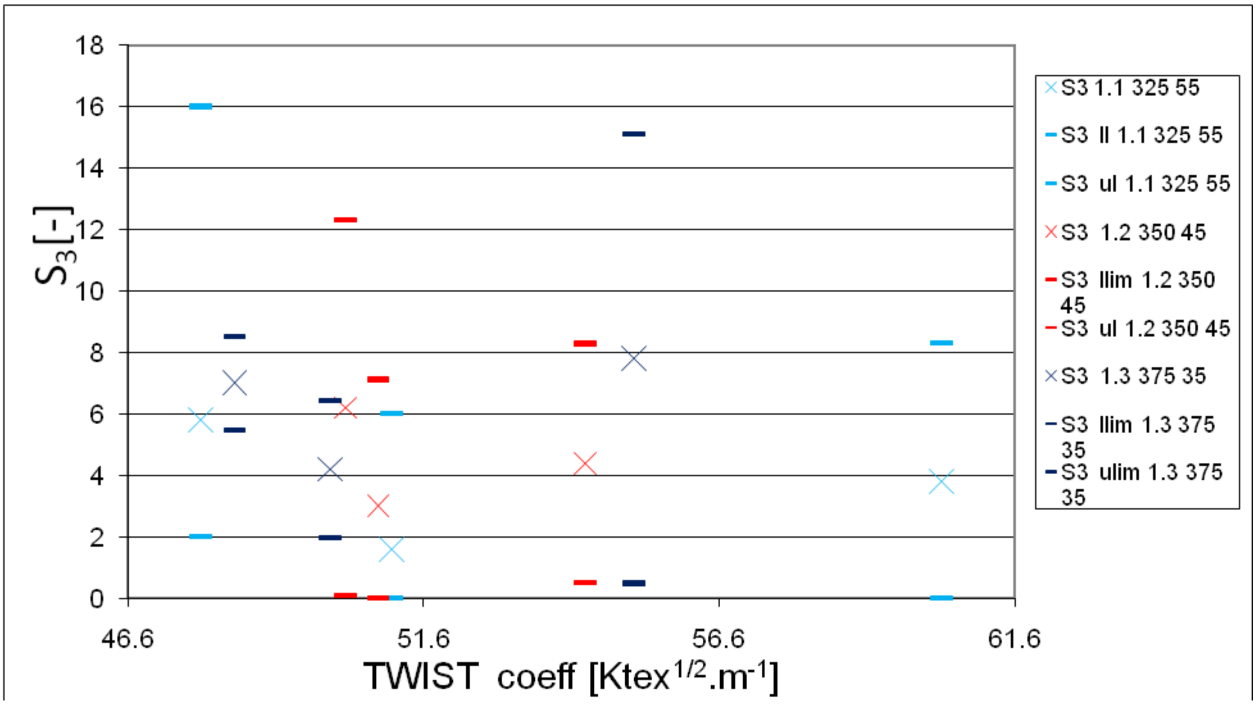


Figure 28: Hairiness as function of twist coefficient

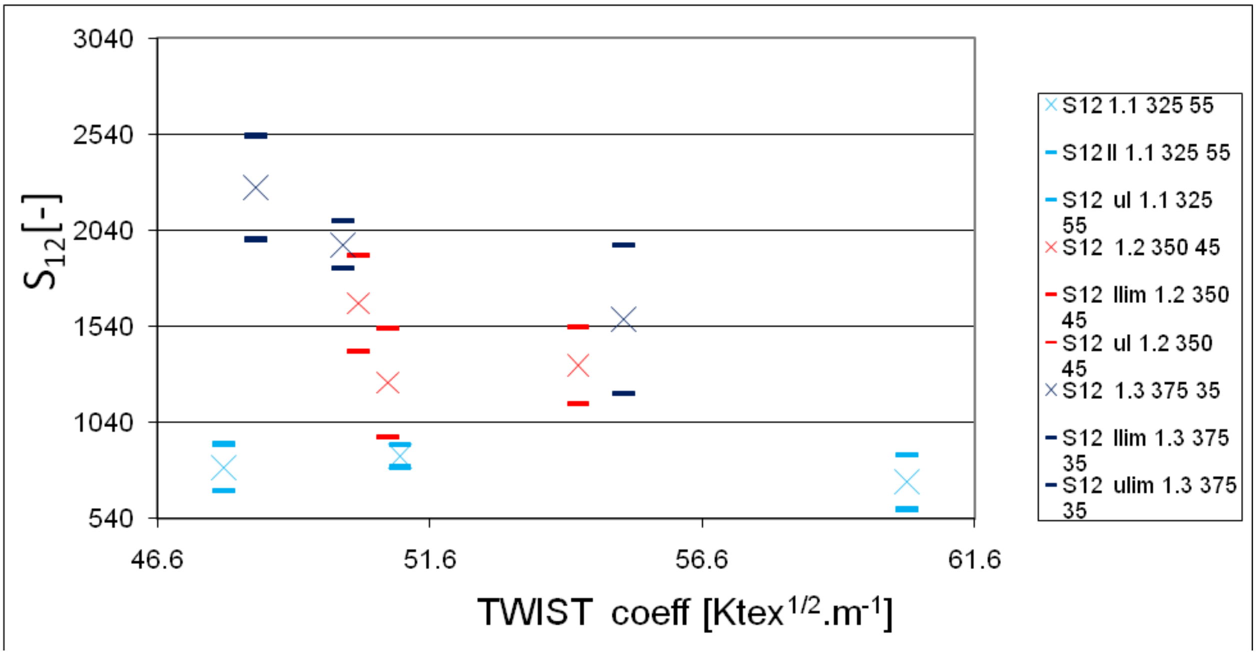


Figure 29: Hairiness (S12) as function of twist coefficient

4.2 TENSILE PROPERTIES RESULTS

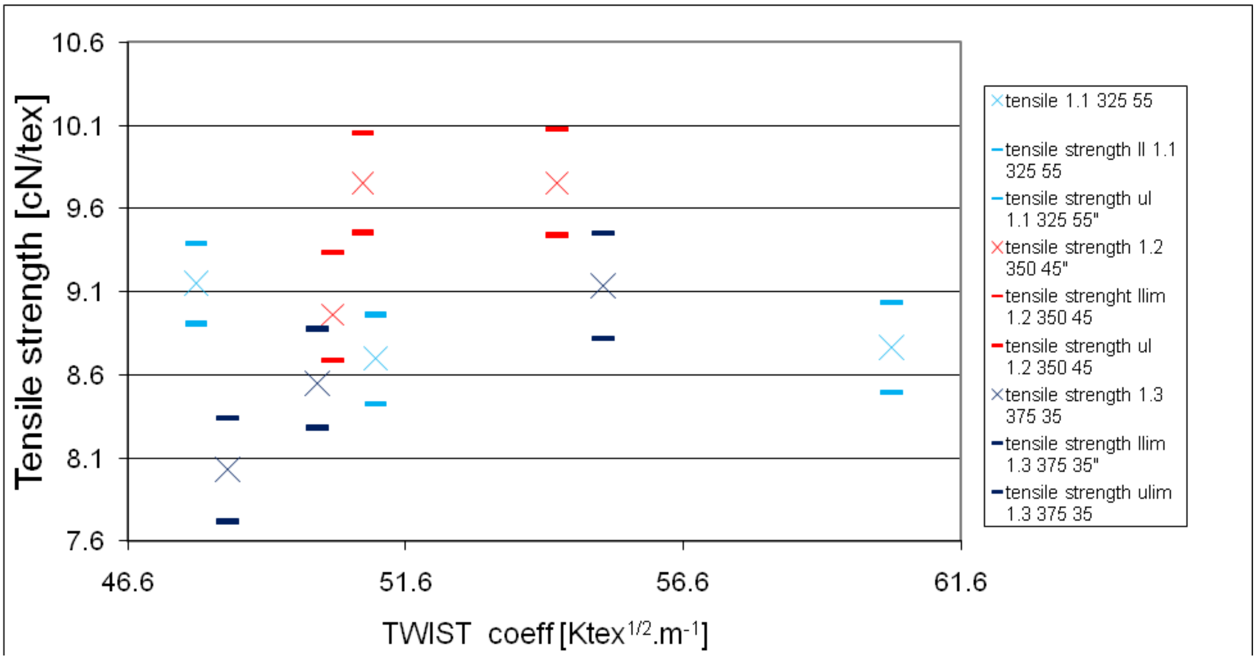


Figure 30: tensile strength as function of twist coefficient

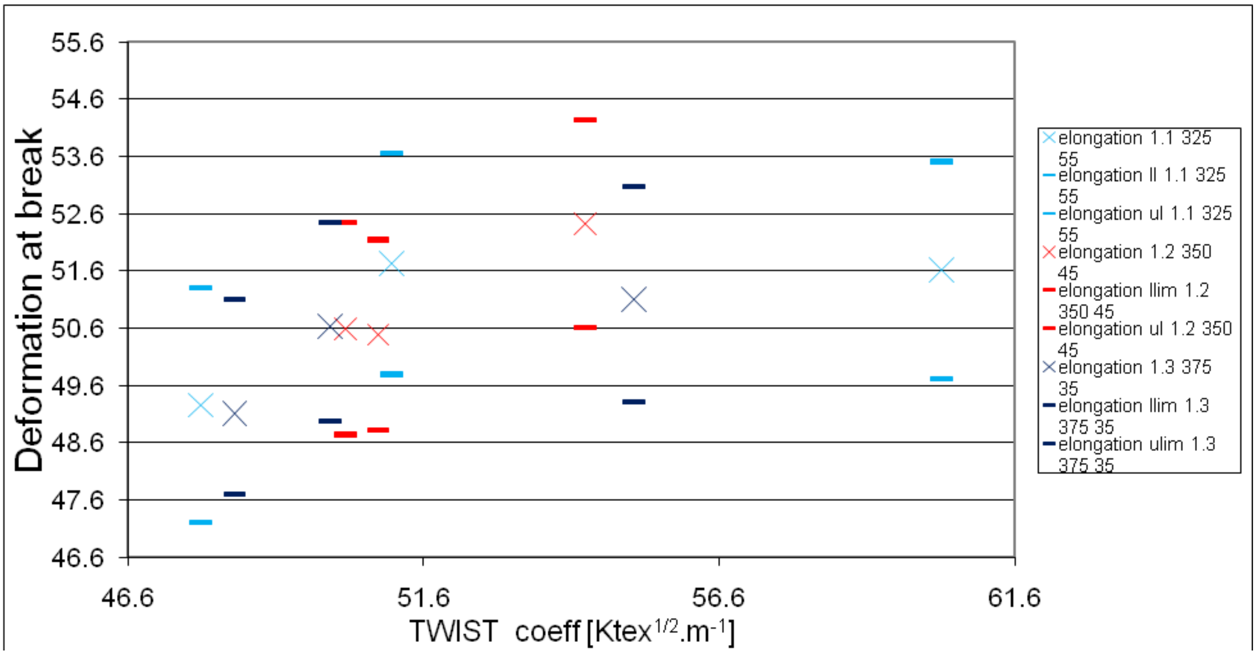


Figure 31: deformation at break as function of twist coefficient

The results shows that twist coefficient has influence on the tensile and deformation at break .As twist increases the deformation at break increases .

5 CONCLUSION

High speed and larger spindle diameter yield yarns with better evenness and strength compared produced at low speed. However smaller spindle diameter and low speed produce yarns with less hairiness. Speed and spindle diameter have influence on some properties of the yarn. Coarser yarns have better evenness compared to finer yarns. Fineness has influence on the hairiness, ribbon diameter and ribbon length of the yarns. Twist and twist coefficient have significant influence on the some mechanical properties and geometrical part. High twist increases the ribbon angle.

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7 APPENDICES

Table 4 : Yarn diameter (Image Analysis)

Fineness	**Nozzle pressure**	**Speed [m/min]**	**Draft**	**Spindle diameter**	**Twist Factor** [ktex$^{1/2}$.m^{-1}]	**Ribbon fiber diameter [mm]**	**Helix angle**	**Wrapper fiber length [mm]**
16.5	0.5	350	45	1,2	5.03	0.17831	29.603	0.82134
20	0.5	350	45	1,2	5.08	0.191293	0.30294	0.885384
25	0.5	350	45	1,2	5.43	0.215483	0.303	0.930175
16.5	0.5	325	55	1,1	4.78	0.169439	0.2.823	0.859242
20	0.5	325	55	1,1	5.11	0.182928	0.2824	0.884855
25	0.5	325	55	1,1	6.04	0.193535	0.32041	0.831975
16.5	0.5	375	35	1,3	4.84	0.171247	0.26657	0.841900
20	0.5	375	35	1,3	5	0.194031	0.28646	0.904720
25	0.5	375	35	1,3	5.5	0.210552	0.31253	0.912899

Table 5 : Yarn Diameter [Uster Tester 4]

sample number	**Fineness**	**spindle diameter [mm]**	**delivery speed [m/min]**	**dR**	**Twist factor** [ktex$^{1/2}$.m^{-1}]	**Mean**	**lower limit**	**Upper limit**
4	16.5	1.1	325	55	4.78	0.188	0.185	0.191
5	20	1.1	325	55	5.11	0.207	0.205	0.209
6	25	1.1	325	55	6.04	0.231	0.229	0.234
1	16.5	1.2	350	45	5.03	0.194	0.191	0.197
2	20	1.2	350	45	5.08	0.216	0.213	0.219
3	25	1.2	350	45	5.43	0.238	0.234	0.241
7	16.5	1.3	375	35	4.84	0.198	0.195	0.202
8	20	1.3	375	35	5	0.219	0.215	0.223
9	25	1.3	375	35	5.5	0.243	0.24	0.247

3.3 Yarn properties

Table 6 : Yarn Imperfections

Fineness [tex]	Process parameters			Thin places			Thick places			Neps		
	Spindle d. [mm]	Del. speed	dR	-30%	-40%	-50%	+35%	+50%	+70%	+140%	+200%	+280%
16.5	350	45	1,2	5507	1740	372	1517	285.4	24.6	1061	95.4	14.8
20	350	45	1,2	3949	928.6	130	938	135.4	6.6	634	48.8	7.2
25	350	45	1,2	1908	258.2	15.6	427.6	39.8	3.2	195	22.4	5
16.5	325	55	1,1	6666	2648	747.4	2181	547.2	55.6	1544	164	18.8
20	325	55	1,1	5106	1563	310.2	1507	268	20.2	1016	91.8	12.2
25	325	55	1,1	2494	439	45.2	631.4	67.6	5.6	260.8	23.6	5.6
16.5	375	35	1,3	5063	1445	255.4	1261	232.4	19.4	991.4	85.6	10.6
20	375	35	1,3	3611	754.6	78.6	785.8	102.2	7.2	653.2	46.2	7.4
25	375	35	1,3	1677	185.2	8.4	358.8	37.8	3.8	263.4	31.2	8

Keys: Del. Speed=delivery speed, spindle d. =spindle diameter

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Table 7 : Deformation at break

spindle diameter [mm]	delivery speed [m/min]	Draft	Twist factor [ktex$^{1/2}$.m^{-1}]	Mean	lower limit	Upper limit
1.1	325	55	4.78	49.2575	47.20592513	51.3090749
1.1	325	55	5.11	51.7295	49.7942151	53.6647849
1.1	325	55	6.04	51.6165	49.72359433	53.5094057
1.2	350	45	5.03	50.5915	48.74638933	52.4471912
1.2	350	45	5.08	50.49	48.82967782	52.1503222
1.2	350	45	5.43	52.424	50.60730094	54.2406991
1.3	375	35	4.84	49.11578947	47.70967865	51.1058739
1.3	375	35	5	50.631	48.97842042	52.4501301
1.3	375	35	5.5	51.113	49.31572449	53.0726375

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Table 8 : Tensile strength

Fineness	**sample number**	**spindle diameter [mm]**	**delivery speed [m/min]**	**Draft**	**Twist factor [ktex$^{1/2}$.m^{-1}]**	**Mean**	**lower limit**	**Upper limit**
16.5	**4**	**1.1**	**325**	**55**	4.78	**9.14947**	**8.908972**	**9.389975**
20	**5**	**1.1**	**325**	**55**	5.11	**8.699**	**8.423752**	**8.963188**
25	**6**	**1.1**	**325**	**55**	6.04	**8.7645**	**8.495717**	**9.033283**
16.5	**1**	**1.2**	**350**	**45**	5.03	**8.9625**	**8.688448**	**9.338039**
20	**2**	**1.2**	**350**	**45**	5.08	**9.755**	**9.456436**	**10.05356**
25	**3**	**1.2**	**350**	**45**	5.43	**9.7525**	**9.44205**	**10.079**
16.5	**7**	**1.3**	**375**	**35**	4.84	**8.02894**	**7.71843**	**8.339465**
20	**8**	**1.3**	**375**	**35**	5	**8.549**	**8.282009**	**8.877597**
25	**9**	**1.3**	**375**	**35**	5.5	**9.1355**	**8.819652**	**9.451348**

Table 9 : Force

Fineness	**spindle diameter [mm]**	**delivery speed [m/min]**	**Draft**	**Twist factor** $[\mathbf{ktex}^{1/2}.\mathbf{m}^{-1}]$	**Fineness [tex]**	**Mean**	**lower limit**	**Upper limit**
16.5	**1.1**	**325**	**55**	4.78	**16.5**	**1.51052632**	**1.4708955**	**1.550157**
20	**1.1**	**325**	**55**	5.11	**20**	**1.7395**	**1.6845318**	**1.791694**
25	**1.1**	**325**	**55**	6.04	**25**	**2.191**	**2.1240009**	**2.257999**
16.5	**1.2**	**350**	**45**	5.03	**16.5**	**1.479**	**1.4332083**	**1.540696**
20	**1.2**	**350**	**45**	5.08	**20**	**1.952**	**1.8921881**	**2.011812**
25	**1.2**	**350**	**45**	5.43	**25**	**2.4385**	**2.3607414**	**2.521283**
16.5	**1.3**	**375**	**35**	4.84	**16.5**	**1.32473684**	**1.2740235**	**1.37545**
20	**1.3**	**375**	**35**	5	**20**	**1.709**	**1.6558129**	**1.774259**
25	**1.3**	**375**	**35**	5.5	**25**	**2.2835**	**2.2044934**	**2.362507**

Table 10 : Hairiness [Uster Tester 4]

Fineness [tex]	**sample number**	**spindle diameter [mm]**	**delivery speed [m/min]**	**Draft**	**Twist factor [ktex$^{1/2}$.m^{-1}]**	**Fineness [tex]**	**Mean**	**lower limit**	**Upper limit**
16.5	**4**	**1.1**	**325**	**55**	4.78	**16.5**	**3.19**	**3.113981**	**3.25401923**
20	**5**	**1.1**	**325**	**55**	5.11	**20**	**3.28**	**3.193083**	**3.36691669**
25	**6**	**1.1**	**325**	**55**	6.04	**25**	**3.18**	**3.147544**	**3.21645572**
16.5	**1**	**1.2**	**350**	**45**	5.03	**16.5**	**3.7**	**3.641508**	**3.75449238**
20	**2**	**1.2**	**350**	**45**	5.08	**20**	**3.75**	**3.700884**	**3.80711622**
25	**3**	**1.2**	**350**	**45**	5.43	**25**	**3.73**	**3.652752**	**3.79924824**
16.5	**7**	**1.3**	**375**	**35**	4.84	**16.5**	**4.09**	**4.012785**	**4.17121483**
20	**8**	**1.3**	**375**	**35**	5	**20**	**4.19**	**4.147892**	**4.2321076**
25	**9**	**1.3**	**375**	**35**	5.5	**25**	**4.18**	**4.084048**	**4.28395211**

Table 11 : Hairiness [Zweigle 567], S3

Fineness [tex]	**sample number**	**Spindle diameter [mm]**	**delivery speed [m/min]**	**Draft**	**Twist factor [ktex$^{1/2}$.m^{-1}]**	**Fineness [tex]**	**Mean**	**lower limit**	**Upper limit**
16.5	**4**	**1.1**	**325**	**55**	4.78	**16.5**	5.8	2	16
20	**5**	**1.1**	**325**	**55**	5.11	**20**	1.6	0	6
25	**6**	**1.1**	**325**	**55**	6.04	**25**	3.8	0	8.311
16.5	**1**	**1.2**	**350**	**45**	5.03	**16.5**	6.2	0.092	12.31
20	**2**	**1.2**	**350**	**45**	5.08	**20**	3	0	7.118
25	**3**	**1.2**	**350**	**45**	5.43	**25**	4.4	0.513	8.287
16.5	**7**	**1.3**	**375**	**35**	4.84	**16.5**	7	5.479	8.521
20	**8**	**1.3**	**375**	**35**	5	**20**	4.2	1.979	6.421
25	**9**	**1.3**	**375**	**35**	5.5	**25**	7.8	0.486	15.11

Table 12 : Hairiness [Zweigle 567],S12

Fineness [tex]	**sample number**	**spindle diameter [mm]**	**delivery speed [m/min]**	**Draft**	**Twist factor [ktex$^{1/2}$.m^{-1}]**	**Fineness [tex]**	**Mean**	**lower limit**	**Upper limit**
16.5	**4**	**1.1**	**325**	**55**	4.78	**16.5**	806.4	685.3	927.5
20	**5**	**1.1**	**325**	**55**	5.11	**20**	866.6	807.3	925.9
25	**6**	**1.1**	**325**	**55**	6.04	**25**	729.2	589	869.4
16.5	**1**	**1.2**	**350**	**45**	5.03	**16.5**	1660	1410	1909
20	**2**	**1.2**	**350**	**45**	5.08	**20**	1246	962.9	1530
25	**3**	**1.2**	**350**	**45**	5.43	**25**	1336	1137	1535
16.5	**7**	**1.3**	**375**	**35**	4.84	**16.5**	2263	1993	2533
20	**8**	**1.3**	**375**	**35**	5	**20**	1964	1842	2087
25	**9**	**1.3**	**375**	**35**	5.5	**25**	1576	1189	1963

Graphs Geometrical properties

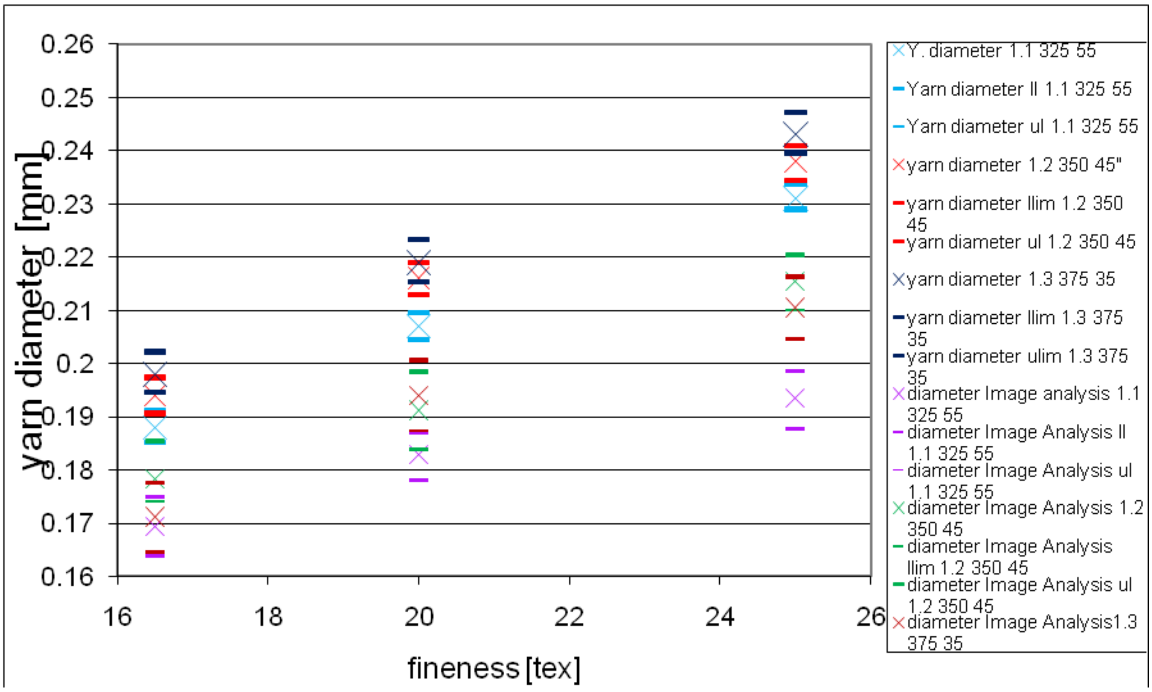

Figure 32: yarn diameter versus fineness

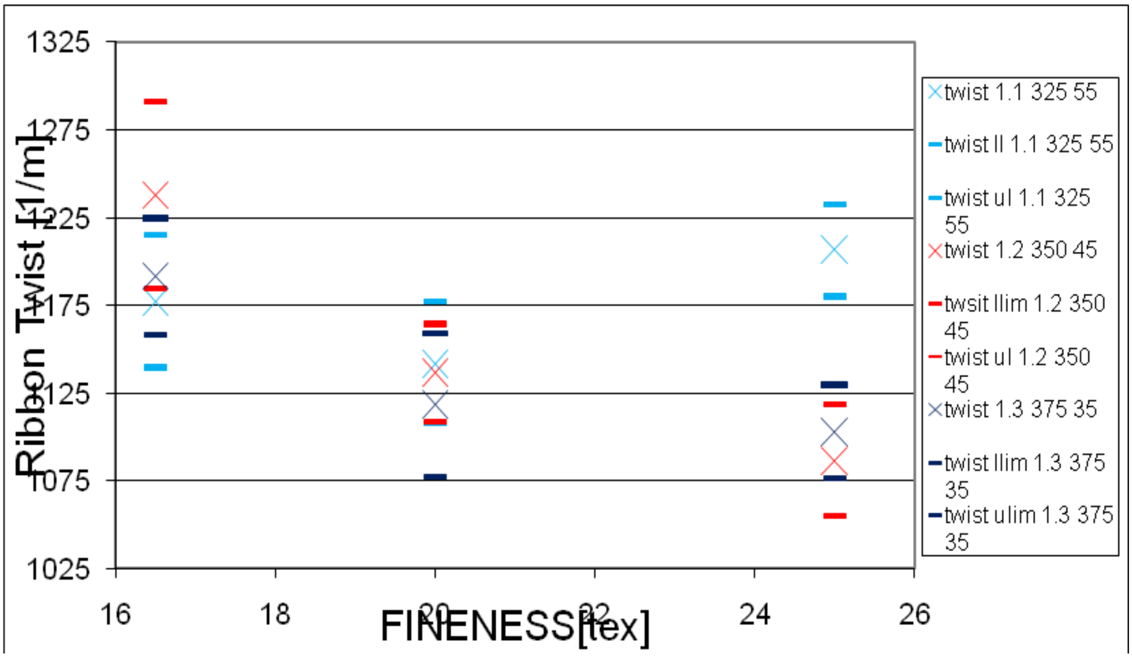

Figure 33: Ribbon twist versus Fineness

Uster Tester

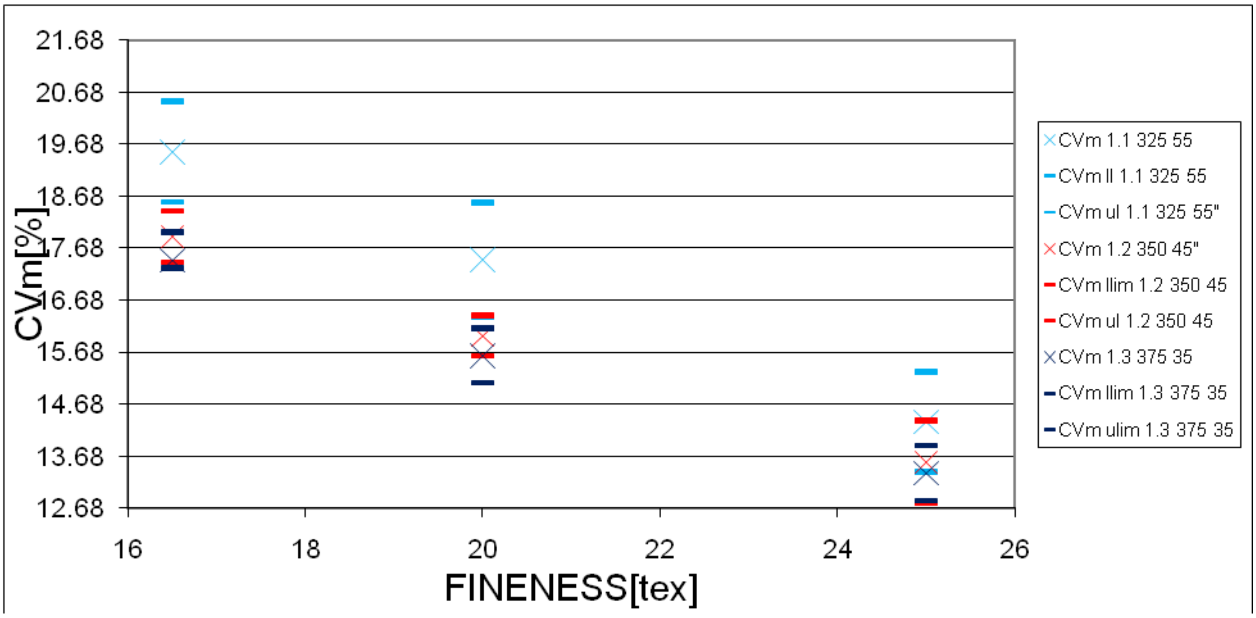

Figure 34: yarn unevenness versus Fineness

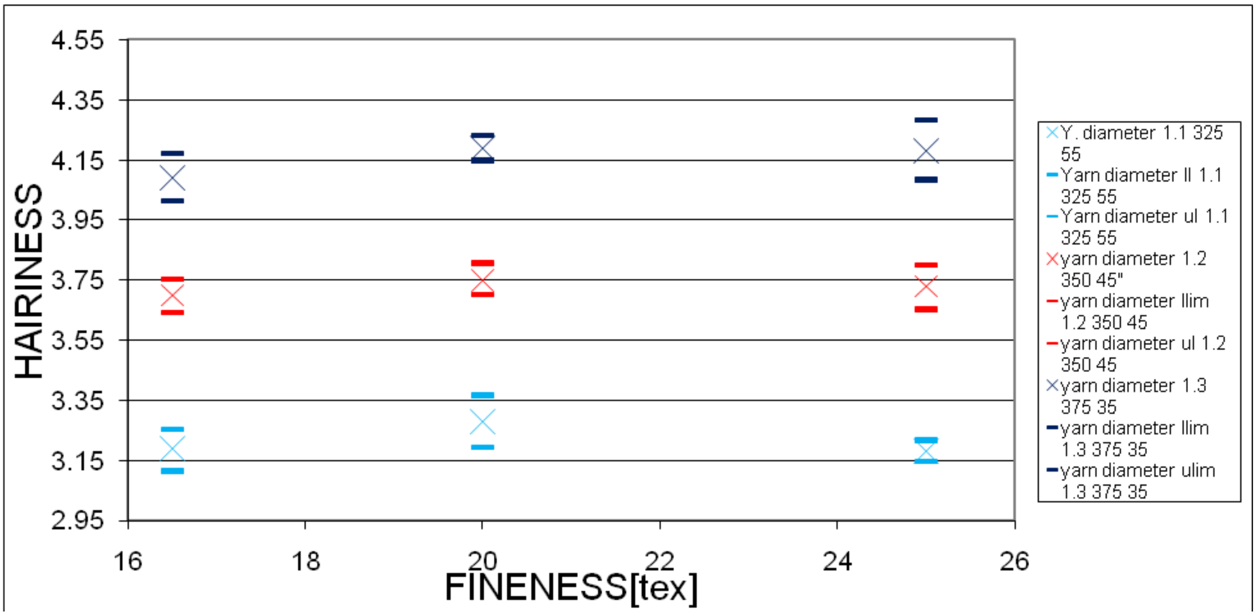

Figure 35: Hairiness versus fineness

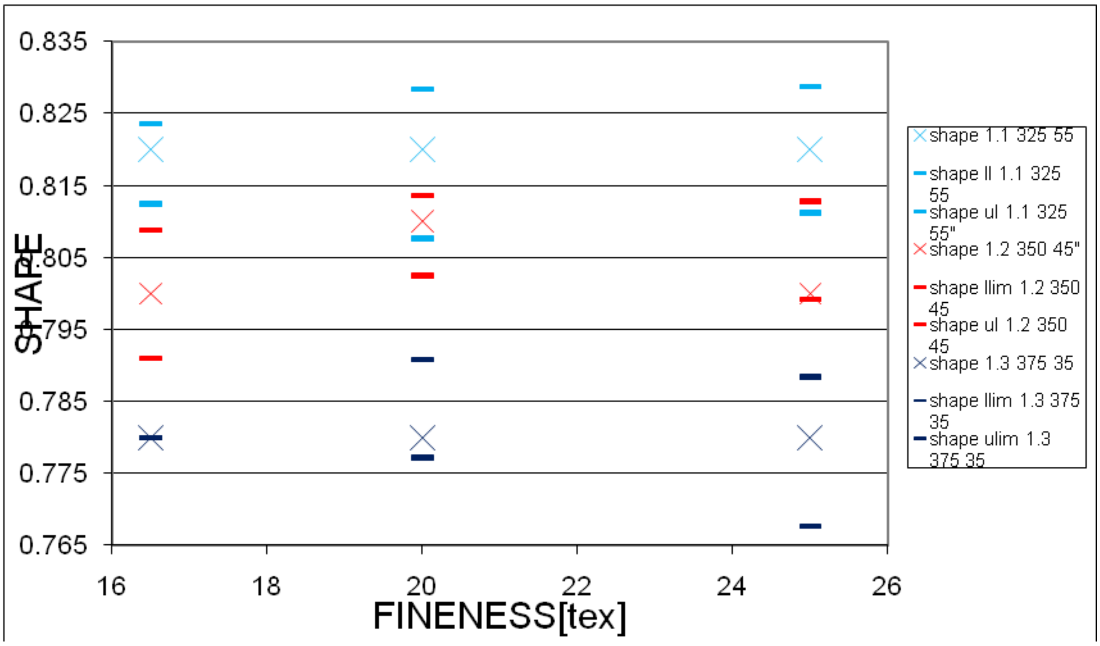

Figure 36: Shape of yarn versus Fineness

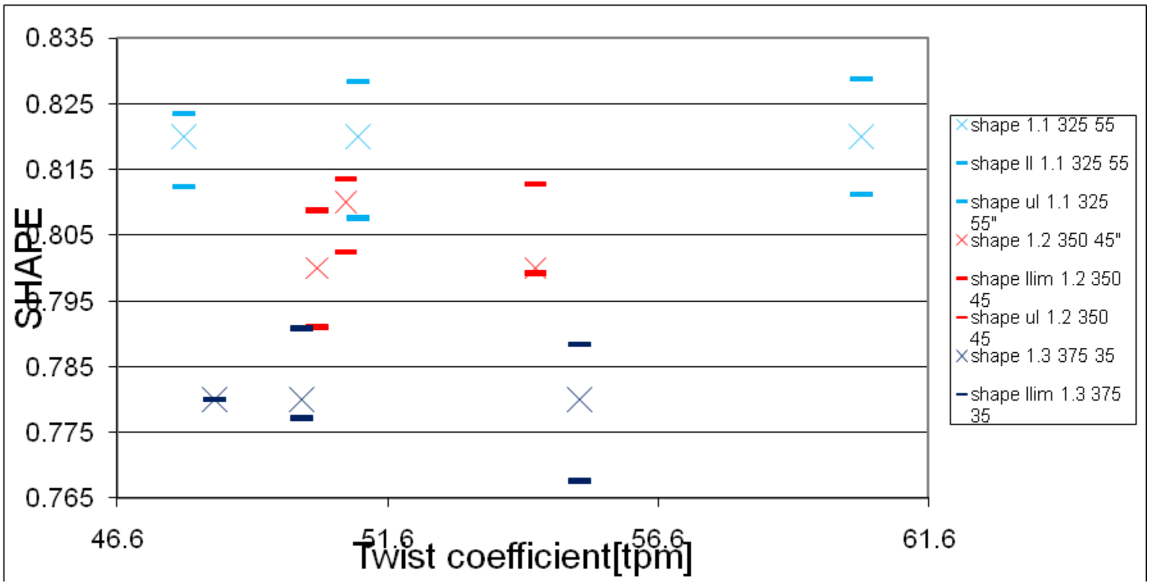

Figure 37: Shape of yarn versus twist coefficient

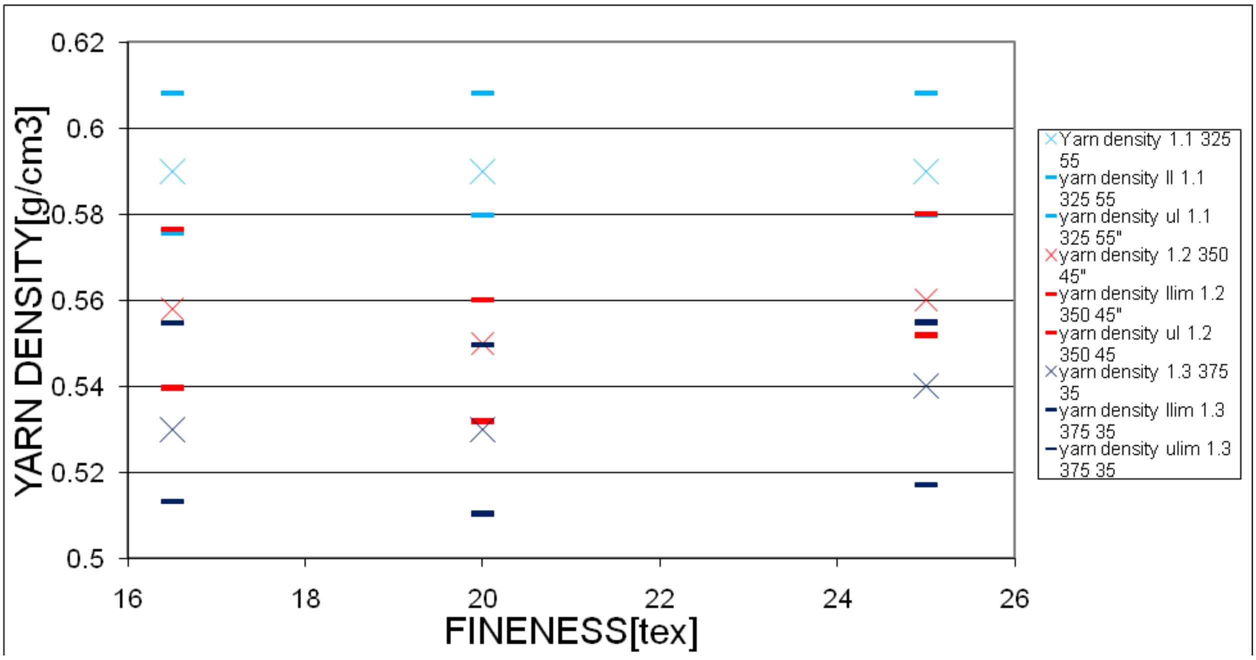

Figure 38: Yarn density versus Fineness

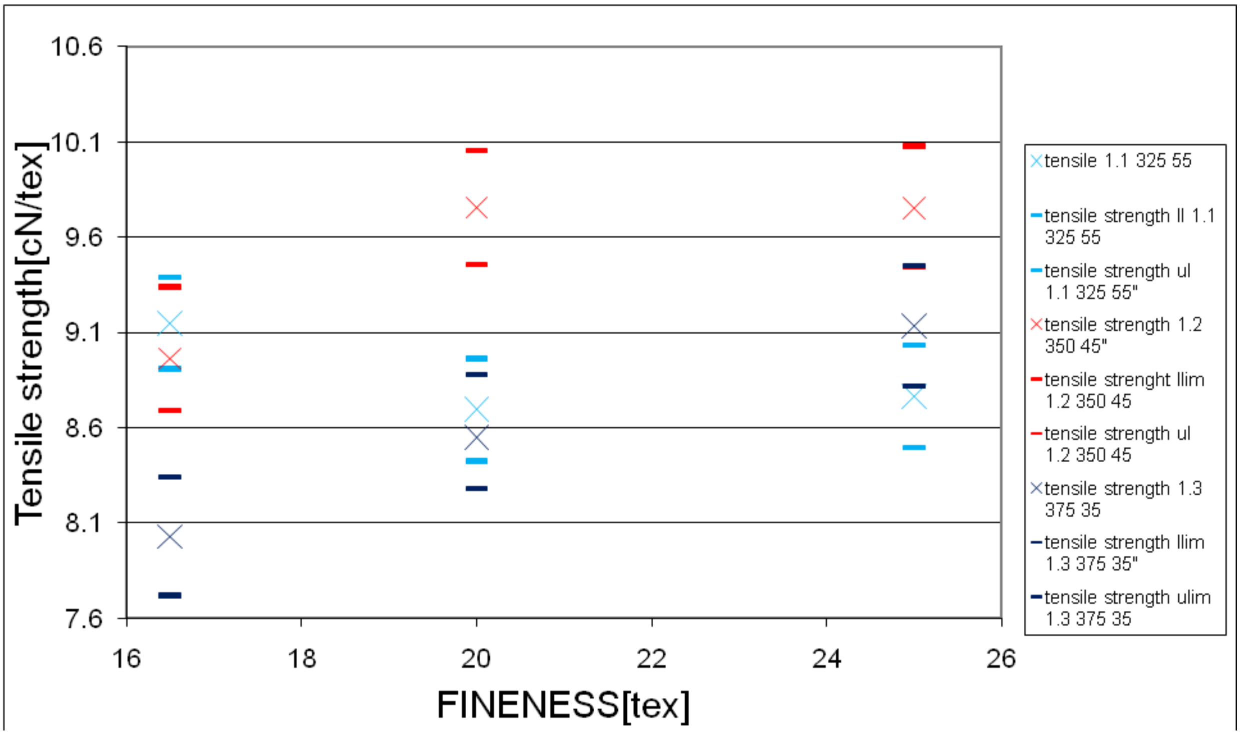

Figure 39: Tensile strength versus Fineness

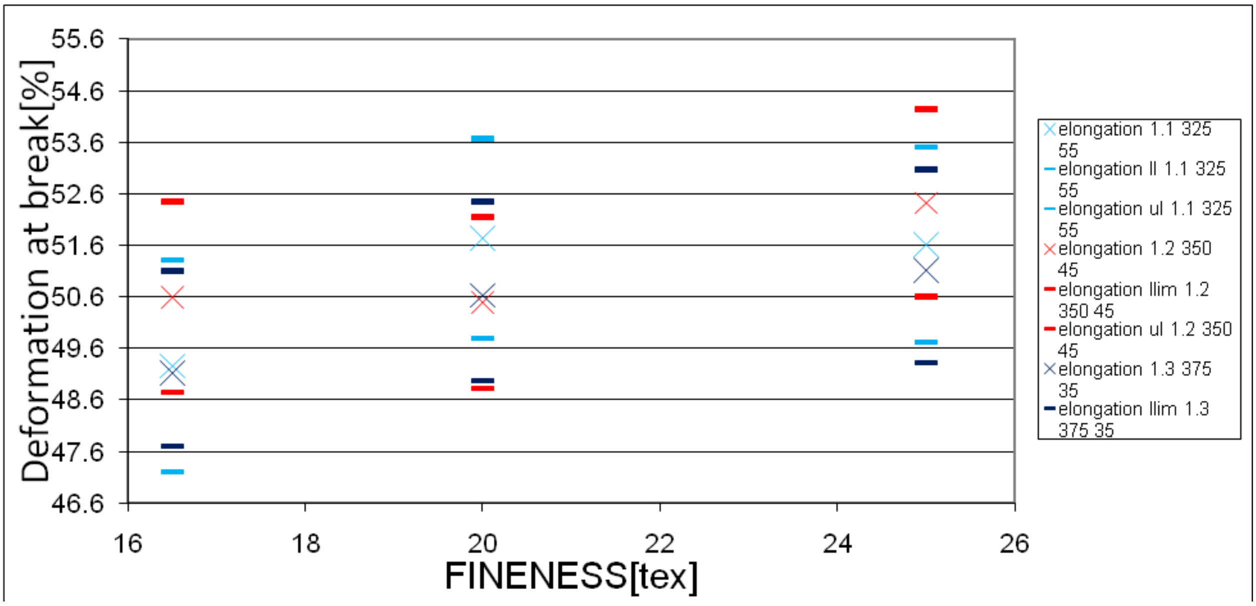

Figure 40: Deformation at break versus Fineness

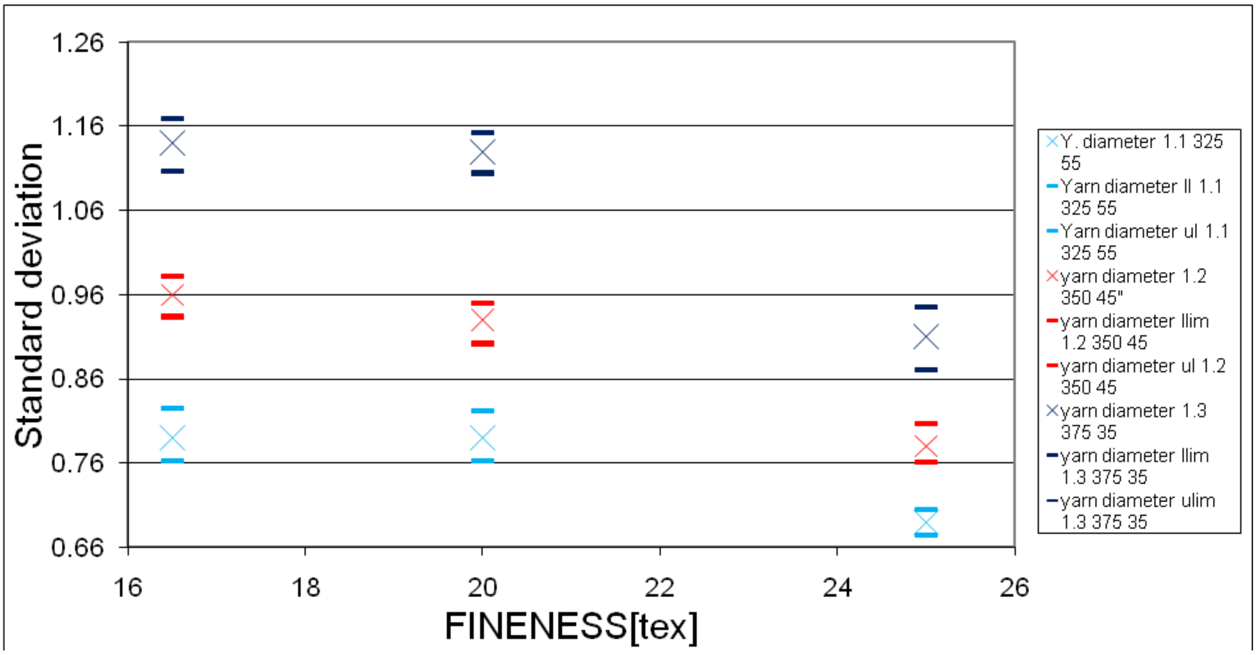

Figure 41: Standard deviation (from Uster Tester) versus Fineness

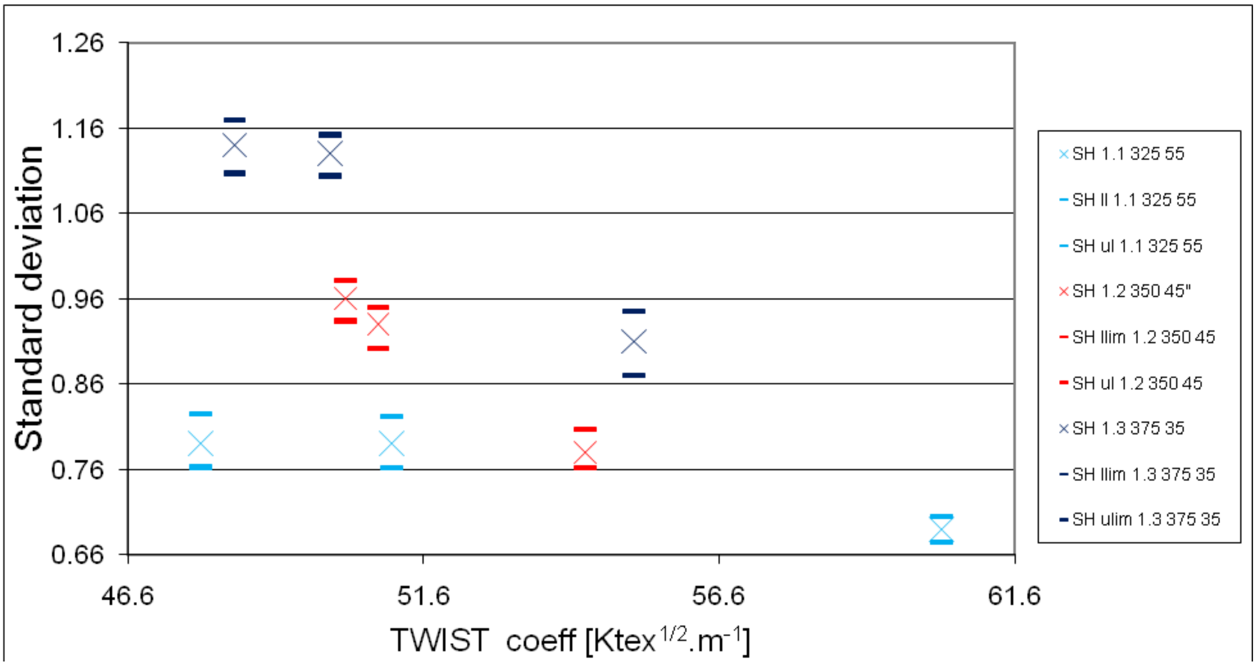

Figure 42: Standard deviation versus twist coefficient

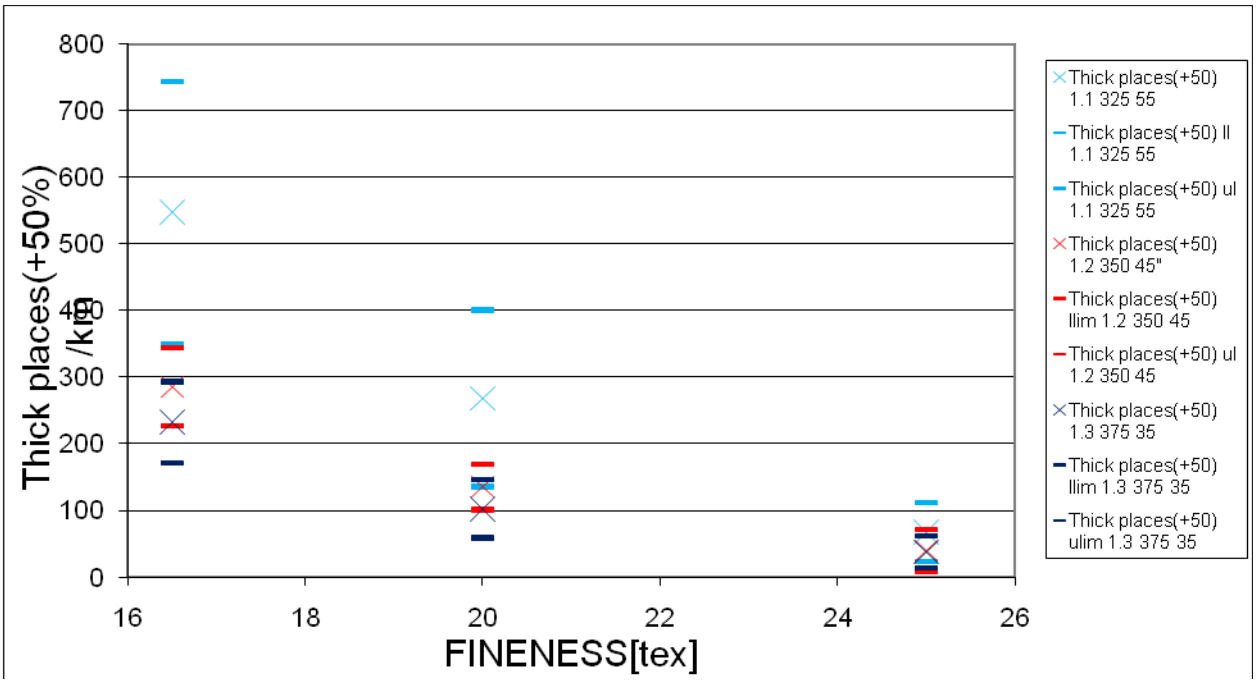

Figure 43: Thick places (50%) versus Fineness

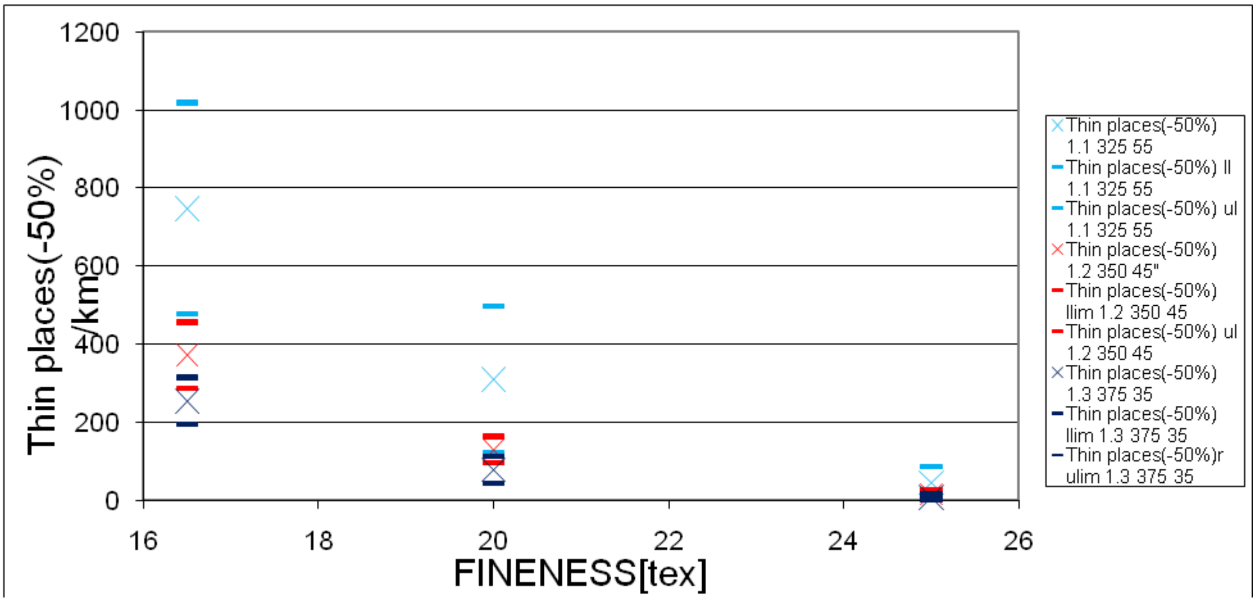

Figure 44: Thin places (50%) versus Fineness

Hairiness-Zwigle 567

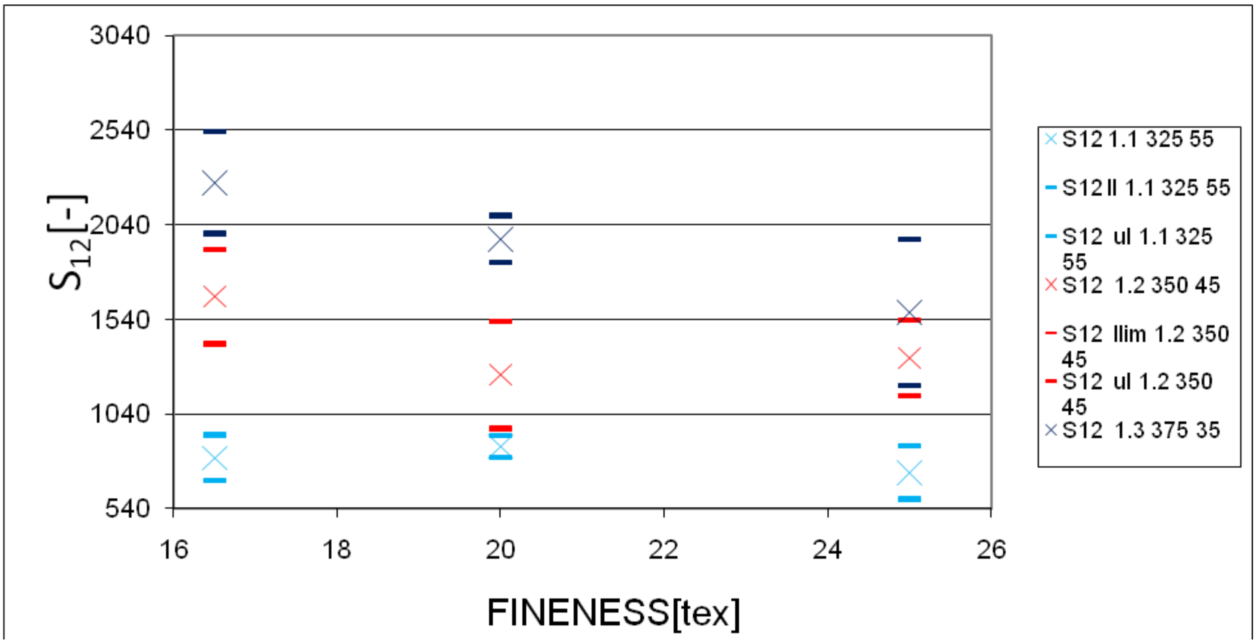

Figure 45: S12 versus Fineness

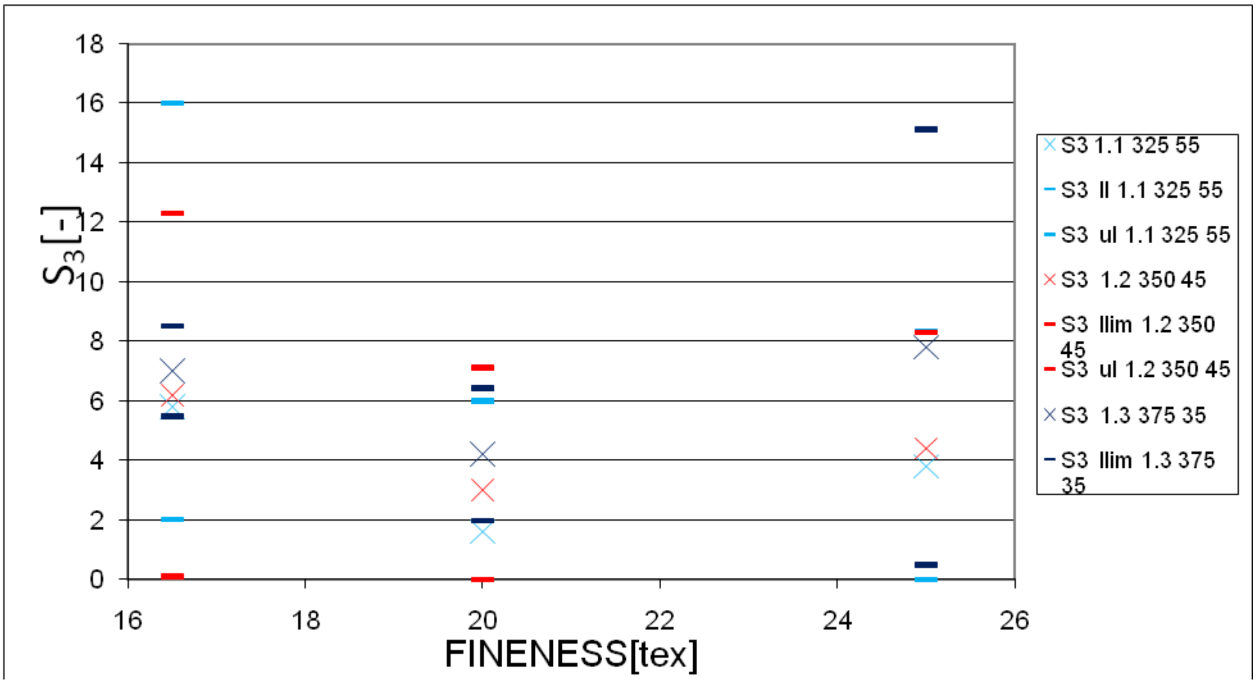

Figure 46: S3 versus Fineness

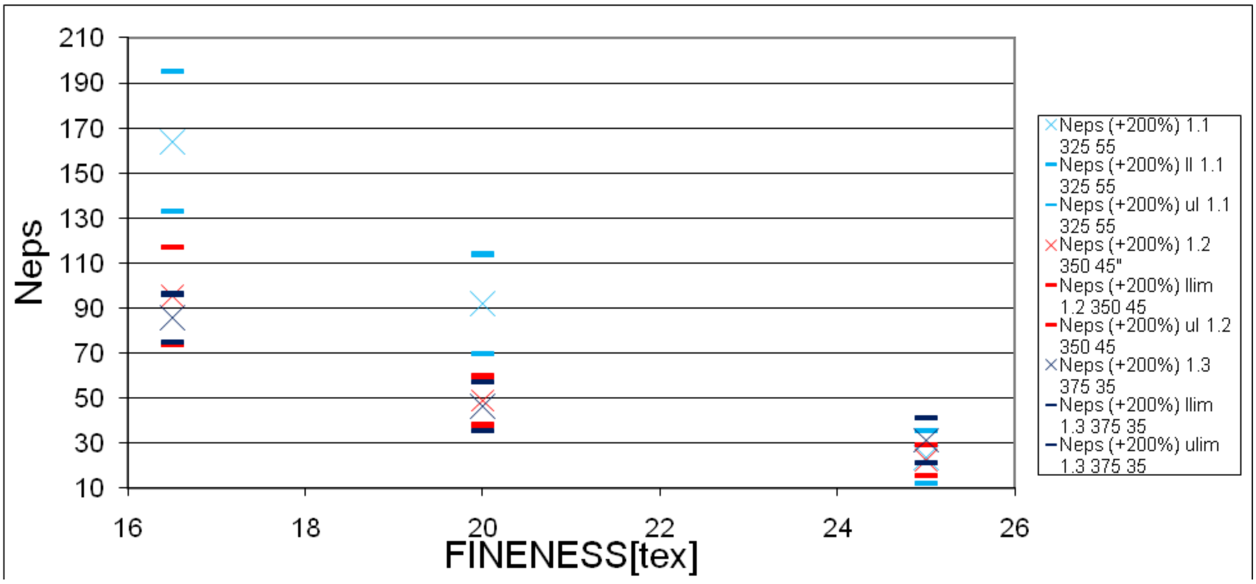

Figure 47: neps versus Fineness