NATIONAL INSTITUTE OF TEXTILE NGINEERING AND RESEARCH

A Qualitative Study on Comfort Performance of Denim

A Thesis By

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Abstract

In this study, denim fabrics manufactured using standard processes were selected as reference fabric and subjected to mechanical and chemical finishing treatment. The effects of the two finishing treatments on the performance properties of the denim fabric was investigated. The test samples were the reference fabric, denim jeans with three different fiber contents. The performance tests were for abrasion resistance, dimension stability, tearing strength and fastness. Color analysis of the samples were also made and evaluated. Evaluating the performance, fastness and color properties of the denim jeans samples did not reveal any significantly negative outcomes.

Declaration

We hereby declare that this submission is our own work and that, to best of our knowledge and belief, contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of the university or other institute of higher degree, except here due acknowledgement has been made in the text.

Acknowledgement

The following thesis, while an individual work, benefited from the insights and direction of several people. First, my Thesis Head Supervisor, Mohammad Mohsin Ul Hoque has inspired me and my team to get to a goal. Mohammad Mohsin Ul Hoque has provided timely and instructive comments and evaluation at every stage of the process. Thank you for your support and believing in me and my team. Next, I wish to thank the Co-Supervisor, Suza Ahmed for supporting his best. Each individual provided insights that guided and challenged my thinking, substantially improving the finished product. In addition to the technical and instrumental assistance from my thesis committee, I have received equally important assistance from family and friends. Thank you all for believing in my vision. The help from everyone has allowed me to achieve my goals.

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CHAPTER ONE

INTRODUCTION

Modern consumers are interested in clothing as it has not only aesthetic appearance but also provides great feeling. Clothing is in direct contact with the human body and interacts with the skin during use. The interaction between clothing and the human body stimulates sensorial properties which lead to perception of either comfort or discomfort. Comfort and convenience are very important for the selection of garments and style of construction is the thing customers try to find which means high quality of garments to the customer. The most influential role in the development of textile materials belongs to customers and increasing significance of consumer's perception of comfort forces apparel producers to have continuous innovations and improvement of their products. At this point the moisture management properties of clothing have much importance as the subject of clothing comfort. Denim apparel has an important role in the fashion industry. Denim jeans are preferred by most people all over the world and thanks to its durability and slightly worn look for fashionable appearance. The value of denim products are related to comfort and physical properties of the fabrics as well as the various washing effects. In the changing climate conditions and the living conditions people require innovative products. As a result, people prefer wearing more comfortable denim garments in their life. Denim products, keeping their critical position as a major ready-made product in the whole range, started to be produced with higher comfort and physical properties. The denim garments which have improved cotton denim fabrics consist of higher moisture management. As an important marketing strategy the denim brands highlight their functional values like comfort properties that enable consumers to feel better while using their products.

1.1 Purpose of Thesis

The aim of this study is to have its position in the literature by investigating comfort properties of various denim fabrics and keeping an eye on their physical performance. Therefore, it is significant to make a research on the factors influencing comfort properties of cotton and cotton blends based denim fabrics. An experimental study was conducted to reach this objective and it has been aimed to have informative and explanatory results on the subject.

1.2 Literature Review

It is seen that there are different methods to evaluate the comfort like there are various explanation of comfort. These methods can be categorized sensorial comments of people and measurable values of comfort evaluations. Some researchers like Parser support that comfort is a property that can be related to human sense and people should be used to decide and define the comfort properties. On the other hand, people who are a part of these scientific research may explain their sense wrongly. Also there may be any possible factor that may affect feeling participants. Besides these disadvantages, this method is expensive and requires a long time. The evaluation method depending on measurement of moisture, water vapor, air and thermal permeability is more useful and confident. Since it requires the inspection of fabric properties in the laboratory conditions and gives measurable values, its results are convenient to control. Even though there are evaluation methods mentioned above, comfort is not a property that can be defined with only laboratory test results so it is ideal to evaluate mostly the comfort properties of fabrics as a support to comfort researching.

CHAPTER TWO

DENIM FABRIC WEAVING TECHNOLOGY

The warp yarn (length-wise) used in denim fabrics is uniquely prepared for denim manufacturing compared to conventional woven fabrics. The yarn goes through numerous processing steps before it is placed on the weaving machine. Unlike the warp yarn, most filling yarn (width-wise) is put onto yarn packages and delivered directly to the weaving machine where it is inserted into the fabric without any further preparation in the same manner as conventional woven fabrics. The following flow chart reveals the necessary steps in the manufacture of denim fabrics, beginning with the production of the warp yarns used. The chart forms an outline for most of the topics that will be covered in denim section of this study.

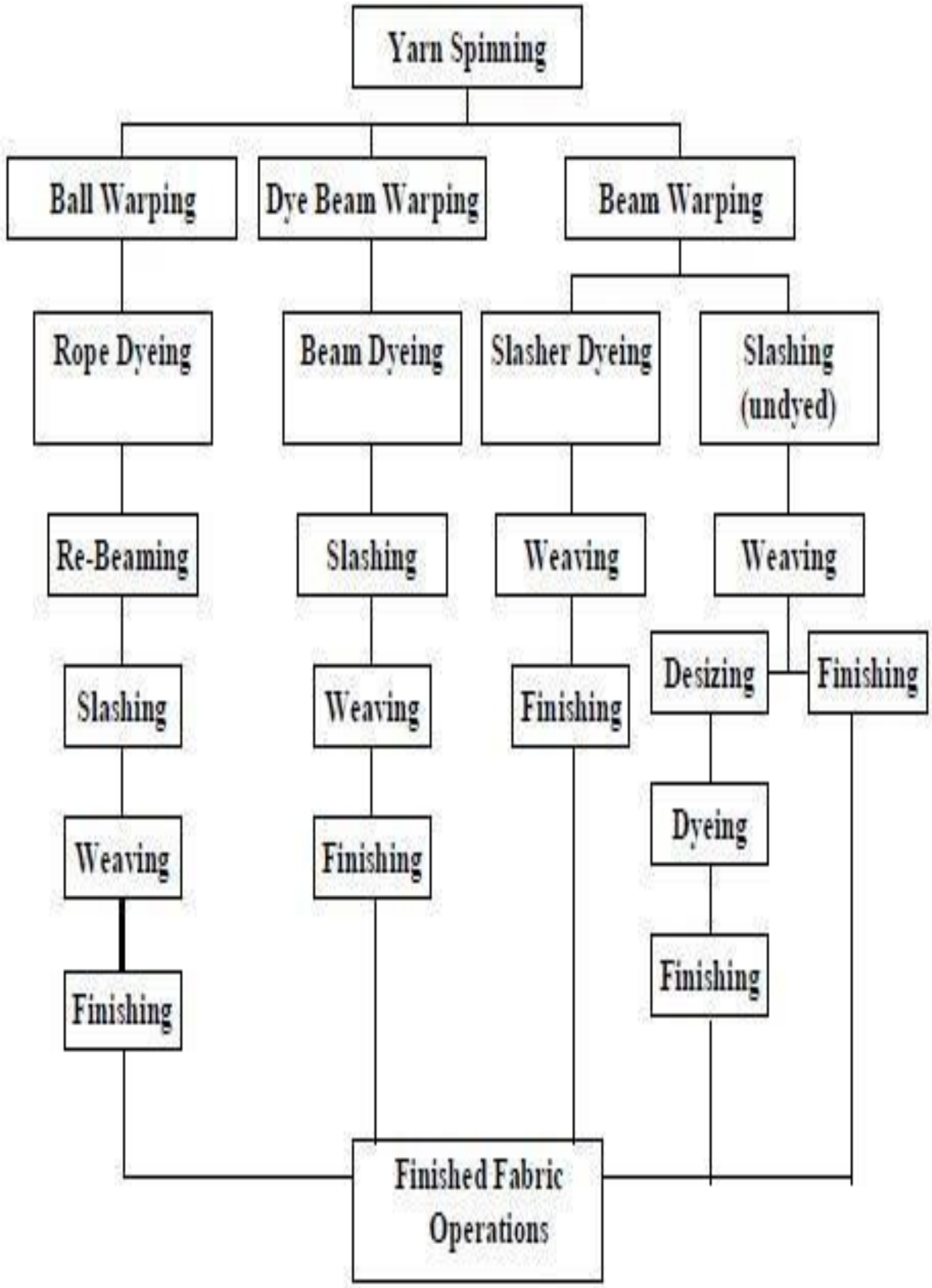

Figure 1: Flow chart of Denim

2.1 Warp Preparation

The warping process is the most significant step of denim fabric production. Warping is the process of transferring multiple yarns from individual yarn packages onto a single package assembly. Individual strands of warp yarn (the lengthwise yarn in a fabric) are removed from yarn packages prior to being gathered into a rope form suitable for dyeing in the warping process. Individual strands are gathered into rope form and wound onto a log, thus forming a ball warp.

Two rope-dye ranges are able to produce pure indigo, sulfur top, sulfur bottom, and colored denim yarn. The yarn goes through scour/sulfur dye, wash boxes, indigo dye vats, over a skying device (to allow oxidation to occur), through additional wash boxes, over drying cans and then is coiled into tubs which are transferred to the long chain beaming process.

In the long chain beaming process the dyed yarn is separated into individual strands, these strands are paralleled and finally these strands are wound onto a large section beam in preparation for slashing. The slashing process takes section beams, coats the yarn with a starch/wax solution, and winds the yarn onto a loom beam.

Normally, yarns are collected in a sheet form where the yarns lie parallel to each other onto a beam, which is a cylindrical barrel with side flanges. This is beam warping and it is shown in Figure. If the yarns are brought together and condensed into a rope before being wound onto a relatively short cylindrical barrel (sometimes called the shell or log) that has no end flanges this is ball warping and it is shown again in Figure. In both cases, the supply yarn packages are placed on spindles, which are located in a framework called a creel.

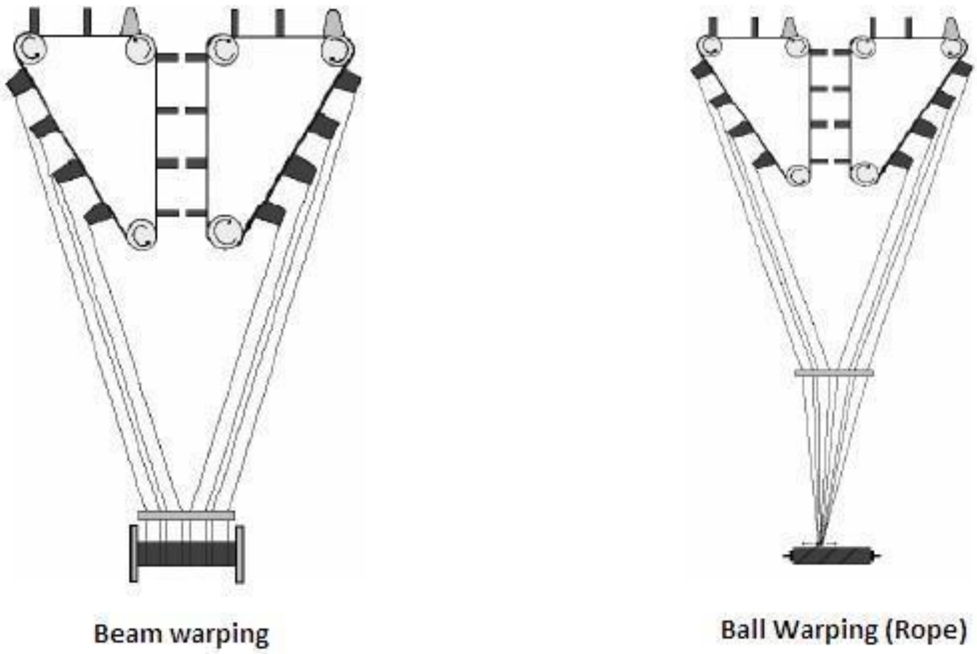

Figure 2: Warping systems

2.1.1 Beam warping

In the beam warping process the yarns are in an open sheet form and they are wound parallel to each other onto a slightly wider flanged beam. These yarns won't go through the rope indigo dye range, but are left "natural" and will end up either slasher dyed or in an un-dyed fabric, which can later be piece dyed, or left natural. Another option would be to beam dye the yarns using a dye other than indigo.

2.1.2 Ball warping

In ball warping (Figure), 250 to 400 yarn ends are pulled from the creel. The yarns then pass through reed (a comb-like device), which keeps each warp yarn separate and parallel to its neighboring ends. At intervals of every 1000 or 2000 meters, a lease string is placed across the sheet of warp yarns. This aids yarn separation for the re-beaming operation, which will occur later. The yarns then go through a tunnel-shaped device (sometimes called a trumpet or condenser), which collapses and condenses the sheet of yarn into rope form. The condenser located at the base of the warper head traverses back and forth, guiding the newly formed rope of yarn onto a log. The rope must be wound at a constant tension to keep the yarns from tangling.

Figure 3: Ball warping

2.2 Rope dying

Most of denim fabrics are yarn-dyed fabrics with the warp yarns dyed with indigo dye and the filling yarns left undyed. There are a number of modifications or alternatives in the dyeing process that are routinely used to change the overall look or performance of the fabric. The consistencies of the indigo dyeing process and its modifications have become crucially important in determining the quality and performance of indigo denim products with the advent of denim garment washing techniques.

The properties of the indigo dye account for the wide variety of color designs especially for denim materials. Indigo has a very low affinity for the cotton fiber and this makes indigo unique for textile materials. Because of the low substantively of the indigo, the ball warp dyeing process ring dyes cotton. Unlike almost all other commercially successful dyestuffs, the indigo dye concentrates in the outer layers of the cotton yarn and fiber. This produces an intense ring of color around a white core in the cotton yarn and the cotton fiber thus the name ring dyeing. Regarding most of other dyes, if the ring-dyeing effect occurs, it would be considered a dyeing defect.

Indigo dye in its normal form is insoluble in water, and it will not dye cotton fiber. In order to dye cotton, the indigo must be converted to a water-soluble “leuco” form and then applied to the cotton. This process is known as chemical reduction. Reducing agents such as sodium hydrosulfite with sodium hydroxide chemically convert the indigo dye to leuco form. The leuco form of dye is very pale greenish yellow color unlike the blue insoluble form. The leuco form of indigo is readily absorbed by the outer layers of the cotton yarn. Once in the fiber/yarn, the indigo is made insoluble by oxidizing the yarn by passing the yarn through the air (skying) The oxygen in air converts the dye back to its original blue and insoluble form. Thus the dye becomes trapped inside the outer layers of the cotton yarn. This results only light blue dyed yarn because only a small percent of dye is being deposited outer surface of yarn. In order to obtain deep blue indigo dyed yarns, the dye is layered by using multiple passes of the rope of yarn into the soluble dye and then exposing it to the air for oxidation. This multiple passing (normally 3-12 times) of yarn into dye is called dips. The number of dips is limited to the number of dye boxes on the dye range. If the concentration of indigo dye in the dye boxes is doubled, this will result in slightly darker denim. This acts as a multiplier when labeling the denim. For instance, a triple concentration of dye in nine dye boxes makes it an 27-dip denim. For darker shades a sulfur black or blue dye can be applied before indigo dyeing. This application is known as a sulfur bottom an if the sulfur dye is applied after the yarn has been indigo dyed, it is known as a sulfur top.

Figure: 4 Indigo dye range

In rope dyeing, typically 12-36 individual ball ropes of yarn are fed side-by-side simultaneously into the rope or chain-dyeing range for application of the indigo dyeing. The ropes are kept separate from each other throughout the various parts of the dye range. For example, if the total number of ends on the loom beam is 3456, and each ball would have 288 ends, then the dye set would have a total of 12 ball warps.

The ropes are first fed into one or more scouring baths, which consist of wetting agents detergents and caustic. By feeding the ropes into these baths naturally occurring impurities found on the cotton fiber such as dirt, minerals, ash etc are removed. It is important to remove these materials to guarantee uniform wetting and uniform dyeing. The ropes are subsequently fed into one or more water rinsing baths. After either rinsing following indigo dyeing or rinsing following sulfur topping, the yarn ropes pass through squeeze rolls to mechanically extract water. The yarns are then dried and coiled into large tubs. The typical type of drying apparatus is a multiple stack of Teflon® covered drying cans filled with steam under pressure. Maintaining a consistent pressure of steam within the cylinder can accurately control the temperature of the surface of each cylinder. Care must be taken not to attempt to dry the rope of yarn too quickly, which causes the dye to migrate to the surface of the rope. Additionally, over-drying of the yarns will weaken them adversely affecting re-beaming, slashing, and weaving.

After drying, the color of the yarn is checked either visually or with instruments, which are electronically linked to the controls of the indigo dye baths. This type of control systems can automatically adjust the dynamics of the process to obtain the most consistent color of yarn contained within a single dye lot.

2.2.1 Re-beaming

It is then necessary to change the yarn alignment from a rope form to a sheet form after the rope dying to enter the next process, which is slashing or sizing. Beaming or re-beaming (Figure) involves pulling the ropes of yarn out of storage tubs and moving them upward to a guiding device (satellite). This upward travel allows the ropes to untangle before nearing the beamer head. When the ropes come down from the guiding device, they go through tensioning rollers to help further the separation of the ropes before going through a comb at the warper, which separates individual yarn ends parallel to one another. From the comb, the warp yarns are guided onto a flanged section beam. Multiple warp section beams are made forming a set of beams (each set normally contains 8 to 14 section beams), which will be no crossed, lost, or tangled yarn supply for the slashing operation. The total number of yarns on all the beams in the set should meet specifications for the given fabric to be woven.

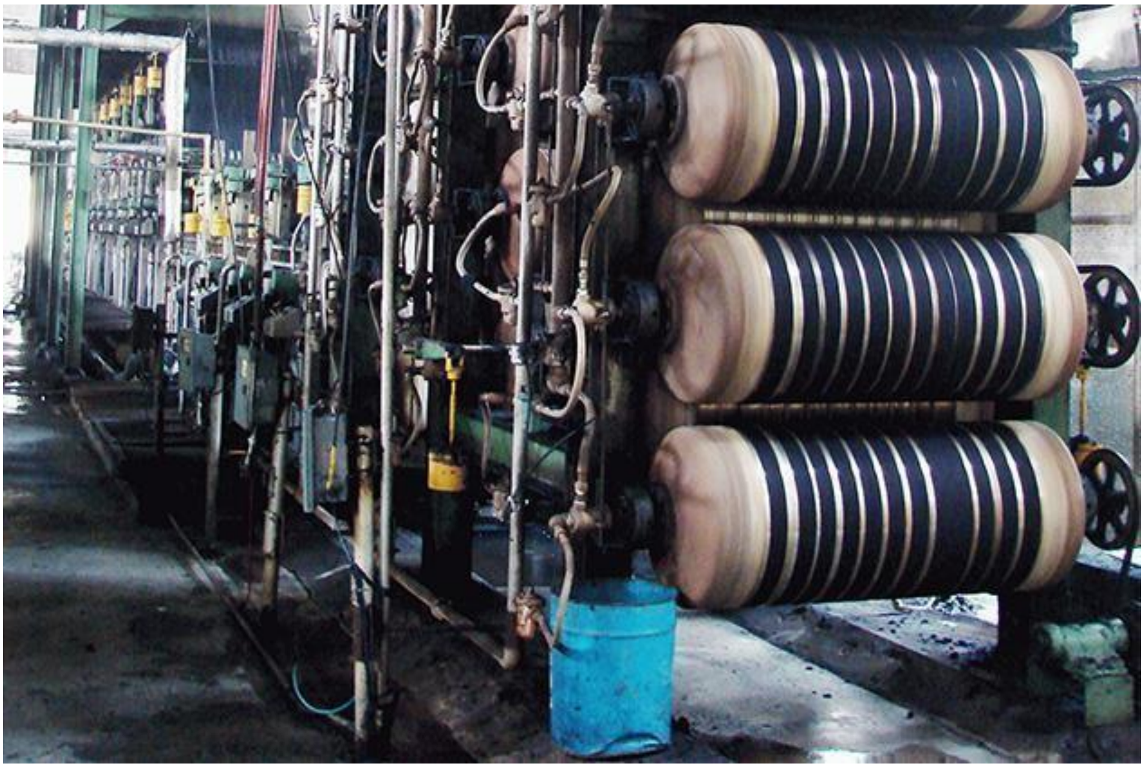

Figure 5: Rope dyed yarn being re-beamed

The beams need to be in good condition with smooth inside flanges, to be non-eccentric barrels, and to contain no high or low selvages. It is critical that all the yarns wound onto a given section beam be under equal tension. This is maintained by using guides, tension devices, and stop motion controls.

2.3 Sizing (Slashing)

The purpose of sizing is to improve the strength of yarn by chemically binding the fibers with each other and also improve upon its friction resistance capacity by chemically coating the surface of yarn/fibers. Further, the multiplication of sheets by drawing yarns together from many warp beams and again making one sheet is also performed on sizing machine because number of threads in warps beam sheet is very less against number of threads required in whole width of fabric. On sizing, normally, 8-12 % size material on warp thread is and frictional resistance characteristic of warp yarn is essential because during weaving, yarn has to undergo severe strain and stress as well as frictional operations.

An another significant purpose for sizing warp yarns is to encapsulate the yarn with a protective coating which reduces yarn abrasion that takes place during the weaving operation and reduces yarn hairiness preventing adjacent yarns from entangling with one another at the weaving machine. Also, this protective coating keeps the indigo dye from rubbing off during the weaving process. In order to size indigo warps many times the type and quantity of size used are determined by the subsequent fabric and garment finishing operations that follow.

At the back end of the slasher range, the section beams from the beaming process are creeling (Figure). The yarns from each beam will be pulled over and combined with the yarns from the other beams to form multiple sheets of yarns, the number of sheets corresponding to the number of size boxes (size applicators) on the machine.

Figure 6: Slasher creel

As each yarn sheet enters a size box (Figure), the yarns are guided downward and submerged in the liquid size. The yarn sheet leaves the size box via a set of squeeze rolls that helps control the wet pick-up. After this, the yarns are pulled over steam- heated, Teflon® coated cylinders where drying takes place. At this point, the yarns are monitored to maintain from 6-8% moisture typically. Most warp yarns for weaving denim have 7-14% size add-on (actual dry solids weight added to the original weight of the yarn). This depends on what type of spinning system is used. Too much size causes yarn chaffing and excessive shedding of size particles at the weaving machine, and too little size causes excessive yarn abrasion resulting in dye streaks, clinging, broken and entangled ends. In many denim styles, the size is left on the fabric and acts as a stiffening agent for cut-and-sew operations.

This accounts for the stiffness of certain jeans, which are purchased by the consumer.

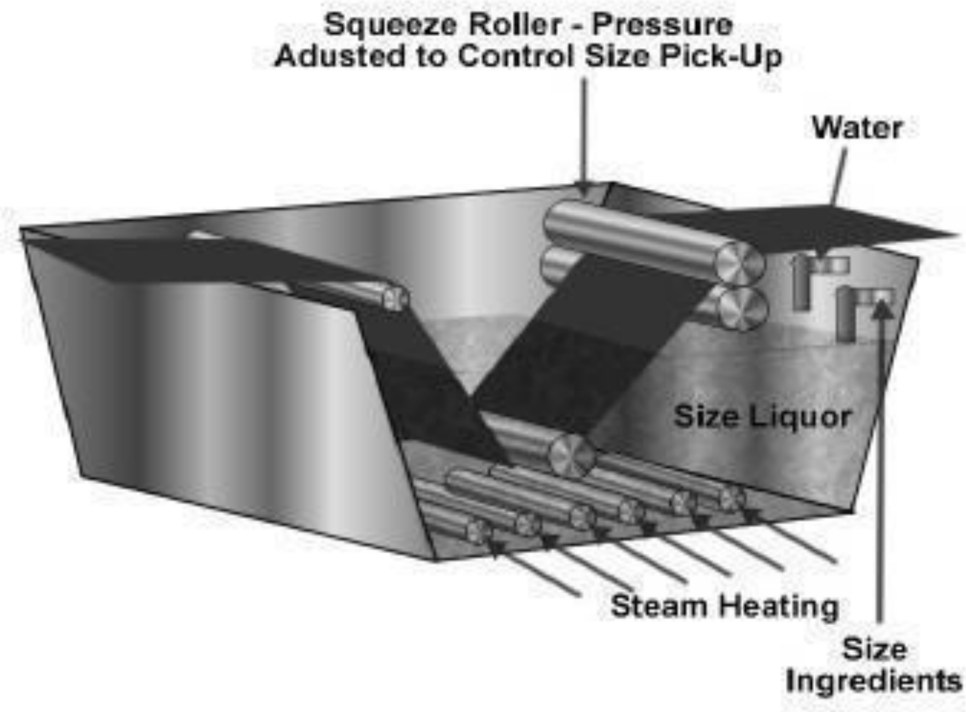

Figure 7: Size box

All the yarns go through a set of stainless steel split rods, which help to separate them into individual sheets, equivalent to the number of section beams in the creel. After passing through the split rods, the warp yarns are collected into one single sheet and passed through a comb, which helps to separate individual yarns. This expansion type of comb is adjusted to the desired loom beam width. At this point, all the warp yarns are wound onto the loom beam (Figure). Normally, several loom beams will be produced from a single set of section beams in the slasher creel.

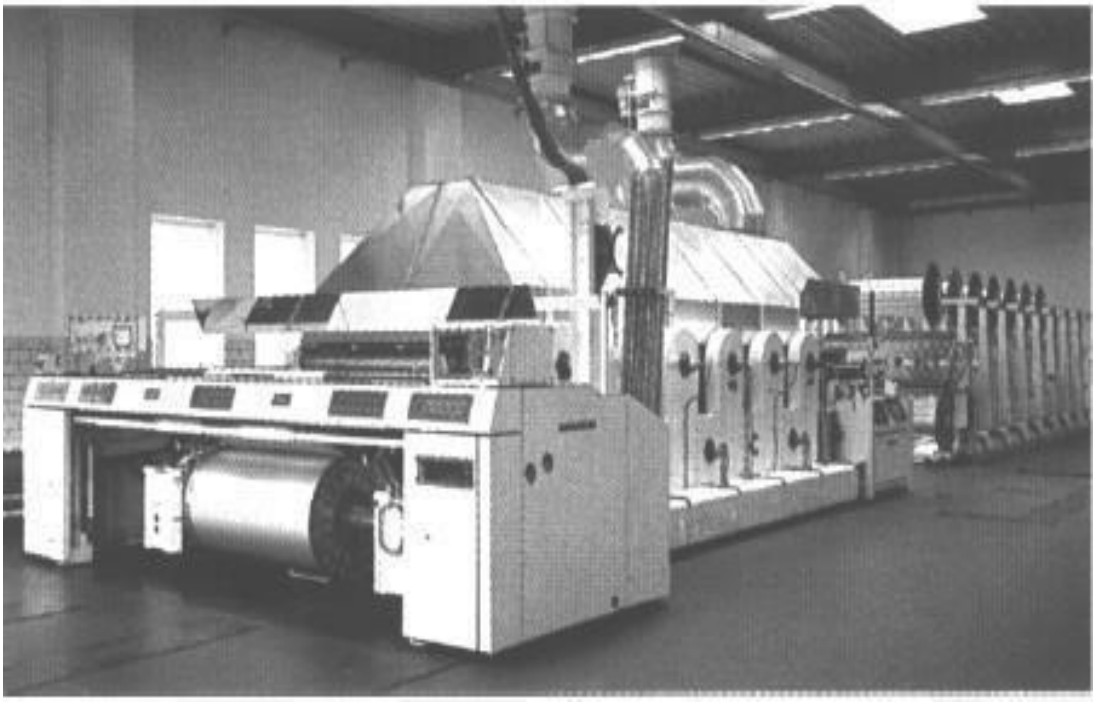

Figure 8: Slasher loom

2.4 Drawing in and tying in of warp yarns

It is necessary to draw (thread or insert) the warp yarns through stop motion devices (drop wires), weave design control devices (harnesses and heddles), and filling "beat-up" devices (reed) as in Figure when a new denim style is put on a weaving machine. Each end of yarn must have its own individual element and this procedure can be done manually or automatically on drawing-in machines. If same style is being produced and if the current loom beam is nearly empty of yarn, an identical full beam of yarn can be tied to the yarns of the old beam. This is done by a tying-in machine, which automatically selects an end of yarn from the old beam and ties it to the appropriate end on the new beam. The knots are then pulled through the weaving machine before fabric is put into production. It is well documented that many loom stops are caused by improper tying-in of the warp yarns.

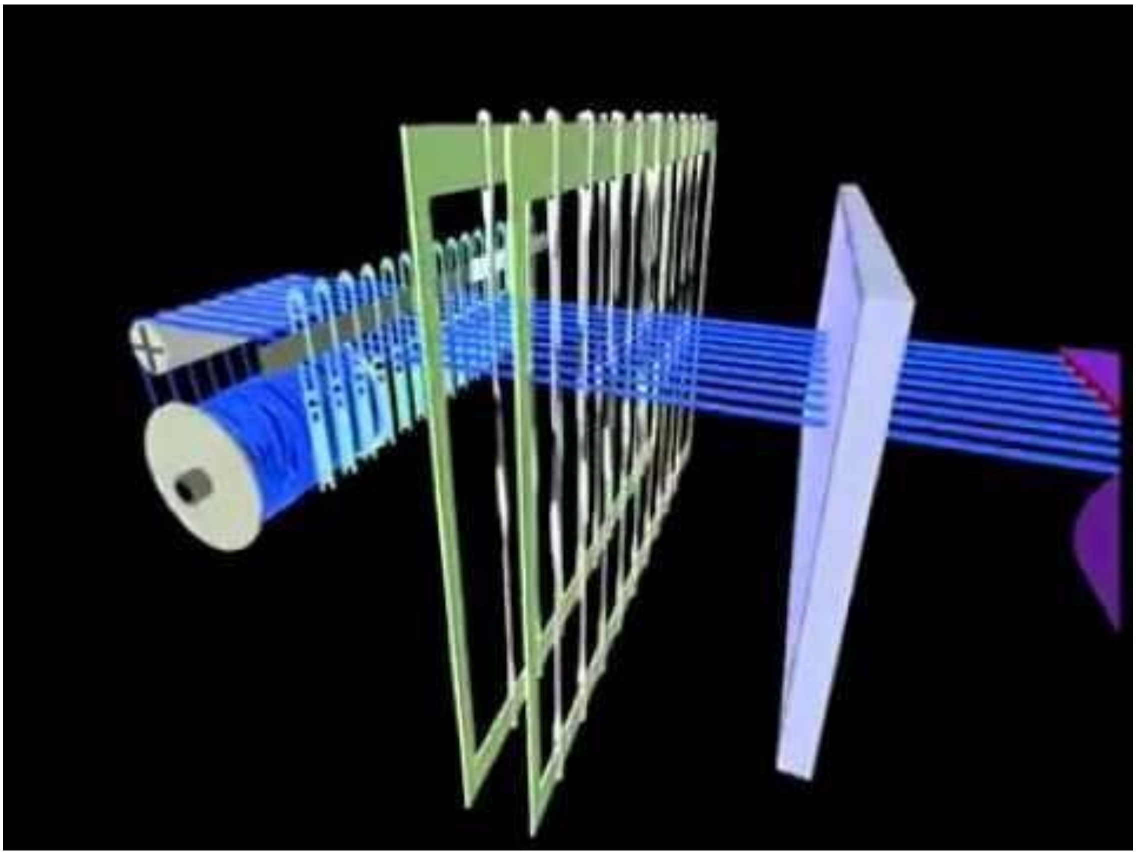

Figure 9: Warp drawing-in

2.5 Weaving Process

2.5.1 Weaving

Weaving is interlacing two sets of yarn and making fabric. One set is called warp thread which is in sheet form, the other one is called weft thread which is inserted between two layers of warp sheet by means of a suitable carrier i.e. Shuttle, Projectile, Rapier, Air current, Water current, etc. Depending upon the type of the weaving machines there are different types of technologies available for weaving machines are shown below:

- Conventional Shuttle Weaving System by Ordinary Looms or Automatic Looms.
- Shuttle less Weaving System by Air jet /Waterjet/Rapier/Projectile

Shuttle loom is a conventional technology with much less production on account of slow speed and excessive wear and tear of machinery. Denim is woven through shuttle less weaving system by using 96 ZAX-e Type Tsodakoma Corporation's Airjet looms or rapier looms or projectile looms.

Airjet looms adopt the latest development in weaving technology where weft insertion is done with the help of compressed air. A very high weft insertion rate up to 1800 meter per minute is achieved. Compared to rapier and projectile looms, these looms are less versatile but are economical and are used in mass textile production unit like denim.

2.5.2 Structure of denim fabrics

Denim fabrics are woven by interlacing two sets of yarns (Figure) perpendicular to one another in fabric form. The warp yarns in the machine direction and they are interlaced with weft yarns (fillings or picks). The sequence or order of interlacing the two sets of yarns can be varied to produce many different weave designs. The finished fabric construction is determined by the number of warp and filling yarns per square inch or centimeter. For example, a typical construction for bottom weight denim may be 62 x 38. This is interpreted as 62 warp yarns per inch of width and 38 filling yarns per inch of length and always in that order. This thread count along with the yarn counts used will influence fabric properties such as weight, fabric tightness, cover, drape, hand, tensile strength, tear strength, and other fabric properties.

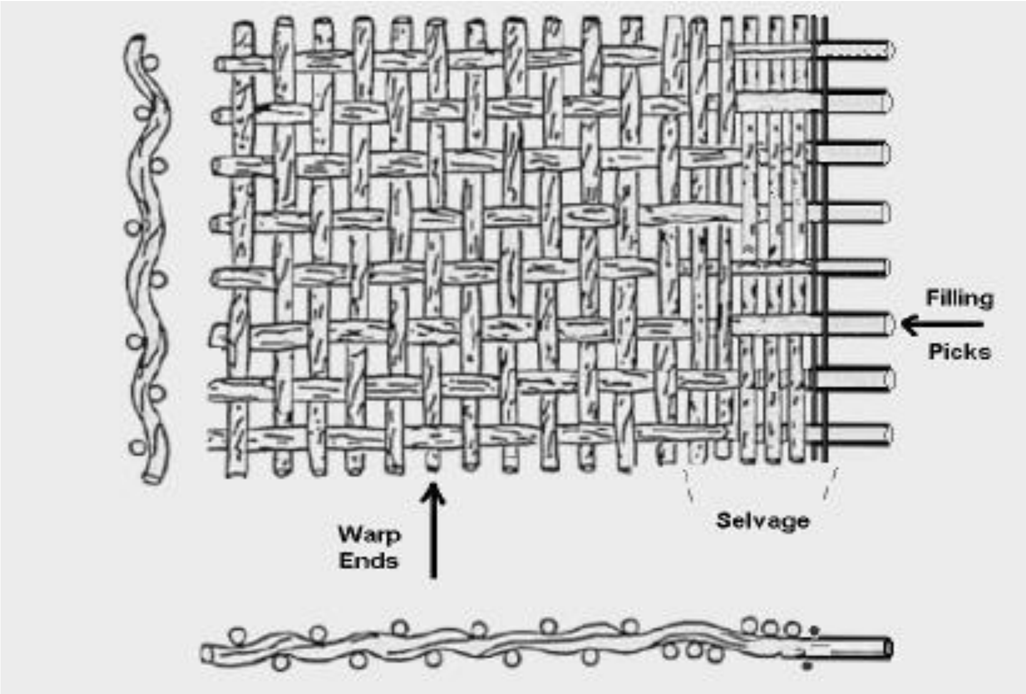

Figure 10: Woven fabric structure

2.6 Typical denim constructions, weaves and weights

The typical construction of a bottom weight 14-15 ounce denim is 60-64 warp yarns per inch and 38-42 filling yarns per inch. The weight is influenced by the size of the yarn used, the fabric weave design, and the fabric tightness. Other denim fabrics may vary in construction from 52 to 70 warp yarns per inch and from 36 to 52 picks per inch. As a rule, denim is woven as 3/1 twill, 2/1 twill, 3/1 broken twill, or 2/2 broken twill. The weights of these finished fabrics can vary between 3.5 and 16.5 ounces per square yard. The weight of the fabric usually determines what the final garment application will be:

3.5-8.0 ounces per square yard – blouses, tops, shirts, and top of bed fabrics

8.0-16.5 ounces per square yard – trousers, jeans, jackets, and upholstery

Numerical notations (3/1) for different denim designs, denote what each warp yarn is doing relative to the filling yarns that it is interlacing with. Regarding 3/1 each warp yarn is going

"over" three picks and then "under" one pick. This would be verbally stated as "3 by 1" twill or "3 by 1" denim. At the next end, moving to the right, the same sequence is repeated but advanced up one pick and this advancing upward gives the characteristic twill line. In this case, the twill line is rising to the right, and the fabric is classified as a right-hand twill weave. If the twill line is made to rise to the left, then the design is left-hand twill. Broken twills are designed by breaking up the twill line at different intervals thus keeping it from being in a straight line.

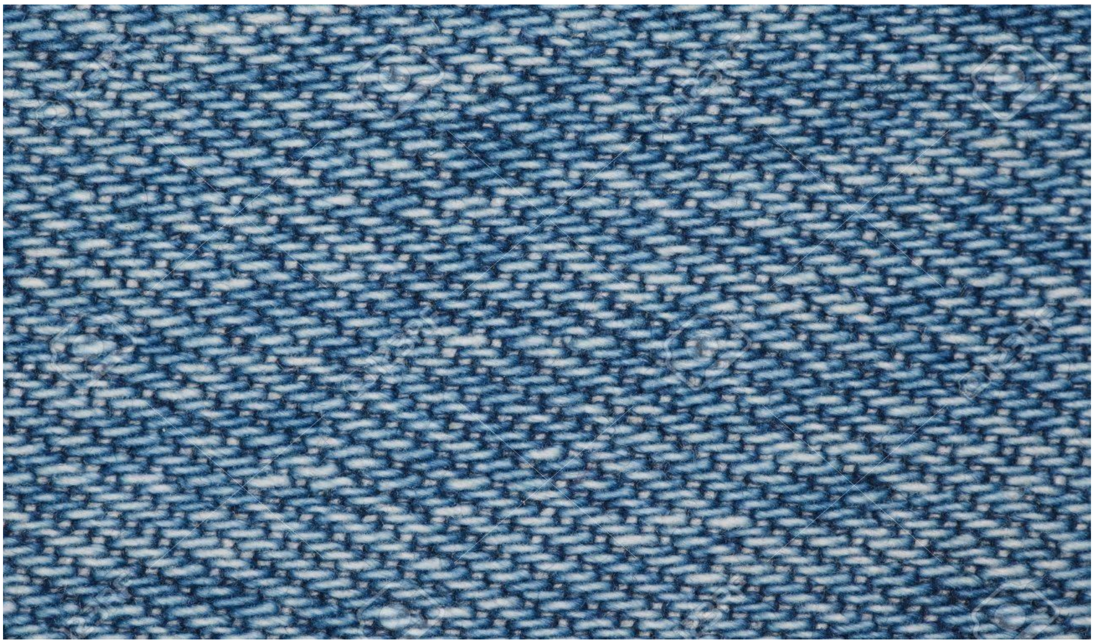

Figure 11: Denim structure

2.7 Finishing

The cloth is brushed and singed by finishing range prior to the cloth entering a finishing solution. The cloth is then pulled to the proper width, skewed, dried and rolled for the compressive shrinkage process. In this process the amount of shrinkage in the warp or lengthwise direction that a finished garment will have after laundering are reduced. As the cloth

enters the machine, it is moistened with water and then fed between a thick rubber belt and a heated steel cylinder where approximately 14 percent shrinkage in the warp yarn takes place.
After drying, the cloth is rolled onto a frame.

2.8 Quality control

The Elbit Vision System (EVS) uses cameras to inspect denim for defects. An inspection process utilizes an I-Tex 200 EVS model, an automatic fabric inspection system that evaluates the quality of the denim by identifying visible defects that result during spinning, weaving, dyeing and finishing. This system can detect defects as small as 0.5 mm on fabric up to 68 inches wide at speeds up to 42 yards per minute. As denim is fed through the system, three cameras photograph the back of the fabric, and four cameras photograph the front continually and save only the frames containing identified defects. They also log all pertinent information such as lot number and the exact location of the defect on the fabric. This information then is fed to the cutting tables where computers help locate the defect. This high-tech system increases fabric inspection efficiency and reduces garment seconds. At the 3/1 process, the cloth is measured and cut into rolls of proper quality and size. Each roll is carefully weighed to ensure correct weight and yard per roll.

2.9 Denim dyes

Indigo is commonly used to dye blue jeans. There are different types of indigo dye, both natural and synthetic. The synthetic indigo dye is commonly used in the textile industry. Indigo is challenging to dye because it is not soluble in water. To be dissolved, the indigo must undergo a reduction. Generally the indigo has a poor staining to the cotton fiber, which could cause dry- and wet fade and color loss. When dying dark, especially black denim jeans, Sulphur dye is used. Like the indigo dye, the Sulphur dye is insoluble in water and a reduction has to be made to make it attach to the fiber. Fibers, yarn, fabric and garment can be dyed. For jeans, it is normal to dye the warp before weaving and keep the weft undyed. Sometimes additional dying are made on the garment, this is called garment dying. Dyes itself rarely cause damage on the fibers and negative affect the durability of the jeans. The poor color fastness to cotton can sometime be a problem.

CHAPTER THREE

QUALITY MANAGEMENT

Quality

According to the standard ISO 9004-2, quality is the essential nature of something, an inherent or distinguishing characteristic or property, superiority, excellence, or perceived level of value. Exact characteristics experienced as quality features vary between people. Each person has their own references of quality, some people find good durability and functionality as good quality, for others, attractive design and brand status is good quality. Costumers rely on a wide variety of aspects to decide if the product meets their quality references. The quality characteristics of a product have to be incorporated so that the customers desire and will to purchase the product can be cost-effective.

The broad concept of quality can be divided into three subcategories:

- Intrinsic
- Extrinsic
- Perceived

Intrinsic quality is created during product development and production and is depending on materials, methods and processes. Extrinsic quality is not a part of the specific product; it is everything around the product like brand, shop, price, merchandising, marketing and reply of retailers. Perceived quality is the intrinsic and extrinsic quality together.

3.1 Denim quality

The intrinsic qualities of jeans are affected by two main groups; material and production. By dividing into these two groups when researching quality, it will be easier to analyze possible improvements. The material category holds fiber, yarn and fabric structure whilst production consists of the production phase with pre-treatment, making (cutting, sewing and trimming) and finishing, see Figure. Several different finishes or washes can be applied to jeans to achieve different looks. Many of the washes aim to give the jeans a worn and torn look Fiber, fabric and garment properties are tested with the purpose to ensure both high durability and quality. Durability properties can be tested in laboratories, but test results from the laboratories do not always accurately predict how the garment will perform when used by consumers. The test results will only indicate how the fabric may perform, it is also possible to notice fabrics or garments that do not stand the quality tests.

3.2 International standards

The International Organization of Standardization (ISO) is an international institution with an aim to simplify and improve the quality management of companies and organizations. By establishing standards, routines can be simplified, money saved and quality improved. Most of the 16 000 standards of today are international. The benefit of international standards is that the common base of information will simplify trade and production across the world. The standards make it easier to compare and to assess capacity, quantity, content, extent, value and quality. Standards are optional, but by deciding to follow them there are certain rules to meet. Many standards are used as regulations and also to guide or define properties that may secure material and products to be sufficient for its end use.

3.3 Quality audits

3.3.1 Quality standards

A quality standard is a common tool in the product development, planning and production processes of a company. The standard contains the intrinsic quality level that the company requires. The fundamental idea of having quality requirements is to make it possible to maintain a consistency among products and between orders of the same product, to avoid large variations. The company standards say how many products that shall be tested, how the tests shall be performed and what the different requirements are for different products, both regarding the materials and the final garment. The testing of materials may be done several times during the developing and production processes. The first tests that may be done, called base tests, are made on the same fabric as the first prototype. Tests can also be made on the fabric of the sales samples. The last test before production start is made on final fabric, the bulk material. There are no obligations to perform any tests, it is entirely up to the company to decide how thoroughly they want to be. It is also up to the company to decide where and by whom the tests shall be conducted. Test may be done by fabric manufacturer, by a third party laboratory or perhaps by the company themselves.

3.3.2 Size and fit standards

Measurement standards are set up by companies to avoid and to prevent large measurement variations among and between garment styles. The standard provide accepted variations and tolerances for the measurements of every size. The ability to keep a consistency of the measurements is an important aspect of quality, therefore it is important to minimize the risk of having too large variations in production. The sizing system and measurement tolerances are normally based on the sizing standard of the company. For example, the waist measurement of a pair of jeans in size 27 inch are according to the measurement list 73,5 cm with a tolerance of ± 1 cm in variation. If the waist measurement is 75 cm, it exceeds the tolerance. This is classified as deviation, or a defect. A measurement lower than 72,5 cm would also be considered as a defect. Tolerances vary between measurements and some deviations in a garment are considered to be more critical than others. Large variations in waist are more critical than variations in bottom hem.

Tolerances allow variation from specified value in specification. A more detailed specification, leads to less variation allowed and there will be more consistency in the finished products. Specified minimum and maximum values vary by the amount of allowed tolerance, therefore, while making the measurement lists the very lowest and highest value that can be used must be determined. Anything above or below the tolerance can as mentioned be rejected and classified as a defect. The most critical measure variations are not accepted, therefor tolerances are only included when variations are accepted. Variations of measurements from production are normal and are difficult to fully avoid. This is why it is of great importance that denim suppliers set tolerances that apply for their garments and each measurement. Quality controls are randomly made on garments by quality control personnel, from the manufacturer itself, the denim buyer or a third party controller. Which measurements that are controlled depend on the complexity of the garment and what the requirements are. The measures that are commonly checked during quality audits 13 of denim jeans are: waist, thigh, knee, bottom hem, inseam, back rise and front rise.

3.3.3 AQL – Accepted quality level

Accepted Quality Level (AQL) is a quality control tool for inspection of products. As earlier mentioned, products (in this case jeans) can be inspected in several different ways. For evaluations, tests or other types of comparisons, AQL is a good tool to control how well the products stand in relation to the quality requirements. The AQL will tell the amount of products that should be inspected and how many that defects are accepted, rather than dictating what tests should be made. Based on the AQL, randomized inspections are made, which gives the company a result that indicates the status for a majority of the products. The amount of products that will get inspected and how many faults that are accepted are determined by a combination of the AQL-level, the inspection level and the size of the order. Each company chooses what levels they want to work with. An AQL of 1,5 will not accept faults in more than 1,5 % of the inspected lot. There are three inspection levels; I, II and III. Inspection level II is most commonly used, but at less comprehensive inspections level I is used, and at more comprehensive inspections level III is used. Defects are classified by their severity; minor, major or critical. Three minor defects are equal to one major defect. If the amount of defected products in the inspected lot exceeds the AQL, the order should be rejected, otherwise it can be accepted.

CHAPTER FOUR
AN OVERVIEW OF TESTING METHODS FOR QUALITY AND COMFORTABILITY TESTING FOR DENIM FABRICS

Quality testing

Denim fabrics were tested considering five durability aspects: abrasion resistance, tear strength, colorfastness to rubbing, colorfastness to washing and dimension stability. The tests resulted in quantified data that was put together and analyzed. On four out of five tests; abrasion resistance, colorfastness to rubbing, colorfastness to washing and dimension stability the result are subjective judged by the authors. The selection of tests to perform and what denim styles to tested were based on the claim statistics of the company. The chosen denim styles were some of the most frequent styles in the claim statistics, and some of the styles were available on the market at the moment. These new styles did therefor not figure in the statistics.

Quality is a subjective notion, which means that what one person considers to be high quality, another one might not. Because of this it is hard to define exactly what high quality jeans are. Maintaining properties is not typical for jeans but is something that most people desire in other garments as well. But since many jeans are processed to get a worn look, this issue becomes an important quality aspect.

All different parts such as fibers, yarn, cutting, sewing etc. are building blocks that create the final jeans quality. Thereby all parts can be viewed as “critical” and of importance to be able to manufacture high quality jeans. For example, by choosing a high quality cotton fibre, i.e. a long stapled cotton fiber, the chances of withstanding the following processes and the wearing phase increase, and a solid ground for the jeans to maintain its properties is laid.

4.1 Testing material

The tests were performed on denim jeans with three different fiber contents and weight between 8,44 and 12,79 oz./y2. The yarn size and the weave type were not the same for every sample, but considered to be similar. Tests were made on seven denim finishing represented by 14 different styles. Six styles had a material composition of pure cotton, eight had blended compositions of 98 % cotton and 2 % elastane .Three samples were heavy stone washed. One were heavy stone washed and bleach washed. Two out of 14 were stone washed, one enzyme washed, two bleach washed and one rinse washed. Two samples were raw and did not have any finishing.

4.2 Methods

Quality testing physical properties

4.2.1 Fabric Weight

Fabric is generally measured either in metric grams, producing GSM (grams/square meter), or, in countries that employ imperial measurements, ounces (oz), producing the measurement of OZ (ounces/square yard). A higher number means a heavier fabric.

It’s important not to confuse these numbers as ‘product weights’. For example, a 400GSM suit does not weigh 400 grams in total – that is just the weight for a single meters squared of the fabric.

Reporting Date		**Description**	**Regular Cotton Denim**
Composition	100% Cotton	Weave & Design	3/1 RHT
Construction	70x47/7x8	Fabric Color	Indigo
Fabric Wt. BW-Oz/Sq.Yd		Fabric Wt. AW-Oz/Sq.Yd	12.5(40min Desize)
Finish Fabric Full width	60”-61”	Fabric cut able width	

4.2.2 Fabric thickness

Fabric thickness is one of the most important factors determining thermal comfort. It was found that fabric thickness had a direct effect on thermal transmittance, where the thicker the material, the lower the thermal transmittance. Dorkin and Beever also stated that the thermal resistance through individual layers of dry fabrics was primarily dependent upon their thickness and was approximately two togs per 1 cm thickness varying from about 0.05 for cotton poplin to about 1 tog for a heavy overcoat. This value would be lower if the wind was present to cause more air penetration and higher natural convective heat loss.

TS 251 was used to measure fabric weight.

4.2.3 Tensile strength

The tensile strength, σT, is determined from the load at failure, L, divided by the diameter of the plug or disk, D, and the thickness of the plug or disk, t

$$\sigma_{\mathrm{T}} = \frac{2L}{\pi D t}$$

TS EN ISO 13934-1 test method was used and maximum force and elongation at maximum for were reported by using strip method.

4.2.4 Tear strength

Tear strength was tested with the Elmendorf method, the ISO 13937-1, Tear properties of fabrics – Part 1: Determination of tear force using ballistic pendulum method. Specimens were randomly taken form the garment and torn in the testing apparatus. The mean tear force across warp and weft were calculated. Test load D was used during the tests.5.2.3 Abrasion resistance

Abrasion resistance tests were performed according to ISO 12947-2, Determination of abrasion resistance of fabrics by the Martindale method – Part 2: Determination of specimen breakdown, and judged according to the company's quality requirements. After the end of each series the specimen was evaluated to determine if it yet had reached its breakdown limit. The color change and appearance of the specimens was also evaluated. The test load of 9 kPa was used to press the specimens down. The evaluations were made at 3000, 5000, 10 000, 12 000, 14 000, 16 000 and 17 000 revolutions. 17 000 revolutions is the limit of the company's abrasion requirement. The shade change was assessed after every test interval.

4.2.5 Color fastness to rubbing

The color fastness to rubbing was evaluated according to ISO 105-X12, Tests for color fastness – Part X12: Color fastness to rubbing. Two specimens, of each warp and weft direction measuring a minimum of 50 mm x 140 mm, were cut from testing sample. The tests were made with both wet and dry rubbing cloths.

4.2.6 Color Fastness to washing

A test specimen measuring 10 X 4 cm of the material to be tested is cut out. Yarn is knitted into a fabric from which a piece of the same dimensions can be obtained. The specimen to be tested is placed between two pieces of undyed fabric measuring 10 X 4 cm anf the three pieces are held together by stitching round the edges. In the case of loose fiber, the compressed mass is held in place by sewing it between pieces of cloth measuring 10 X 4cm. The composition of one the colorless materials enclosing the specimen will be the same as the dyed sample and the other will be as indicated below:

If the first piece is	The second piece will be
Cotton	Wool
Wool	Cotton
Silk	Cotton
V.rayon	Wool
Polyamide	Wool or Viscose
Polyester	Wool/Cotton
Acrylic	Wool/Cotton

A solution is made containing 5 gpl of soap in which free alkali calculated as Na_2CO_3 should not be more than 0.3% free alkali calculated as NaOH should not be more than 0.1% and total fatty matter should not be more than 85%.

4.2.7 Dimension stability

The dimensional stability was tested according to two standards, ISO 3759, Preparation, marking and measuring of fabric specimens and garments in tests for determination of dimensional change , considering the fabric and ISO 5077, Determination of dimensional change in washing and drying considering the garment.

Before laundering, the areas on the denim jeans were marked length wise and width wise with three parallel benchmarks. After the first and the third laundering, the dimensional change in percentage were determined and calculated with the formula:

$$\frac{Xt-Xo}{Xo}\ X\ 100$$

where x_o is the garments original measurement and x_t is the measurements after the wash and dry cycle.

In the dimension stability test of garments, measurements were taken according to the instructions for measuring positions on trouser-like garments of ISO 3759. The positions measured are width of waist, thigh, knee and bottom of leg, the length of inside leg from crotch to hem and length from junction of leg seams to top, both back and front, excluding waistband. The premeasuring is carried out after drying. The dimension change is calculated with the formula:

$$\frac{Xo-Xt}{Xo} X\ 100.$$

The premeasuring was made after both one and three washing and drying cycles.

4.2.8 Abrasion resistance

Abrasion is one aspect of wear and is the rubbing away of the component fibers and yarns of the fabric. Abrasion may be classified as follows-

- Plane or flat abrasion-A flat area of material is abraded.
- Edge abrasion-This kind of abrasion occurs at collars and folds.
- Flex abrasion-In this case, rubbing is accompanied by flexing and bending.

Methods of comfort properties

4.2.9 Water vapor transmission test

Water vapor permeability properties of fabrics were measured using test method based on the ASTM E96-00. Water vapor transmission test model used is shown below in Figure.

The moisture vapor transmission properties of fabrics are very important clothing systems intended to be worn during vigorous activity. During the periods of high activity human body cools itself by sweat production and evaporation where the ability of clothing to remove this moisture in order to maintain comfort and reduce the degradation of thermal caused by moisture build-up is an important factor .

A simple way of measuring moisture vapor transmission through test fabric is using upright cup method shown in Figure. The amount of moisture vapor loss from an enclosed dish, with a test fabric on top, is determined over a period of time and used to calculate a moisture vapor transmission rate .

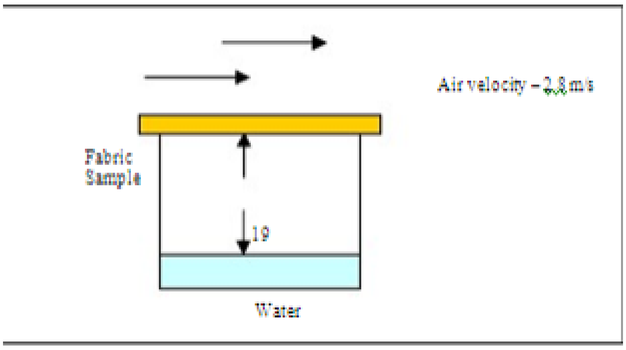

Figure 12: Upright cup method

Moisture vapor transmission rate is calculated, in g/m2.hours, for upright cup method as below, where G is the mass difference, obtained by the weight change, of the liquid in grams, t is the time during which G occurred in hours, and A is the effective area of the fabric in m2:

MVTR=G/(T.A)

4.2.10 Air permeability test

Permeability is a property composed of performance and thickness of a material in [m^3/m^2/min.] in SI system. Air permeability can be defined as the volume of air permitted to pass a certain area of the textile material in a period of time under a specific pressure. Air permeability of a fabric is an auxiliary factor affecting the comfort properties of textile materials. For instance, it is the main factor setting the water vapor transmission rates of fabrics of different fiber types owing to the same fabric structures after reaching equilibrium. The air permeability of a fabric can be described as a measure of how well it allows the passage of air through it. The reciprocal of air permeability, air resistance, is defined as the time in seconds for a certain volume of air to pass through a certain area of fabric under a constant pressure. The advantage of using air resistance instead of air permeability is to be sum of the individual air resistances while air permeability is just characterizing a fabric.

4.2.11 Measurement of wicking

The wicking term is a spontaneous transport of a liquid driven into porous system by capillary forces. The wicking is the result of spontaneous wetting in capillary system because capillary forces are caused by wetting, in the simplest case of wicking in a single capillary tube a meniscus is formed

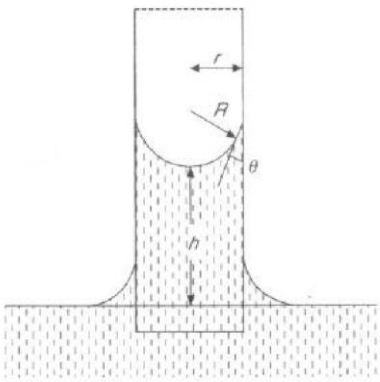

Figure 13: Wicking in a capillary

For a capillary with a circular cross section, the radius of the curved interface, where r is capillary radius, is as given in Equation 3.2:

R=r/Cos □ (3.2)

The wicking rate is dependent on the capillary dimensions of fibrous assembly and the viscosity of the liquid. When wicking takes place in a material whose fibers can absorb liquid the fibers may swell as the liquid taken up which reduces the capillary spaces between fibers, potentially altering the wicking rate. The rate of progress of liquid for a simple capillary of radius r can be expressed as follows where θA is advancing contact angle, η is the viscosity of the liquid and l is the length of liquid front:

By using above formula the distance traveled along a capillary by a liquid in a given time t can be found using Equation.

The height to which the liquid wicks is limited by gravitational forces and ceases when the capillary forces are balanced if the material is vertical, so the equilibrium height can be calculated as follows where ρ is liquid density and g is the gravitational acceleration.

Trans planar wicking is the transport of liquid into fabric structure in the direction perpendicular to the fabric plane and longitudinal wicking occurs when fabric is partially immersed into an unlimited reservoir parallel to the fabric plane. The measured longitudinal wicking rates of fabrics are not always correlated with corresponding trans planar wicking rates. Since the mechanism of removal of liquid perspiration from the skin involves its movement through the fabric thickness trans planar wicking is perhaps of more importance than the longitudinal wicking.

The wicking is affected by the morphology of fibrous assemblies because fibrous structures are never of a perfect capillary and are changeable in shape due to swelling of fibers (if hydrophilic). Because of this complicated problem, wicking flow on periodically irregular capillaries, an efficient and precise way of representing the intricate structure of fibrous structure of fibrous assemblies is still awaited.

CHAPTER FIVE
TEST RESULT AND ANALYSIS

5.1 Results

Quality testing physical properties

5.1.1 Fabric weight

The GSM of the Fabric is 440 grams.

5.1.2 Fabric thickness

5 measurements were taken from different parts of the fabrics and the test was conducted according to BS 2544 and then average values were obtained.

5.1.3 Tensile Strength

Warp(N)	**550.00N**
Weft(N)	**350.00N**

5.1.4 Tear Strength

Eight styles had less than 10 % in strength decrease. Three of them decreased more than 10 % in weft direction. Half of the styles were in 100 % cotton and the other half were in 98 % cotton and 2 % elastane. Out of eight styles that passed the test, three of them did not lose strength, but increased its strength after three washes. Six styles lost more than 10 % strength after three washes. Two of them were in 98 % cotton and 2 % elastane. Except one style, the test showed that styles with great decrease in warp direction also lost strength in weft direction. But the lost in warp direction was lower in relation to weft direction (10-20 N). Eight styles lost more than 10 % in weft direction.

Heavy Stone Wash showed a significant change in strength before and after washing in three of the fabrics. With the forth fabric the strength increased.

The Stone Wash fabric was basically unaffected by the washing.

The Enzyme Washed fabric decreased in strength in warp but not in weft. But the tear strength was still after three washes very high, this probably due to that enzymes are more merciful to the fabric compared to other wet processes.

The Rinse Washed model decreased in warp as well as in weft although the decrease in weft was larger. The deterioration in weft meant that it after three washes reached the lower limit for what it should withstand. The warp in this case is stronger than the weft and mainly that is the crucial point with a denim fabric, however a fabric is not stronger than its' weakest link. Probably the rinse wash is the reason of why the fabric decreased in tear strength.

The unwashed fabrics was not affected by the washing in a noticeable way, both of the fabrics were strong before and after washing. One of the fabrics, NW 2, displayed a decrease of strength in weft, however the decrease will most likely not affect the fabric as a whole since it is still far above the accepted requirements.

The Bleach Washed fabrics decreased a lot in both warp and weft. This was not unexpected since bleaching leads to weakening of the cotton fiber, and particularly the elastane fiber. Both of the two bleached fabrics were a mix of cotton and elastane. BW 1's strength decreased severely, whilst the decrease with BW 2 was acceptable.

The Heavy Bleach and Stone Washed fabric was the one with the greatest decrease, both in warp and in weft. Earlier heavy treatments are probably the reason of such great decrease. The test results varied a lot and no obvious connection between washes and tear strength could be notices. No obvious connection between elastane and increased or decreased tear strength was either not noticed. Fabrics with elastane both increased and decreased in tear strength. For example, the bleach washed samples showed a fairly great decrease, which probably is caused by the bleaching chemicals that harms the cotton and elastane fibers. The stone washed sample with elastane was basically unchanged. A Resin finishing earlier in the process could in this case be a reason for this result.

Test	Result
WARP(N)	50.00N
WEFT(N)	25.00N

5.1.5 Color fastness to rubbing

Loss of color when rubbing is normal for raw denim fabrics. This is due to the hydrophobic property of the Indigo dye. Therefore, some dry fading is something that has to be accepted when it comes to denim jeans. However, too much dry fading means a risk of unsatisfied customers.

The colorfastness has also been subject to some tests in this study. Overall, the samples displayed good results and the authors can only establish that they, in this case, were not a problem. The fact that the colorfastness is evaluated and judged visually, and thereby also subjectively judged, by the authors, should also be mentioned. In spite of accuracy, there is a risk of different judgements from one day to another. In contrast to this study’s test results, the colorfastness is a recurring problem, especially when it comes to cotton jeans colored with indigo. As mentioned earlier, to ensure high quality jeans companies need to be careful from the beginning and set high demands on fabric and manufacturing. Add to that quality tests and inspections of both fabric and final products.

Color Fastness to Rubbing (ISO 105 X12)

		Result(Grey Scale)
Length wise	DRY	3/4
	WET	2/0
Width Wise	DRY	3/4
	WET	2/0

The reason of why faded when wet is probably due to the characteristics of the indigo. But it is surprising that two of three heavy stonewashed jeans did not pass the test for wet fade. Heavy stone washing is a process when the fabric is heavy treated and lot of color is removed during abrasion. In this case, probably and obviously, lot of color are, despite the heavy treatments, still in the fabric and cause wet fade.

5.1.6 Color fastness to washing (ISO 105 CO6)

After three washes, all jeans maintained good color and passed the test.

Test	**Result**
Color Change	4/0
Color Staining	N/A
Acetate	3/4
Cotton	3/4
Nylon	3/4
Polyester	4/0
Acrylic	4/0
Wool	3/4

5.1.7 Dimension stability to washing

The one reason for the dimensional change, shrinkage, for all of the fabrics is hard to tell. The result could indicate the influence of denim finishing on dimensional stability, but it could also be randomly given result. As mentioned in *Dimensional Stability*, fiber and fabric structure plays an important role for dimensional stability. Dimensional stability, or dimensional changes can be caused by different reasons. In this case, when all fabrics shrank, is possible that the change is caused by tension. Fabrics with no significant difference between warp and weft, tension might be caused by different processes after weaving. Fabrics with greater shrinkage in warp, tension probably been mainly caused from weaving. But also from different denim processes, due to shrinkage even in weft. To reduce the difference in dimensional change in warp and weft, one solution could be some kind of relaxing process of fabric after weaving. This would probably made the shrinkage due to denim processes more equal between warp and weft. Equal shrinkage can be preferable, because even if the garment shrinks, it will maintain good proportions. Shrinkage in warp direction is more critical than shrinkage in weft direction when it comes to denim jeans, especially denim jeans of cotton and elastane. Shrinkage in weft direction, easier returns to original measurements during use. Shrinkage in weft direction could in some cases be appreciated, when this helps to maintain fit. The shrinkage in warp direction is more critical due to it do not returns to its original length during use like the weft does. But, to minimize the risk of shrinkage, the garment can be stretched when wet. Because of the increased strength of the cotton fiber, stretching do not weaken the fiber or affect the durability of the jean.

By washing the jeans and then do quality tests you can get an indication of how well they will withstand the wearing phase. Though, it only gives an indication and not a totally correct result. The wearing phase is incredibly difficult to emulate and tests after washing only give a hint. But, you can possibly detect jeans that, for example, decreases too much in tear strength, by comparing test results before and after a number of washes. Through this, perhaps the processes containing wearing can be made a bit more careful so that the jeans are not worn too much.

In this study all jeans were washed in the same washing machine, with the same washing program and with the same laundry detergent. In spite of accuracy, the amount of laundry detergent may have varied which might have affected the results. The tests were also made on unconditioned fabric, the effect of this on the test results is difficult to determine, but should be kept in mind. No clear conclusions could be made since several different styles, but only a few samples of each style were tested. This makes it difficult to tell by the test results whether they show a pattern or simply random results.

Dimensional Stability to Washing:

Test	Result(After Desize Wash)
Length	+/- 3%
Width	+/- 3%

5.1.8 Abrasion resistance

Except one, all samples passed the abrasion test. HSW 1 was the one that did not pass and broke at 3000 revolutions. The fact that HSW 1 was heavy treated is probably the reason why it broke at such early stage. But chemical residues in the fabric could also be a reason, especially when the washed sample broke at 12 000 revolutions. If there were any chemical residues, they were probably rinsed during the laundering. That HSW 1 differs from the other heavy stone washed sample, could also indicate that the test result for HSW 1 is just random. Eight out of 14 washed samples passed the test. Abrasion, cause by finishes as well as washing, is probably the reason why the remaining six samples did not make 17 000 revolutions. Both jeans with and without elastane broke before 17 000 revolutions, and therefore the effect from the elastane cannot be demonstrated on the abrasion resistance. It is likely that the bleaching cause damage fibers and weaker fabrics, but this could not be seen in this abrasion test.

Results for comfort properties

5.1.9 Water vapor transmission test

Cup method

In the British Standard version of this method the specimen under test is sealed over the open mouth of a dish containing water and placed in the standard testing atmosphere. After a period of time to establish equilibrium, successive weightings of the dish are made and the rate of water vapor transfer through the specimen is calculated.

The water vapor permeability index is calculated by expressing the water vapor permeability (WVP) of the fabric as a percentage of the WVP of a reference fabric which is tested alongside the test specimen.

Each dish is filled with sufficient distilled water to give a 10 mm air gap between the water surface and the fabric. A wire sample support is placed on each dish to keep the fabric level. Contact adhesive is applied to the rim of the dish and the specimen, which is 96 mm in diameter, is carefully placed on top with its outside surface uppermost. The cover ring is then placed over the dish and the gap between cover ring and dish sealed with PVC tape as shown.

A dish which is covered with the reference fabric is also set up in the same way. All the dishes are then placed in the standard atmosphere and allowed to stand for at least 1h to establish equilibrium.

Each dish is then weighed to the nearest 0.001g and the time noted. After a suitable time for example overnight the dishes are reweighed and the time noted again.

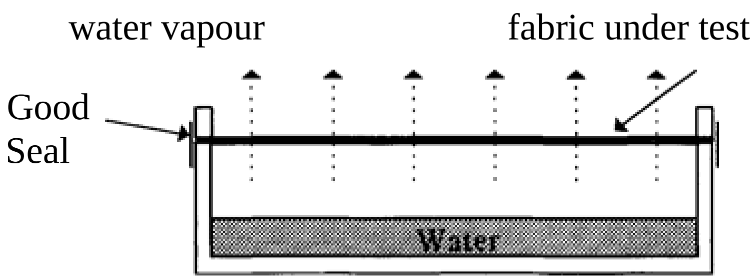

Figure 14. The water vapor permeability test

The experiment is sometimes carried out with the cup inverted so that the water is in contact with the inner surface of the fabric . This form of the test tends to give more favorable results for hydrophilic films.

Before Testing	**Weight in gram**
1.Sample Weight	**16.1**
2.Water Weight	**1015.7**
After Testing	
1.Sample Weight	**17.5**
2. Water Weight	**1013.2**

5.1.10 Air permeability test

The air permeability test results are given in the table below. Air permeability values depict a reduction in most of test samples during washing treatments except for Ne8 warp and Ne10 weft yarns of fabrics. There is an increasing trend of air permeability values for the washed samples of these rigid samples. The differences of air permeability values of all rigid and washed samples are plotted together in the figure below.

Fabric Samples	Machine Readings
A	8.42
B	8.04
C	9.26

From the results of air permeability tests as can be seen the lightest fabric of all samples has the highest air permeability values. As a result it can be seen that there is not a significant effect of fiber composition on air permeability behaviours. The most important parameters that effects the air permeability behaviours of fabrics are the space between fibers and yarns. Since in this study all samples have the same fabric structure and similar yarn counts, the parameter of fabrics did not cause a significant difference of air permeability values of studied samples.

Figure 15. Air permeability test

5.1.11 Measurement of wicking

Transfer wicking ratios were calculated for both wet fabrics, R, and for dry fabrics, 1-R, using the water concentrations of the fabric samples measured during the test period. Due to having the concentrations on certain time intervals every single graph of all fabric samples demonstrating the average transfer wicking properties of them could be formed. Transfer wicking ratios obtained from before washing transfer wicking tests are listed below in Table 5.3 showing the ratios for every 5 minutes interval.

Table 5.3: Transfer wicking ratios for wet fabrics

Fabric Code	R						
	0	5 min	10 min	15 min	20 min	25 min	30 min
1A	1	0,233	0,300	0,0374	0,385	0,400	0,420
1B	1	0,085	0,109	0,122	0,132	0,141	0,188
2A	1	0,200	0,314	0,400	0,457	0,514	0,557
2B	1	0,131	0,145	0,143	0,142	0,139	0,138
3A	1	0.040	0,045	0,091	0,115	0,136	0,150
3B	1	0,072	0,082	0,080	0,080	0,078	0,076
4A	1	0,088	0,117	0,139	0,153	0,148	0,175
4B	1	0,140	0,166	0,166	0,166	0,016	0,225
5A	1	0,355	0,420	0,484	0,516	0,540	0,160
5B	1	0,054	0,072	0,081	0,084	0,087	0,089
6A	1	0,069	0,108	0,138	0,167	0,186	0,596
6B	1	0,056	0,074	0,083	0,088	0,088	0,091

From the results of transfer wicking tests of dry fabrics it can be seen that after 30 minutes time period 100% cotton washed fabrics of Ne7 yarns show the highest transfer wicking ability where 85/15% cotton-polyester rigid fabrics of Ne7 yarns have the lowest transfer wicking ratios among the fabrics tested.

Table: Transfer wicking ratios for dry fabrics

Fabric Code	1-R						
	0	5 min	10 min	15 min	20 min	25 min	30 min
1A	1	0,766	0,700	0,962	0,615	0,600	0,580
1B	1	0,915	0,891	0,878	0,868	0,859	0,812
2A	1	0,800	0,686	0,600	0,543	0,486	0,443
2B	1	0,869	0,855	0,857	0,858	0,861	0,862
3A	1	0,960	0,955	0,909	0,885	0,864	0,850
3B	1	0,928	0,918	0,920	0,920	0,922	0,924
4A	1	0,912	0,883	0,861	0,847	0,852	0,825
4B	1	0,86	0,834	0,834	0,834	0,984	0,775
5A	1	0,645	0,580	0,516	0,484	0,460	0,840
5B	1	0,946	0,928	0,919	0,916	0,913	0,911
6A	1	0,931	0,892	0,862	0,833	0,814	0,404
6B	1	0,944	0,926	0,917	0,912	0,912	0,909

The data above was used to plot the figures of transfer wicking abilities of both wet fabrics (Figure) and dry fabrics (Figure).

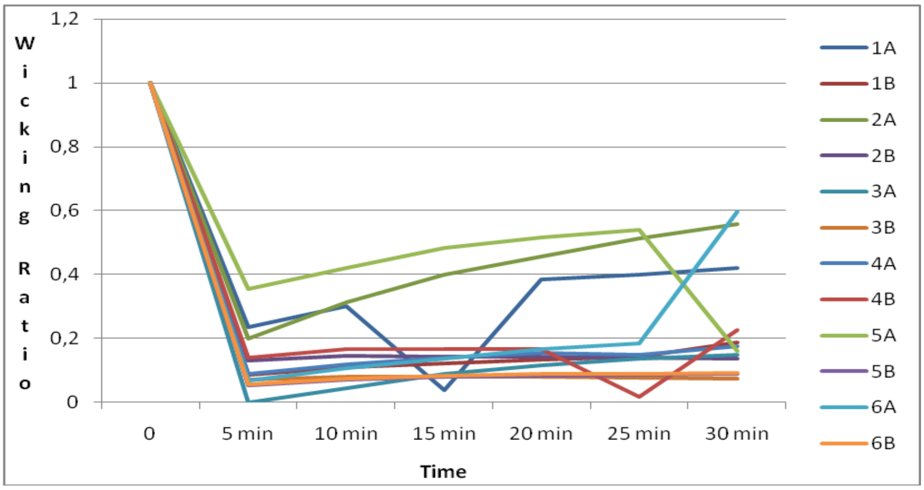

Figure 16: Transfer wicking for wet fabrics

The transfer wicking ratios of rigid and washed samples are similar to water-vapor transmission rates. For instance 98/2% cotton-elastane and 85/15% cotton-polyester washed denim fabrics and 100% cotton of Ne8 warp and Ne10 weft washed fabrics have better values regarding both transfer wicking ratios and water vapor transfer rates. Figure reveals that 100% cotton of Ne8 yarns, 100% cotton of Ne7 yarns rigid and washed fabrics have lower transfer wicking values. Regarding water-vapor transmission results it can be seen from the Figure 100% cotton of Ne8 yarns, 100% cotton of Ne7 yarns rigid and washed fabrics have lower values compared to values of 98/2% cotton-elastane and 85/15% cotton-polyester rigid and washed denim fabrics and 100% cotton of Ne8 warp and Ne10 weft rigid and washed fabrics. There is a relation of wetting and wicking properties of studied denim fabrics with the water vapor permeability. Most of the studied samples showed similar results both for wicking tests and water vapor transmission tests.

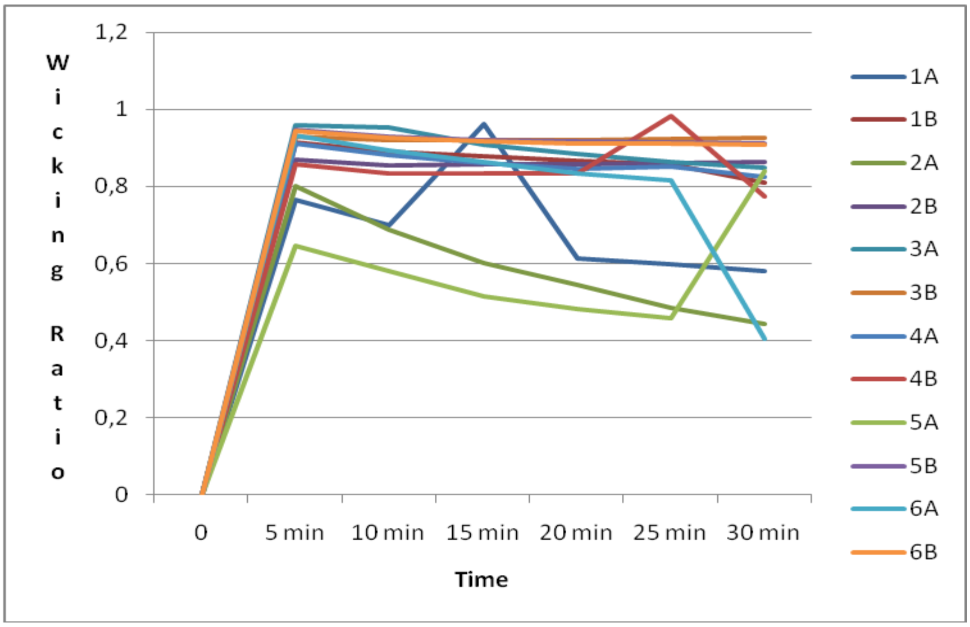

Figure 17: Transfer wicking for dry fabrics

Comparing the transfer wicking ratios of rigid fabrics and washed fabrics, it appears that washing, in general, make the wicking rates improve.

Even though all fabric types investigated have similar transfer wicking ratio curves they have different wicking ratios for the end of certain time periods which reflect the difference between their transfer wicking behaviors.

Univariate analysis of variance results make clear that all three categorical variables, yarn count, fiber composition and washing are statistically significant on transfer wicking at 95% confidence interval. Pairs of “fiber composition and yarn count”, “fiber composition and washing” and “yarn count and washing” have statistically significant interaction effects on transfer wicking ratios, as well. Furthermore, “fiber composition, yarn count and washing” have significant triple interaction effects on this behavior.

Regarding effect of finishing agents on wettability and wickability of samples. Since low level crease recovery application, the crosslinked structure of fibres has an increased level of surface tension that makes them less wettable. The presence of magnesium chloride on the finished fabric surface reduces the wetting time and wicking ratios compared with samples after several laundering cycles.

It is obvious that washing has more increased the wicking ability of 100% cotton group of fabrics. As stated before, agreeing with the results of previous researches, wicking rates of cotton increases after consecutive launderings. Another important categorical variable affecting transfer wicking is the yarn count. The coarser yarns lead to a better wicking ability for 100% cotton group of fabrics. Our findings are also parallel to the one of previously made researches concluded that coarser yarns show faster wicking than finer yarns which is reflected in wicking behavior of fabrics of coarser and finer yarns as seen on the transfer wicking test results of this study.

The results of this study states that there are no severe problems regarding the tested products, the quality requirements are generally reached. Deviations from requirements were most frequent in the quality audit performed. The measurement deviations are one of the critical aspects of quality. It might not be one of the main reasons why customers reclaim their jeans, especially not for customers who try the garment on in the store before buying.

CONCLUSION

The object of this study was to investigate comfort properties of denim fabrics of cotton, cotton-elastane and cotton-polyester blends besides analyzing their physical performance. For this purpose, an experimental study was conducted. The water interaction with fabrics which incorporates water vapor permeability, wicking abilities, drying behaviors and air permeability of fabrics were examined to see and recognize the comfort related abilities of fabrics studied and categorical variables and other fabric parameters effective on these properties were tried to be found out. It is clear from the results that washing has a positive influence on wicking abilities of fabrics studied and wicking abilities in longitudinal direction. The transfer wicking ratios and water vapor transmission values are correlated with each other and the test results show similar characteristics in behavior. Both wicking abilities increase with increasing yarn count values. Moreover, water vapor transmission values and transfer wicking abilities of fabrics studied increase with blends of fiber composition.

For further studies about denim fabric comfort it should be stated that thermal and moisture behaviors can be investigated together. In the light of water vapor transmission test results of this study correlation between water vapor transmission rate and wicking behaviors of denim fabrics can be further investigated for different fiber compositions and with different washing treatments. The elements of this subject can be studied with different finishing treatments and can be compared the data of this study to have valuable feedback about denim comfort performance.

According to above mentioned analysis, it is better to have optimum blend ratio, yarn count and warp-weft density which best suits to the specific end use requirements of the product type where cotton and cotton-polyester denim fabrics will be used. In the view of the results obtained, it can be concluded that, blends of cotton, elastane and cotton polyester in denim fabrics should be advised to be used so as to have a fine performance of comfort owing to natural feeling of cotton.

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