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THE EFFECT OF WEFT YARN TWIST LOSS AND WEFT TENSION ON FABRIC PROPERTIES PRODUCED BY AIR JET LOOM

By

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In Fulfillment of the Requirements for the Degree of Master of Science

In

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Under the supervision of

ASST. PROF. ADDISU FEREDE

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ABSTRACT

The efficiency of air jet weaving machines and fabric properties are influenced by many factors wherein the twist and weft tension during picking greatly affect physical and mechanical properties of woven fabrics. Many scholars agreed that weft yarn twist and tension affects physical, mechanical and comfort fabric properties. But they did not consider the twist loss of rotor spun weft yarn during air jet weft insertion. Freedom of the filling to untwist during air jet weft insertion results in twist loss during weaving which affects fabric properties.

Fabric samples were produced from 20 Ne, 16 Ne, 10 Ne (single) and 10 Ne plied rotor spun weft yarns by changing air pressure and weft tension in an air jet weaving machine. Physical and mechanical properties were investigated by using different testing equipments according to ASTM standards. The result shows that the weft yarns have significance twist loss at 95 confidence level and twist loss on the right side of the fabric is higher than the left side. We found that the twist loss percentage of weft yarns varies with weft count and air pressure. For example the twist loss percentage of 20 Ne, 16 Ne, and 10 Ne weft yarns are 6.63 %, 5.74% and 4.44 % respectively with same air pressure. The result shows that twist loss percentage of plied weft yarn is higher than single weft yarn of the same count and the twist loss of weft yarn during air jet weft insertion significantly affects fabric thickness, tensile strength, and air permeability though other fabric properties like tear strength, bursting strength and GSM did not show significance effect. Moreover, tension of the weft yarn during air jet weft insertion affects fabric GSM, tear strength and bursting strength.

We found that at 2 bar main nozzle with 3 bar relay nozzles air pressure and PFT/B+ gives minimum weft breakage rate (0.56 breaks/1000picks) for insertion of 20 Ne weft yarn in 190 fabric width.

Key words: twist loss, weft tension, air jet loom, rotor spun yarn, woven fabric, fabric properties.

ADVISOR'S APPROVAL

ETHIOPIAN INSTITUTE OF TEXTILE AND FASHION
TECHNOLOGY (EiTEX)
POSTGRADUATE OFFICE

This is to certify the thesis entitled '' the effect of weft yarn twist loss and weft tension on fabric properties produced by air jet loom'' submitted in fulfillment of the requirement of the degree of masters with specialization in textile manufacturing, the graduate program of the Ethiopian Institute of Textile and Fashion Technology, and has been carried out by WASSIE MENGIE, ID No.MTM/R/008/08 under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the institute.

ASST. PROF. ADDISU FEREDE ____________ ____________

Signature Date

Approval page

I certify that I have supervised/ read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in quality and scope, as a thesis for fulfillment of the requirements for the degree of Master of Science

……………………………………………………………………………….

Supervisor

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External Examiner

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Internal Examiner chairman Examination Committee Member

This thesis was submitted to the Ethiopian Institute of Textile and Fashion Technology, Bahir Dar University and is accepted as fulfillment of the requirements of for the degree of degree of Master.

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Scientific Director Director of Postgraduate Studies

EXAMINER'S APPROVAL

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POSTGRADUATE OFFICE

We, the undersigned, members of the board of examiners of final open defense by have read and evaluated his thesis entitled ''the effect of weft yarn twist loss and weft tension on fabrics properties produced by air jet loom'', and examined the candidate. This is therefore, to certify that the thesis has been accepted in fulfillment of the requirement for the degree of Master of Science in textile manufacturing.

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DECLARATION

I hereby declare that the thesis is submitted in fulfillment of the master degree is my own work and that all contributions from any other persons or resources are properly and duly cited. I further declare that the material has not been submitted either in whole or in part, for a degree at this or any other university. In making this declaration, I understood and acknowledge any breaches in this declaration constitute academic miss conduct, which may result in my expulsion from the program and /or exclusion from the award of the degree.

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Wassie Mengie Ademe

June 2017

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LIST OF ABBREVIATIONS

SN	stretching nozzles
mm	millimeter
PAexp	expected position of arrival
Ps	starting position
BDTSC	Bahir Dar textile share company
cm	Centimeter
rpm	revolution per minute
PFT	programmable filling tensioner
AJL	air jet loom
min	minute
T.M.	twist multiplier
WFs	wrap fibers
GSM	gram per square meter
EPC	ends per centimeter
PPC	picks per centimeter
ASTM	American Society for Testing and Materials
ISO	International Organization for Standardization
SPSS	Statistical Package for the Social Sciences
ANOVA	analysis of variance
α	confidence level
P	probability that the observed result was obtained by chance
Emax	maximum elongation in percent
Ebreak	breaking elongation in percent
F max	maximum force
Sec	Second
SD	standard deviation
CV	coefficient of variation
TPM	twist per meter
TF	twist factor

ext%	extension percentage
df	degree of freedom
sig.	Significance
L	Left (on the weft insertion side)
R	Right (opposite to the weft insertion side)

CHAPTER ONE

INTRODUCTION

1.1. Background and justification

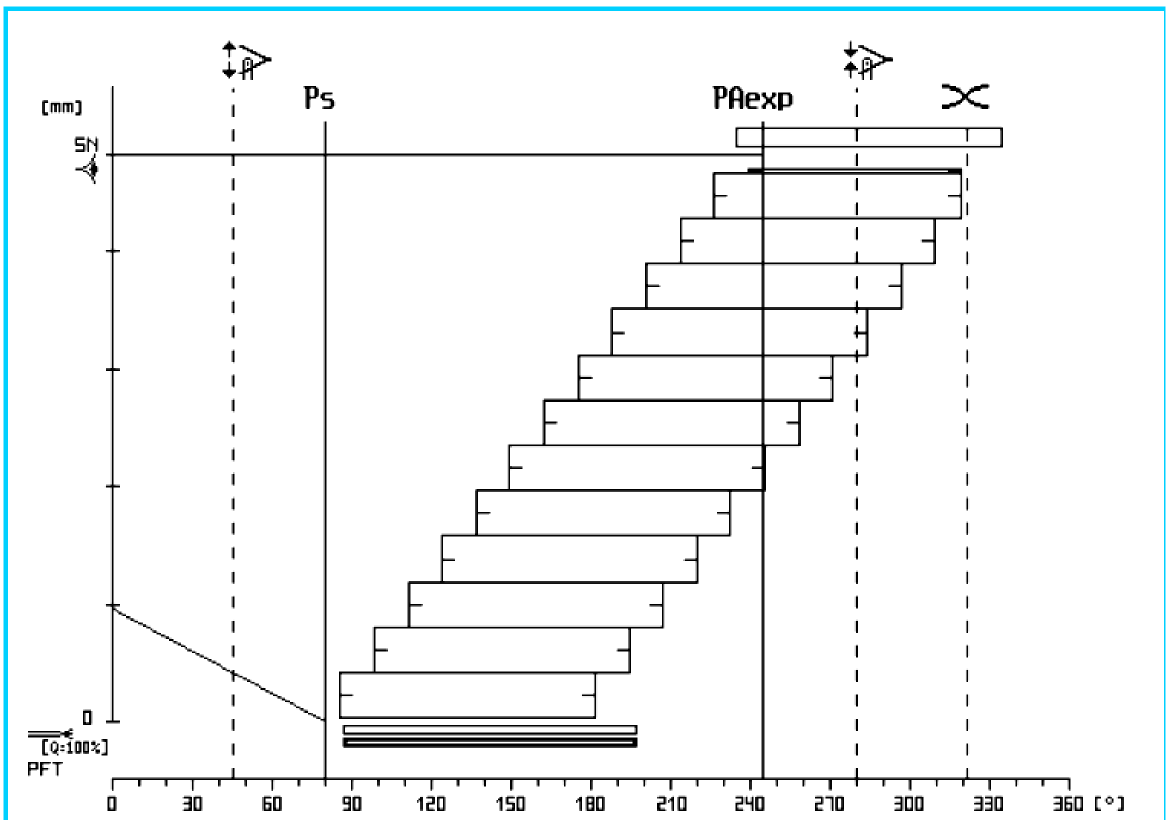
Weaving interlaces two or more perpendicular yarn systems. On a loom weft yarn is woven between tight, parallel warp yarns (the shed). The warp yarns are under tension and are subjected to stress during weaving as the weft yarn is inserted between them at great speed(Walters, 2005).

The weft insertion is carried out with: Shuttle, Projectile, Rapier, Water jet, Air jet, Special weft insertion techniques and Circle weave technique (Schäf, 2003). The air jet weaving machines are the weaving machines with the highest weft insertion performance and are considered as the most productive in the manufacturing of light to medium weight fabrics, preferably made of cotton and certain man-made fibers(sheets, shirting fabrics, linings, taffetas and satins in staple yarns of man-made fibers); it has anyway to be pointed out that technically positive results are obtained at present also with heavy weight fabrics (denims) and that some manufacturers produce also machine models for terry production. These machines are the ideal solution for those who want to produce bulk quantities of customized fabric styles.

The weaving widths range generally from 190 to 400 cm. As regards the multicolor weft carrier, up to 8 different wefts can be fed. It has however to be considered that the air jet weaving machines require a high energy consumption to prepare the compressed air and that this consumption rises definitely with increasing loom width and running speed. The reduction in the energy consumption is in fact one of the main concerns of the manufacturers, and builds for the user an important selection criterion (Giovanni Castelli, 2000).

Air-jet weaving is an advanced weaving method with high efficiency and productivity. However, the weft yarn motion in air-jet filling insertion is very complicated. It is not a positively controlled process, and the air stream during the filling insertion process is turbulent and unsteady with regard to its velocity, it could be compressible. The transferred material, i.e. weft yarn, also has its complications, especially in the case of staple yarns. The weft yarn propulsion force is provided by the friction between the yarn surface and the air stream(H Nosratya, 2008).

Upon release of the filling yarn by the stopper, the filling is fed into the reed tunnel via tandem and main nozzles. The tandem and main nozzle combination provides the initial acceleration, where the relay nozzle provides high air velocity across the weave shed. Profiled reed provides guidance for the air and separates the filling yarn from the warp. The insertion medium mass to be accelerated is very small, relative to the shuttle, rapier or projectile machines, which allows high running speeds.



Source: Manual of picanol air jet loom

Figure 1.1 Typical diagram of relay nozzle during picking

A typical timing diagram of relay nozzles is shown in the Figure 1.1. The timed groups of relay nozzles blow air on the tip of the yarn across the machine width. As result, the yarn is pulled by the air at the tip (rather than pushed from behind) throughout the insertion, minimizing the possibility of buckling which may cause weaving machine stops. This also assures the lowest possible air consumption.

In air jet weft insertion the tip of the weft thread is not griped and there is freedom of the filling to untwist during insertion results in twist loss during weaving which affects fabric properties. This twist loss varies with weft parameters, air pressure and fabric width.

The other main parameter of weft yarn in air jet loom is weft tension which affects weft crimp and woven fabric properties. Weft tension affects both quality of the product and productivity of weaving machine. So the weft tension should be adjusted depending on yarn count, fabric weight, loom speed, yarn strength and twist.

1.2. Statement of problem

The efficiency of air jet weaving machines and fabric properties are influenced by many factors. From these weft parameters especially twist and weft tension during picking greatly affect physical and mechanical properties of fabric and loom efficiency.

During my observation from weaving practical classes in BDTSC air jet weaving machines, weft parameters are set randomly without considering yarn count, twist and other yarn properties see Table 1.1. This causes weft breakage and non uniform fabric properties. So this variation results variation on fabric properties within same types of articles. For example two looms producing identical fabrics have different air pressure, loom speed and rpm of weft accumulator.

Table 1.1 Weft insertion parameters of two looms producing identical fabrics (from BDTSC Feb. 2017)

No.	Reed width (cm)	Weft count Ne	Air pressure(bar)			Loom speed(rpm)	Speed of weft accumulator(rpm)
			Main nozzle	Left relay nozzle	Right relay nozzles		
1	220	20	5	6	5.75	450	5000
2	220	20	5	5	4	400	4500

My research work helps to set optimum values of the different weft parameters (weft tension and air pressure of relay and main nozzles) in air jet loom to increase loom efficiency and fabric quality.

1.3. Objectives

1.3.1. Main objective

This thesis is designed to study the effect of twist loss and tension of weft yarn on physical and mechanical properties of woven fabric produced by air jet loom.

1.3.2. Specific objectives

The specific objectives are:

i. To compare twist loss of the weft yarn at the left and right side of the fabric
ii. To study the effect of yarn count on twist loss of weft yarn in air jet loom
iii. To study physical properties woven fabrics
iv. To study mechanical properties woven fabrics
v. To compare twist loss of single and plied weft yarn
vi. To know the effect of air pressure on twist loss of weft yarn
vii. To study the effect of weft tension on fabric properties and weft breakage rate
viii. To set optimum weft insertion parameters

1.4. Scope of the research

This research focus on, the study of effect of twist loss and weft tension on fabrics properties produced by air jet weaving machines from 100% cotton rotor spun yarn. Fabric properties were tested at grey stage. The sample fabrics are only plain structure which produced from 10 single and ply, 16, and 20 Ne weft yarns and 20 Ne warp yarns.

1.5. Limitations

This research work only focused on the effect of twist loss and tension of weft yarn on physical and mechanical properties of woven fabrics produced from coarse range warp and weft yarns in air jet loom, because BDTSC rotor spinning machines produces 20 Ne and coarser yarn. The study has been done only in grey fabrics and only in one particular loom width. Weft tension couldn't express in numbers, because unavailability of measuring instrument.

1.6. Benefits and beneficiaries

1.6.1. Research benefits

The output of the research helps to improve fabric quality and loom productivity and also reduces air consumption of weaving machine.

1.6.2. Beneficiaries

Some of the beneficiaries are:

i. Textile factories which have air jet weaving machines,
ii. Researchers
iii. EiTEX
iv. Fabric buyers

CHAPTER TWO

LITERATURE REVIEW

2.1. Features of air jet weaving machine

In air jet weaving machines weft is accelerated and taken through the shed by the flow impedance between the flowing air and the weft. Air jet weaving machines belong to the set of intermittent-operation weaving machines. The energy resulting from air pressure directed from the central air tank to the weaving machine changes into kinetic energy in the nozzle, which accelerates and delivers the weft in the air channels differently, shaped by machine types. The air leaving the nozzle mixes with the still air, it disperses, and the speed of the axis of the flow drops quickly as it moves away from the nozzle; therefore, in order to reach bigger reed width, the air speed must be kept up in the line of the weft course(Lóránt Szabó, 2010).

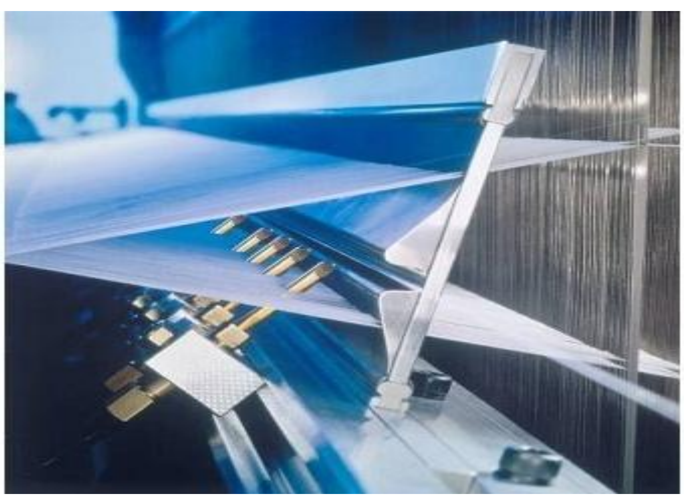
2.1.1. Insertion configurations and the movement of weft yarn during insertion

The movement of the inserted yarn in weft passage is a complex motion. It is not a positively controlled process(Szabó, 2012). The impact on fabric quality for most of the insertion time, two consecutive main nozzles are accelerating the yarn. The first main nozzle the weft yarns pass through is fixed in one position on the loom frame. The second nozzle is mounted on the sley and moves along. This movable main nozzle is positioned next to the entrance of the profile reed. Both nozzles are supposed to blow air at equal pressure and for the same time. Another group of important elements for an efficiently run weft insertion are the auxiliary or relay nozzles.

The relay nozzles create airflow in the reed channel in order to compensate for loss of the air flow through reed dents and warp sheets. The airflow in the reed channel is responsible for the efficient transport of the yarn once the main nozzle accelerates it. The basic action of the relay nozzles is not to give speed to the yarn but to keep it at such speed that the yarn remains largely stretched during its flight through the shed. As the yarn is set in motion by the air-producing drag force applied to the yarn, the speed of the yarn will depend on its properties(*Alessandro Brun*, 2008).

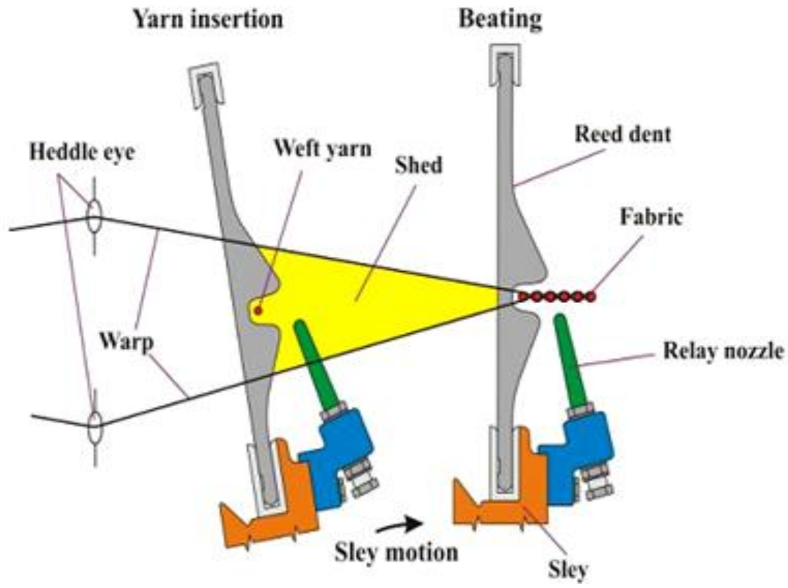
For the weft insertion mechanisms of air jet looms (AJL), the profile reeds with sub-nozzle systems are the most advantageous in terms of improving high speed weaving and wider cloth width. Not only the airflow from the main nozzle and sub-nozzles but also the airflow in the weft passage is closely related to the flying state of the yarn at the time of weft insertion in this system. In order to manufacture high quality textiles with AJL, it is necessary to establish optimum weaving conditions. These conditions include the supply air pressure and air injection timing for the main nozzle and sub-nozzles according to the kind of well yarn(Atsushi, 2001).

The air jet weaving machines require air ducts capable of maintaining an effective air flow on the whole weaving width. To obtain this, the machine manufacturers prefer today to use the system with profiled reed, in which the air and the thread are guided through a tunnel-shaped reed (Figure. 2.1).



Source: Lóránt SZABÓ, 2012

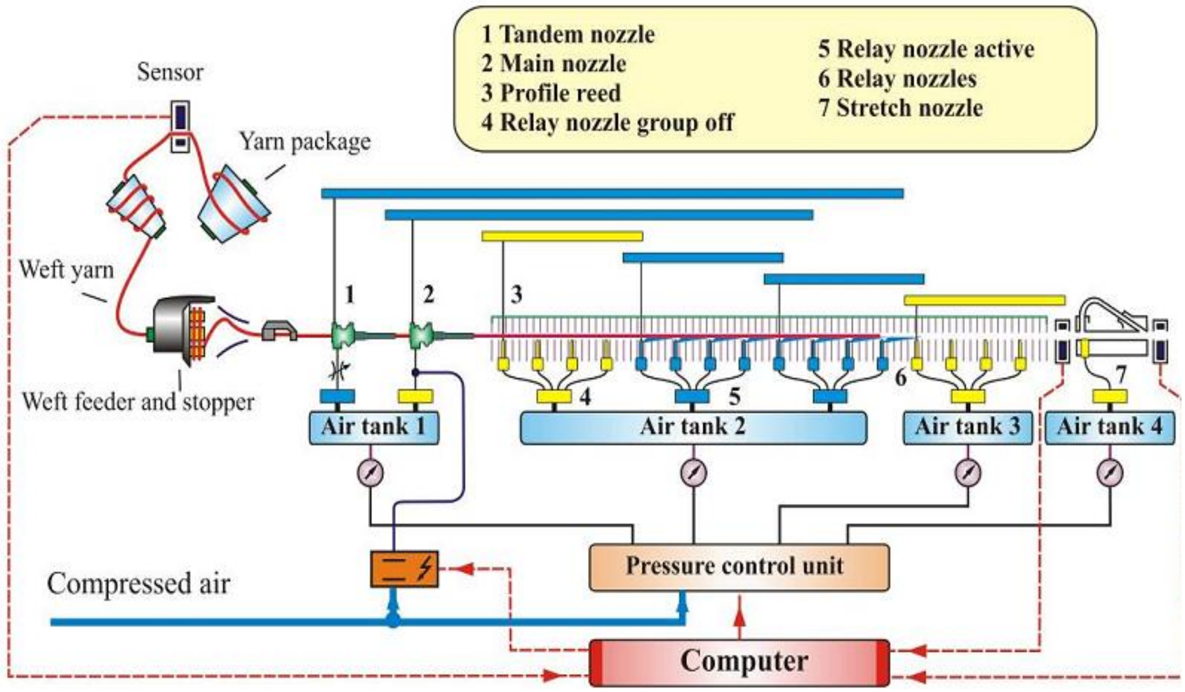
Figure 2.1 Relay nozzles and profile reed on an open shed



Source: Lóránt SZABÓ, 2012

Figure 2.2 Yarn insertion system with relay nozzles and open profile reed

The weft is placed in the groove formed by the reed's profiled dents, in which it remains until the reed stroke. The manufacturers are increasingly installing on the weft delivery side of the shed a suction nozzle which has the function of maintaining stretched the weft pending the stroke of the sley and the consequent weft binding in the fabric. This ensures a perfect stretching of the weft inside the shed with any kind of yarn, even with the most critical yarns(Giovanni Castelli, 2000).



Source: Lóránt Szabó, 2011

Figure 2.3 Schematic diagram of air jet insertion with profile reed

The weaving reed is used on weaving looms for the fabric creation by the beat-up effect on each just picked weft yarn. There are very complicated interactions of air flows with the complicated shape of the reed channel with partially permeable walls of the reed(Karel Adamek, 2015).

There are many quantities influencing on the weft picking: nozzle position toward the reed channel (coordinates x, y and nozzle pitch z), nozzle setting (inclination and elevation angles of the nozzle stream), reed dent shape (rectangular, rounded, convergent…), reed density (thickness of metallic sheets and dividing gaps, too, depending on the cloth type), air pressure in the supply, cross section of nozzle outlet etc(Adámek, 2000).

In the nozzles the compressed air generates kinetic energy. The air erupting from the circular cross section slot at high speed grabs the weft yarn into the middle of the nozzle and accelerates it to high speed. The transporting substance, the air has a complicated flow. The exact theoretical and mathematical description of the flow is not known.

The propelling force on a weft yarn placed in a stream of air consists of skin friction (equal to the sum of all shear stresses taken over the surface of the yarn). This force parallel to the undisturbed initial velocity is referred to as the friction force. The values of the air flow velocity distribution along the weft passage depend on two variables: pressure of main tank and distance in the direction x(Szabó, 2012).

Each pre-winder can be equipped with a new type of Programmable Filling Tensioner. This PFT is microprocessor controlled and ensures optimum yarn tension during the complete insertion cycle. Reducing the basic tension is an important advantage when picking up weak yarns, while adding tension is an advantage at transfer of the yarns and avoids the formation of loops. The tension control enables you to weave strong or weak yarns at even higher speeds. It also drastically reduces the amount of filling stops, and enables you to set an individual waste length per channel and reduce the waste length for some channel. PFT mode: PFT deactivated; PFT/B-: brakes until the set stretching time, PFT/B+: brakes until the next insertion of the same channel and PFT/B+T: brakes until the moment the insertion is cut (manual of picanol air jet loom).

2.1.2. Influence of weft yarn properties on performance of air jet weft insertion

In a weft-insertion process by air jet, the properties of the yarn have a great effect. This is because the weft yarn is not positively pulled but is inserted by the drag force created by the air flow. The insertion time depends on the mass of the yarn. The force that is necessary to move the yarn mass is provided by friction between the air and the yarn surface; this force depends on the yarn structure. Yarn-and air-velocity distributions are used to determine the effectiveness of the air-guiding system in air-jet weft insertion(S. A. M. H. Mohamed, 1988)**.** The factors that essentially determine whether the yarn is suitable for pneumatic insertion are its count, structure and twist (Adanur, 2001).

A further factor that influences both the resistance to the stress and the capacity to be transported is the count of yarn. In fact, a count change leads to variations in resistance as well as in transport capacity, all other characteristics being equal. In particular, an increased count leads to an increase in resistance but also to a bigger difficulty in transport.

Finally, regarding the materials made of several twisted fibres, a certain rate of torsion leads to a bigger fibre cohesion affecting the stress resistance (*Alessandro Brun*, 2008). The effects of twist coefficient and yarn count, which are discussed below, are the main effective parameters of the weft yarn velocity along the tube.

Higher twist values of the yarn provide a more compact structure and prevent mutual movements of fibres. Yarn hairiness decreases with the twist increments. Lower yarn hairiness causes less friction between the yarn and the air jet. It is known that yarn twist is directly related to hairiness. For this reason, friction between the fibres and air decreases when the yarn has a smooth surface. High twisted yarn has lower velocity than low twisted yarn. Open End rotor yarns showed that high twist ratio increases the weft insertion time as a result of the decrement of yarn diameter and the smooth yarn surface.

Different yarn counts have different linear densities, and so the velocity of a thin weft yarn is much higher than the velocity of the thick weft yarn, which also has low starting velocity as a result of the inverse relationship between velocity and mass. Since a high twist coefficient makes the yarn more compact and smoother, it reduces the yarn velocity and increases the insertion time. Increase in yarn count increases the velocity of the weft yarn led through the tube (M. Cengiz Kayacan, 2004).

(M. Cengiz Kayacan, 2004) studied that the effect of weft yarn twist coefficient and yarn count on weft yarn velocity of rotor spun yarn in air jet weaving machine by fuzzy logic principles. As tex count decreases, the yarn velocity increases. In contrast, when the twist value increases, the yarn velocity decreases.

OE yarns give higher mean yarn velocity than ring spun yarns but ring spun yarns have higher initial acceleration. OE yarns are composed of concentric structure with in an inner core which contains most of the fibers in a compact and highly twisted assembly.

The outer layers are wrapped around the core and are less packed. OE yarns are 15% bulkier and less hairy than ring spun yarns. The bulkier structure of OE yarns, which increases the yarn surface area, causes increased air friction. Although OE yarns have higher average velocity, Rs yarns have higher velocity at the beginning of the insertion. The initial acceleration of the RS yarn is slightly higher than that of OE yarns which must be due to the higher hairiness of RS yarn.

There is no significant difference between S and Z twist for air jet insertion. Plying is done by twisting several yarns together to obtain more durable yarn together. The ply yarn is applied in the opposite direction to the twist direction of component strands. Plied yarns give longer insertion times with the same count. The reason is that additional twist makes the yarn surface smooth and reduce air friction(Adanur, 2001).

(S. A. M. H. Mohamed, 1988) studied the effect of weft characteristics on performance of air jet weaving machines and conclude that: high air-supply pressures increase the air velocity inside the tube, which reduces insertion time and increases yarn velocity. The yarn initial loop length affects the yarn velocity. By increasing the loop length for the same feed speed, the insertion time is decreased and the average yarn velocity increased.

2.2. Influence of weft yarn twist on fabric properties

The final properties of fabrics depend more or less on many various technical and technological parameters, which should already be adjusted during the design phase of a fabric. Only in this way, will production be efficient and the desired final properties of the fabric attained, related to its type and end-use.

Many factors influence, directly or indirectly, the final values of the breaking force and elongation at break of a fabric in the warp and weft directions. It is the yarn used (warp and weft), i.e. its mechanical and physical properties (count, breaking force and breaking elongation, fineness, number of twists, raw material composition, after-treatments etc.), which has the most significant effect (Helena Gabrijelčič, 2008).

The change in the fiber packing in turn determines the cover of fabric and such other properties as warmth, crease recovery, permeability and various other related characteristics. Twist also affects the hairiness of yarns, which is a very important property in determining the pilling behavior and the economics of the singeing process. The study of twist, therefore, is very important to understanding the structure and behavior of yarns and their ultimate influence on the end-use properties of fabrics(R. Khanum, 2011).

Twist is an important yarn parameter that affects the yarn characteristics such as strength, handle and appearance. The twist variation in a yarn creates irregular patterns on the fabric due to different dye absorption levels because low twisted regions absorb more dye compared with high twisted regions the major reason for ‘barre effect’ in fabrics(Y.A. Ozkaya, 2008).

The effect of yarn type and yarn twist on fabric properties differed from the properties of the yams in a free state. The inclusion of OE yarns into woven fabrics affects the topography and properties of the fabrics. Some of these fabric properties are: pilling resistance, tensile and tear strength and elongation, abrasion resistance, fabric stiffness and drapeability, air permeability etc(Winsor, 1988).

2.2.1. Fabric thickness

The yarn thickness affects the yarn cross sectional dimensions such as yarn minor and major diameter. Obviously the fabric thickness is the measurable dimensional parameter of fabric and as a function of yarn diameter particularly the yarn minor diameter. Theoretically, the fabric thickness is equal to the sum of minor diameter of crossed yarns. Therefore, the changes in minor diameter in the fabric by the yarn twist may have an obvious effect on fabric thickness. The result of measuring the fabric thickness show that there is the linear relationship between the fabric thickness and the minor diameter of the constitute yarns(Siavash Afrashteh, 2013).

2.2.2. Tensile strength and breaking elongation

(Winsor, 1988) study the effect of twist level of warp yarns was highly significant for the warp direction of flex abrasion, tensile strength, and breaking elongation but not significant for the filling direction of those properties. The twist level of filling yarns influenced only filling tensile strength and breaking elongation measurements in case of unbalanced weave and its effect is same to the warp yarn for balanced weave.

(M.D. Teli, 2008) studied the effect of twist and yarn count on different types of fabric properties and conclude that count of yarn has negative influence and twist level of the yarn has positive effect on fabric tensile strength woven from rotor spun yarn. An analysis of tensile measurements revealed that the twist level of warp yarns significantly influenced the breaking strength in the warp direction and that the filling yarn twist level affected filling tensile measurements(Winsor, 1988).

2.2.3. Bursting strength

Bursting strength of the fabric increases with an increase in T.M. of yarns and a decrease in its value with increase in count. In the case of fabrics with rotor yarns in the weft yarn, the influence of T.M. is more significant than in the case of fabrics with ring yarn as weft (Chopra, 2007).

2.2.4. Tear strength

The tearing strength was found to be the most sensitive of the three different strengths when variations were made in the weft yarn. There is a significant effect of weft yarn twist on tear strength of woven fabric. As the weft yarn twist increases, the fabric tear strength also increased due to the increase in yarn strength and breaking extension and reduce yarn diameter lead to more freedom of yarn movement(Chopra, 2007).

2.2.5. Air permeability

For a woven fabric, yarn twist is also important. As twist increase, the yarn diameter and the cover factor are decreased. This increases air permeability. Increasing yarn twist may also allow the more circular, high-density yarns to be packed closely together in a tightly woven structure with reduced air permeability(D737, 1996).

2.3. Influence of weft yarn tension on fabric properties

The very fact that a woven cloth is formed by the interlacement of the warp and weft yarns implies that, the characteristics of the woven fabric network depend a great deal on the weaving tensions of these two sets of yarn. Besides the weave and yarn parameters like count, twist, etc., yarn tensions determine the magnitudes of crimp of both the warp and weft yarns and these show their effects on the structural, physical (or mechanical) as well as comfort properties of the cloth(Neogi, Jan 5, 2016).

Increase in weft tension results decrease in weft crimp and increase in warp crimp values. The higher crimp in one set of threads is compensated by lower crimp in other set and the total crimp is maintained approximately the same in similar fabric structure(Arora, 1992).

Structural parameters like warp and weft densities and dimensional properties like width, length, thickness and weight of a finished cloth are of immense importance for the end use the cloth is made for. Weaving tensions of the warp and weft yarns play key roles in deciding these characteristics of the cloth. Again, these structural properties of a given type of cloth differ at the loom and grey states, because of changes in the tensions of its constituent yarns within the cloth, held taut on the loom and relaxed off the loom(Neogi, Jan 5, 2016).

2.3.1. Fabric thickness

Thickness of a cloth is primarily determined by the diameters, in other words, counts and crimps of the warp and weft yarns. As yarn crimp is dependent on the weaving tensions of the constituent yarns, yarn tension may show its effect on the fabric thickness. Generally speaking, the thickness of a cloth is the minimum when the crimps of the warp and weft yarns are most evenly distributed. Greater crimp in any set of the yarns increases the cloth thickness(Neogi, Jan 5, 2016). (Qi, 2008) have not observed any significant effect of weft tension on the cloth thickness.

2.3.2. Fabric weight

As the yarn tensions show their effects on the yarn densities of a fabric, the weight of the fabric is also supposed to be affected by changes in yarn tensions. (V. C. M. H. Mohamed, 1986) have found that the increase in peak tension of the weft that is, the maximum tension during insertion of the pick in projectile loom has caused increase in the weights of the spun fabrics and reduction in the weights of the filament fabrics although the average weft tensions have no effects on the weights of the filament fabrics. The increase in weft tension with a given warp tension increases the warp crimp and the effects are more prominent at lower warp tensions.

2.3.3. Tensile strength and elongation

The weft strength always increases with the increase in weft tension. In regard to the shuttleless picking system, increase in weft insertion tension in air-jet picking has been found to decrease the breaking load of the cloth(Qi, 2008). The increase in weft tension increases the warp breaking elongation and decreases the weft breaking elongation with the same warp tension(Neogi, Jan 5, 2016).

2.3.4. Tear strength

(Qi, 2008)have observed that the fabrics woven with lower weft tensions register higher tear strength. With long weft float of 3/1 denim fabric as the weft tension decreases the picks can assemble together more easily under stress and thus, increase the tearing strength.

2.3.5. Air permeability

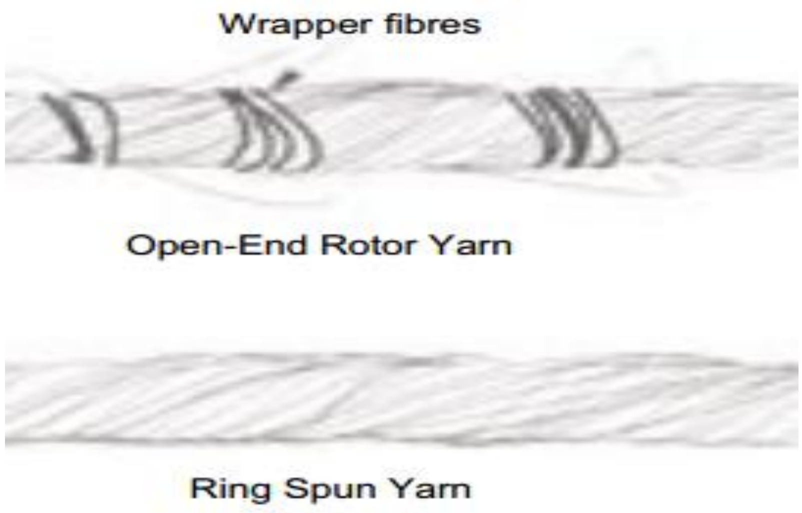
As mentioned above, (Qi, 2008) have studied the effects of weft tension on the various properties of denim fabrics woven on air-jet weaving machine. They have observed greater air permeability of the cloth with increase in weft tension. Increase in weft tension makes the yarn more compact and produces larger openings to increase the air permeability but after the fabrics are scoured they become denser after laundering and hence the air permeability reduces at this latter state. While studying the effects of weft tension on the other comfort properties,(Qi, 2008)have observed that increase in weft tension increases flexural rigidity, which determines the stiffness and hence drape coefficient, but decreases the wrinkle recovery angle of the fabrics mainly at the grey state.

2.4. Twist loss of rotor spun yarn during air jet weft insertion

2.4.1. Properties of rotor spun yarn

Open-end rotor spun yarns have certain characteristics which differentiate them from conventional ring-spun yarns. This is because of differences which can be noted between their production method and structure. In rotor yarns, the outer layer or the surfaces of the yarn have wrap fibers or belts, which is a typical characteristic of rotor-spun yarns. OE rotor-spun yarns, unlike ring spun yarns, are basically of a three-part construction: a densely packed core of fibres substantially aligned (straight) with the yarn axis, more loosely packed fibres twisted around the core, and WFs on the outside.

The presence of wrap fibres on the yarn surface is an identification feature of OE spun yarns. Figure 2.4 shows the outer yarn structure for both the rotor and ring spun yarns(Erdem Koç, 2005).



Source: Erdem Koç, 2005

Figure 2.4 Outer yarn structure of ring and rotor spun yarns

Rotor spun yarns have a high twist at the centre of the yarn, which decreases towards the surface of the yarn. Wrapper fibres improve yarn abrasion resistance but reduce the wicking property of the yarn. For both short and long staple yarns, an increase in wrapper fibres results in deterioration in yarn strength and yarn density in general.

The twist of rotor spun yarns is in principle built up from the inside to the outside. Unlike for ring yarns, the measured twist values are lower than the machine twist values for rotor spun yarns, thus indicating that there is indeed fibre slippage during yarn formation within the rotor. This is an inevitable consequence of the system of yarn formation and is one of the reasons for the high machine twist setting requirements of rotor spun yarns(Lawrence, 2010)

Rotor spun yarn has the advantage of good evenness, less count variation and imperfections(Ghanmi, 2016).

2.4.2. Twist loss of weft yarn in air jet weft insertion

As discribed above many researchers study about the importance of twist and tension of weft yarn to determine the properties of woven fabric. So any change in either twist or tension of the weft yarns affects physical and mechanical properties of fabric.

(Chopra, 2007) compares tear strength of similar woven fabric (same construction, design and other parameters) produced by projectile and air jet weaving machines. The fabrics woven on air jet loom exhibit significantly lower tear strength in weft direction. The difference in weft way contraction may be explained on the basis of yarn withdrawal force, which is found to be more in weft for air jet loom.

On an air jet loom, there occurs a significant loss of twist in the weft yarn because of the presence of free leading end. This twist loss results in lower weft yarn strength simultaneously, loosening the yarn structure, which may lead to its easy flattening in the fabric thereby increasing fabric cover and the friction contact between warp and weft yarns.

Freedom of the filling to untwist during insertion results in twist loss during weaving which affects the strength of the fabric; its dye up take and possibly other properties. Twist factors used in the yarns influence such fabric properties as tensile strength, tearing strength, resistance to abrasion, handle, and so on(Raichurkar, 2011).

(Raichurkar, 2011) studies on the twist loss of ring spun weft yarn on air jet weaving machine and its effect on tensile strength of the fabric. The result of this research shows that there is significant twist loss difference between the left and the right side of the fabric. It can be concluding that variation in twist loss at left side and right side of fabric also affects the strength throughout the width of fabric. It results that lesser strength found around and higher extension around at right side of fabric.

The effect of air pressure analyze on twist of weft yarn. As air pressure of main and relay valves increases the twist loss in weft yarn increased. The twist loss in weft yarn is directly proportional to air pressure.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Materials and Equipment

3.1.1. Materials:

Plain woven fabric produced from 20 Ne, 16 Ne, 10 Ne single and 10 Ne plied 100% cotton rotor spun weft yarns and 20 Ne warp yarn. The twist, strength and elongation and imperfections of all weft yarns were tested as shown in Table 3.1 and Table 3.2 and appendix I.

Table 3.1 Strength and elongation of weft yarn

Package	Linear density Ne	Emax %L	Ebreak %	F max cN	Work cN*cm	Tenacity cN/tex	Time sec
Mean	10	6.65	6.67	759.67	1311.5	12.86	4.06
SD		0.53	0.55	55.87	206.77	0.95	0.32
CV		8.04	8.15	7.35	15.77	7.35	7.99
Mean	20	5.24	5.32	193.94	286.39	6.37	3.17
SD		0.92	0.95	32.87	85.88	1.11	0.55
CV		17.52	17.93	16.95	29.99	16.95	17.29
Mean	16	5.82	5.88	283.63	454.31	7.68	3.52
SD		0.41	0.43	17.31	57.86	0.47	0.24
CV		6.98	7.36	6.10	12.74	6.10	6.90
Mean	10 plied	7.32	7.40	580.05	1126.3	9.84	4.46
SD		0.44	0.48	32.98	134.88	0.56	0.27
CV		6.01	6.32	5.68	11.98	5.68	6.06

Table 3.2 Twist per meter of weft yarn before weaving

No.	20 Ne			16 Ne			10 Ne single			10 Ne plied		
	TPM	ext %	TF	TPM	ex %	TF	TPM	ex %	TF	TPM	ex %	TF
1	884.8	4.5	152.6	860	8.6	165.2	655	6.8	159.1	610	6.8	148
2	894.3	4.9	153.6	869	8.4	166.9	682	7	165.5	618	7.1	150
3	846.5	5.2	145.4	921	9.4	177	673	7.9	163.4	621	7.2	151
4	926.5	5.3	159.1	791	6.2	151.9	682	7.5	165.6	608	6.7	148
5	894.5	4.8	153.7	770	5.6	147.9	665	6.7	161.4	595	6.5	145
6	912.5	5.1	156.7	832	6	159.7	654	6.7	158.9	615	6.9	149
7	968.5	6.4	166.8	807	5.8	155	660	6.8	160	612	6.8	149
8	939.3	5.3	161.3	832	6	159.8	658	6.7	159	614	6.8	149
9	921	5.3	158.2	835	7.2	162.4	665	6.6	161	616	6.7	150
10	935.5	5.9	160.7	835	6.9	158.4	655	6.6	159	612	6.8	149
Mean	912.3	5.27	156.8	835.3	7	160.4	667.5	6.7	160	612.1	6.83	149
SD	34.04	0.54	5.8	48.01	1.52	9.25	4.76	0.1	1.2	7.11	0.2	1.73

*TF is twist factor in terms of metric count, TPM is twist per meter and ex% is percentage of extension during untwisting

3.1.2. Equipment

The required equipment are: balances, scissors, rulers, Uster 5 yarn evenness tester, pick glass, GSM cutter, electronic twist tester, digital fabric thickness tester, crimp tester, tensolab universal strength tester, digital burst strength tester, air permeability tester, digital Elmendorf tear strength tester, pressure gauge and air jet loom.

Air jet weaving machine uses main nozzle and multi-hole relay nozzle with profile reed weft insertion system and tappet shedding mechanism. It has electronic warp let of and cloth take up motion. This loom runs with 500 rpm for 190 cm fabric width. Warp stop motion is electronic type with 6 row contact bars and it has also PFT, optical type weft detector, electronic weft and selvedge cutter, e-leno selvedge device and weft accumulator with winding and braking magnetic sensors.

3.2. Methods

3.2.1. Sample fabrics production and weft breakage rate

The study of the research has been carried out in air jet weaving machines of BDTSC. This factory has 66 air jet weaving machines which produces different articles to the customers. All these air jet weaving machines use only OE rotor spun yarn as warp and weft threads. Sometimes plied yarns are used to produce canvas. In my observation of BDTSC air jet weaving machines which produce same article have different air pressure, speed of weft accumulator, and position of PFT. Sampled fabrics ware produced in BDTSC air jet weaving machine by varying weft count, air pressure of main and relay nozzles and mode of PFT (determines weft tension during picking).

Table 3.3 Sample fabrics production parameters

Sample no	Weft count	Fabric density	Air pressure (bar) Main nozzle	Air pressure (bar) Relay nozzles	Weft breakage/10,000 picks	Mode of PFT
S1	20 Ne	24 EPC & 18PPC	2	3	0.11	B+T
S2	20 Ne		2	3	0.56	B+
S3	20 Ne		2	3	2.78	B-
S5	20 Ne		2	5	1.11	B+
S7	20 Ne		4	3	0.56	B+
S8	20 Ne		5	3	0.56	B+
S9	16 Ne		2	4.5	3.89	B+T
S10	16 Ne		2	4.5	0.56	B+
S11	16 Ne		4	3	1.11	B+
S12	16 Ne		5	3	0.11	B+
S13	10 Ne S	24 EPC & 15PPC	5	5	0.11	B+
S14	10 Ne S		5	3	10	B+
S15	10 Ne S		6	4	0.11	B+
S16	10 Ne P		6	4	6.11	B+
S17	10 Ne P		5	5	0.11	B+

3.2.2. Fabric property testing

To study the effect of weft yarn twist loss and weft yarn tension on fabric properties produced by air jet loom, some selected fabric properties were tested for each sample fabric. These are twist of weft yarn, fabric GSM, thickness, tensile strength, tear strength, bursting strength and air permeability. All the test results of these fabric properties are found in appendix II- appendix IV.

i. Twist of weft yarns were measured by ravel the weft yarn from each sample fabrics both on the left and right side of the fabrics.
ii. Grams per square meter (GSM) of all sample fabrics are measured both on the left and right side of the fabric according to ASTM **D 3776 – 96.**
iii. Thicknesses of sample fabrics were measured by using digital thickness tester according to ASTM **D 1777 – 96 standards.**
iv. Fabric breaking extension and breaking force are tested by using universal strength testing machine. This test was done according to ASTM **D** 5035 – 95 Breaking Force and Elongation of Textile Fabrics (Strip Method).
v. Tear strength of sample fabrics are measured by using Falling-pendulum type (Elmendorf) instrument according to ASTM D 1424-96 standard.
vi. Bursting strength of sample fabrics were tested by diaphragm bursting strength tester according to ASTM D-3786 method.

3.2.3. Data analysis

After completion of fabric property test, data was analyzed by the help of Microsoft excel and SPSS. Tested data was analyzed by using SPSS software. One-way ANOVA examines equality of population means for a quantitative out- come and a single categorical explanatory variable with any number of levels. We have two hypotheses; first hypothesis is there is no difference in mean values of the properties of fabric when there is change weft yarn twist or tension. The second hypothesis is that there is mean difference between values of properties of fabric when there is a change in weft yarn twist or tension. To determine whether any of the differences between the means are statistically significant, compare the sig. value (p-value) to significance level to assess the null hypothesis. The null hypothesis states that the population means are all equal. Usually, a significance level (denoted as α or alpha) of 0.05 works well. A significance level of 0.05 indicates a 5% risk of concluding that a difference exists when there is no actual difference. P values = the probability that the observed result was obtained by chance.

P-value ≤ α: the differences between some of the means are statistically significant. If the p-value is less than or equal to the significance level, you reject the null hypothesis and conclude that not all of population means are equal. P-value > α: the differences between the means are not statistically significant.

If one-way ANOVA p-value is less than significance level, it's to mean that some of the group means are different, but not which pairs of groups. Use the grouping information table and tests for differences of means to determine whether the mean difference between specific pairs of groups are statistically significant and to estimate by how much they are different by Using multiple comparisons to assess differences in group means.

An F ratio is calculated - variance between the groups divided by the variance within the groups. Large F ratio means more variability between groups than within each group. The values of the F-statistic tend to fall around 1.0 when the null hypothesis is true and are bigger when the alternative is true. So if we can compute the sampling distribution of the F statistic under the null hypothesis, then we will have a useful statistic for distinguishing the null from the alternative hypotheses, where large values of F argue for rejection of null hypothesis.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Twist loss of rotor spun weft yarn in air jet weaving machine

Twist loss of weft yarn is determined by twist difference between weft yarn from the supply package and twist of ravel weft yarns from the fabric**.** The significance of the twist losses of weft yarns having different count and air pressure is analyzed by one sample t-test.

Table 4.1 Summary of average TPM of weft yarns from each sample

Sample no		N	Mean	Std. Deviation	Std. Error Mean
2	TPM	20	885.4015	32.86933	7.34981
5	TPM	20	841.2379	19.01595	4.25210
8	TPM	20	851.5070	20.01255	4.47494
10	TPM	20	796.9658	20.82081	4.65568
11	TPM	20	789.2044	35.05047	7.83752
12	TPM	20	787.0919	28.58782	6.39243
13	TPM	20	645.5218	21.52160	4.81238
14	TPM	20	638.3408	9.29507	2.07844
15	TPM	20	632.6127	7.55973	1.69041
16	TPM	20	580.5983	10.54688	2.35836
17	TPM	20	575.4514	10.69715	2.39195

Table 4.2 Significance test of average twist loss of 20Ne weft yarn

One-Sample Test

Sample no		Test Value = 912					
		t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
						Lower	Upper
2	TPM	-3.619	19	.002	-26.59848	-41.9818	-11.2152
5	TPM	-16.642	19	.000	-70.76208	-79.6618	-61.8623
8	TPM	-13.518	19	.000	-60.49296	-69.8591	-51.1268

Table 4.3 ANOVA table for significance of average twist loss of 16 Ne weft count

One-Sample Test

Sample no		Test Value = 835					
		t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
						Lower	Upper
10	TPM	-8.169	19	.000	-38.03425	-47.7787	-28.2898
11	TPM	-5.843	19	.000	-45.79558	-62.1997	-29.3914
12	TPM	-7.495	19	.000	-47.90813	-61.2876	-34.5286

Table 4.4 ANOVA table for significance of average twist loss of 10 Ne weft count (single)

One-Sample Test

Sample no		Test Value = 668					
		t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
						Lower	Upper
13	TPM	-4.671	19	.000	-22.47820	-32.5506	-12.4058
14	TPM	-14.270	19	.000	-29.65920	-34.0094	-25.3090
15	TPM	-20.934	19	.000	-35.38730	-38.9254	-31.8492

Table 4.5 ANOVA table for significance of average twist loss of 10 Ne weft count (plied)

One-Sample Test

Sample no.		Test Value = 612					
		t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
						Lower	Upper
16	TPM	-13.315	19	.000	-31.40172	-36.3378	-26.4656
17	TPM	-15.280	19	.000	-36.54864	-41.5551	-31.5422

For all samples in Table 4.2, Table 4.3, Table 4.4 and Table 4.5 the p-values are less than 0.05, this shows that the average twist of weft yarn before weaving has been found different from the average twist of weft after fabric formation and the twist loss is statistically significance with 0.05 significance level since the tip of weft yarns is free during the insertion of weft yarn.

4.2. Effect of air pressure on twist loss of weft yarn

Figure 4.6 shows effect of air pressure on twist loss of weft yarn within the same weft count. For example sample No. 2, 5 and 8 are produced from 20 Ne weft count with different air pressure of main and relay nozzles. Twist loss increases as air pressure increases and there is significance twist loss due to change in air pressure during weft insertion by air jet has been found. Mean TPM of sample 2 is higher than sample 5 and 8 because air pressure during the weft insertion is less.

Table 4.6 Effect of air pressure on average twist loss of weft yarn by multiple comparisons

Dependent Variable: TPM

(I) Sample no	(J) Sample no	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2	5	38.81400*	11.88745	.012	6.7984	70.8296
	8	35.30400*	11.88745	.026	3.2884	67.3196
5	2	-38.81400*	11.88745	.012	-70.8296	-6.7984
	8	-3.51000	11.88745	.991	-35.5256	28.5056
8	2	-35.30400*	11.88745	.026	-67.3196	-3.2884
	5	3.51000	11.88745	.991	-28.5056	35.5256

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

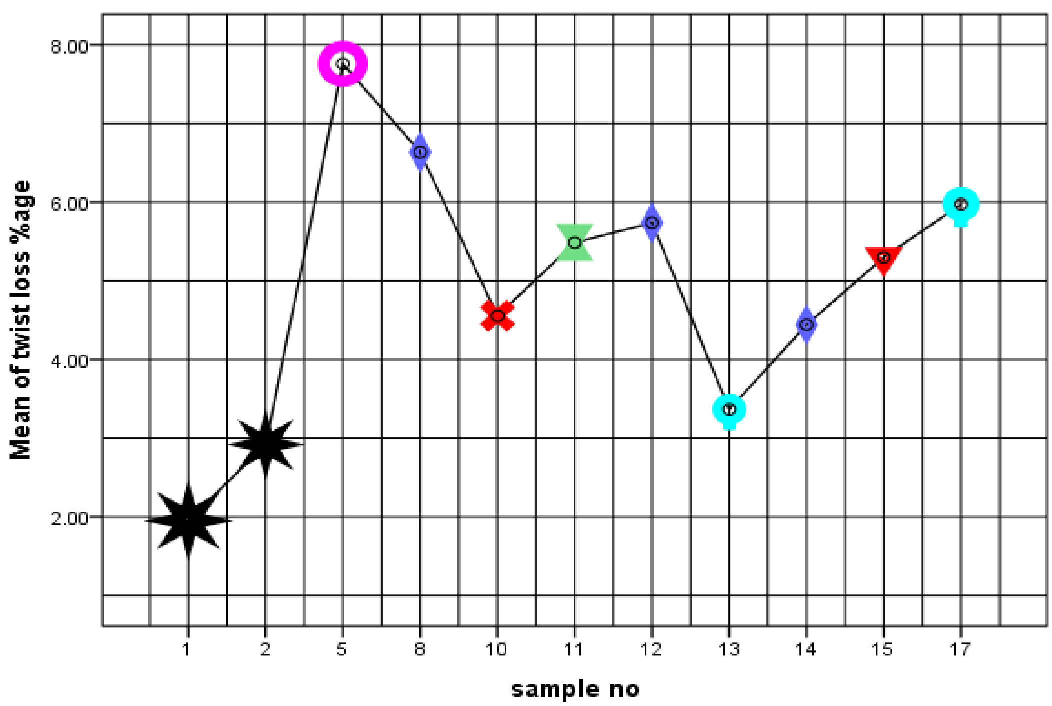


Figure 4.1 Percentage of weft yarn twist loss with different weft count and air pressure

4.3. Effect of yarn count on twist loss of weft yarn

Twist loss percentage of weft yarn is different for different weft count. Figure 4.2 shows that the effects of weft count on twist loss percentage of weft yarn by maintaining air pressure constant. The twist loss percentage is high for fine weft yarn and less for coarse weft yarn. Sample 8, 12 and 14 are produced from 20, 16 ad 10 Ne weft counts respectively with air pressure of 5 bar for main nozzle and 3 bar for relay nozzles. We found that twist loss percentage is different for different weft count at constant air pressure.

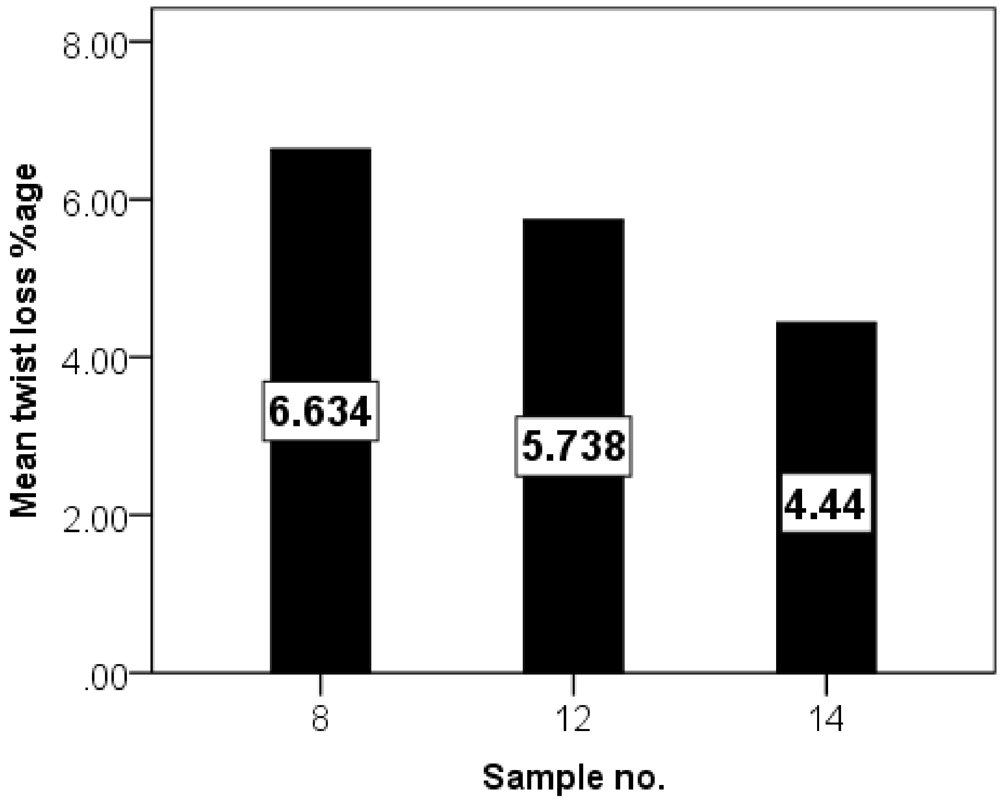


Figure 4.2 Percentage of weft yarn twist loss with different weft count

4.4. Twist loss comparison on the left and right side of the fabric

The twist loss percentage of weft yarn on left and right side of the fabric is different see Figure 4.3. During weft insertion by air jet, the right side of weft yarn has more contact time with air jet and it loss more turn of twist as compared to the left side.

Table 4.7 Average twist loss on the left and right side of the fabric

Position of specimen on the sample	Mean	N	Std. Deviation
L	4.1263	130	3.18379
R	5.6462	130	2.86598
Total	4.8863	260	3.11762

P-value on Table 4.8 is 0.001 which is less than 0.05. This indicates that the twist loss of weft yarn at the left and right side of the fabrics are not statistically equal.

Table 4.8 Twist loss percentage on left and right side of the fabric

		Sum of Squares	df	Mean Square	F	Sig.
Twist loss %age * position of specimen on the sample	Between Groups (Combined)	150.1	1	150.1	16	.000
	Within Groups	2367.1	258	9.17		
	Total	2517.3	259			

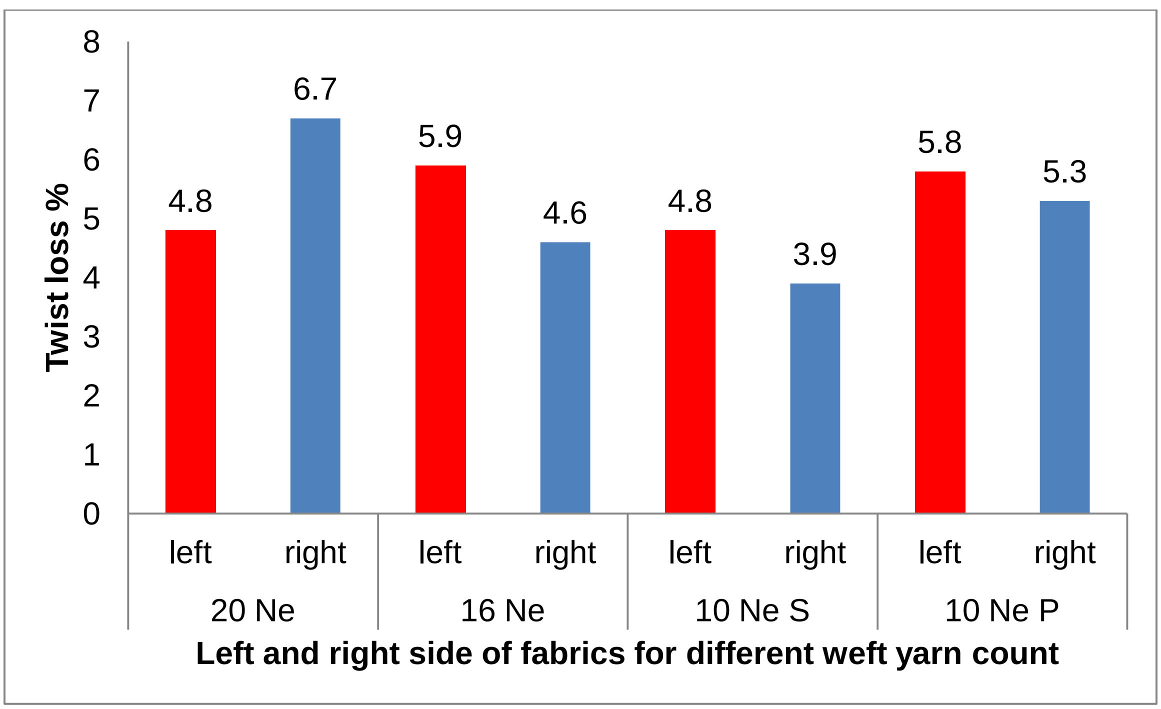


Figure 4.3 Twist loss at the left and right side of different samples

4.5. Effect of twist loss on fabric thickness

Thickness of woven fabric is determined by minor diameter of crossed yarns. If there is any change in minor diameter of either set of yarns due to twist change, there will be change in fabric thickness as shown in the Figure 4.4.

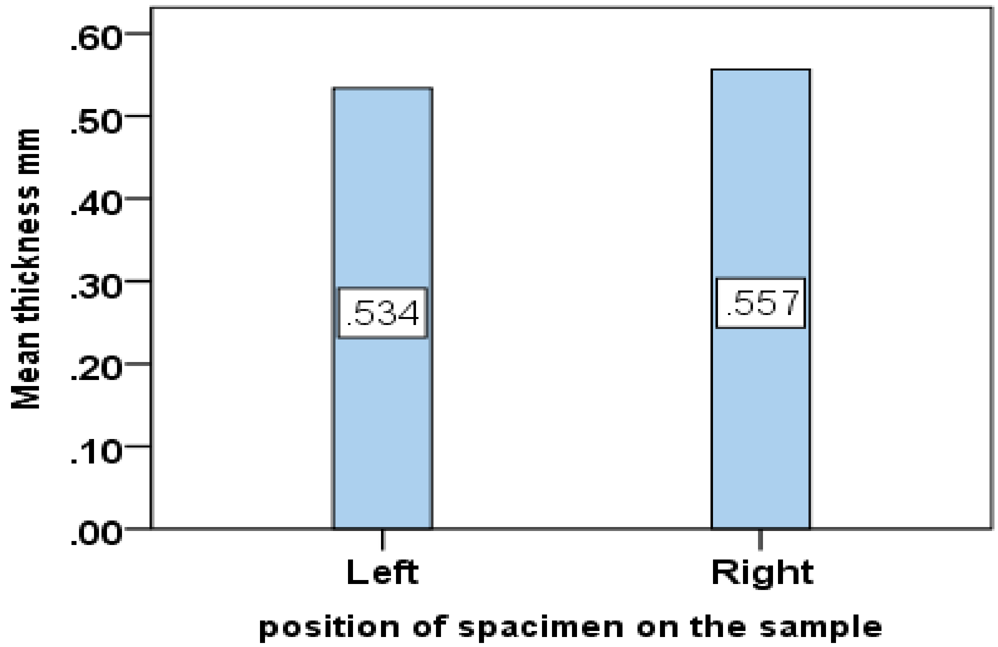


Figure 4.4 Average thickness on the left and right side of the fabric

Figure 4.4 indicates that the thickness of the fabric at left and right side of the fabric is different. The thickness of fabric at right side is greater than left side. This thickness difference is the result of change in weft diameter by twist loss. When yarn twist is reduced, yarn diameter will increase and then fabric thickness also increases. As shown in Table 4.9 both TPM and weft count (Ne) have significance effect on fabric thickness.

Table 4.9 Correlation of TPM and weft count with fabric thickness

Correlations

		Thickness	Weft count Ne	TPM
Pearson Correlation	Thickness	1.000	-.910	-.892
	weft count Ne	-.910	1.000	.966
	TPM	-.892	.966	1.000
Sig. (1-tailed)	Thickness	.	.000	.000
	Weft count Ne	.000	.	.000
	TPM	.000	.000	.
N	Thickness	260	260	260
	Weft count Ne	260	260	260
	TPM	260	260	260

Table 4.10 Average thickness on the left and right side of the fabric

Thickness in mm

Position of specimen on the sample	Mean	N	Std. Deviation
L	.5337	140	.04260
R	.5570	140	.04156
Total	.5454	280	.04360

Table 4.11 Fabric thickness on the left and right side

ANOVA Table

			Sum of Squares	df	Mean Square	F	Sig.
Thickness mm * position of specimen on the sample	Between Groups	(Combined)	.038	1	.038	21.42	.000
	Within Groups		.492	278	.002		
	Total		.530	279			

The average thickness value on the left and right side are 0.5337 mm and 0.557 mm respectively as shown Table 4.10. ANOVA Table 4.11 also shows that there is significance difference between right and left side of fabrics due to twist difference.

4.6. Effect of twist loss on fabric weight

Figure 4.5 indicates GSM of right and left side of all sample fabrics and there is small difference between the right and left side of the fabrics.

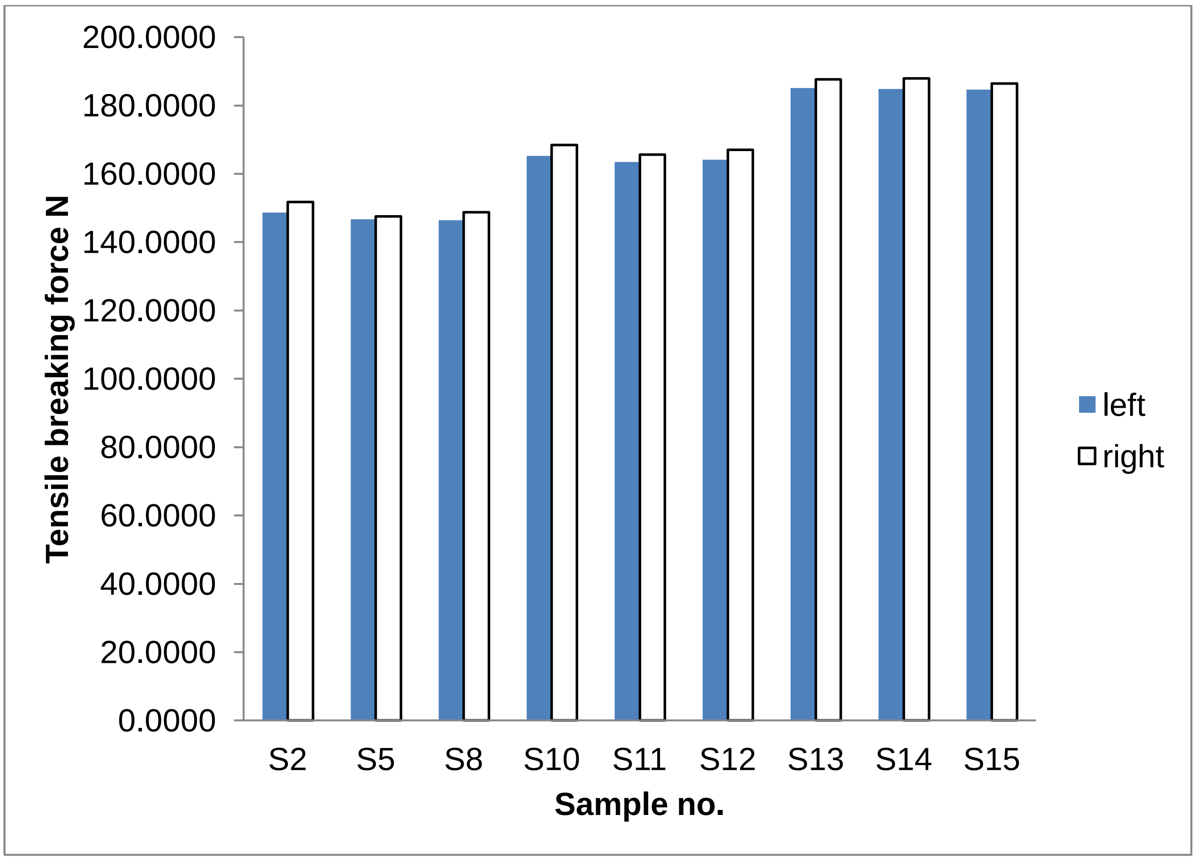


Figure 4.5 Fabric weight

Table 4.12 Average weight on the left and right side of the fabric

Weight * position of specimen on the sample	Mean	N	Std. Deviation
L	167.6414	70	18.96127
R	170.1771	70	19.51765
Total	168.9093	140	19.21431

Table 4.13 Comparison of fabric weight at the left and right side of the fabric

ANOVA Table

			Sum of Squares	df	Mean Square	F	Sig.
Weight * position of specimen on the sample	Between Groups	(Combined)	225.045	1	225	.61	.437
	Within Groups		51092.313	138	370		
	Total		51317.358	139			

Since p-value is 0.437 which is greater than 0.05, it is 95% confidence that the mean weight of left and right side of the fabric have not significance difference see Table 13.

4.7. Effect of twist loss of weft yarn on tensile strength of woven fabrics

Tensile strength of woven fabric depends on fabric construction parameters and the properties of the constitute yarns. Any change in yarn properties affects fabric breaking strength and elongation. Table 4.14 shows the relation between breaking force of fabric and TPM of weft yarn on the same fabric.

Table 4.14 Correlations between breaking force and TPM of 20 Ne weft yarn

Correlations

		Breaking force	TPM
Pearson Correlation	Breaking force N	1.000	.290
	TPM	.290	1.000
Sig. (1-tailed)	Breaking force N	.	.010
	TPM	.010	.
N	Breaking force N	64	64
	TPM	64	64

Table 4.15 Correlations between breaking force and TPM of 16 Ne weft yarn

Correlations			
		Breaking force N	TPM
Pearson Correlation	Breaking force N	1.000	.705
	TPM	.705	1.000
Sig. (1-tailed)	Breaking force N	.	.000
	TPM	.000	.
N	Breaking force N	48	48
	TPM	48	48

Table 4.16 Correlations between breaking force and TPM of 10 Ne weft yarn (single)

Correlations			
		Breaking force N	TPM
Pearson Correlation	Breaking force N	1.000	.746
	TPM	.746	1.000
Sig. (1-tailed)	Breaking force N	.	.000
	TPM	.000	.
N	Breaking force N	48	48
	TPM	48	48

Table 4.17 Correlations between breaking force and TPM of 10 Ne weft yarn (plied)

Correlations			
		Breaking force	TPM
Pearson Correlation	Breaking force	1.000	.616
	TPM	.616	1.000
Sig. (1-tailed)	Breaking force	.	.000
	TPM	.000	.
N	Breaking force	32	32
	TPM	32	32

Table 4.14, Table 4.15, Table 4.16 and Table 4.17 shows that, there is positive correlation between breaking strength of fabric in the weft direction and TPM of weft yarn and the relation is statistically significant for all counts because, all p values are less than 0.05 significance level.

Table 4.18 Average breaking force on left and right side of the fabric

Tensile breaking force N*

position of specimen on the sample	Mean	N	Std. Deviation
L	235.1395	1016	53.42336
R	225.9111	1016	48.96759
Total	230.5253	2032	51.43878

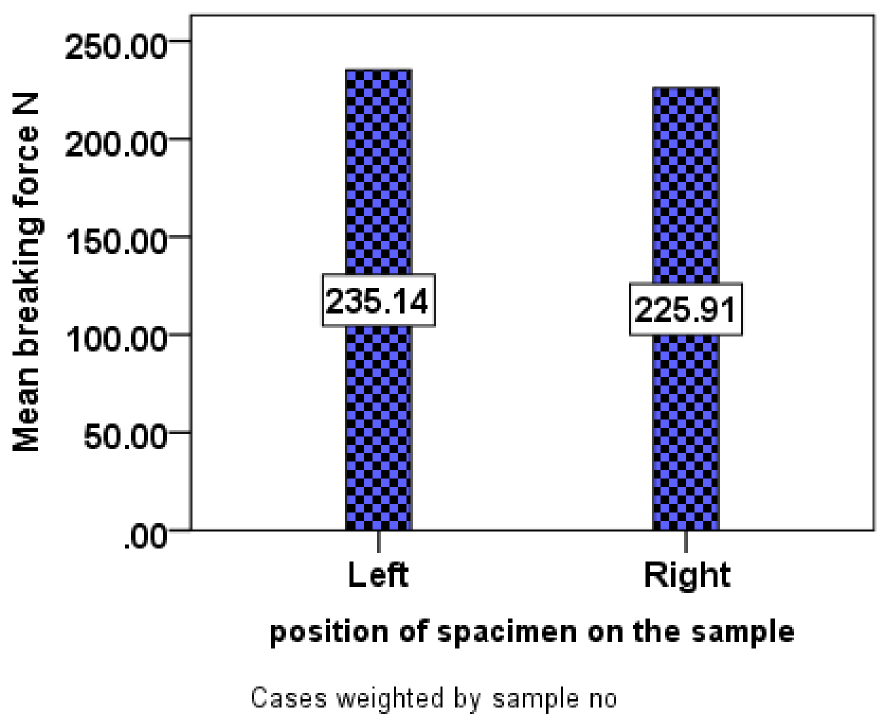


Figure 4.6 Average breaking strength of left and right side of fabrics

Table 4.19 Breaking strength comparison of fabrics on the left and right side

ANOVA Table							
			Sum of Squares	df	Mean Square	F	Sig.
Tensile breaking force N * position of specimen on the sample	Between Groups	(Combined)	43262.8	1	43262	16.5	.000
	Within Groups		5330658.6	2030	2625		
	Total		5373921.5	2031			

Since p=0.001 which is less than 0.05, there is significance difference between mean strength at the left and right side of fabric. So, mean breaking strength of fabric on the left side is greater than the right side because of high twist loss of weft yarn on the right side of the fabric. Tensile strength decreases as the air pressure increases, since the twist loss of weft yarn increases as air pressure of main and relay nozzle increases.

Table 4.20 Multiple comparisons among tensile strength of fabrics produced with different air pressures

Dependent Variable: Tensile breaking force Tukey HSD						
(I) Sample no	(J) Sample no	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2 (2 and 3) bar	5	6.67125*	1.66034	.001	2.6472	10.6953
	8	5.37000*	1.66034	.006	1.3460	9.3940
5 (2 & 5) bar	2	-6.67125*	1.66034	.001	-10.6953	-2.6472
	8	-1.30125	1.66034	.715	-5.3253	2.7228
8 (5 &3) bar	2	-5.37000*	1.66034	.006	-9.3940	-1.3460
	5	1.30125	1.66034	.715	-2.7228	5.3253

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

Table 4.20 shows that tensile breaking force of sample no. 2 is statistically greater than sample no. 5 and 8 at 0.05 confidence level because, the twist loss of weft yarn on sample no. 2 is higher than sample no. 5 and 8.

4.8. Effect of twist loss of weft yarn on tear strength of woven fabric

Twist loss of weft yarn has not significance effect on tear strength of fabrics in the weft direction at 95% confidence level as shown Table 4.22. As shown in Table 4.21 shows mean tear strength on left and right side of the fabric are statistically equal because p- value 0.908 is greater than 0.05.

Table 4.21 Tear force on left and right side of fabrics for fabrics produced from 20 Ne weft count.

ANOVA Table

			Sum of Squares	df	Mean Square	F	Sig.
Tear force N * position of specimen on the sample	Between Groups	(Combined)	.143	1	.143	1.629	.210
	Within Groups		3.333	38	.088		
	Total		3.476	39			

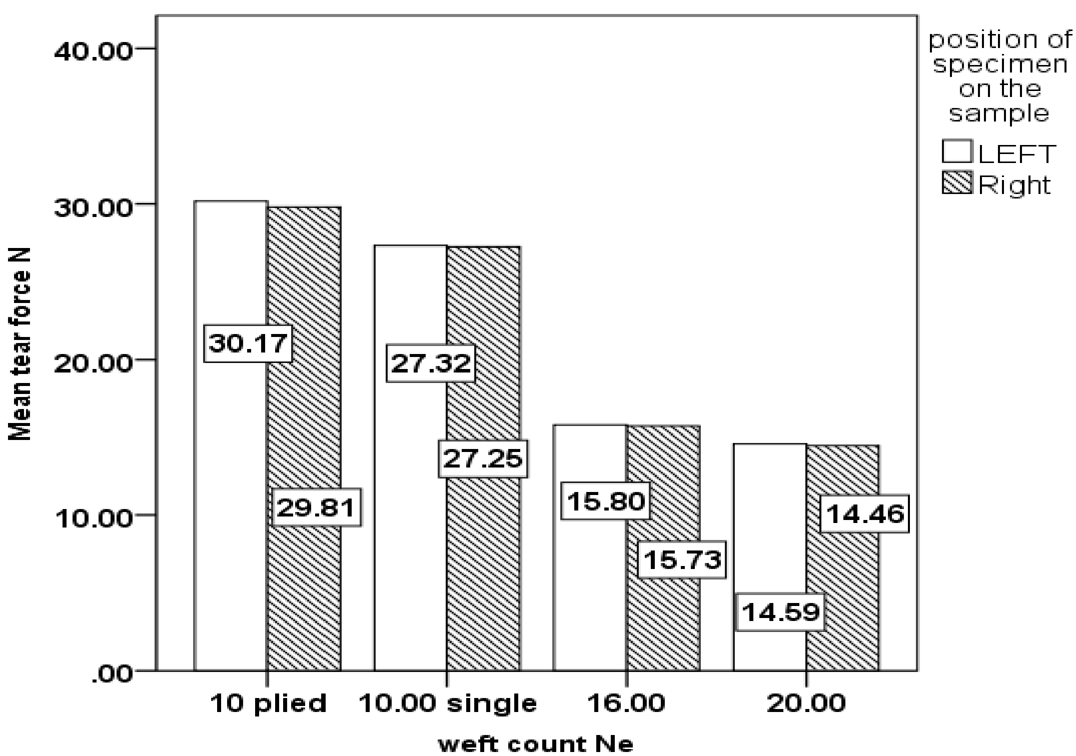


Figure 4.7 Tears strength of fabrics with different weft count

Table 4. 22 Comparison of tear strength on the left and right side for all counts

ANOVA Table							
			Sum of Squares	df	Mean Square	F	Sig.
Tear force N * position of specimen on the sample	Between Groups	(Combined)	.594	1	.59	.02	.91
	Within Groups		5669.6	128	44.2		
	Total		5670.2	129			

4.9. Effect of twist loss on bursting strength of woven fabrics

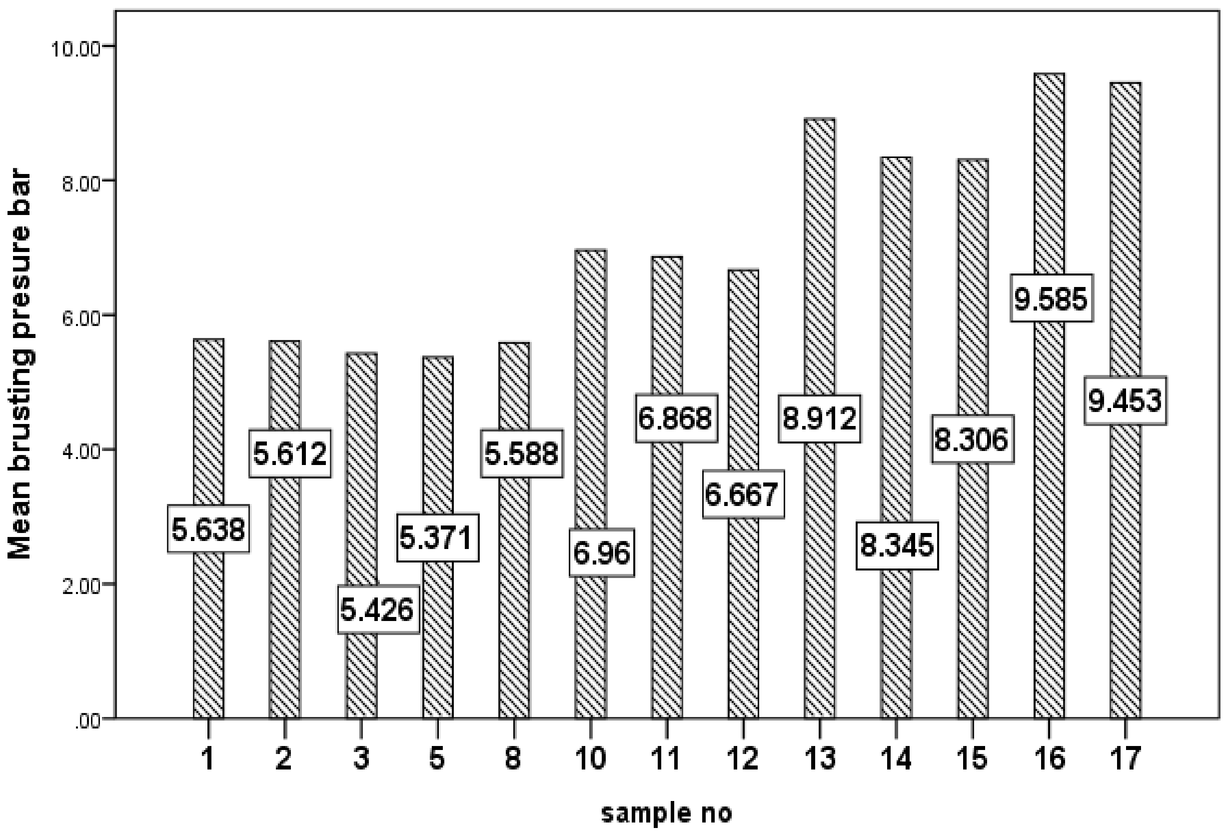


Figure 4.8 Mean burst strength of sample fabrics

The Figure 4.8 shows the difference in mean bursting strength of sample of the same weft count is small. Table 4.23 shows that there no significant difference in bursting strength among samples produced from 20Ne weft count.

Table 4. 23 ANOVA table for bursting strength of fabrics produced from 20Ne weft count

	Sum of Squares	df	Mean Square	F	Sig.
ANOVA					
bursting pressure					
Between Groups	1.157	4	.289	3.543	.010
Within Groups	7.757	95	.082		
Total	8.914	99			

Table 4. 24 Multiple comparisons among bursting strength of samples produced from 20 Ne weft count

Multiple Comparisons

Dependent Variable: bursting pressure

Tukey HSD

(I) sample no	(J) sample no	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2	5	.24150	.09036	.066	-.0098	.4928
	8	.02400	.09036	.999	-.2273	.2753
5	2	-.24150	.09036	.066	-.4928	.0098
	8	-.21750	.09036	.122	-.4688	.0338
8	2	-.02400	.09036	.999	-.2753	.2273
	5	.21750	.09036	.122	-.0338	.4688

In Table 4.24 mean bursting strength of all samples are statistically equal at 95 % confidence level.

4.10. Effect of twist loss on Air permeability of woven fabrics

Air permeability of fabric is affected by twist of the constitute yarns. As discussed earlier there is significance twist loss difference between left and right side of fabrics produced by air jet loom and there is also significance twist loss due to variation in air pressure of nozzles. This twist loss difference causes difference in air permeability of those fabrics as shown Table 4.25 and Table 4.26.

Table 4. 25: Mean air permeability of fabrics on the left and right side of fabrics

Report

Air permeability $cm^3/cm^2/s$ *

position of specimen on the sample	Mean	N	Std. Deviation
L	68.8529	70	6.21804
R	79.0829	70	5.35033
Total	73.9679	140	7.73010

Table 4. 26 Air permeability left and right side of fabrics for 20Ne weft count

ANOVA Table

sample no				Sum of Squares	Df	Mean Square	F	Sig.
2	Air permeability * position of specimen on the sample	Between Groups	(Combined)	729.6	1	729	41.5	.000
		Within Groups		316.2	18	17.5		
		Total		1045.8	19			
5	Air permeability * position of specimen on the sample	Between Groups	(Combined)	165.8	1	165.8	6.2	.000
		Within Groups		481.0	18	26.7		
		Total		646.9	19			
8	Air permeability * position of specimen on the sample	Between Groups	(Combined)	240.1	1	240.1	7.9	.000
		Within Groups		546.4	18	30.3		
		Total		786.5	19			

Air permeability at the right side is higher than the left side of the fabric and the difference is significance at 95% confidence level for all sample fabrics produced from 20 Ne weft counts. Weft yarn twist on the left side is higher than the right side of fabrics produced by air jet loom. If weft yarn twist is higher on the left, yarn diameter becomes less and it has low hairiness this helps close spacing between weft yarns by beating up forces. So air permeability of the left side is lower than the right side of the fabric.

Table 4. 27 Multiple comparison of air permeability of sample fabrics produced from 20 Ne weft count.

Multiple Comparisons

Dependent Variable: air permeability

Tukey HSD

(I) Sample no	(J) Sample no	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2	5	-7.85000*	2.24659	.006	-14.0975	-1.6025
	8	-7.52500*	2.24659	.010	-13.7725	-1.2775
5	2	7.85000*	2.24659	.006	1.6025	14.0975
	8	.32500	2.24659	1.000	-5.9225	6.5725
8	2	7.52500*	2.24659	.010	1.2775	13.7725
	5	-.32500	2.24659	1.000	-6.5725	5.9225

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

In Table 4.27 the mean difference of air permeability is significant at the 0.05 level for sample 2 and 5 and 2 and 8. All these samples (sample 2, 5, and 8) are produced with the same production and fabric parameters except air pressure during weft insertion. So mean differences of air permeability is due to air pressure of nozzles, this result difference in twist loss of weft yarn and then air permeability of fabrics.

4.11. Effect of weft tension on fabric thickness

Three sample fabrics were produced from 20 Ne weft yarn in air jet loom by varying position of PFT to study the effect of weft tension on fabric properties like thickness, GSM, tear and burst strength.

As shown in Table 4.27 and Figure 4.9, tension of weft yarn has not significance effect on fabric thickness.

Table 4. 28 Effect of weft tension on fabric thickness by one way ANOVA

ANOVA

Thickness mm

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.000	2	.000	.508	.604
Within Groups	.017	57	.000		
Total	.018	59			

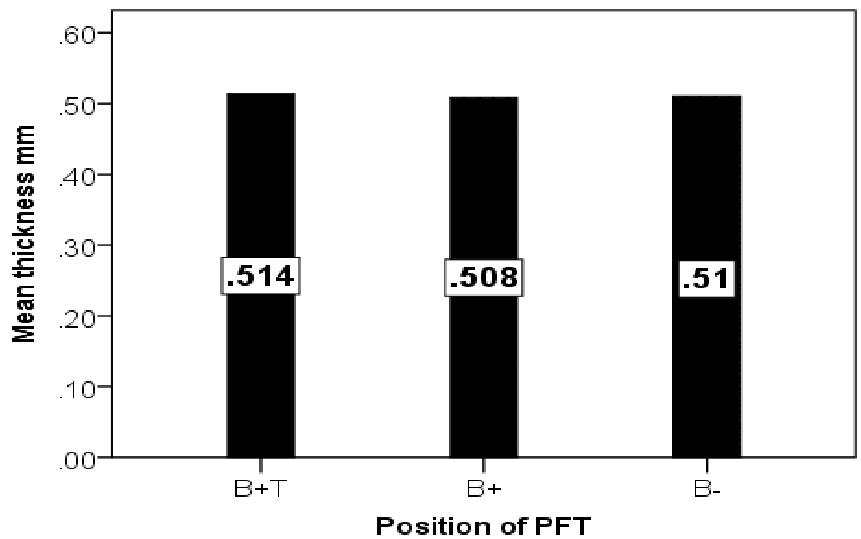


Figure 4.9 Mean fabric thickness with three different weft tensions

As shown in Table 4.26, average fabric thickness of the three samples are statistically equal with 0.05 significance level because of p=0.0604 which is greater than alpha 0.05 values. Thickness of fabric produced with B+ position of PFT which has medium weft tension has minimum as shown in Figure 4.9. This means that weft tension and warp tension is balanced and crimp percentage is low for both warp and weft yarns which causes reduction in fabric thickness.

4.12. Effect of weft tension on fabric weight

The effect of weft yarn tension on the weight of fabric has a significance effect since p value is 0.001 which is less than alpha 0.05 values. So, multiple comparison of ANOVA is required to identify which group combination shows significance difference. Table 4.30 shows fabric produced with PFT of B- has different fabric weight as compared with samples produced with PFT of B+T and B+. Figure 4.10 show that fabric produced by B- weft tension has smallest fabric GSM.

Table 4. 29 Significance test of weft tension on fabric weight

ANOVA

Weight

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	69.221	2	34.610	13.100	.000
Within Groups	71.334	27	2.642		
Total	140.555	29			

Table 4. 30 Significance test of weft tension on fabric GSM by multiple comparisons

Multiple Comparisons

Dependent Variable: weight

Tukey HSD

(I) Sample no	(J) Sample no	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-.25000	.72691	.937	-2.0523	1.5523
	3	3.09000*	.72691	.001	1.2877	4.8923
2	1	.25000	.72691	.937	-1.5523	2.0523
	3	3.34000*	.72691	.000	1.5377	5.1423
3	1	-3.09000*	.72691	.001	-4.8923	-1.2877
	2	-3.34000*	.72691	.000	-5.1423	-1.5377

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

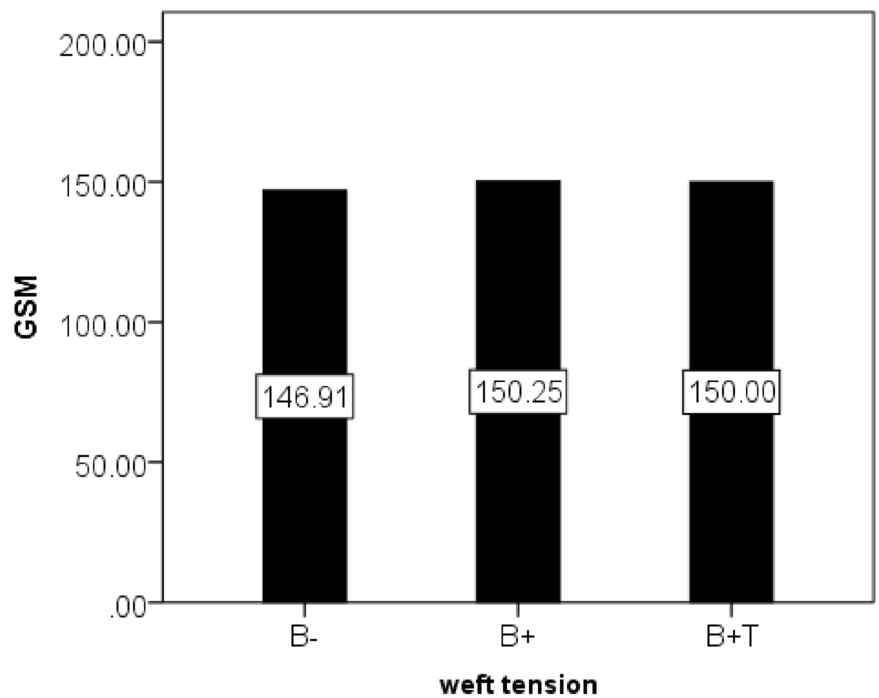


Figure 4.10 Average weights of fabrics produced with weft tension

4.13. Effect of weft tension on fabric tear strength

Figure 4.11 shows that mean tear strength of fabrics produced by different weft tension. Tear strength of fabrics produced with low weft tension is higher than fabrics produced with high weft tension and difference in tear strength is significance at 0.05 significance level for sample no. 1 and 3 as shown in Table 4.31 and 4.32. During the process of tearing, if the yarns are allowed to group together they become more capable of sharing the stress to register higher tear strength of the cloth. As the weft tension decreases the picks can assemble together more easily under stress and thus, increase the tearing strength.

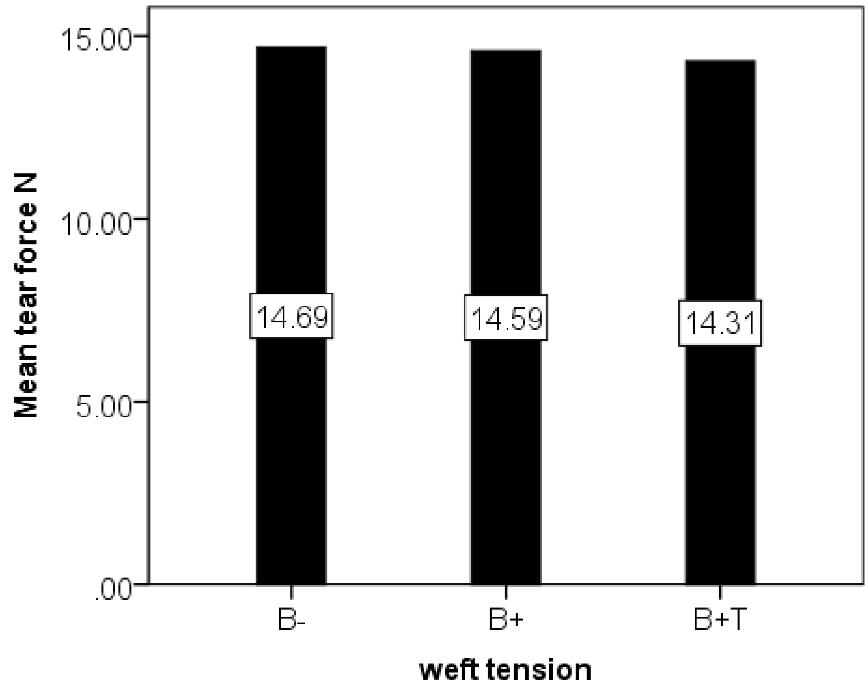


Figure 4.11 Mean tear strength of fabrics with different weft tension

Table 4. 31 Significance test of weft tension on fabric tear strength

ANOVA

Tear force

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.791	2	.396	4.137	.027
Within Groups	2.582	27	.096		
Total	3.373	29			

Table 4. 32 Significance test of weft tension on fabric tear strength by multiple comparisons

Dependent Variable: tear force

Tukey HSD

(I) Sample no	(J) Sample no	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-.28690	.13829	.114	-.6298	.0560
	3	-.38203*	.13829	.027	-.7249	-.0392
2	1	.28690	.13829	.114	-.0560	.6298
	3	-.09513	.13829	.772	-.4380	.2477
3	1	.38203*	.13829	.027	.0392	.7249
	2	.09513	.13829	.772	-.2477	.4380

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

4.14. Effect of weft tension on fabric bursting strength

As shown from Figure 4.12, the bursting pressure of fabrics increases with weft tension. For all sample fabrics only the weft yarns break during bursting strength test and busting strength of these sample fabric depends on the strength of weft yarns and crimp percentage of weft yarns. Crimp percentage has negative effect on fabric bursting strength and weft tension and weft crimp have inverse relation. Therefore weft tension has a positive effect on fabric bursting strength and why bursting strength of fabrics produced with PFT of B+T registers highest value than the others.

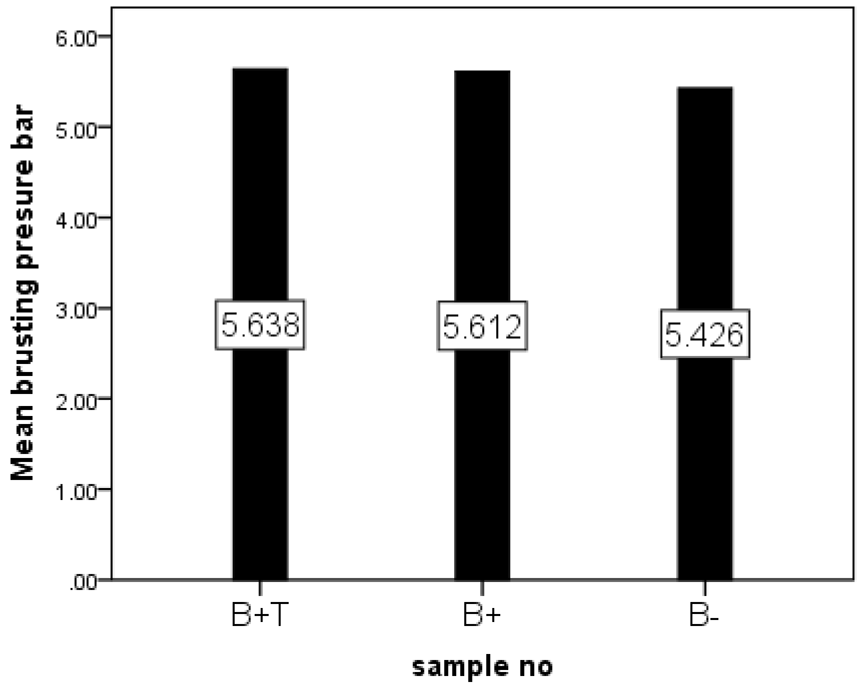


Figure 4.12 Mean bursting pressure of fabrics with different weft tension

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The twist loss and tension variation of rotor spun weft yarns and their effects on properties of woven fabrics have been investigated. Twist loss of rotor spun weft yarns during air jet weft insertion is significance at 95 confidence level. The twist loss percentage of 20 Ne, 16 Ne, and 10 Ne weft yarns are 6.63 %, 5.74% and 4.44 % respectively with same air pressure. Twist loss percentage of fine yarn is high than coarse yarns. Twist loss of 20 Ne weft yarns are 2.92 %, 7.75 % and 6.63 % with air pressure of 2 bar main with 3 bar relay nozzles, 2 bar main with 5 bar relay nozzles and 5 bar main with 3 bar relay nozzles respectively. So we can conclude that twist loss increases as the amount of air pressure increases during air jet weft insertion and the effect is statistically significance at 95 confidence level. Twist loss of 10 Ne single and plied weft yarns are 5.29 % and 5.97 % with constant air pressure and this shows twist loss percentage of plied weft yarn is higher than the same count of single weft yarn. Twist loss percentage on the right side of the fabric is higher than left side and this results higher fabric thickness on the right side.

We found that twist loss of weft yarns significantly affect fabric breaking strength, thickness and air permeability with 0.05 confidence level whereas, its effect is not statistically significant for bursting strength, tear strength and GSM. The twist loss of weft yarn has positive effect on fabric thickness and air permeability but fabric breaking strength decreases as twist loss increases.

Thickness of fabric produced with PFT of B+ is minimal. Tear strength of fabrics produced with low weft tension is higher than fabrics produced with high tension, however; the bursting pressure of fabrics increases with increase in weft tension with the same warp tensions. Bursting strength of fabrics produced in PFT of B+T, B+, and B- are 5.638 bar, 5.612 bar, and 5.426 bar respectively. This indicates weft tension has a positive effect on fabric bursting strength and why bursting strength of fabrics produced with PFT of B+T registers highest value than the others.

The result shows that at 2 bar main with 3 bar relay nozzles air pressure and PFT/ B+ gives minimum weft breakage rate (0.56 breaks/1000picks) for 20 Ne weft yarn in 190 fabric width. Similarly air pressure of 2 bar main with 4.5 relay nozzles and PFT/B+ for 16 Ne, 6 bar main with 4 relay nozzles air pressure and PFT/B+ for 10 Ne single and 5 bar main with 5 relay nozzles air pressure and PFT/B+ for 10 Ne plied weft yarn air pressures are optimal for 190cm width fabric.

5.2. Recommendation

The investigation of twist losses on selected physical and mechanical properties of the fabric will give a clue to carry out further studies on abrasion resistance, pilling resistance, handle properties, and comfort properties of fabrics produced by air jet looms. In addition twist loss of rotor spun weft yarn will analyze at different fabric width and weft tension measurement during air jet weft insertion needs further study.

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APPENDICES

Appendix 1 Appendix I Evenness of weft yarns by Uster 5 tester

Nr	Count	U%	CVm	Thin -40 /km	Thin -50%/km	Thick +35%/km	Thick +50%/km	Neps +140%	Neps +200%	Neps +180%	Rel. Cnt +/- %	H	sh
1	20 Ne	11.8	14.9	258	8	552	52	1834	208	12	-0.3	5.43	1.37
2		12.1	15.31	280	14	580	60	1950	220	30	-0.8	5.28	1.39
3		12.0	15.3	266	6	578	86	2004	174	10	0.5	5.28	1.41
4		12.0	15.32	306	6	610	108	1030	214	22	0.4	5.25	1.42
5		12.0	15.31	246	10	630	66	2032	222	18	0.8	5.27	1.41
6		12.1	15.28	188	0	558	56	1946	210	26	-0.5	5.32	1.40
Mean		12.01	15.24	257.3	7.3	584.7	71.3	1966	208	19.7	0	5.31	1.40
Cv		0.8	0.9	15.4	63.8	5.2	30.2	3.8	8.4	39.9	0.6	1.2	1.3
1	16 Ne	11.69	14.78	154	4	430	46	1040	80	8	3.7	6.24	1.51
2		11.54	14.6	154	4	442	46	1052	94	14	1.2	6.05	1.53
3		11.57	14.59	134	2	366	28	1114	94	4	-0.4	6.12	1.54
4		11.18	14.12	124	4	376	30	1042	96	6	-0.5	6.11	1.55
5		10.98	13.85	116	2	338	18	1004	78	2	-0.9	6.11	1.54
6		11.19	14.12	134	0	414	20	1070	96	2	-3.1	6.15	1.57
Mean		11.36	14.34	136	2.7	394.3	31.3	1054	89.7	6	0	6.13	1.54
Cv		2.4	2.5	11.4	61.2	10.3	39.1	3.5	9.3	76	2.3	1	1.3
1		19.71	28.02	1342	28	1828	1054	2792	1144	478	3.3	6.89	1.74

2	10 Ne	19.51	26.90	850	18	1686	818	2544	724	174	3.2	6.64	1.76
3	singles	17.59	23.85	548	4	1464	560	2142	474	86	-1.1	6.59	1.77
4		16.99	22.59	512	8	1286	418	1916	380	48	-0.7	6.57	1.78
5		15.85	20.80	386	0	1220	348	1820	280	22	-2.4	6.57	1.8
6		15.35	19.99	342	8	1074	252	1678	218	10	-2.3	6.57	1.79
Mean		17.50	23.69	663	11	1426	575	2149	537	136.3	0	6.64	1.77
Cv		10.4	13.7	56.9	93.2	20.2	53.3	20.3	64.5	130.2	2.6	1.9	1.2
1	10 Ne	7.54	9.43	0.00	0.00	16	2	24	4	2	-11.2	6.55	1.42
2	plied	10.14	12.98	0.00	0.00	18	4	30	8	6	-14.6	6.48	1.57
3		7.38	9.29	0.00	0.00	8	2	20	2	2	6.4	6.52	1.62
4		7.33	9.19	0.00	0.00	8	6	34	6	4	6.1	7.05	1.84
5		7.22	9.07	0.00	0.00	4	0	22	2	0	7.3	7.12	1.87
6		7.23	9.07	0.00	0.00	2	2	28	2	2	6.1	7.14	1.9
Mean		7.77	9.84	0.00	0.00	9.3	2.7	26.3	4	2.7	0	6.81	1.71
Cv		14.9	15.7	0.00	0.00	68.7	77.5	20	63.2	77.5	10.1	4.8	11.4

*Testing condition v= 400m/min, t=1.2 sec, temp. 22^{o}c 100 % cotton rotor spun yarn

Appendix 2A Selected fabric properties woven from 20 Ne weft count (sample 2)

Sample		TPM		Thickness mm		Bursting [pressure		Air permeability		GSM		Tear strength N		Tensile strength			
	Tests no.	Left	Light	Left	Right	Left	Light	Left	Right	Left	Right	Left	Right	Left		Right	
														Breaking force N	Breaking elo. %	Breaking force N	Breaking elo. %
	1	918	875	0.49	0.51	5.47	5.1	58.7	74.2	147.7	152.6	14.89	14.68	144	12.53	134	14.4
	2	850	847	0.51	0.52	5.52	5.66	59	62.5	149.8	152.2	14.48	14.84	149.5	12.39	137.4	12.63
	3	849	845	0.5	0.51	6.11	5.93	64	76	148	151.8	14.46	14.44	136	12.53	140	13.1
	4	910	895	0.5	0.51	6.25	5.79	67	79.7	147.9	151.4	14.62	14.36	133.3	12.28	137	13.6
	5	902	885	0.5	0.52	5.33	5.49	60.2	81.5	150.1	151	14.65	14.5	142	11.2	132.7	14.26
	6	935	892	0.5	0.5	5.73	5.32	63.4	69					127	12.53	138	12.8
S2	7	925	893	0.49	0.53	6.1	5.29	63.7	76					148	12.27	136	12.5
	8	932	834	0.5	0.52	5.4	5.35	63.3	75					134.6	12.4	131.3	14.11
	9	894	830	0.5	0.53	5.91	5.41	63.2	76								
	10	887	910	0.5	0.52	5.5	5.58	62	75.4								
	Mean	900	871	0.5	0.52	5.73	5.49	62.5	74.5	149	152	14.6	14.6	139	12.3	136	13.4
	SD	30.9	28.9	0.01	0.01	0.34	0.25	2.54	5.36	1.15	0.63	0.17	0.19	7.83	0.44	2.92	0.77

Appendix 3B Selected fabric properties woven from 20 Ne weft count (sample 5)

Sample		TPM		Thickness mm		Bursting [pressure		Air permeability		GSM		Tear strength N		Tensile strength			
		Left	Light	Left	Right	Left	Light	Left	Right	Left	Right	Left	Right	Left		Right	
	Tests no.													Breaking force N	Breaking elo. %	Breaking force N	Breaking elo. %
S5	1	842	867	0.48	0.49	5.76	5.07	67.7	71.3	145.8	146.9	15.3	14.99	137	12.13	130	13.5
	2	845	824	0.47	0.49	6.07	5.36	61.7	74.7	146.9	147	14.52	14.5	127	12.53	128	12.8
	3	843	815	0.48	0.49	5.24	5.39	76.9	77.8	145.7	148.6	14.06	13.99	133	12.18	129	13.87
	4	848	832	0.46	0.49	4.95	5.42	79.4	78.6	147	148.5	14.71	14.13	138	12.27	120	13.9
	5	845	825	0.47	0.5	5.18	5.34	78.3	78	148.1	146.5	14.69	14.37	130	12.29	130	13.6
	6	851	825	0.48	0.5	4.7	5.3	77.7	86.6					131	11.73	137	14.13
	7	865	852	0.49	0.5	5.44	5.2	74.5	86.3					137	11.47	128	12.7
	8	891	825	0.49	0.49	5.53	5.73	72.5	83.4					132	12.23	127	12.53
	9	828	813	0.47	0.49	5.58	5.39	73.8	76.4								
	10	847	842	0.48	0.51	5.4	5.36	72.1	79.1								
	Mean	850	832	0.48	0.5	5.39	5.36	73.5	79.2	147	148	14.7	14.4	133	12.1	129	13.4
	SD	16.9	17	0.01	0.01	0.39	0.17	5.42	4.91	0.99	0.98	0.45	0.39	3.91	0.34	4.66	0.62

Appendix 4C Selected fabric properties woven from 20 Ne weft count (sample 8)

Sample	Tests no.	TPM		Thickness mm		Bursting [pressure		Air permeability		GSM		Tear strength N		Tensile strength			
		Left	Light	Left	Right	Left	Light	Left	Right	Left	Right	Left	Right	Left		Right	
														Breaking force N	Breaking elo. %	Breaking force N	Breaking elo. %
	1	865	866	0.55	0.55	5.64	5.14	48.9	55.4	147.2	150.2	14.94	14.68	133.3	13.6	132	13.2
	2	839	855	0.54	0.57	6.11	5.29	40.3	52.7	146.4	147.6	14.82	14.51	135	13.6	130.7	13.46
	3	845	856	0.54	0.56	6.14	5.9	39.2	47.9	145.2	148.1	14.39	14.28	136	13.33	129	13.6
	4	856	858	0.53	0.53	5.65	5.23	46.4	58	146.2	147.9	14.06	14.46	127	12.4	134.5	13.43
	5	887	856	0.54	0.54	5.52	5.14	47.3	55.7	147	150.1	14.47	14.47	131	12.81	133	13.2
	6	835	816	0.53	0.53	5.77	5.37	44.7	57.3					136	12.94	129.4	12.94
S8	7	848	865	0.53	0.55	5.49	5.74	56	58.9					134.6	13.07	132	13
	8	815	812	0.53	0.56	5.75	5.5	54.7	58.1					128.3	12.8	133.1	13.3
	9	878	863	0.55	0.55	5.95	5.41	57.5	62.3								
	10	865	850	0.53	0.57	5.5	5.52	47.5	47.9								
	Mean	853	850	0.54	0.55	5.75	5.42	48.3	55.4	146	149	14.5	14.5	133	13.1	132	13.3
	SD	21.4	19.5	0.01	0.01	0.24	0.25	6.24	4.68	0.79	1.26	0.35	0.14	3.51	0.42	1.9	0.23

Appendix 5A Fabric properties woven from 16 Ne single weft yarn (sample 10)

Sample		TPM		Thickness mm		Bursting [pressure		Air permeability		GSM		Tear strength N		Tensile strength			
		Left	Light	Left	Right	Left	Light	Left	Right	Left	Right	Left	Right	Left		Right	
	Tests no.													Breaking force N	Breaking elo. %	Breaking force N	Breaking elo. %
S10	1	805	752	0.51	0.55	6.8	6.67	44.7	47.7	165.4	168.8	15.77	15.67	206	13.6	202.2	13.21
	2	805	808	0.52	0.55	7.21	6.94	47.7	51.9	164.4	167.7	15.81	15.74	211	13.2	189.1	13.72
	3	788	820	0.51	0.54	7.17	6.52	44.1	53.7	165.3	167.8	15.6	15.57	213.3	13.35	210	13.8
	4	773	803	0.52	0.55	7.44	6.88	50.9	47.2	165.1	168.6	15.69	15.76	198	13.2	204.2	13.35
	5	817	746	0.52	0.54	7.05	7.2	57.7	56.6	166.1	169.1	15.69	15.67	203	13.07	193	14
	6	805	815	0.51	0.54	6.6	6.29	43.2	51.7					211.2	13.21	208	13.6
	7	819	820	0.5	0.54	7.06	7.07	54	50.5					205	13.2	202	13.2
	8	803	795	0.52	0.54	6.79	7.19	52.3	52					200.9	12.94	191.1	13.86
	9	785	787	0.51	0.54	7.07	6.94	50	50.5								
	10	800	791	0.51	0.55	7.15	7.16	48.9	49.8								
	Mean	800	794	0.51	0.54	7.03	6.89	49.4	51.2	165	168	15.7	15.7	206	13.2	200	13.6
	SD	14.3	26.3	0.01	0.01	0.24	0.31	4.63	2.75	0.61	0.62	0.08	0.07	5.43	0.19	7.9	0.31

Appendix 6B Fabric properties woven from 16 Ne single weft yarn (sample 11)

Sample		TPM		Thickness mm		Bursting [pressure		Air permeability		GSM		Tear strength N		Tensile strength			
		Left	Light	Left	Right	Left	Light	Left	Right	Left	Right	Left	Right	Left		Right	
	Tests no.													Breaking force N	Breaking elo. %	Breaking force N	Breaking elo. %
S11	1	794.4	821	0.53	0.56	6.98	7.14	51.8	52.3	161.6	166.2	15.86	15.83	201	13.6	194	12.54
	2	806.4	789	0.53	0.55	7.03	6.94	47.7	54.6	164.6	165.2	15.72	15.79	181	12.8	187	13.2
	3	882.4	748	0.54	0.56	7.18	7.03	48.5	50.1	163.8	164.2	16.23	15.76	212.3	11.73	198	12.8
	4	785.4	760	0.52	0.55	6.91	6.57	49.5	55.1	162.8	166.8	15.68	15.66	210	11.6	195	12
	5	798.4	847	0.53	0.54	6.9	6.32	52.1	53.5	164.5	165.7	15.92	15.75	197	13.33	189.1	13.35
	6	750.4	785	0.51	0.56	6.81	7.14	53	51.8					210.2	11.61	196	12.67
	7	795.4	780	0.52	0.54	6.9	6.56	46.8	49.7					199	13.46	191	12.4
	8	813.4	736	0.52	0.53	6.72	7.16	49	48.5					192	13.2	187.2	13.21
	9	768.4	798	0.53	0.53	7.03	6.79	48.5	52.3								
	10	770.4	751	0.54	0.53	6.82	6.43	47.1	53.5								
	Mean	763	754	0.5	0.52	6.68	6.55	47.3	49.4	151	153	14.5	14.4	192	12.3	186	12.5
	SD	35.7	34.6	0.01	0.01	0.13	0.32	2.18	2.16	1.26	0.99	0.22	0.06	10.6	0.88	4.19	0.46

Appendix 7C Fabric properties woven from 16 Ne single weft yarn (sample 12)

		TPM		Thickness mm		Bursting [pressure		Air permeability		GSM		Tear strength N		Tensile strength			
														Left		Right	
Sample	Tests no.	Left	Light	Left	Right	Left	Light	Left	Right	Left	Right	Left	Right	Breaking force N	Breaking elo. %	Breaking force N	Breaking elo. %
S12	1	772.2	799	0.53	0.54	7.06	6.3	43.5	54.6	164.4	167	15.4	15.82	202	12.5	202	11.6
	2	784.2	774	0.52	0.55	7.02	5.7	46.7	58.4	163	166.9	15.44	16.61	194	12	212	12.5
	3	786.2	774	0.52	0.56	7.13	6.11	51.7	58.3	164.1	167.4	16.13	15.38	216.4	13.6	214.3	12.64
	4	749.3	816	0.52	0.55	6.74	6.38	42.5	53.6	163.8	166.8	16.18	15.4	214	12.63	209	12.4
	5	771.2	739	0.52	0.54	6.77	6.71	45.1	57.9	165.1	167.2	15.9	15.53	200	11.09	188.1	12.28
	6	826.7	772	0.54	0.54	7.02	6.79	51.2	50.5					214.2	13.6	212.2	12.51
	7	777.2	746	0.51	0.57	7.21	6.7	46.7	55.1					202	10.98	190	12.4
	8	839.3	793	0.51	0.57	5.99	6.87	44.5	56					198	11.2	186.2	12.15
	9	788.3	777	0.53	0.55	7.05	6.47	45.7	54.2								
	10	839.3	816	0.52	0.55	6.88	6.44	46.1	52.5								
	Mean	750	740	0.49	0.51	6.55	6.34	45.7	49.7	146	149	14.1	14	189	11.8	184	12
	SD	31	26	0.01	0.01	0.35	0.35	3	2.6	0.77	0.24	0.37	0.51	8.52	1.07	11.9	0.32

Appendix 8A Selected fabric properties woven from 10 Ne single weft count (sample 13)

Sample		TPM		Thickness mm		Bursting [pressure		Air permeability		GSM		Tear strength N		Tensile strength			
		Left	Light	Left	Right	Left	Light	Left	Right	Left	Right	Left	Right	Left		Right	
	Tests no.													Breaking force N	Breaking elo. %	Breaking force N	Breaking elo. %
	1	656	658	0.56	0.59	8.8	9.37	46.1	55.3	183	186.3	28.08	28	263.6	11.37	240.6	12.28
	2	651	658	0.57	0.6	9.05	8.8	44.3	58.6	187.3	189.1	28.22	28.11	269	11.6	260	13.2
	3	680	679	0.57	0.58	9.56	8.97	45.9	56.3	185.1	187.6	28.27	28.12	271.3	12.41	268.9	12.13
	4	643	670	0.58	0.57	9.05	8.43	52.4	59.4	186.4	188.2	28.13	27.92	266.3	11.48	243	12.4
	5	628	628	0.59	0.6	8.85	9.29	54.7	58	183.9	186.9	28.16	28.01	271	12	266.3	12.01
	6	646	643	0.58	0.58	9.26	8.25	47.4	58.1					274	12.54	284	12
S13	7	669	591	0.57	0.6	8.79	8.75	49.5	57					261	12	238.1	12.15
	8	626	618	0.56	0.59	9.3	8.41	48.8	55.1					271	12.4	266	12
	9	636	639	0.58	0.59	9.56	8.36	46.5	58.5								
	10	648.4	643	0.57	0.59	8.86	8.53	47.1	58.7								
	Mean	648	643	0.57	0.59	9.11	8.72	48.3	57.5	185	188	28.2	28	268	12	258	12.3
	SD	17	25.9	0.01	0.01	0.3	0.39	3.19	1.5	1.76	1.09	0.07	0.08	4.4	0.45	16.3	0.4

Appendix 9B Selected fabric properties woven from 10 Ne single weft count (sample 14)

Sample	Tests no.	TPM Left	TPM Light	Thickness mm Left	Thickness mm Right	Bursting [pressure Left	Bursting [pressure Light	Air permeability Left	Air permeability Right	GSM Left	GSM Right	Tear strength N Left	Tear strength N Right	Tensile strength Left Breaking force N	Tensile strength Left Breaking elo. %	Tensile strength Right Breaking force N	Tensile strength Right Breaking elo. %
	1	651	643	0.57	0.61	8.67	7.26	54.4	61	185.8	189	26.43	26.94	246.5	11.09	251	12.4
	2	638	626	0.57	0.62	8.67	8.01	58.7	60.3	183.7	187.9	26.59	26.66	257	11.2	254	13.2
	3	636	634	0.56	0.6	8.03	8.43	55	56.9	184.6	188.2	27.04	26.73	265.9	12.94	257	12.4
	4	624.1	633	0.57	0.61	8.54	8.92	55.5	60.2	185.3	188.1	26.48	27.53	249	11.2	251.5	13.07
	5	640	630	0.56	0.59	8.26	8.44	53.8	58.5	184.9	186.5	26.65	27.07	263.3	12.81	255.3	11.21
	6	637.8	633	0.6	0.64	8.38	7.95	54.5	59.7					277	12	257.8	11.32
S14	7	644.4	633	0.59	0.59	8.66	8.54	58	61.5					244	10.98	248.9	12.94
	8	638	636	0.59	0.63	8.45	8.52	55.8	60.1					263	12.8	255	11.2
	9	642.7	634	0.58	0.6	8.66	8.02	53.2	60								
	10	666.3	646	0.58	0.63	8.24	8.24	55.7	58.5								
	Mean	642	635	0.58	0.61	8.46	8.23	55.5	59.7	185	188	26.6	27	258	11.9	254	12.2
	SD	11	5.85	0.01	0.02	0.22	0.45	1.74	1.35	0.79	0.91	0.24	0.35	11.2	0.86	3.1	0.86

Appendix 10C Selected fabric properties woven from 10/1 Ne weft count (sample 15)

Sample		TPM		Thickness mm		Bursting [pressure		Air permeability		GSM		Tear strength N		Tensile strength			
		Left	Light	Left	Right	Left	Light	Left	Right	Left	Right	Left	Right	Left		Right	
	Tests no.													Breaking force N	Breaking elo. %	Breaking force N	Breaking elo. %
	1	651	636	0.58	0.6	8.3	7.64	43	58.6	183.6	185	27.29	26.43	261	11.2	252	12.8
	2	628	631	0.58	0.6	8.42	8.68	51.9	50.1	185.6	187.5	26.58	27.12	247.9	10.98	254.4	12.28
	3	641	638	0.58	0.6	8.65	7.26	49.6	56.4	185.5	187.2	27.33	26.85	278	11.2	259	12.4
	4	638	626	0.57	0.59	8.48	8.97	51	63.2	184.8	185.9	27.3	26.68	261.3	11.21	252.3	12.81
	5	629	620	0.57	0.6	8.2	8.61	50.4	65.6	183.9	186.5	27.31	26.65	250.5	11.09	257	12.4
	6	634	642	0.55	0.58	8.19	7.79	53	65.4					263.9	11.32	262	12.4
S15	7	636.9	632	0.57	0.57	9.23	7.93	61.6	62.4					253	11.2	251.9	12.15
	8	629	627	0.56	0.58	8.66	8.5	55.2	68.5					250	10.4	254.8	12.94
	9	635.9	620	0.59	0.59	7.99	7.72	54.9	62.2								
	10	630.4	626	0.57	0.58	9.12	7.77	55	61.5								
	Mean	635	630	0.57	0.59	8.52	8.09	52.6	61.4	185	186	27.2	26.7	258	11.1	255	12.5
	SD	7.06	7.38	0.01	0.01	0.4	0.56	4.81	5.26	0.91	1.01	0.33	0.26	10	0.29	3.67	0.29

Appendix 11A Fabric properties woven from 10/2 Ne weft yarn (sample 16)

Sample		TPM		Thickness mm		Bursting [pressure		Air permeability		GSM		Tear strength N		Tensile strength			
		Left	Light	Left	Right	Left	Light	Left	Right	Left	Right	Left	Right	Left		Right	
	Tests no.													Breaking force N	Breaking elo. %	Breaking force N	Breaking elo. %
S16	1	580	576	0.59	0.63	9.78	9.39	44.2	45.2	201.1	204.5	31.66	31.71	302	12	278.2	12.28
	2	574	579	0.6	0.64	9.84	9.49	49.2	53.4	198.4	205.2	29.96	30.37	304	11.6	269	13.6
	3	588	568	0.6	0.63	9.49	9.38	42.7	59.2	199.7	204	30.84	30.71	307.4	11.73	308	11.6
	4	569	569	0.6	0.62	9.53	9.83	51.4	59.2	200.9	204.7	31.47	30.75	304	12.8	281	12.4
	5	596	583	0.58	0.61	9.54	9.59	41	61.1	198.3	205.7	31.33	31.05	296	11.76	272	13.75
	6	565	575	0.6	0.61	9.46	9.68	53.2	54.2					304.3	11.61	289	12
	7	603	582	0.61	0.61	9.81	10	42.1	61.3					299	11.88	275.4	12.15
	8	574	598	0.62	0.61	9.05	9.07	52.4	61.4					279	12.8	269.3	13.61
	9	589	575	0.6	0.6	10.0	9.73	54.5	63.2								
	10	590	579	0.61	0.62	9.91	9.1	54.5	61								
	Mean	582.8	578	0.6	0.62	9.64	9.53	48.5	57.9	199.6	204.8	31.05	30.91	299.4	12.02	280.2	12.67
	SD	583	578	0.6	0.62	9.64	9.53	48.5	57.9	200	205	31.1	30.9	299	12	280	12.7

Appendix 12B Fabric properties woven from 10/2 Ne weft yarn (sample 17)

Sample		TPM		Thickness mm		Bursting [pressure		Air permeability		GSM		Tear strength N		Tensile strength			
		Left	Light	Left	Right	Left	Light	Left	Right	Left	Right	Left	Right	Left		Right	
	Tests no.													Breaking force N	Breaking elo. %	Breaking force N	Breaking elo. %
	1	569	559	0.57	0.61	9.81	8.85	41.9	49.9	200	199	29.5	28.9	277	11.5	256	12.6
	2	575	586	0.62	0.62	9.71	9.41	52	49.3	202.8	200.9	28.7	28.12	282	11.6	268	11.6
	3	546	567	0.62	0.62	9.9	9.11	47.8	48.1	199.5	197.1	29.49	29.28	294	11.2	250	12.4
	4	575	567	0.61	0.61	10.1	9.28	58.9	46.2	201.7	197.9	29.3	28.8	284	12	252.8	12.54
	5	570	581	0.61	0.62	9.9	9.36	57.3	49.2	200	198.5	29.44	28.86	276.2	11.48	255.4	12.67
S17	6	582	580	0.57	0.63	9.65	9.24	42.4	52.3					285.1	11.73	250.3	12.41
	7	578	573	0.59	0.62	9.53	8.71	49.9	55.7					279	11.6	285	12.8
	8	590	579	0.58	0.63	9.75	8.81	47.7	51.7					273.4	11.37	258	12.8
	9	575	565	0.58	0.62	9.92	8.75	42.4	50.5								
	10	573	571	0.6	0.62	9.88	8.79	46.1	55.5								
	Mean	573	573	0.6	0.62	9.81	9.01	48.6	50.8	201	199	29.3	28.8	281	11.6	259	12.5
	SD	11.4	8.56	0.02	0.01	0.16	0.3	6	3.04	1.35	1.42	0.34	0.42	6.52	0.24	11.8	0.39