GAZİANTEP UNIVERSITY GRADUATE
SCHOOL OF NATURAL & APPLIED
SCIENCES

INVESTIGATION OF INFLUENCE OF TWILL WOVEN FABRIC PATTERNS ON FABRIC PHYSICAL PROPERTIES

M. Sc THESIS
IN
TEXTILE ENGINEERING

BY
H. KÜBRA TÜLÜCE
July 2005

Investigation of Influence of Twill Woven Fabric Patterns on Fabric Physical Properties

M.Sc. Thesis
in
Textile Engineering
University of Gaziantep

Supervisor: Assist. Prof. Dr. Mehmet TOPALBEKİROĞLU

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ABSTRACT

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Weaving has been used more widely than any other method of fabric construction and gives a tremendous range of fabric character. Woven fabrics are composed of two yarn sets that make interlacings to form a woven fabric. By varying the sequence of these interlacings many fabric structures can be obtained. Each of these structures are called as "weave patterns". There are three main weave patterns for woven fabrics. These are plain, twill, satin. There are many derivatives of these fundamental patterns. Different fabric weaves differentiate the structure of fabrics and these different structural properties of fabrics will cause the fabrics to behave differently from each other. In this point of view fabric pattern must be evaluated not only as an appearance property but also a very important structure parameter indeed.

In this thesis work the influence of weave patterns on fabric properties such as yarn crimp, fabric weight, fabric thickness, breaking strength and elongation, abrasion resistance, pilling resistance, dimensional stability properties for twill weaves were investigated. The satin and plain weave derivatives are included in this experimental study additionally. Analyses of variance (ANOVA) was performed in order to understand the statistical importance of weave type on fabric properties and Tukey Tables were used to determine the best and worst weave types. In addition to these, correlation analysis was done to examine the relationship between fabric properties from statistical approach. According to test results and statistical analysis it is observed that weave type has an important effect on these mentioned properties.

Key words: weave pattern, abrasion resistance, pilling resistance, dimensional stability, breaking strength

ÖZET

DİMİ KUMAŞ DESENLERİNİN DOKUMA KUMAŞLARDA FİZİKSEL ÖZELLİKLERE ETKİSİNİN İNCELENMESİ

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Temmuz 2005

Kumaş yapıları içerisinde en geniş kullanım alanına ve en çeşitli kumaş karakteristiğine sahip olan dokuma kumaşlardır. Dokuma kumaşlar birbirine dik iki iplik sisteminin bağlantılar yaparak biraya gelmesiyle oluşurlar. Bu bağlantıların sıralarının değiştirilmesiyle desen adı verilen birçok değişik kumaş yapısı elde edilebilir. Bezayağı, dimi ve saten olmak üzere üç tane temel dokuma deseni vardır. Farklı kumaş desenleri kumaş yapısını değiştirmekte ve bu kumaşların birbirlerinden farklı davranışlar sergilemesine yol açmaktadır. Bu sebeple dokuma kumaş deseni sadece bir görünüm özelliği olarak değerlendirilmemeli aynı zamanda önemli bir yapısal parametre olarak göz önüne alınmalıdır.

Bu çalışmada, dimi desenli kumaşlar için kumaş deseninin iplik krimpi, kumaş ağırlığı, kumaş kalınlığı, kopma mukavemeti ve uzaması, aşınma dayanımı, boncuklaşma dayanımı, yıkama sonrası çekmezlik özellikleri test edilmiştir. Dimi desenli kumaşların dışında bezayağı ve saten türevleri için de bu testler uygulanmıştır. Kumaş deseninin bu özellikler üzerine etkisinin istatistiksel açıdan önemi ANOVA analizleri yapılarak araştırılmış ve Tukey tablolarına göre en iyi ve en kötü özellik gösteren kumaşlar belirlenmiştir. Ayrıca korelasyon analizleri ile kumaş özelliklerinin arasındaki ilişkiler incelenmiştir. Test sonuçlarına ve istatistiksel analizlere göre dokuma kumaş deseni bu özellikler üzerinde önemli etkiler göstermektedir.

Anahtar kelimeler: desen, aşınma dayanımı, boncuklaşma dayanımı, boyutsal stabilite, kopma mukavemeti

ACKNOWLEDGMENTS

I would like to express my deepest gratitude to my supervisor, Assist. Prof. Dr. Mehmet Topalbekiroğlu for his advice and guidance in the preparation of this thesis.

I am gratefull to Kipaş Textile to supply the fabric samples for this study.

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CHAPTER 1

INTRODUCTION

1.1. Introduction

A fabric is a pliable, planelike structure that can be made into two or three-dimensional products where some shaping and flexibility is needed. Fabrics are used in apparel, furnishing and many industrial products. In general terms, a textile fabric may be defined as an assembly of fibers, yarns or combination of these. Fabrics can be made from a wide variety of starting materials. Fabrics from solutions are classified as films and foams, fabrics from fibers are; fiberweb structures, felt and netlike structures, fabrics from yarns are; weaving, knitting, braids and laces and multiplex fabrics are classified as; coated fabrics, poromeric fabrics, suedelike fabrics, flocked-pile fabrics, tufted-pile fabrics, laminates, stitch-bonded fabrics, quilted fabrics [1].

There are several ways to manufacture a fabric and each manufacturing method is capable of producing a wide variety of fabric structures. Fabric selection for a given application depends on the performance requirements imposed by the end use or the desired aesthetic characteristics of the end user, with consideration for cost and price. Figure 1.1 shows the major steps in fabric manufacturing [2].

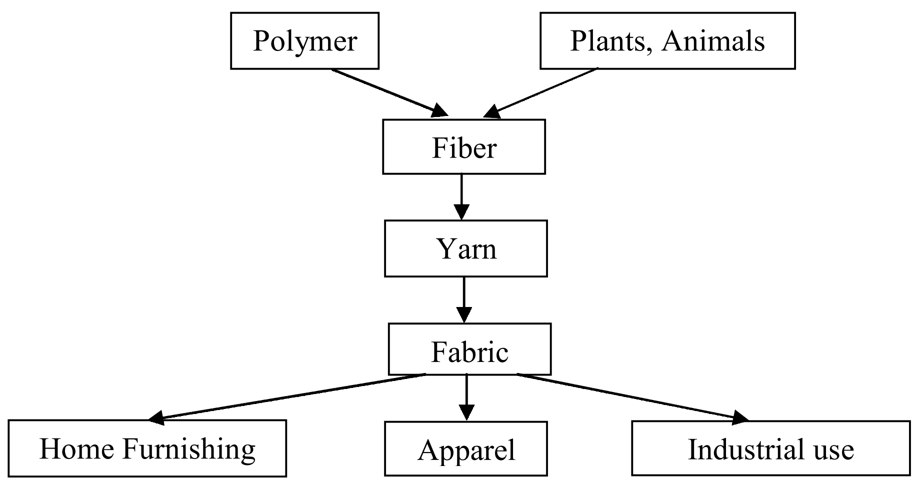


Figure 1. 1 Major steps of fabric manufacturing

Polymers, which are the resource for man-made fibers are derived mostly from oil. Plant fibers and animal fiber constitute the natural fibers. After the fabric is formed, it is generally subjected to a finishing and/or dyeing process, in which the raw fabric properties are modified for the end use. The most commonly used fabric forming methods are weaving, knitting, nonwoven manufacturing, braiding, and tufting [2]. The majority of the fabric production is based on the woven fabrics.

Weaving is the interlacing of warp and weft yarns perpendicular to each other given in Figure 1.2. The lengthwise-direction yarns in a woven fabric are called warp yarns or ends. Crosswise yarns are called filling yarns, weft yarns or picks.

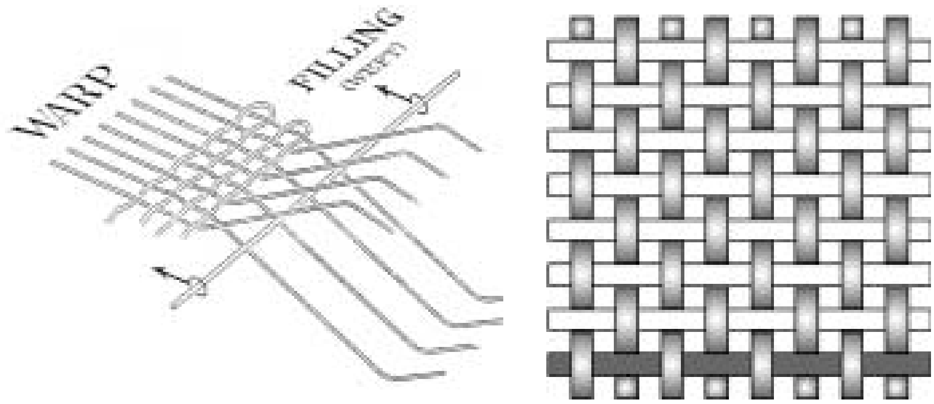


Figure 1. 2 A representative figure of the weaving; plain weave [3]

There are practically an endless number of ways of interlacing warp and weft yarns. By varying the interlacings, a wide variety of different fabric constructions can be made [2, 4]. Detailed information about the weaving is given in Chapter 2.

1.2. Influence of Fabric Patterns and Parameters on Woven Fabric Properties

The design of a fabric to meet the requirements of a certain end use is a complicated engineering problem. There are many factors involved in the fabric design and it is difficult to predict the properties of woven fabrics. However there are empirical relationships between some of the fabric parameters and the fabric properties [3].

Fabric properties are the result of fiber and yarn characteristics, and the special geometry of the fabric itself, which includes fabric structure (the order of thread interlacing-weave), number of yarns per inch, yarn crimp, and tension on yarn components. Fabric geometry can be defined as the relationship of fibers and yarns to their ultimate shape and the arrangement in finished fabric. According to several authorities, geometric factors influence the following properties important to consumers:

- Transmission of heat through fabric, or its prevention
- Air permeability or the ability of a fabric to permit air flow
- Transmission of moisture absorbency, except that caused by inherent fiber properties
- Dimensional stability
- Abrasion resistance
- Fabric soiling and cleaning problems and the production of fabrics that are soil resistant
- The hand and drape of the fabric

Knowledge of geometric features provides clues to possible fabric behavior and can be used by the informed consumer in fabric selection and care [5].

1.2.1. Crimp

Crimp is the waviness or distortion of a yarn that is due to interlacing in the fabric. In woven fabrics, the crimp is measured by the relation between the length of the fabric sample and the corresponding length of yarn when it is removed there from and straightened under suitable tension [6].

Yarn crimp is affected by the pattern of yarn interlacing in a fabric; high frequency of interlacing increases yarn crimp. Designs, which have a higher number of intersections in the repeat, tend to have high crimp and produce a rough fabric. Long floats, however, produce smooth fabrics with low crimp levels. For example, the plain weave has the highest frequency of interlacing and therefore the highest yarn crimp level in both warp and weft yarn. Satin or sateen weaves have the lowest frequency of interlacing and hence lowest degree of yarn crimp [2,3].

1.2.2. Fabric sett

Fabric sett indicates the number of warps and wefts in a woven fabric, usually expressed as the number of yarns per centimeter. The number of yarns per centimeter and the yarn size give some idea of the compactness and the density of the fabric. Balanced fabric sett – in which the number of yarns per centimeter in warp and weft are similar – frequently are considered to offer better wearing qualities than unbalanced ones [5-7].

1.2.3. Fabric weight

Fabric weight can be expressed in two ways: direct and indirect system. In the direct system, the fabric weight per area is given. In the indirect system, which is used less in practice; usually the running length per weight is given. However, in this case the fabric should also be specified. Fabric weight is affected by; fiber density, yarn size, contractions, fabric construction, weave pattern, tension during weaving and finishing [2].

1.2.4. Fabric thickness

Fabric thickness is the distance between the highest point of fabric face and the lowest point of fabric back. Fabric thickness is important since it affects permeability and insulation characteristics of fabric. Warmth in textile products can be estimated from the thickness of fabric. Tests that measure change in thickness resulting from rubbing or shrinkage are helpful in evaluating performance [2,5].

1.2.5. Breaking strength and elongation

Breaking strength is the load or force required to break or rupture a specimen in a tensile test and elongation is the deformation in the direction of load caused by a tensile force. Elongation is measured in units of length or calculated as a percentage of the original specimen length. Elongation may be measured at any specified load or at the breaking load [7].

The important fabric variables effecting strength of woven fabrics are weave and fabric count. The particular weave in woven fabrics affects both breaking strength and tearing strength. Fabric weaves with high number of interlacing, such as plain weaves, can transfer the tensile stresses at the intersection points and therefore have higher breaking strength than satin weaves. The effect of fabric count is similar.

Fabrics with a high count exhibit high breaking strength while lower count fabrics have lower breaking strength [4,8].

Equally important to the fabric strength is its ability to extend under load. When the fabric is subjected to tension in one direction, the extension takes place in two main phases. The first phase is decrimping or crimp removal in the direction of the load. The removal of the crimp is accompanied by a slow rate of increase of the load. The second phase is the extension of the yarn, during which the fabric becomes stiffer, the stiffness depending mainly on the character of the yarn. The more crimp there is in the yarn, the more extensible is the fabric. Therefore, the longer floats, the less extensible is the fabric [3].

1.2.6. Pilling resistance

Pilling is the entangling of fibers during washing, dry cleaning, testing or in wear to form balls or pills stand proud of the surface of a fabric and which are of such density that light will not pass through them. Hairs on the surface of a fabric tend to collect into little balls and if the fibers are strong, these balls do not break off; this spoils the appearance of the fabric. Low twist yarns are usually hairy and the hairs form sites for the pills to form, especially when strong synthetic fibers are used. Fabric structure plays a part and plain weaves give a higher pill resistance than fabrics with floats [3,6].

1.2.7. Abrasion resistance

Abrasion is the mechanical deterioration of fabric components by rubbing against another surface. Abrasion ultimately results in the loss of performance characteristics, such as strength, but it also affects the appearance of the fabric [8].

The abrasion resistance of woven fabrics is greatly affected by the yarn properties, fabric geometry and construction. The most important factors are the crimp levels and the height of the crowns – the part of the yarn that protrudes above the surface of the fabric – caused by the crimp. The extent to which the crowns are displaced out of the plane of the fabric depends on the weave, yarn number, yarn crimp and fabric count. The greater the number of crowns per unit area or the greater the area of each crown, the less will be the stress concentration on the crowns, and this leads to higher abrasion resistance. The weave also has a considerable effect on the abrasion resistance of the fabric. Where there are floats, the longer these are, the less restricted are the yarns to move. Also the longer the floats, the larger is the area of contact between the yarn and the abraidant and the higher is the abrasion resistance. For this reason, twills and some tightly woven satin fabrics may show superior abrasion resistance [3,4].

Fabrics can be damaged by flat abrasion or rubbing, by flex abrasion, or by edge abrasion. Damage from abrasion is the result of certain inherent fiber properties and selected geometric factors. Smooth fabrics constructed of firm yarns with optimum yarn interlacing and relatively compact yarn arrangement are less subject to damage by flat abrasion than fabrics with irregular surfaces, low yarn count and minimal yarn interlacing. The latter are easily roughened and snagged by rubbing. Loop yarns and other complex yarns with similar characteristics, as well as pile fabrics, are subjected to abrasion damage [5].

The size of yarns also influences abrasion resistance. Thick yarns resist damage from abradants, while fine yarns may abrade easily. Yarn uniformity is important, for irregular yarns may show wear very quickly if abraded [5].

Flex abrasion damage occurs when fabrics is flexed or folded upon itself or other fabrics. In this situation the fabric surface is of less importance, and fiber properties for example, stiffness and yarn mobility are much more significant. Edge abrasion is effected by the same factors applicable to flex damage and rubbing of the surface [5].

1.2.8. Dimensional stability

The dimensional stability of fabric is its ability to resist shrinkage or stretching. While fiber content has some influence on this property, geometric factors are extremely important. One of the most significant elements in dimensional stability is the degree of tension under which yarns are held during fabric construction. Yarns are held taut during weaving, and after removal from the loom they relax. This relaxation is accelerated when the fabric is first subjected to moisture. As the yarns relax, they return to their original length and pull closer together, so that fabric shrinkage results. Extremely compact fabrics with firm yarns and a high fabric or thread count are less subject to size change than those with loose, soft yarns and low thread count [5].

1.3. Previous Works

Many workers have investigated the influence of raw material, yarn production technology, yarn twist, chemical treatments on woven fabric properties such as abrasion resistance, pilling resistance, dimensional stability, tensile properties [9-15]. However, a few studies are found on the influence of weave type on woven fabric properties in the available literature. Three studies are seen on this topic.

Dilsiz (2001) studied the effects of weave type and fabric count on the fabric performance [16]. The stiffness, crease resistance, shrinkage, breaking and tearing strength and pilling resistance properties were investigated. For this purpose 10 different types of fabrics were tested. There were 5 weave types; 1/1 Plain, 2/2 Twill (S), 2/2 Twill (Z), 1/3 Twill (Z), 3/1 Twill (S). The fabrics were woven with Ne 28/2 and 67%-33% Pes/Vis yarn. No chemical treatment was applied to fabrics before tests. For breaking strength results; there wasn’t a considerable difference between the weave types. But at the point of weft sett, an increase of breaking strength was observed for both warp and weft direction by changing the weft sett from 16 to 20 wefts/cm for all weave types. For tearing strength, 1/1 plain fabrics with weft sett of 16 and 20 exhibits the lowest values. Also they observed that; decreasing the number of interlacing causes the tearing strength values for both warp and weft direction to become higher and increasing the weft sett causes the tearing strength values for both warp and weft direction to decrease. For dimensional stability, 1/1 plain fabrics show the highest values. Except 1/1 Plain warp direction shrinkage values decrease and weft direction shrinkage values increase by increasing the weft sett. For pilling resistance, all weave types exhibit 3-4 pilling degree. Increasing the weft sett caused the pilling to decrease for both 1/1 Plain and 2/2 Twill (Z). But for 1/3 Twill (Z) pilling resistance deteriorates by increasing the weft sett.

Kurtca (2001), investigated the breaking strength, tearing strength and pilling resistance properties of 100% cotton yarn fabrics [17]. For breaking strength measurement Testometric, for tearing strength Elmatear and for pilling resistance I.C.I. Piling test instruments were used. For this purpose 72 samples were woven with the same warp yarn and warp density by changing the weft yarn, weft density and weave type. Sample fabrics were woven with 1/1 Plain, 3/2 Twill (Z) and 1/4 (2) Satin structures. For weft yarn Ne 10/1 Carded Ring and O.E., Ne 20/1 Carded Ring and O.E., Ne 30/1 Carded Ring and O.E., Ne 40/1 Combed Ring yarns were used. According to the test results it was determined that average breaking strength values increase as the weft density increases. For different weave types the effect of weft yarn number on strength properties were discussed. As the weft yarn gets finer both tearing and tensile strength in weft direction decreases. The effect of weave type was only discussed on pilling resistance of fabrics woven from same yarn with the same setts and no difference was observed from the results. Three weave types for the same weft yarn number and warp sett have 5 (no pilling) scale degree at 3 different weft sett of 24, 26 and 28 wefts/cm.

Göktepe (2002) investigated the factors effecting pilling performance of woven, particularly polyester/viscose blended fabrics [18]. For this purpose 100% cotton, polyester/viscose, polyester/viscose/lycra blended that are most common in use total 12 samples were tested with Pilling Drum, I.C.I. Pilling Box and Martindale Abrasion tester. To observe the effect of weave type on pilling performance a combination of plain and ribs and a twill type fabrics were compared. But the weft and warp setts were different from each other. It is observed that the combination of plain and ribs fabric has less pilling than twill according to test results of I.C.I. Pilling Box and Pilling Drum. But for Martindale Abrasion tester there was no difference between the fabrics with degree of 2-3 scale.

1.4. Purpose of This Thesis

Fabric pattern must be evaluated not only as an appearance property of a woven fabric but also an important structure parameter indeed. Despite the fact that fabric properties are influenced with a wide range by this structure parameter the literature survey shows that there is almost no detailed research on this parameter. So we decided to study described in this thesis to investigate the influence of twill woven fabric patterns on fabric physical properties in an attempt to suggest the suitable weave types for use. In addition to twill derivatives, plain and sateen derivatives were also included to compare three main weave types in this experimental study.

The properties of fabrics that will be tested are;

1. Yarn crimp
2. Fabric weight
3. Thickness
4. Breaking strength and elongation
5. Pilling resistance
6. Abrasion resistance
7. Dimensional stability

These properties were tested with the equipments and devices in the laboratory of Textile Engineering Department of Gaziantep University in accordance with the standards of TSE.

Fabrics with different twill weave patterns were tested to determine the fabric physical properties and evaluate the influence of different twill woven fabric patterns on fabric physical properties. These are; balanced or even-sided twills, unbalanced or uneven-sided twills, weft-faced twills, warp-faced twills, waved twills, diamond twills, herringbone twills, diaper or diced twills, broken twills, entwined twills, elongated twills, flattened twills, curved twills, combined twills, rearranged twills.

For this study 36 woven fabrics were produced. 26 samples were produced with twill weave derivatives and in addition to these samples, 10 samples were produced with plain and sateen weave derivatives. For warp and weft the same yarn was used by providing the same weft and warp sett. Weft sett is 28 wefts/cm and warp sett is 46 warps/cm. The component yarn used for both warp and weft is Ne 30/1, 100% cotton combed ring yarn.

1.5. Structure of Thesis

Chapter 2 includes the information about weaving, history of weaving. Then woven fabric geometry and basic geometrical models were explained.

In Chapter 3, concept of quality and quality control methods were described. Classification for fabric properties was done. Then detailed information about fabric properties (yarn crimp, fabric thickness, fabric weight, fabric breaking strength, pilling resistance, abrasion resistance, dimensional stability), which were examined in this study, was given.

Chapter 4 is about the experimental studies. Fabric properties, standards, graphical representations and tables according to test results of yarn crimp, fabric thickness, fabric weight, fabric breaking strength, abrasion resistance, pilling resistance and dimensional stability were given in this chapter. In addition to these assessments, statistical analyses were done according to ANOVA results in evaluations.

The conclusion of thesis and recommendation for further studies were given in Chapter 5.

CHAPTER 2

PRINCIPLES OF WEAVING

2.1. Introduction

Weaving is the method of interlacing the warp and weft yarns to form a fabric. In any type of weaving, four operations are fundamental; shedding, picking, beating up, taking up and letting off. They are performed in sequence and are constantly repeated. Shedding is raising specific warp yarns by means of the harness or heddle frame. Picking is inserting weft yarns through the shed. Beating up is pushing weft yarns firmly in place by means of the reed. Taking up and letting off are winding the finished fabric on the cloth beam and releasing more of the warp from the warp beam respectively [2,19].

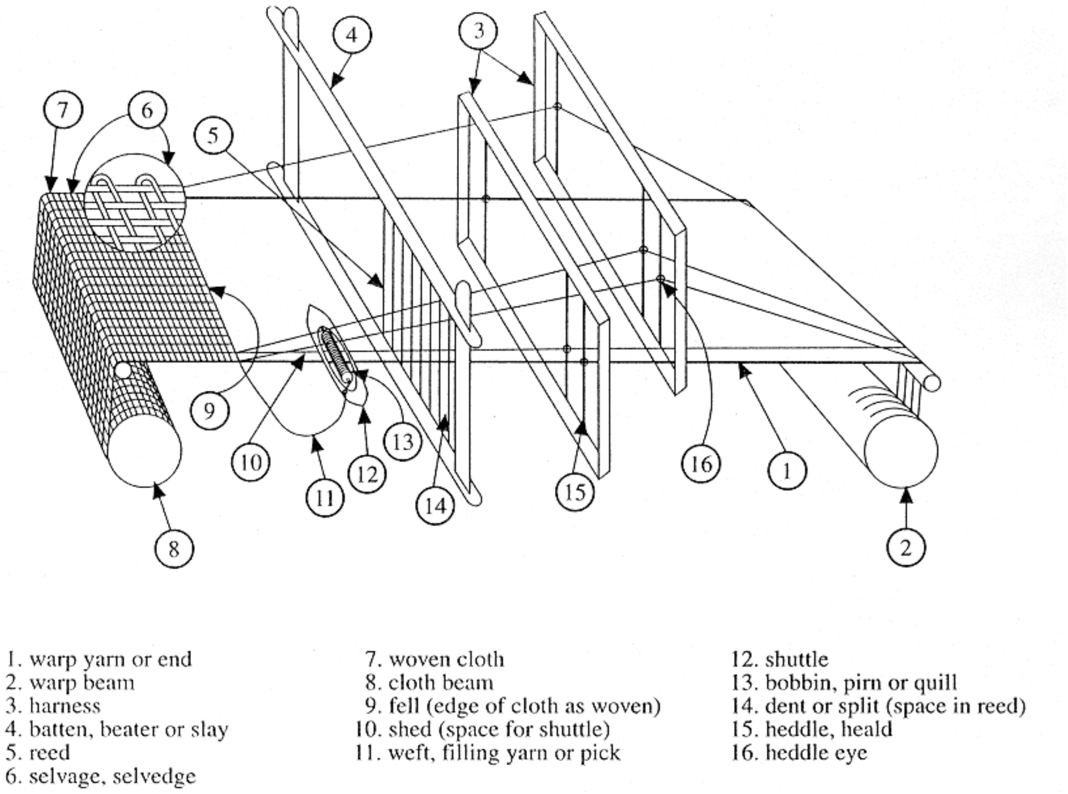


Figure 2. 1 Simplified diagram of important parts of a two-harness shuttle loom[20].

Woven fabrics are made of two sets of yarns: warp and weft. These yarns are interlaced at right angles to each other. The warp yarns are parallel to each other and run lengthwise through the fabric or along the weaving machine direction. Weft yarns run perpendicular to warp yarns. The structure of the woven fabric and its appearance are affected by the pattern of interlacing to a large extent. As a result woven fabrics made of the same yarns may differ greatly in appearance and properties if the interlacing pattern is different. It is accepted that there are three basic weaves: plain weave, twill weave, satin/sateen weave. Also there are many derivatives of these basic weaves [2].

Woven fabrics can be classified in many ways:

a. Classification of weave type, i.e., plain, twill.
b. Classification by common names, i.e., denim, cheesecloth.
c. Classification by weight, i.e., heavy fabrics, light fabrics.
d. Classification by coloration method, i.e., solution dyed, stock dyed.
e. Classification by the end-use, i.e., apparel fabrics, home furnishing [2].

2.2. History of Weaving

Weaving is probably as old as human civilization. One of the basic necessities of human is to cover their bodies to protect themselves from outside effects and look more civilized to the eye. Other reasons for development of different clothing throughout the history are social status, religious requirements, etc. Clothing trends depend on location as well [2].

Historical findings suggest that Egyptians made woven fabrics some 6000 years ago. In the earliest primitive civilizations, the threads used for weaving were very coarse. In general therefore, the cloth produced was also crude and coarse, although there are references in even the oldest literature for fine fabrics. Chinese made fine fabrics from silk over 4000 years ago. The filaments extruded by the silkworm were used by Chinese to make the finest of fabrics. It is said that Emperor Huang Ti's Empress invented the loom. However it is probable that the hand loom has been invented many times in different civilizations [2,3].

Weaving started as a domestic art and stayed as a cottage industry until the invention of the fly shuttle. In 1773 Kay invented the fly shuttle, which enabled weft to be inserted more rapidly, and this led to a shortage of yarn. Kay's shuttle was hand operated and although it made possible considerable increases in productivity, it also opened the door to even greater advances as soon as power could be applied to the loom. In 1785, Cartwright invented the power loom, which could be operated from a single point. In 1745, de Vaucanson made a loom, further developed by Jacquard, on which intricate patterns could be achieved by lifting the warp ends almost separately as required. This invention established a line of looms, which are still known today as Jacquard looms [2,3].

In the early 1800s looms made of a cast iron, were operated by steam power. By 1821 there were over 5000 looms in operation in 32 mills in the north of England. Just over 10 years from that date the number had increased 100.000 shuttle looms operating in England. Power loom required stronger warp yarn, resulting in development of the first sizing machine in 1803. The processing principles of these looms were pretty much the same as today's shuttle looms [2,3].

In the early 20th century, improvements were made in winding and warping of yarns. The looms were improved further, including warp tying machines and warp drawing-in machines. After the end of World War II, the modern textile industry began to emerge. Inventions of synthetic fibers change the scope of textile industry drastically. In 1930 an engineer named Rossmann developed the first prototype of projectile weaving machines. In 1953 the first commercial projectile weaving machines were shipped. Production of rapier and air jet weaving machines started in 1972 and 1975, respectively [2].

The fundamental principle of weaving has remained unchanged for centuries. Today, as in the past, woven fabrics are made by crossing yarns over and under at right angles to one another. This method of producing textiles has many advantages, e.g., stability and resistance to deformation by compressing and tensile stress. These are features that distinguish woven fabrics from the cheaper nonwovens and knitted goods. Until recently, all the woven fabrics in the world have been produced on single phase weaving machines, and the focus in technological progress has been on accelerating the conventional weaving process. Over a period measured in centuries the weft insertion rate, for example, has increased from a few meters per minute to over 2000 m/min. The weft insertion rates of today's conventional single phase weaving machines are approaching physical limits. Further major increase in performance can only be achieved with new technologies such as multi phase weaving machines [2].

1.2. 2.3. Weaving Structures and Their Properties

The manner in which groups of warp yarns are raised by the harnesses to permit the insertion of the weft yarn determines the pattern of the weave, and in large measure the kind of fabric produced. Weave patterns can create varying degrees of durability in fabrics, adding to their usefulness and also to their appearance. There are three basic weaves in common use for majority of fabrics are plain, twill and satin, with some variations [19].

2.3.1. Plain and plain derivatives

The plain weave is sometimes referred to as the tabby, homespun or taffeta weave. It is the simplest type of construction and is consequently inexpensive to produce. On the loom, the plain weave requires only two harnesses. Each weft yarn goes alternately under and over the warp yarn across the width of the fabric. As the manufacture of the plain weave is relatively inexpensive, it is used extensively for cotton fabrics and for fabrics that are to be decorated with printed designs, because the surface that it produces is receptive to a direct print. The appearance of the plain weave may be varied by differences in the closeness of the weave, by different thickness of yarn, or by the use of contrasting colors in the warp and weft. The last method gives the effect of a design [19].

Plain weave is the most important of all structures and forms the foundation for many combinations and techniques. It is undoubtedly one of the most used weaves. The variations are endless, from very light sheer fabrics made of silk or rayon, to the heaviest canvas made of hemp or cotton. Plain weave can be woven with only two shafts [21].

Plain weaves as indeed many other weaves, are classified according to their warp or weft predominance. In plain weave however this predominance extends to both sides of the fabric, unlike some other weaves where it is only on the face. Square or balanced plain weaves are woven with the same number of ends and picks per 1 cm and also with the same yarn. Both warp and weft threads will do an equal amount of bending. The fabric is reversible, except when it has been through a finishing process that is applied only to the face of the cloth.

Warp faced plain weaves have a substantially higher number of ends than picks, and the warp covers the weft on both sides of the fabric. The warp yarn is usually finer in count than the weft, causing a rib like effect. The weft thread tends to lie almost straight and the warp is bending, resulting in a higher shrinkage of the cloth in the warp direction.

Weft faced plain weaves have a considerably higher number of picks than ends and the weft covers the warp on either side of the fabric. To achieve the best results in coverage, the weft yarn should be of a light twist and very little tension while a high warp tension should be applied. Commercially these fabrics are not woven in great quantities as the production costs, due to the large number of picks are too high [21].

The derivatives of plain weave are;

- Rib weaves
    - Warp ribs
        - Regular warp rib
        - Irregular warp rib
        - Self stitched warp rib
        - Figured warp rib
    - Weft ribs
        - Regular weft rib
        - Irregular weft rib
        - Self stitched weft rib
        - Figured weft rib
        - Combined warp and weft ribs
- Basket weaves

- Hopsack weaves
  - Regular hopsack
  - Irregular hopsack
  - Stitched hopsack
  - Combined hopsack
- Bedford cord
  - Regular bedford cord
  - Irregular bedford cord
  - Wadded Bedford cord
  - Figured Bedford cord

2.3.2. Twill and twill derivatives

Diagonal lines in the fabric are the most characteristic features in twill weaves. Closer setting, more weight and better draping can be achieved with twill weaves, and diagonal lines in different sizes add decoration to the fabric. The variations with twill weaves and their ultimate end uses are manifold, ranging from apparel fabrics and household textiles to industrial fabrics produced in man-made fibers. In Z-twill the diagonal lines are formed by advancing one end to the right on every successive pick. Generally twills are woven in Z-direction. In S-twill the diagonal lines are formed by advancing one end to the left on every successive pick. When the direction of the diagonal starts from the upper left-hand side of the fabric and moves down toward the lower right is called a left-hand twill. When the direction of the diagonal starts from the upper right-hand side of the fabric and moves down toward the lower left, it is called a right-hand twill. Although there is no advantage of one over the other, the direction of the diagonal can aid in the recognition of the face of the fabric [19, 21].

Increased ornamentation may be obtained by varying the slant of the diagonal and yarn colors. The values of the twill weave include its strength and drapability. The diagonally arranged interlacings of the warp and weft provide greater pliability and resilience than the plain weave. Also twill fabrics are frequently more tightly woven and will not get dirty as quickly as plain weave, though twills are more difficult to clean when they do get soiled. The yarns are usually closely beaten, making an especially durable fabric. Twill weaves are therefore commonly used in men's suit and coat fabrics for work clothes, where the strong construction is essential [19].

Twill weaves are also classified as even and uneven according to the number of warp and weft yarns that are visible on the face of the fabric. Square or balanced twills are made from the same number of ends and picks having the same yarn count and an identical sequence of interlacing. The diagonal line lies at an angle of 45° to warp and weft. All examples have identical warp and weft floats on either side of the fabric. If woven with the same yarn counts, colors and sett they can be reversed. Most twill weaves are uneven. Uneven twill may show more warp than weft yarns in the recurring design; this is called a warp-faced twill. If more weft yarns than warp yarns show on the face, the weave is called weft-faced twill. Face and back of the fabric are therefore not identical [21].

Weft-faced twill weaves show predominantly the color and yarn of weft. They are achieved by two ways. Firstly with a higher number of picks than ends and a weave structure that has predominantly weft floats. The diagonal line has a lower angle. Secondly with an identical warp and weft sett and a weave structure that has predominantly weft floats. The diagonal line lies at an angle of 45° to warp and weft. All examples are predominantly weft-faced[21].

Warp-faced twill weaves show predominately the color and yarn of the warp. They are achieved with a higher number of ends than picks and a weave structure that has predominantly warp floats. With more ends than picks the diagonal line will have a steeper grading. With an identical warp and weft sett and a weave structure that has prominently warp floats. The diagonal line lies at an angle of 45° to warp and weft. Warp-faced twills generally have much more warp than weft yarns; consequently, such fabrics hold their shape better and drape better due to the warp's greater twist and resilience [19, 21].

The derivatives of twill weave are;

- Waved and diamond twill
    - Vertical waved effect
    - Horizontal waved effect
    - Diamond effect
- Herringbone and diaper twill
    - Horizontal herringbone effect
    - Vertical herringbone effect
    - Diaper or diced effect
- Broken twill
- Entwined twill
- Rearranged twill
- Elongated twill
- Curved twill
- Combined twill

2.3.3. Satin and satin derivatives

Fabrics made from these weaves have a typically smooth and generally lustrous appearance without strong diagonal lines of the type associated with twill weaves. The satin weave is used in fabrics from a wide range of fibers. Flat continuous filament yarns are very commonly used, since their bright lustrous surface enhances the smooth appearance of the fabric. However, cotton yarn, mercerized or unmercerized, and worsted yarns are both put into these weaves. A satin is warp-faced, whereas a sateen is weft-faced fabric. Satin/sateen structures are used for the production of apparels, curtains, upholstery and household textiles [22].

Regular satin/sateen weaves are developed with the help of a move or count number. To establish this number certain rules have to be considered. The number must be larger than one and must not be one less than the number of threads in the repeat, as this would create a twill. The number must not be a factor. The move number can be applied by counting warp ways or weft ways. The repeat of a satin/sateen weave is also expressed in numerical terms. Each end and pick intersect only once in a repeat [21].

The derivatives of satin weave are;

- Reinforced satin
- Rearranged satin

2.4. Woven Fabric Geometry

Yarns are interlaced into an interlocking structure to produce a sheet-like material, which has a three-dimensional macro structure. The weave shown in Figure 2.2 is a plain weave [3].

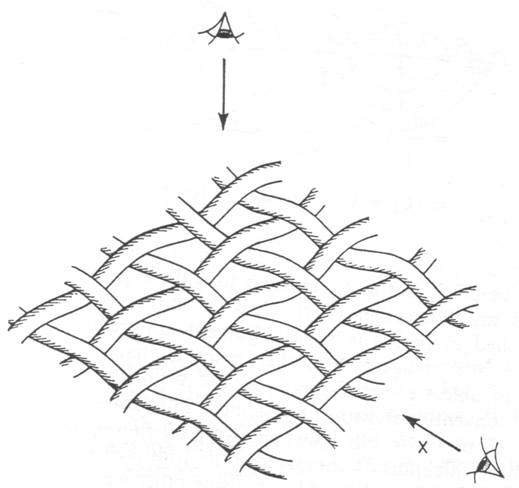


Figure 2. 2 Three dimensional macro structure of fabric

Frequently, a woven fabric is used to obscure whatever lies beneath it and in such cases the covering power of the material is important. There are two aspects of covering power; the optical and the geometrical. The optical aspect is a function of the readiness with which the surface of the material reflects and scatters the incident light. The geometrical aspect is a function of the extent to which the superficial area is covered by the component yarns.

The optical effects are controlled by the nature of the fibers and the surfaces presented to the incident light. Optical characteristics are also affected by the structure into which the fibers are fitted. Thus both the yarn and fabric structures will influence greatly the overall optical behavior. Dyeing and finishing will also play a part [3].

Cover Factor

The geometrical aspect may be defined by the cover factor shown in Figure 2.3. This differs from covering power, which takes into account the optical effects; cover factor is concerned only with the geometry [3].

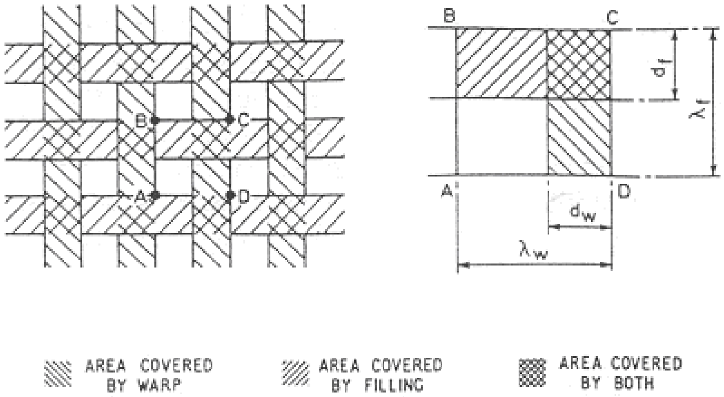


Figure 2. 3 Cover factor

Where d_W = the width of the warp yarn as it lays in the fabric, d_f = the width of the filling yarn as it lays in the fabric, λ_W = the pitch of the warp yarns, and λ_f = the pitch of the filling yarns.

The warp wise cover may be defined as;

$$C_W = \frac{d_W}{\lambda_W} \tag{2.1}$$

The filling wise cover may be defined as

$$C_f = \frac{d_f}{\lambda_f} \tag{2.2}$$

The percentage fabric cover factor;

$$C_{fab} = \frac{\text{Total area obscured}}{\text{Area enclosed}} * 100\% \tag{2.3}$$

$$C_{fab} = \frac{(\lambda_W - d_W) d_f + d_W \lambda_f}{\lambda_W \lambda_f} \tag{2.4}$$

$$C_{fab} = \frac{\lambda_W d_f + d_W \lambda_f - d_W d_f}{\lambda_W \lambda_f} * 100\% \tag{2.5}$$

$$C_{fab} = \frac{d_f}{\lambda_f} + \frac{d_W}{\lambda_W} - \frac{d_W d_f}{\lambda_f \lambda_W} * 100\% \tag{2.6}$$

$$C_{fab} = C_f + C_W - C_f C_W) * 100\% \tag{2.7}$$

Geometrical Models

The structure, appearance and hand properties of a fabric depends on yarn number, fabric sett and weave pattern so the researches on fabric geometry begins with investigating the fabric sett [23].

Ashenhurst (1884), Armitage (1907), Law (1922), Brierley (1931), Snowden (1965), Von Bergen (1969) made important researches on fabric sett and defined the maximum available fabric sett values and normal fabric sett values according to these maximum values by some coefficients obtained from the experiments and formulas. These researches are followed by geometry works. At the beginning of all geometrical researches Pierce (1937), explains the first model that defines the shape of yarn and the location of warp and weft yarns against each other. Then Kemp (1985) developed geometrical models based on Pierce model, and Hamilton (1964) showed the way of applying these models on fabrics except plain weave type. The first reliable model belongs to Pierce that assumes the yarn as a flexible structure. This model was developed by Oloffson (1964) with a wide range [23].

Pierce's Geometrical Model

Pierce suggested the geometry shown in Figure 2.4 for a fabric of plain structure. In this model, the interior forces were not taken into consideration [24].

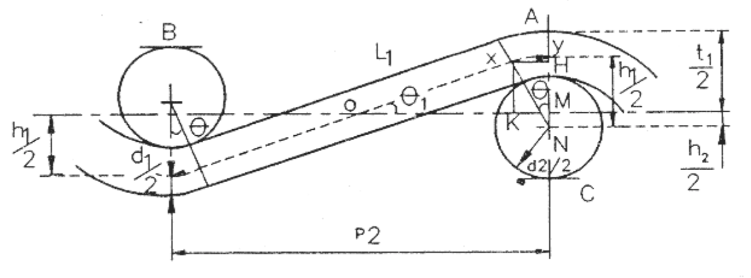


Figure 2. 4 Pierce's geometrical model for plain weave

The foundations of this model are as follows:

a. The cross section of yarn is circular.
b. Yarn is flexible enough that shows no response against interior forces in a woven fabric.

c. The shape of yarn is circular when surrounding the other yarns is a straight line at all other points.

Kemp's Geometrical Model

Kemp (1958) suggested an acceptable and simple geometrical model in comparison to Pierce model [23]. This model takes the yarn flattening into consideration and defines the cross section of yarn as race track as shown in Figure 2.5.

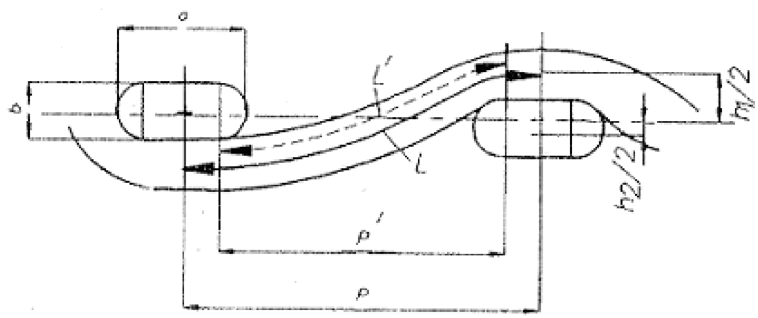


Figure 2. 5 Kemp's geometrical model

Hamilton's Geometrical Model

Hamilton (1964), developed a geometrical model for weave types except plain, by depending on the Kemp's race track model for plain fabrics shown in Figure 2.6 [23].

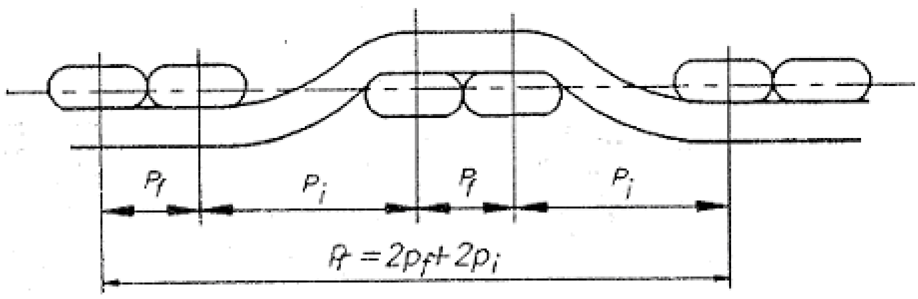


Figure 2. 6 Hamilton's geometrical model

Pierce's Elastic Geometrical Model

As shown in Figure 2.7, in this model, it is accepted that the yarn changes shape as a result of forces that effects at interlacing points of a woven fabric. Yarn may be misshapen by flattening and the shape of cross section isn't important, may be neglected [23].

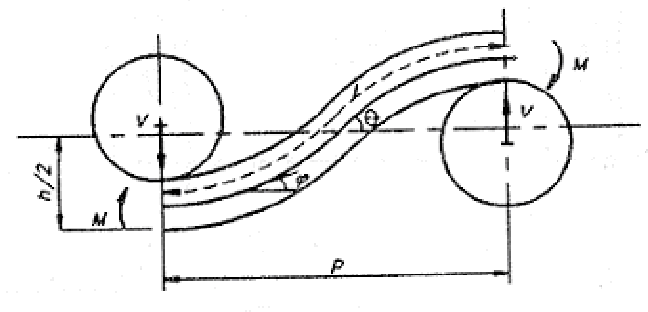


Figure 2. 7 Pierce's elastic geometrical model

Oloffson's Geometrical Model

Oloffson evaluates the yarn geometry shown in Figure 2.8 as a function of exterior forces that affects the fabric and opposite reaction forces in the fabric. This model accepts a relationship between the yarn crimp in a fabric and the released form of yarn after taken from the fabric [23].

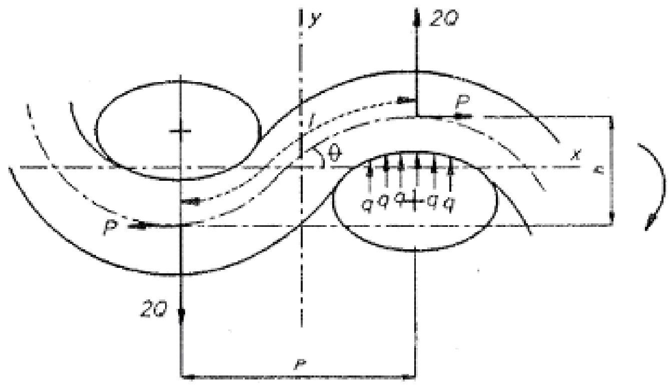


Figure 2. 8 Oloffson's geometrical model

CHAPTER 3

WOVEN FABRIC PROPERTIES AND TESTING

3.1. Introduction

Textile fabrics are manufactured for many different end uses, each of which has different performance requirements. The chemical and physical structures of textile material determine how it will perform, and ultimately whether it is acceptable for a particular use [8].

Textile tests provide information about the physical and structural properties and the performance properties of the textile. Physical properties include those that characterize the physical structure of the textile, and test that measure these properties are sometimes called characterization properties. Physical properties include factors, such as the length, fineness, linear density of fibers and yarns, yarn twist, and fabric thickness, width, weight, and the number of yarns per unit fabric area. Performance properties are those properties that typically represent the textile's response to some type of force, exposure, or treatment. These include properties such as strength, abrasion resistance, pilling, and colorfastness. Performance properties are always influenced by physical properties. Although performance properties are often the primary factor in product development, aesthetic properties, such as the way a fabric feels or drapes, also enter into design and development decisions. Professionals developing textile products use results from textile testing in selecting materials [8].

The reasons for carrying out tests on fabrics are numerous and varied, some common ones being [25]:

- To check that the fabric conforms to specification.
- To note the effects of changes in structural details.
- To note the effects of physical and chemical treatment, exposure to weather, laundering, etc.

- To obtain some indication of probable performance in use.
- To investigate causes of failure and costumer complaints.
- To help in design of a fabric for a specific purpose.
- To study the interaction of fiber, yarn and fabric properties.

3.2. Quality Control

Textile products are tested at various stages of production to assure quality processing and products. Manufacturers may use quality control testing as a marketing tool, in that trade names imply to the consumer that certain levels of quality are assumed to be standard for products produced by the manufacturer. Quality control testing aids the manufacturer in assuring that the expected level of quality is maintained [8].

3.3. Standard Test Methods

Test methods are developed for textile products by several different organizations. They are typically developed in response to a need expressed by an individual manufacturer, a product user or occasionally by a consumer group.

Over the years many organizations dealing in textiles and textile products have written specifications for what they sell or what they want to buy. Clearly that means that different companies' specifications for the same product are often different. Some might even choose different test methods to measure the same characteristics of a material. Consequently, each time buyers set out to write contracts with various sellers, they have to make sure they are talking about the same specifications and test methods. Many buyers in particular do not have the expertise to write good specifications and they want to be able to buy the goods with some confidence that they will be serviceable. In other words, there are strong incentives for those buying and selling textiles and textile products to agree on standard specifications and standard test methods that everyone can refer to end use [25].

A specification or test method becomes "standard" because one or more groups of people agree to use it. One or more employees of a company can decide on a company standard; members of an association can agree on an association standard; companies and associations in a whole country can agree on a national standard; and by extension, a group of different countries can develop an international standard. The concept of agreed on standards is not limited to specifications and test methods but also applies to definitions, classifications, and various procedures for doing things.

Finally, once a test method is approved as a standard test method for the organization, American Association of Textile Chemists and Colorists (AATCC) and the American Society for Testing and Materials (ASTM) and the International Organization for Standardization (ISO), the method must undergo periodic reconsideration and re-approval in order to be retained as a standard test method. This extensive development and review process is intended to assure that standard test methods meet the needs of users. Test method development and revision are on going processes. New test methods are introduced every year and older methods are dropped in response to the changing needs of the textile, apparel, and home furnishings industries and their consumers [8].

Although many voluntary international groups promote technical cooperation, the major worldwide specialized organization for standardization is the ISO. Its work brings together the interests of standards procedures and standards users in almost all areas of technology except electricity and electronics. ISO is a nongovernmental organization, but many of its national members are government agencies [25].

3.4. Properties of Fabrics

The demands made on a fabric, and hence the properties and characteristics it must have, are determined by the use to which it is put and also the requirements of satisfactory behavior in making-up. Certain requirements are common to most fabrics, adequate strength and durability for example, whilst other properties such as water proofness or resistance to agencies such as acids or alkalis are demanded for fabrics to be used for special purposes. The uses to which fabrics are put are extremely wide and diverse and the properties and characteristics which are of importance are correspondingly diverse, as are the corresponding methods of examining and testing fabrics.

The performance characteristics of fabrics can be grouped in a number of broad categories as follows. The entries in each category are illustrative only, since they cannot be exhaustive:

Mechanical properties

- Tensile,
- Tearing strength,
- Bursting strength,
- Resistance to abrasion,
- Dimensional stability,
- Stretch and recovery.

Aesthetic acceptability

- Handle and drape,
- Crease recovery,
- Easy care properties,
- Luster,
- Appearance retention including color fastness,
- Color matching.

Comfort

- Permeability to air and moisture vapor,
- Thermal insulation,
- Stiffness,
- Smoothness.

Garment manufacture

- Sewability,
- Dimensional stability,
- Tailorability,
- Freedom from static.

Special applications

- Flame retardance,
- Waterproofness,

- Wind resistance,
- Resistance to-acid,
- Alkalis and industrial solvents.

The above classification is mainly applicable to clothing fabrics but it should be remembered that the textile industry produces a vast range of industrial fabrics from the extremely lightweight to very heavy fabrics, for uses such as conveyor belts and other engineering purposes [22].

3.5. Woven Fabric Properties

Fiber, yarn, fabric structure, and finish each play a role in the way in which a given textile product will behave during its “use lifetime.” The sum total of fabric behavior is affected by fiber, yarn, fabric construction, and special finishes. Some of the aspects of fabric performance that are affected include durability, appearance and comfort [4].

The structural characteristics are fabric sett, yarn twist, weave, the warp and the weft count, crimp and mass per unit of surface. Many of these parameters are linked together in a theory on fabric structure from which the important concept known as cover factor [26].

It is a very detailed expression to explain all members of fabric performance characteristics classified above. So in this chapter the structural parameters; fabric thickness, fabric weight, fabric sett, yarn crimp and the mechanical properties; breaking strength and elongation, pilling resistance, abrasion resistance and dimensional stability included in this thesis will be described in a detailed manner.

3.5.1. Fabric thickness

Although the thickness of a textile fabric is just as much a basic physical property as the fabric's width or weight, thickness is of major practical concern only in certain end uses. In some industrial applications, the thickness of a fabric "may require rigid control within specified limits." Changes in thickness may be used to measure the effect of wear or abrasion, as in carpets. Wool fabrics subjected to felting shrinkage may show increases in thickness. The thickness of fabrics made of bulk yarns will be a function of the degree of yarn bulkiness and fabric construction factors [27].

A very interesting area of research is the relationship of fabric thickness to the warmth or thermal insulation of fabrics and garments. Even though thickness is almost irrelevant in many apparel fabrics, it becomes very important for thermal underwear and for winter outerwear. Studies of the relationship between fabric thickness and thermal insulation or warmth indicate that for most materials warmth and thickness are directly proportional; the thicker a material, the warmer it is.

All instruments for measuring fabric thickness consist of a flat metal surface (the anvil) and a presser foot, usually circular, of known area smaller than the anvil. The instrument must provide for the gradual lowering of the presser foot onto the anvil and for reading the distance between the two to the nearest 0.001 inch or 0.02 millimeter. A randomly selected specimen at least 20 percent larger than the area of the presser foot is placed on the anvil, and the presser foot is lowered into contact with the top surface of the fabric. Then the thickness is read from the dial of the instrument [27]. A model of thickness measurement instrument is shown in Figure 3.1.

Figure 3. 1 Paramount testing instrument for measuring thickness

The testing instruments for measuring thickness are often used for other purposes as well. One can measure the decrease in thickness (compression) as increasing loads are placed on the presser foot resting on a specimen. Afterward, the increments of load can be removed and the increase in thickness is measured over a period of time.

Such measurements are obviously relevant for blanket fabrics, carpets, and all kinds of cold-weather apparel.

3.5.2. Fabric weight

Fabric weight is the weight of yarn per square meter in a woven fabric, which is the sum of the weight of warp and the weight of the weft. Fabric weight can be expressed in two ways: direct and indirect system. In the direct system, the fabric weight per area is given, e.g.. g/m^2 or oz/yd^2. In the indirect system, which is used less in practice; usually the running length per weight is given. However, in this case the fabric width should also be specified. The instruments; sensitive scale and specimen cutter, which are necessary for measurement of fabric weight, are illustrated in Figure 3.2. Fabric weight is affected by the following: [2,28]

- Fiber density
- Yarn size
- Contractions
- Fabric construction
- Weave pattern
- Tensions during weaving
- Finishing

Figure 3. 2 Testing instruments for measuring weight

3.5.3. Warp and weft sett

Sett or thread density is normally expressed as the number of threads per centimeter, although there are still times when threads per inch are used. There are two methods of measurement; direct and indirect. In the direct measurement the fabric sample is placed on a flat surface, making sure it is not under tension or distorted. A piece glass is placed on top and the fabric viewed through the lens. A magnified image of the fabric is produced. A piece glass is basically a magnifying glass mounted within a stand, the base of which is to cut to precise measurements, for example 20 X 20 millimeters, 10 X 10 millimeters, 1 X 1 inch. Otherwise it may be in the form of a cross, with each arm and each cross axis having a different measurement. The indirect measurement is carried out using an optical device known as a taper line grating. This is a flat sheet of glass with a large number of straight lines engraved on it in a tapered fashion so that their density increases form left to right. When it is placed on top of a simple woven construction the threads interfere with the line grating and an optical pattern is produced. The pattern is used to indicate the thread density [28].

3.5.4. Warp and weft crimp

Due to the necessity of interlacing in a woven fabric structure, at least one of the two yarn sets must have crimp. In most of the cases, both warp and filling have crimp. However, theoretically it is possible to have straight filling and crimped warp and vice versa as shown in Figure 3.3. The amount of crimp in each yarn can be largely controlled by controlling the yarn tensions during weaving. Crimp ratio between warp and filling can also be changed to a certain extent for some yarns such as monofilaments with heat setting or finishing processes. Tensioning a yarn causes its crimp to be reduced. This will result in tension increase in the other yarn set. Another method to change crimp ratio is to relax and shrink the fabric with water or heat. Changing the ratio of crimp between the warp and filling yarn is called crimp transfer or crimp interchange.

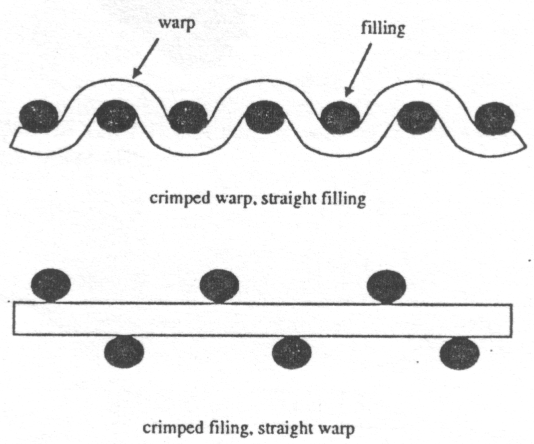


Figure 3. 3 Possible yarn crimp variations in fabrics

Yarn crimp is also affected by the pattern of yarn interlacing in a fabric; high frequency of interlacing increases yarn crimp. For example, the plain weave has the highest frequency of interlacing and therefore the highest yarn crimp level in both warp and filling yarn. Satin or sateen weaves have the lowest frequency of interlacing and hence lowest degree of yarn crimp. Increasing yarn crimp in a particular direction decreases the fabric modulus and increases the elongation in that direction. This is because the tensile load is initially used to de-crimp the yarn which is relatively easier than extending the yarn. Crimp affects the weight, thickness, cover, flexibility and hand of fabric [2].

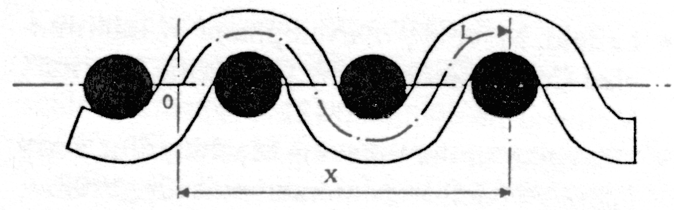


Figure 3. 4 Crimped structure of a plain fabric

The American Society for Testing Materials (ASTM) makes two types of definitions related to crimp; percent crimp and percent take-up as shown in Figure 3.4 [2].

$$\%\,Crimp\,(crimp\ \ factor) = \frac{L-x}{x} * 100 \tag{3.1}$$

$$\%\,Take-up\,(contraction) = \frac{L-x}{L} * 100 \tag{3.2}$$

Where L represents the length of yarn before crimping and x denotes length or width of the fabric.

3.5.5. Breaking strength and elongation

Strength is one of the tensile properties of textile materials; comprising their resistance to stretching or pulling forces. In use and care textile products are subjected to many different forces: stretching, twisting, bending, shearing, and compression. The level of strength required from a yarn or fabric depends on its end use. For some end uses it is that the higher the strength of the materials, the better it is for its end use. This is particularly true for yarns and fabrics intended for industrial products. The level of tensile force that a seat belt or parachute fabric is expected to withstand is higher than that expected for apparel fabrics [8,29].

In a strength test the amount of force required to break a textile material and the amount it extends before breaking are usually reported. For fibers and yarns, the initial resistance to force, the modulus, and the point at which permanent deformation occurs can be obtained from plots of force against extension. Tensile testing machines measure the resistance to force and the extension of specimens to provide these values [8].

Breaking strength is the maximum tensile force recorded in extending a test piece to breaking point. It is generally referred to as strength. The force at which a specimen breaks is directly proportional to its cross-sectional area, therefore when comparing the strengths of different fibers, yarns and fabrics allowances have to be made for this. The tensile force recorded at the moment of rupture is sometimes referred to as the tensile strength at break. The elongation that a specimen undergoes is proportional to its initial length. Strain expresses the elongation as a fraction of the original length [29]:

$$\text{Strain} = \frac{\text{Initial length} - \text{Final length}}{\text{Initial length}} = \frac{\text{Extension}}{\text{Initial length}} \quad (3.3)$$

Extension percentage is the strain expressed as a percentage rather than a fraction. Breaking extension is the extension percentage at the breaking point [29].

$$\text{Extension} = \frac{\text{Elongation}}{\text{Initial length}} * 100\ \% \qquad (3.4)$$

3.5.5.1. Fabric characteristics effecting tensile properties

A number of structural properties are important factors in determining the strength of a textile material. Primary importance is the inherent strength of the fibers that make up the fabric. The strength of fibers depends on polymer length and rigidity, inter-molecular bonding within the fibers, and the relative amounts of crystalline and amorphous regions. High strength fibers, such as aramid and carbon fibers, are very crystalline.

Yarn type, yarn twist, and yarn size greatly affect fabric strength. Staple yarns are weaker than filament and textured filament yarns. When staple yarns are subjected to a tensile force, some fibers are broken, but also the frictional forces holding the fibers in the twisted structure are overcome and the yarn is pulled apart. In filament yarns, however, all the fibers in the yarn must break for the yarn to rupture. Consequently, the strength is higher. Ply and cord yarns should have higher strength than single yarns and are often used in ropes and cables [8].

The degree of yarn twist is also important for spun yarns. A more tightly twisted yarn exhibits a higher frictional force between the constituent fibers and is stronger. However, there is an optimal degree of twist, after which strength starts to decline. Finally, the size or count of yarns is a factor in fabric strength. The larger the yarns, the more they are able to bear tensile loads and the stronger they are in absolute terms [8].

3.5.5.2. Instruments for tensile testing

To get an accurate determination of tensile properties, it is necessary to use a machine that applies a force or extension in a fairly constant manner, so you can evaluate how force relates to elongation. There are three general kinds of tensile testing machines: constant rate of traverse (CRT); constant rate of extension (CRE); and constant rate of loading (CRL) [8].

With CRT instruments, the bottom jaw is driven down at a constant speed to elongate the specimen. The top jaw also has to move down to operate the load measuring device. The elongation of the specimen is the difference between the two movements. If the rate of movement of the top jaw is not constant (because the change in load depends on the nature of the specimen), the rate of elongation of the specimen will be not constant. In other words, constant conditions are not achieved as shown in Figure 3.5[28].

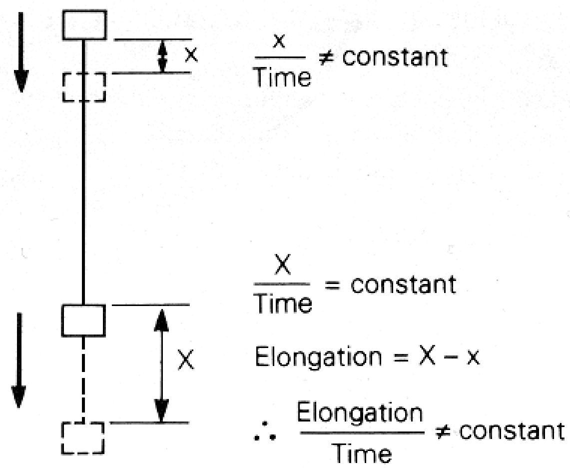


Figure 3. 5 Constant rate of traverse

According to CRE testing principle; the specimen is increased in length by driving the bottom jaw down or the top jaw up at a constant speed shown in Figure 3.6. The rate at which the load changed is variable. All modern electronic instruments use constant rate of extension conditions because it is easy to achieve [28].

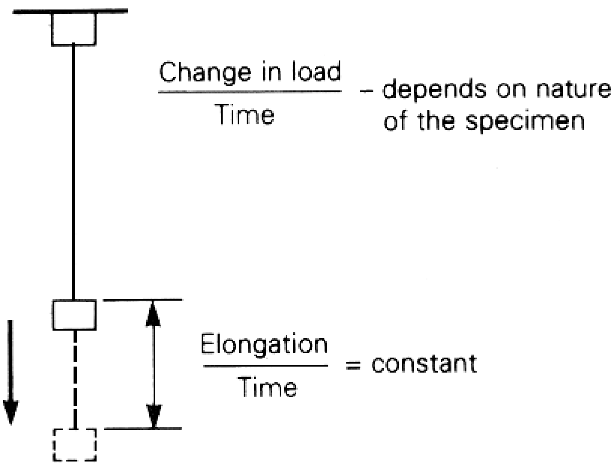


Figure 3. 6 Constant rate of extension

In CRL testing principle illustrated in Figure 3.7, the load on the specimen is increased at a constant rate by varying the speed at which the specimen is increased in length. This is difficult to achieve.

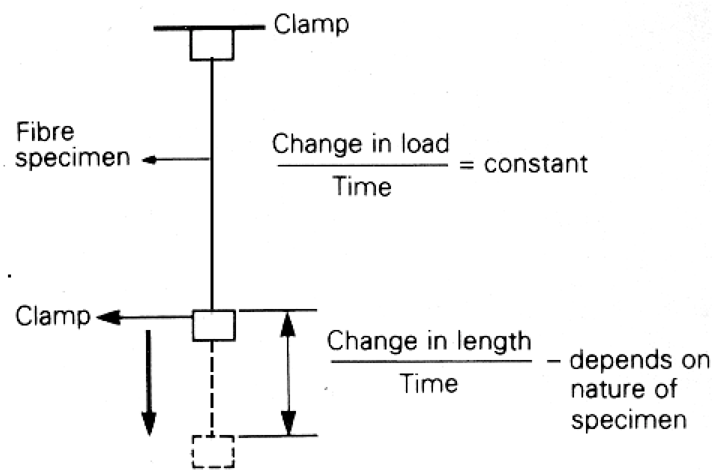


Figure 3. 7 Constant rate of loading [28]

Devotrans G-21 instrument which works with CRE principle is given in Figure 3.8

Figure 3. 8 Devotrans G-21 testing instrument for measuring breaking strength

3.5.5.3. Interpreting results

Tensile tests give useful results for determining applicability of textile materials for specified end uses. Most ASTM specifications for textile end uses include minimum levels of strength that are appropriate for the intended use. Reference to these specifications can aid in selecting fabrics for textile products. Some of these strength specifications are compiled in Table 3.1.

Table 3. 1 ASTM performance specifications for breaking strength [8]

	Breaking Strength	
Fabric For:	N	Ibf
Lingerie	67	15
Women's blouses	111	25
Men's dress shirts	111	25
Men's overcoats	133	30
Men's rainwear	222	50
Sheets	222	50
Women's coveralls	222	50
Upholstery	222	50
Career suits	267	60
Men's coveralls	308	70

3.5.6. Pilling resistance

Pilling is a fabric surface fault characterized by little balls or "pills" of entangled fibers clinging to the fabric surface given in Figure 3.9. During pilling fibers become entangled, and the different fibers around them join this structure, causing a more significant default on the fabric surface. The unsightly pills are formed during use and laundering of the textile product, and most often are seen in areas of a garment that undergo the most rubbing, such as under the arms or inside the collar of a shirt. Pilling is due to yarn structure, both yarn type as well as degree of twist, and inherent fiber strength [8,15].

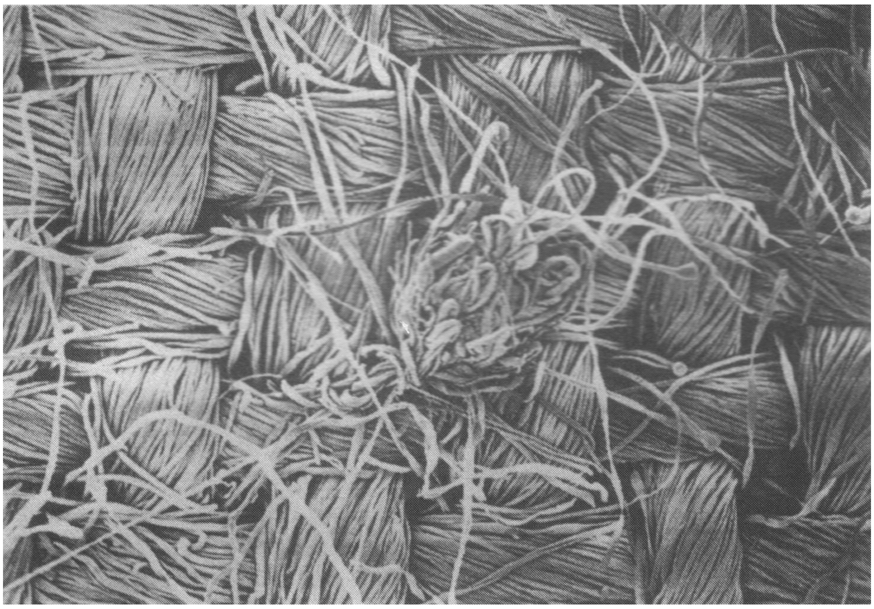


Figure 3. 9 A pill x 50 [29]

Only fabrics made from staple yarns pill significantly. The same types of forces that occur in fabric abrasion can also influence pilling. The initial effect of abrasion on the surface of a fabric is the formation of fuzz as the result of two processes, the brushing up of free fiber ends not enclosed within the yarn structure and the conversion of fiber loops into free fiber ends by the pulling out of one of the two ends of the loop [8,29].

The next stage is the entanglement of the loose fibers and the formation of them into a roughly spherical mass of fibers, which is held to the surface by anchor fibers. As the pill undergoes further rubbing, the anchor fibers can be pulled further out of the structure or fatigued and eventually fractured depending on the fiber properties and how tightly they are held by the structure. In the case of low strength fibers the pills will easily be detached from the fabric but with fabrics made from high strength fibers the pills will tend to remain in place. This factor is responsible for the increase in the propensity for fabrics to pill with the introduction of synthetic fibers [29].

Fabric manufacturers can reduce pilling by increasing the yarn twist so the fibers will not pull out as easily, or by using heavier, stiffer yarns, which will not bend as easily to allow the fibers to become entangled. The use of lower-strength fibers will not prevent pilling, but will alleviate the problem of pilling because pills will be easily brushed off of the fabric during wear. Some fabric finishes that coat the yarn surface will also reduce pilling by preventing the initial loosening of fibers. However, by making any of these changes, it is likely that other properties will be compromised. Higher yarn twist and stiffer yarns will make fabrics more rigid and less drapable, and the use of weaker fibers will result in weaker fabrics. Finishes that reduce pilling by coating the yarn surface may change the fabric hand, make the fabric stiffer, or even alter mechanical properties [8].

Low twist factors and loose fabric structures such as knitwear have a rapid fiber pull-out rate and long staple length resulting in the development of numerous large pills. The life of these pills depends on the balance between the rate of fiber fatigue and the rate of roll up. Pill density can increase steadily, reach a plateau or pass through a maximum and decrease with time depending on the relative rates of pill formation and pill detachment. The pill density is also governed by the number of loose fiber ends on the surface and this may set an upper limit to the number of pills that will potentially develop. This has important implications for the length of a pilling test because if the test is carried on too long the pill density may have passed its maximum. Fibers with reduced flex life will increase the rate of pill wear-off [29].

Because of the fibers that make up the pills come from the yarns in the fabric any changes which hold the fibers more firmly in the yarns will reduce the amount of pilling. The use of higher twist in the yarn, reduced yarn hairiness, longer fibers, increased interfiber friction, increased linear density of the fiber, brushing and cropping of the fabric surface to remove loose fiber ends, a high number of threads per unit length and special chemical treatments to reduce fiber migration will reduce the tendency to pill. The presence of the softeners or fiber lubricants on a fabric will increase pilling. Fabrics made from blended fibers often have a greater tendency to pill as it has been found that the finer fibers in a blend predifferentially migrate towards the yarn exterior due to the difference in properties [29].

3.5.6.1. Pilling tests

Fabric pilling is a serious problem for the apparel industry. Pills present unsightly appearance and can cause premature wear. Resistance to pilling is normally tested in the laboratory by processes that simulate accelerated wear, followed by a manual assessment of the degree of pilling by an expert based on a visual comparison of the sample to a set of test images [30].

The pilling propensity of fabrics is tested by initiating a rubbing action on the fabric surface, and then evaluating the amount of pilling. Evaluation is usually done by comparison to photographic standards, although an alternate method is to count the number of pills in a specified area of fabric. However, pills observed in worn garments vary in size and appearance as well as in number. The appearance depends on the presence of lint in the pills or the degree of color contrast with the ground fabric. These factors are not evaluated if the pilling is rated solely on the number or size of pills. Furthermore the development of pills is often accompanied by other surface changes such as the development of fuzz, which affect the overall acceptability of a fabric. Counting the pills and/or weighing them as a measure of pilling is very time consuming and there is also the difficulty of deciding which surface disturbances constitute pills. The more usual way of evaluation is to asses the pilling subjectively by comparing it with either standard samples or with photographs of them or by use of a written scale of severity [29,8].

In order to assess the amount of pilling on the fabric; they are placed in a suitable viewing cabinet which illuminates the pilled surface with light at a low angle so throwing the pills into relief. The fabric samples shown in Figure 3.10 are assessed by comparing them with a set of photographic standards the rating being a subjective one using the following scale; 1 – very severe pilling, 2 – severe pilling, 3 – moderate pilling, 4 – slight pilling and 5 – no pilling. Points to be taken into consideration in pilling grades are given in Table 3.2 [29].

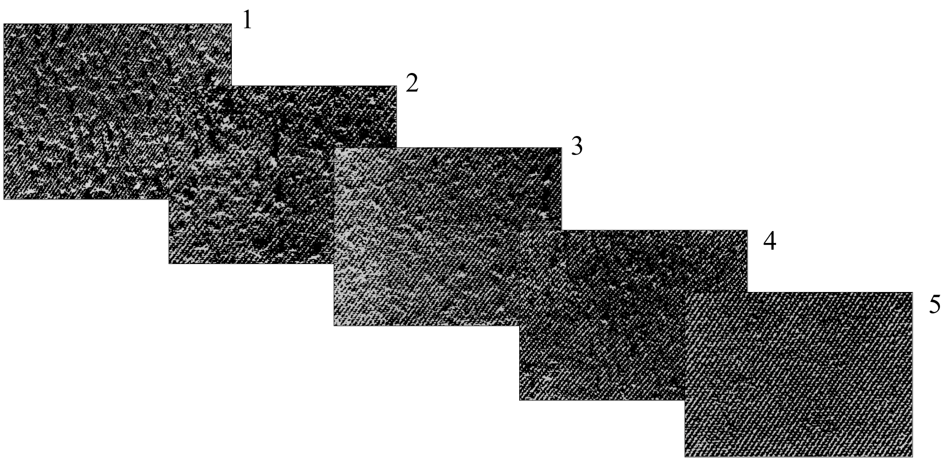


Figure 3. 10 The degrees of pilling

Table 3. 2 Pilling Grades [29]

Rating	Description	Points to be taken into consideration
5	No change	No visual change
4	Slight change	Slight surface fuzzing
3	Moderate change	The specimen may exhibit one or both of the following a. Moderate fuzzing b. Isolated fully formed pills
2	Significant change	Distinct fuzzing and/or pilling
1	Severe change	Dense fuzzing and/or pilling which covers the specimen

3.5.7. Abrasion resistance

Many parts of apparel, such as collars, cuffs, and pockets, are subjected to serious wear during use, which limits their serviceability. The abrasion resistance of textile materials is affected by many factors (e.g. fiber fineness, yarn count, yarn type, weave, e.t.c.) in a very complex and as yet little understood manner. Abrasion first modifies the fabric surface and then affects the internal structure. In many instances, the universal test method, where circular specimens of a fabric are abraded under known pressure against a standard fabric, provides very sensitive results that closely reflect the changes that occur in actual wear. Therefore abrasion can be explained in terms of required number of rubs to cause breakdown of the test specimen or to lead to unwanted visual changes [9].

Fabric wear including abrasion, pilling, and snagging, is influenced by many different factors. The severity of abrasion, pilling, or snagging may vary among fabrics, garments, environmental conditions, and consumers, making it difficult to accurately reproduce actual abrasion in laboratory tests. However, several different types of instruments and test methods have been developed to test for the effects of different abradant factors that might be encountered in actual fabric wear. Abrasion tests are widely used in comparing different fabrics for specific end uses [8].

One of the most important influences on the abrasion resistance of a textile fabric is the fiber content. Some fibers are inherently more resistant to abrasion than are others. Blending either nylon or polyester with wool and cotton is found, to increase their abrasion resistance.

One of the results of abrasion is the gradual removal of fibers from the yarns. Therefore factors that affect the cohesion of yarns will influence their abrasion resistance. Longer fibers incorporated into a fabric provide better abrasion resistance than short fibers because they are harder to remove from the yarn. For the same reason filament yarns are more abrasion resistant than staple yarns made from the same fiber. Increasing fiber diameter up to a limit improves abrasion resistance. Also a decrease in the number of fibers in the cross-section lowers the fiber cohesion [29].

Another factor that is important in woven fabrics is fabric count. The more threads per centimeter there are in a fabric, the less force each individual thread has to take. However, as the threads become jammed together are then unable to deflect under load and thus absorb the distortion [8,29].

There has been found to be an optimum amount of twist in a yarn to give the best abrasion resistance. At low twist factors fibers can easily be removed from the yarn so that it is gradually reduced in diameter. At highest levels the fibers are held more tightly but the yarn is stiffer so it is unable to flatten or distort under pressure when being abraded [29].

The effect of fabric count on abrasion resistance is closely related to yarn size and fabric thickness, which both can affect abrasion resistance as well. The bigger the yarns and, therefore, the thicker the fabric, the more resistant they are to abradant forces [8].

The more pronounced the crimp in a woven fabric is, the more exposed the yarns will be to abrasion, and the faster the fabric will abrade. The crimp of the yarns in the fabric affects whether the warp or the weft is graded the most. Fabrics with the crimp evenly distributed between warp and weft give the best wear because the damage is spread evenly between them. If one set of yarns is predominantly on the surface then this set will wear most; this effect can be used to protect the load-bearing yarns preferentially. One set of yarns can also be protected by using floats in the other set such as in a sateen or twill weave. The relative mobility of the floats helps to absorb the stress [8,29].

Besides the physical structural characteristics of a textile, some types of chemical finishes on a fabric can influence abrasion resistance. Finishes which change the frictional properties of the surface can also alter abrasion resistance. Some finishes which coat the fabric surface can improve abrasion resistance. In contrast, durable press finishes, which are widely used on cellulosic fabrics, may decrease abrasion resistance [8].

3.5.7.1. Durability, serviceability, wear, abrasion

Consumers often include durability as a desirable quality for a particular end use. Several terms that have to do with the durability of textiles are often used interchangeably. The meanings of these terms should be distinguished [8].

The term durability is closely related to fabric performance [8]. It implies a range of specific textile properties associated with the duration of consumer acceptability of the fabric. Durability can be defined as the capability of withstanding wear, thus lengthening the period of usefulness of the fabric or the period of serviceability. The period of usefulness of a fabric is the length of time until one necessary property becomes deficient. This will vary from one consumer to another because of individual differences in use and different expectations among consumers.

Fabric wear is defined as fabric deterioration, which occurs through breaking, cutting, or removal of fibers. This deterioration may be due to mechanical action associated with abrasion. Abrasion is the mechanical deterioration of fabric components by rubbing against another surface. Abrasion ultimately results in the loss of performance characteristics, such as strength, but it also affects the appearance of the fabric [8]. Figure 3.11 shows frictional forces acting on a fabric as it slides across an abradant surface.

There are several ways in which a fabric can be abraded:

- As a fabric rubs on another fabric;
- As a fabric rubs against another object;
- As fibers or yarns within the fabric rub against each other when the fabric bends, flexes, or stretches
- As dust, grit, or other particles held within the fabric rub against fibers inside the fabric.

In many end uses, two or more of these types of abrasion occur simultaneously.

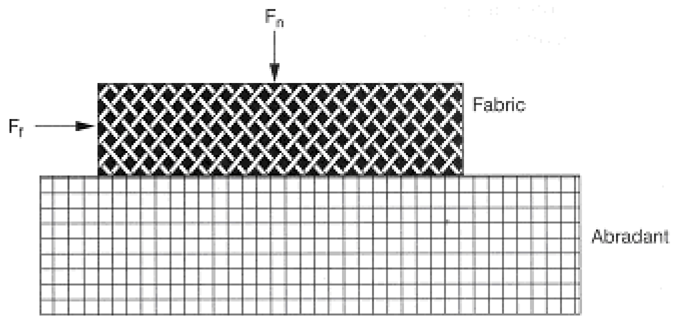


Figure 3. 11 Frictional forces acting on a fabric as it slides across an abradant surface

Fabric against fabric abrasion

If you are wearing a shirt with sleeves, the sleeve fabric will likely rub against the side of the shirt when you move your arms. If you are wearing a jacket over the shirt, the inside of the jacket rubs gently against the outside of the shirt. Similarly, the inside of your shirt rubs against the outer fabric surface of your underwear. If your shirt is worn over pants or a skirt, the two fabrics rub together as you move. When your shirt is laundered, it rubs against other fabrics in the washer or dryer. When you sit in an upholstered chair or lie on a bed, the fabric of your clothing rubs against the upholstery or the bed linens. Although these types of fabric-to-fabric rubbing usually do not involve a significant amount of force individually, eventually fabric abrasion will become noticeable when they occur repeatedly, particularly when other types of abrasion occur simultaneously [8].

Fabric abrasion against a nontextile surface

There are many situations in which a textile fabric comes in contact with another type of surface. The fabric of a long-sleeved shirt is abraded as your elbows rub against your desk. Your swimsuit rubs against the swimming pool or the sand on a beach. The knee area of a trouser is abraded as the child crawls on the floor. In laundering, fabrics rub against the inside of the washer or dryer. The fabric surface of upholstered furniture is abraded as objects are slid across it, and as the upholstery fabric rubs against the metal or wood frame of the furniture [8].

Abrasion between fabric components

Fabric creases are permanent bends and folds in a fabric. When a fabric is creased, its fibers and yarns are forced into the unnatural configuration shown in Figure 3.12.

Instead of being bent back and forth as in a flexing fabric, a creased fabric is intended to maintain this configuration permanently. Creases are particularly subject to abrasion. This is due to the constant pull on the outer side of a creased yarn and the simultaneous compression of fibers on the opposite side. When the creased fabric rubs against another surface, the already stressed crease is more easily abraded than a flat fabric [8].

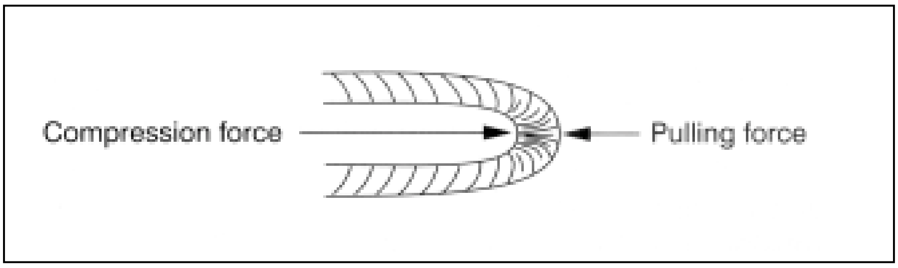


Figure 3. 12 Simultaneous compression and pulling forces in a yarn [8]

Abrasion by foreign materials within the fabric

Just as fibers and yarns within a fabric rub against each other, particles of dust, sand, or other foreign substances held within the fabric can abrade fibers and yarns. Sand and small particles of dirt or clay can accumulate in carpet or in apparel or upholstery fabrics. Sand particles are especially abradant, because of their hardness and sharp edges. As the fabric bends and flexes, and us it rubs against external surfaces, a soil particle in the fabric can abrade the fibers and yarns that it rubs against [8].

3.5.7.2. Fabric configuration during abrasion

Whether abrasion occurs naturally as a fabric is worn or used, or whether the fabric is abraded instrumentally during a test, the type of action that the fabric undergoes during abrasion can be categorized by the fabric configuration during abrasion. These categories include flat abrasion, edge abrasion, and flex abrasion. In flat abrasion, a flat area of the fabric is abraded as it rubs against an abradant surface. Edge abrasion involves rubbing along a fold, as in hems and seamlines. Flex abrasion is rubbing accompanied by flexing and bending. When compared with the types of abrasion, flat abrasion can include; rubbing against another fabric, or against a non-textile surface. Both the flex and edge configurations occur as fabric components rub against each other. Edge abrasion may also include; rubbing against another fabric or against a non-textile surface [8].

The configuration of the fabric determines the accessibility of individual yarns to the abradant force, and influences the pattern of fiber and yarn breakage in the fabric. In apparel, the fabric configuration changes with movements of the wearer, but in some end-uses, the fabric configuration is stationary throughout the period of use. For example, fabric on an upholstered stool maintains a relatively flat configuration on the seat, and an edge configuration where the fabric bends around the edge of the seat. Examination of a fabric, which was abraded over a long period of use in these stationary configurations, shows the different patterns of wear in the flat and edge configurations [8].

3.5.7.3. Abrasion Testing

Because of the difficulty of reproducing "in use" abrasion in the laboratory, there are probably more instrumental methods and instruments for testing abrasion than for any other textile property. Once a textile has been subjected to abrasive action of some kind, there are four ways to assess its resistance to that force [8].

a. Visual Comparison with an Unabraded Specimen

This is a qualitative assessment, which is likely to vary among evaluators. Usually no scale of comparison is used in visual examination.

b. Number of Cycles to Produce a Hole

Several abrasion tests lend themselves to this type of assessment, and most instruments are designed to count the number of times or cycles to produce a hole that the abradant rubs on the specimen surface.

c. Change in a Physical Property

Change in a physical property, such as reduction of fabric strength, loss of weight of the specimen, change in thickness, air permeability, or light transmission can be calculated as a percentage of the original weight or thickness, etc., or the property measurement can be plotted against the number of abrasion cycles to indicate the rate of abrasion.

d. Microscopic Examination

Either light or electron microscopy can be used to examine abraded fabrics. Photomicrographs aid in qualitatively assessing patterns of fiber breakage that occur during abrasion. For this reason, microscopy can be helpful in determining whether a particular instrumental test produces abrasion damage similar to that incurred in an actual use situation.

Martindale Testing Machine

The Martindale abrasion instrument (seen in Figure 3.13) is a British instrument that can be used for woven, knit, or nonwoven fabrics. The instrument subjects specimens to a rubbing motion in a straight line that widens into an ellipse and gradually changes into a straight line in the opposite direction. This pattern of rubbing is repeated until fabric threads are broken or until a shade change occurs in the fabric being tested. A particular advantage of this type of instrument is that it is designed to abrade a fabric uniformly at every point in the specimen. This is achieved by maintaining the flat fabric specimen and the abradant parallel to each other during the test [8].

Figure 3. 13 The Martindale Abrasion Tester

This apparatus is designed to give a controlled amount of abrasion between fabric surfaces at comparatively low pressures in continuously changing directions. The results of this test should not be used indiscriminately, particularly not for comparing fabrics of widely different fiber composition or construction. In the test circular specimens are abraded under known pressure on an apparatus, which gives a motion that is the resultant of two simple harmonic motions at right angles to one another. The fabric under test is abraded against a standard fabric. Resistance to abrasion is estimated by visual appearance or by loss in mass of the specimen [29].

Four specimens each 38 mm in diameter are cut using the appropriate cutter. They are then mounted in the specimen holders with a circle of standard foam behind the fabric being tested. The components of the standard holder are shown in Figure 3.14. It is important that the mounting of the sample is carried out with the specimens placed flat against the mounting block [29].

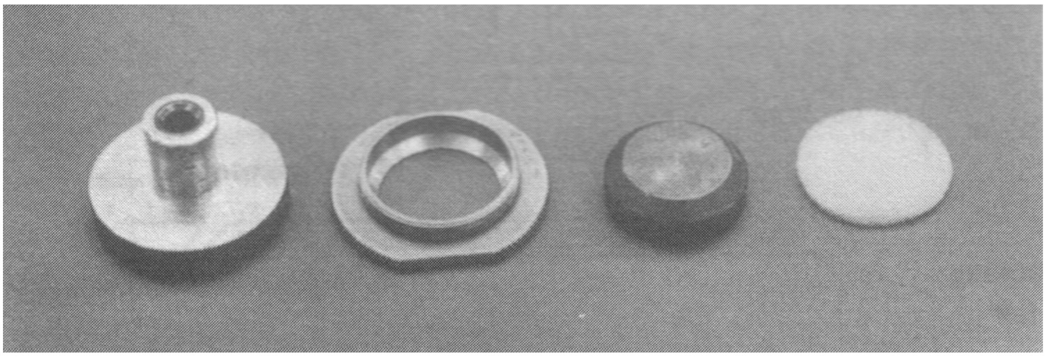


Figure 3. 14 A standard holder for the Martindale Abrasion Tester

The test specimen holders are mounted on the machine with the fabric under test next to the abradant. A spindle is inserted through the top plate and the correct weight (usually of a size to give a pressure of 12 kPa but a lower pressure of 9kPa may be used if specified) is placed on top of this. Figure 3.15 shows the sample mounted in a holder. The standard abradant should be replaced at the start of each test and after 50,000 cycles if the test is continued beyond this number. While the abradant is being replaced it is held flat by a weight as the retaining ring is tightened. Behind the abradant is a standard backing felt which is replaced at longer intervals [29]

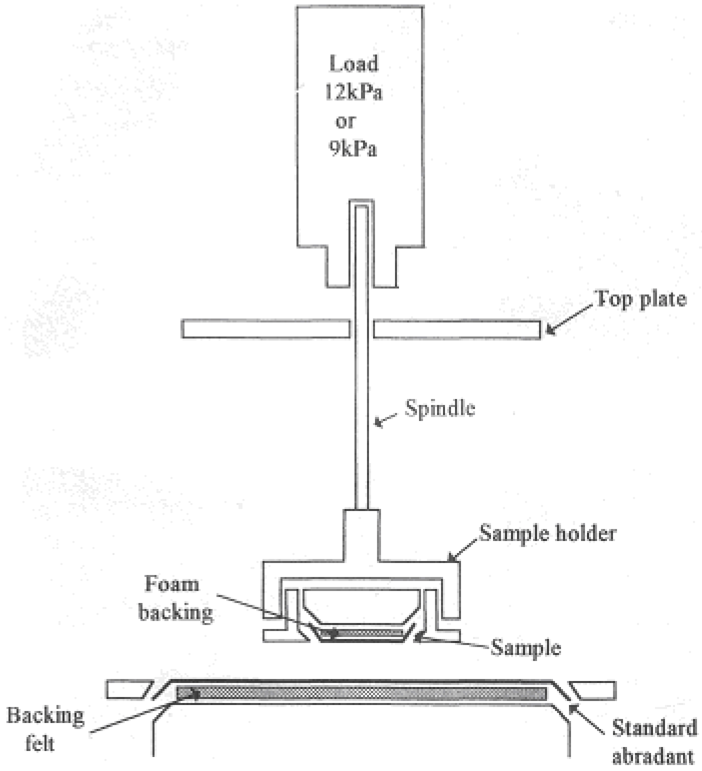


Figure 3. 15 One station of a Martindale Abrasion Tester

3.5.8. Dimensional stability

Woven fabrics account for the majority of the market for cotton goods. Although dimensional instability and distortion after laundering are perceived by consumers as less of a problem in woven cotton fabrics than in cotton knits, these problems do still occur. Refurbishing of textile products, including laundering and dry-cleaning, can affect their shape, dimensions, and other properties. Testing for the effect of refurbishing can help predict consumer satisfaction and is used to develop care labels that are required for textile products. Current care labels include symbols rather than written instructions to provide information on recommended refurbishing procedures [8,13].

Dimensional stability refers to a fabric's ability to resist a change in its dimensions. A fabric or garment may exhibit shrinkage i.e., decrease in one or more dimensions or growth i.e., increase in dimensions under conditions of refurbishing. Items are especially affected by the moisture and heat used in washing, in tumble drying, and in steaming and pressing [8].

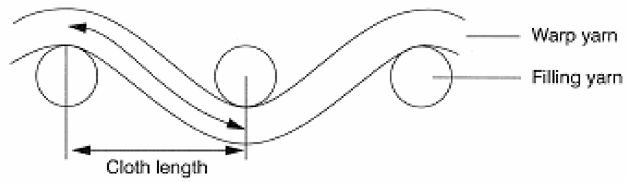
The dimensional stability of a fabric is a measure of the extent to which it keeps its original dimensions subsequent to its manufacture. It is possible for the dimensions of a fabric to increase but any change is more likely to be a decrease or shrinkage. Shrinkage is a problem that gives rise to a large number of customer complaints. Dimensional change can appear early on in the life of a garment so making a complaint more likely [29].

The dimensions of fabrics can become set while they are deformed if they are subjected to a suitable process. Fibers that absorb water can be set if they are deformed while in the wet state and then dried at those dimensions. Thermoplastic fibers can be set if they are deformed at a comparatively high temperature and then allowed to cool in the deformed state. The set may be temporary or permanent depending on the severity of the setting conditions. During relaxation shrinkage it is temporary set that is released. It is generally the case that deformation that has been set can be released by a more severe treatment than the setting treatment. Conversely if it is wished to make the dimensions of the fabric permanent it is necessary to carry out the setting at conditions that the fabric will not meet in use [29].

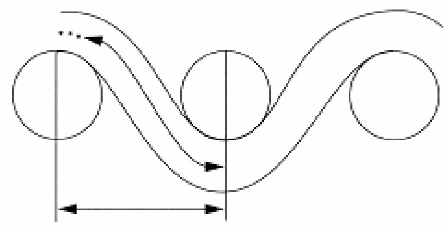
The effect is especially significant in fabrics made of fibers that absorb moisture readily. Hydrophilic fibers absorb water and swell, the magnitude of which depends on yarn and fabric structure. In loosely twisted yarns, there is free space in the yarn for the fibers to swell; but in more tightly twisted yarns, with little free space, the yarn swells with fiber swelling, increasing in diameter. The effect of this swelling in woven fabrics is illustrated in Figure 3.16. When the fibers absorb water, the filling yarns increase in diameter and the warp yarn is stretched to accommodate them [8].

When yarns are woven into fabrics they are subjected to considerable tensions, particularly in the warp direction. In subsequent finishing processes such as entering or calendaring this stretch may be increased and temporarily set in the fabric. The fabric is then in a state of dimensional instability. Subsequently when the fabric is thoroughly wetted it tends to revert to its more stable dimensions which results in the contraction of the yarns. This effect is usually greater in the warp direction than in the weft direction [29].

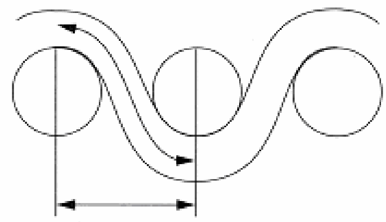
It is easily seen in Figure 3.16 why the moisture regain of the fibers in a fabric is significant. Hydrophobic fibers, such as polyester, swell very little in water and, therefore, fabrics composed of polyester should exhibit minimal relaxation shrinkage. Rayon fabrics, conversely, usually shrink considerably. There are several types of shrinkage that may occur when textiles are subjected to heat and/or moisture [8].



a. Warp and filling yarns before wetting



b. After wetting, filling yarns swell and warp yarns stretch to accommodate them



c. Warp yarns relax to relieve the stress, bringing yarns yarns closer together

Figure 3. 16 Shrinkage in woven fabric

3.5.8.1. Relaxation shrinkage

Relaxation shrinkage results from the relaxation of stresses imposed during weaving or knitting of the fabric. Fabrics are usually stretched during the manufacturing process and, when subjected to conditions that relieve the stresses within the structure, will relax. According to the AATCC definition, relaxation shrinkage can occur when textiles are immersed in water, but are not agitated. Often this effect of swelling and relaxation is more pronounced in unbalanced weaves, with large filling yarns and finer warp yarns, and is sometimes referred to as swelling shrinkage. It is also more likely to occur in fabric with a high fabric count where there is less room for the yarns to swell without affecting those in the opposite direction. There are a number of different causes of dimensional change, some of which are connected to one another. Most mechanisms only operate with fiber types that absorb moisture, but relaxation shrinkage can affect any fiber type [8,29].

Most of the shrinkage due to relaxation occurs with the first washing; a fabric usually relaxes sufficiently during this first laundering, although a small amount of additional shrinkage may occur in subsequent washings. That is why many products are preshrunk by the manufacturer to reduce any shrinkage after purchase by the consumer [8].

Relaxation shrinkage is the irreversible dimensional change accompanying the release of fiber strains imparted during manufacture which have been set by the combined effects of time, finishing treatments, and physical restraints within the structure [29].

Most routine fabric finishing processes, such as scouring, bleaching, and dyeing, allow for some relaxation. However, often these processes include drying of the fabric under tension, which reintroduces strains in the material. To control shrinkage, fabrics can be given a compressive shrinkage treatment in which they are wetted and then mechanically compressed. Garment finishing or dyeing that is used for some products can also inhibit shrinkage. Stone washing of jeans after construction allows for relaxation shrinkage before consumer use [8].

3.5.8.2. Progressive shrinkage

Progressive shrinkage is dimensional change that continues through successive washings. It occurs when a textile is agitated while it is immersed in water. Unlike relaxation shrinkage, which relieves yarn and fabric stresses, progressive shrinkage usually involves fiber movement within the textile structure. Sufficient agitation in the wetted state overcomes the frictional forces between fibers, allowing the fibers to move relative to each other. Fibers with a low wet modulus, such as wool and rayon, are more susceptible to this type of dimensional change. The fibers extend easily when wet and then retract when dried, becoming entangled and consolidating the structure [8].

The more vigorous the agitation, the greater the shrinkage is. Research some years ago showed that rayon fabrics washed in lighter loads showed more shrinkage than those in heavier loads because less agitation occurs with heavier loads. This is why standard test methods for shrinkage specify the total weight of fabric in the wash load in testing for dimensional change. Tumble-drying accompanied by heat may result in some progressive shrinkage. As the water is driven out of swollen fibers, they collapse, leaving room in the yarn and fabric structure for fiber movement. The mechanical action in tumble-drying can promote this fiber movement resulting in a more compact structure [8].

This effect of fiber de-swelling can be seen in Figure 3.17, a series of microscopic views of a cotton fabric heated, wetted, and then photographed again after evaporation of the water. A comparison of views in Figures 3.17a and 3.17b shows that more spaces occur between the fibers after they have been wetted and then dried to drive the water off. Figures 3.17e and 3.17f show that this effect is more significant at higher temperatures. A cotton textile repeatedly washed and dried especially at high temperatures would probably show some progressive shrinkage as the fibers have more room to move. This is especially true for less compact structures. The lower-twist yarns and looser construction in knits, for example, may promote this type of shrinkage. A knitted cotton T-shirt would probably exhibit relaxation shrinkage on the first washing as the fabric stresses are relieved and the garment shrinks lengthwise. Subsequent launderings may result in progressive shrinkage due to fiber movement and consolidation.

Fabrics of wool and other animal hair fibers undergo a further type of progressive shrinkage called felting when exposed to the conditions normally accompanying laundering: moisture, heat, and agitation. The overlapping scales on these fibers produce a frictional effect that is directional in that the fibers move preferentially in one direction. This means that as they are stretched during the agitation of laundering they will continue to move in one direction rather than back to their original position; as a result, these fibers become more entangled with other fibers. Special finishes that decrease the frictional effect, such as coating or degradation of the scales, alter the felting behavior and are used on "washable wools." Unfinished wools, however, usually continue to felt on repeated washings. Felt fabrics are made by intentional imposition of moisture, heat, and agitation to entangle the fibers [8].

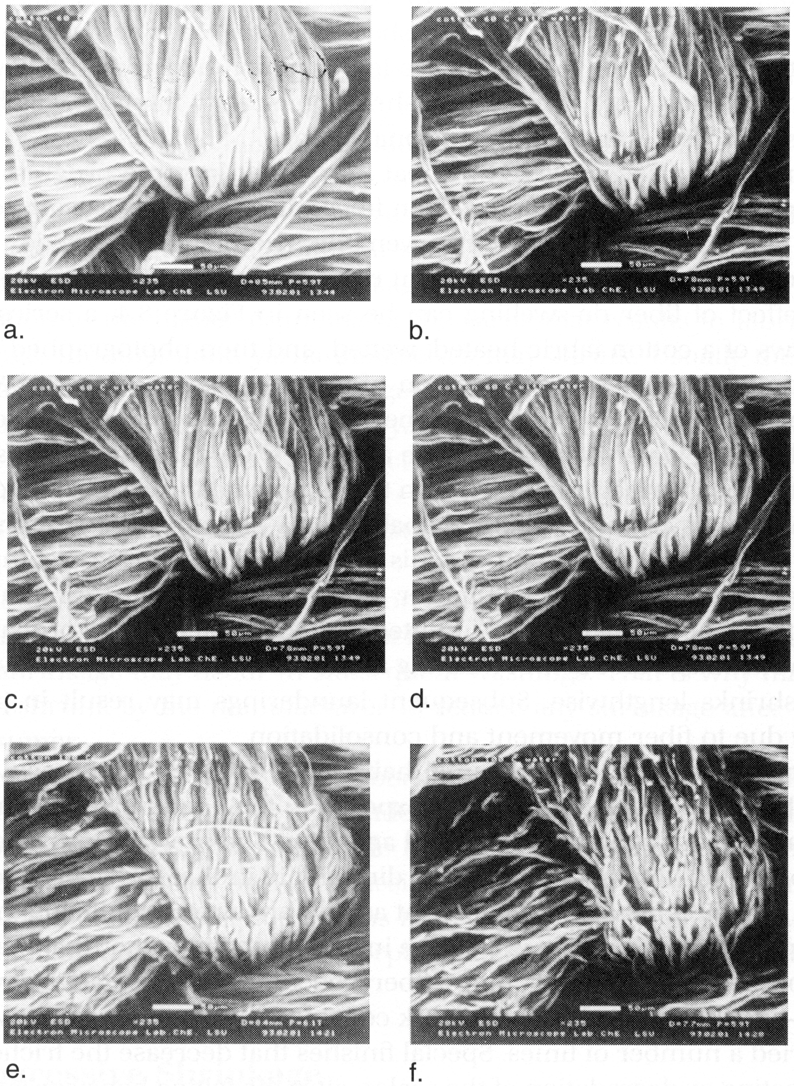


Figure 3. 17 Effect of moisture and temparature on cotton fabric: (a) 60º C before wetting, (b) 60º C after wetting and evaporation, (c) 80º C before wetting, (d) 80º C after wetting and evaporation, (e) 100º C before wetting, and (f) 100º C after wetting and evaporation [8].

3.5.8.3. Growth

An increase in the dimensions of a textile item can also occur during refurbishing. The most frequent instance is growth in the width of a fabric as it shrinks in length. This is often more pronounced in knitted products. Another consideration is the stretching of fabrics when wet. Those made from fibers with low wet strength and high elongation extends under certain conditions, such as line drying. Care instructions often recommend that these items be dried flat [8].

3.5.8.4. Thermal shrinkage

Thermal shrinkage is limited to fabrics composed of thermoplastic fibers, such as acetate, polyester, and nylon. Upon imposition of heat to these fabrics, the polymer molecules in the fibers move and assume a more random, nonlinear form, decreasing their length and shrinking or altering the shape of the fabric. The susceptibility to thermal shrinkage depends on the softening or melting point of the constituent fibers. Because their melting points are lower than other thermoplastic fibers, acetate and olefin fibers are affected at relatively low temperatures, and hot tumble drying can be harmful to fabrics composed of these fibers. A hot iron or drum of a dryer may even melt them, producing holes. Many products made from synthetic fibers are heat-set at high temperatures to prevent this and other types of shrinkage [8].

3.5.8.5. Shape retention

A change in the dimensions of a textile item, of course, affects its shape, but there are other considerations as well. A common problem with woven and knitted textile products is development of skewness after laundering. It results from uneven tensions introduced during weaving or the torsional i.e., twisting stresses occurring in knitting processes, especially in weft knitting. Faulty finishing and product construction processes can also produce distortions. The stresses imposed in fabrics or manufactured products can be released under the moisture and heat of laundering. The resulting skewness is undesirable and may even render an item unserviceable.

Two products that are particularly prone to this type of distortion are pants or jeans made from twill fabrics and knitted T-shirts or sweatshirts. Manufacturers of denim jeans have, for some time, received complaints of twisted legs in the garments after washing. Knitted shirts and tops also may exhibit twisted seams and distortions in their shape after laundering.

Manufacturers concerned about these problems have investigated process modifications to enhance shape retention in finished products. One method for decreasing skewness in jeans is "pre-distortion" of denim fabric during the finishing process. In this technique, the fabric is intentionally skewed in the tentering frame in the opposite direction of the twill line. The effect is to offset the weaving stresses in the twill direction and inhibit the development of skewness in finished garments [8].

3.5.8.6. Testing for dimensional change

The basic procedure for testing fabrics or garments for dimensional change is measurement of length and width benchmarks before and after a selected refurbishing process. The benchmarks, drawn with indelible ink, for better precision, in each direction. After a standard laundering or dry-cleaning method is applied, the marks are remeasured and dimensional change (DC) calculated by:

$$\% \text{ DC} = \frac{(B - A)}{A} * 100 \qquad (3.5)$$

Where A = original dimensıon and B = dimension after treatment

Length and width changes are calculated separately. Growth is reported as a positive percentage, while shrinkage is reported as a negative number [8].

Standard laundering conditions

Washing and drying conditions can affect the dimensional stability of fabrics and garments and, therefore, test methods require that conditions (e.g., water temperature and agitation speed) be specified to provide reproducible results. "Progressive Shrinkage", the amount of agitation can affect dimensional change, and acceptance testing of products should be done as nearly as possible under the same degree of mechanical action. Wash water temperature may have a distinct effect on certain fibers. Cotton fibers shrink and curl more at higher temperatures. The effects on fibers of hotter temperatures, such as may occur in commercial laundering, are even more pronounced.

Most test methods to simulate home laundering require the addition of dummy fabric or ballast to make a full wash load for the samples being tested. This helps to control the amount of agitation to which the test samples are subjected. The construction of ballast fabric is closely specified, with three types of cotton or cotton/polyester fabrics being acceptable. For tumble-drying, the exhaust temperature of the dryer should be specified. In addition to tumble-drying, test methods for dimensional stability also describe procedures for line drying, screen drying, and drip-drying. The last method requires that the fabric or textile item be removed from the washing machine before the final spin cycle [8].

Interpreting results

The inclusion of requirements for dimensional change in many ASTM standards attests to the importance of this property in textile performance and consumer acceptance. Some representative maximum levels are given in Table 3.3. The fiber content, fabric construction, and end use can all affect the acceptable shrinkage level. The allowances for knitted fabrics are usually higher than those for woven [8].

Table 3. 3 ASTM Performance specifications for dimensional change after laundering

Product	Maximum Dimensional Change (%)
Men's and Boy's woven dress shirts	2.0
Men's and Boy's sportswear	3.0
Women's and Girl's knitted sportswear	3.0
Men's and Boy's knitted bathrobes	5.0
Men's and Boy's woven bathrobes	3.0
Women's and Girl's woven robes and nightgowns	2.5
Neckties and scarves	3.0
Curtains and draperies	3.0
Wool Blankets	6.0
Cotton Blankets	5.0
Woven polyester/cotton sheets with durable press finish	2.0
Unfinished woven polyester/cotton sheets	8.0
Knitted flannel sheets	4.0
Kitchen towels	10.0
Dishcloths	15.0
Bath towels and washcloths	10.0

Although most of the standard methods for dimensional change are fairly well established, the precision of these methods has not been determined. AATCC has undertaken several interlaboratory studies to establish precision so that users know the effectiveness of the methods in assessing differences among fabrics and using the methods for acceptance testing. As a general rule for most cases, differences of more than one percent shrinkage between samples tested by the same operator in the same laboratory are significant [8].

CHAPTER 4

EXPERIMENTAL STUDY

4.1. Introduction

Weaving has been used more widely than any other method of fabric construction and gives a tremendous range of fabric character [20]. Woven fabrics are composed of two yarn sets that are placed at right angles to each other. The yarns that run parallel to fabric selvage are called as warp yarns or ends and yarns that run crosswise of the fabric are called as weft yarns, filling yarns or picks. Warps and wefts make interlacings to form a woven fabric. By varying the sequence of these interlacings many fabric structures can be obtained. Each of these structures are called as “weave patterns”. There are three main weave patterns for woven fabrics. These are plain, twill, satin/sateen. And there are many derivatives of these fundamental patterns. In twill weave each warp or weft yarn floats over two or more weft yarns. A very important distinct of this pattern is the diagonals that are seen. By changing the directions of these diagonal lines it is possible to improve different patterns. The diagonal lines may run to right (Z direction) or left (S direction).

Different fabric weaves differentiate the structure of fabrics and these different structural properties of fabrics will cause the fabrics to behave differently from each other. In this point of view woven fabric properties will differ by changing weave patterns. Fabric pattern must be evaluated not only as an appearance property but also a very important structure parameter indeed. Fabric properties are influenced with a wide range by this structure parameter.

4.2. Principle and Purpose

In this thesis work the influence of weave patterns on fabric physical properties for twill weaves and elaborations of twill weaves will be investigated. The effect of weave type on fabric properties will be investigated not only for twill weave types but also satin and plain weave derivatives are included in this experimental study additionally.

The properties of fabrics that will be discussed are;

1. Warp and weft crimp
2. Fabric weight
3. Fabric thickness
4. Breaking strength and breaking elongation
5. Abrasion resistance
6. Pilling resistance
7. Dimensional stability

In order to understand the statistical importance of weave type on fabric properties analysis of variance (ANOVA) was performed and Tukey Tables were used to determine the best and worst weave types for breaking strength and elongation, pilling resistance, abrasion resistance and dimensional stability properties. In addition to these, correlation analysis was done to show the relationship between fabric properties from statistical approach. For this aim the statistical software package SPSS 8.0 was used to interpret the experimental data. All test results were assessed at significance levels of $\alpha \leq 0{,}05$ and $\alpha \leq 0{,}01$. The results of statistical analysis is given in Appendix A.

4.2.1. Materials and apparatus

The fabrics were woven in sample weaving department of Kipaş Textile in Kahramanmaraş. The warp sheet was prepared by a sample warping machine, and then sized with a sample sizing machine. After sizing straight draft was applied to warp sheet with a sample drawing machine. The weaving machine was a Dornier, with electronic dobby shedding mechanism and rapier weft insertion. 12 frames were used for all sample fabrics with straight draft. The weave types were obtained by only changing the drafting plan electronically on loom. Each sample was produced with 1,40 meters width and 1,40 meters length with 450 rev/min loom speed. Sizing recipe is given in Table 4.1.

Table 4. 1 Sizing recipe

150 L liquor
20 kg EMSIZE CMS 60
10 kg BP20 (PVA)
500 gr Glissofil Extra (Oil)

The only finishing treatment applied to the samples was desizing in finishing department of Kipaş Textile in Kahramanmaraş. Fabrics were treated to enzymatic desizing for 6 hours. Then they were washed with 60 m/min washing speed in washing machine which have 5 vats with the liquor temperatures of 95°C, 95°C, 85°C, 65°C, and 30°C respectively. Drying operation of fabrics was done at 120°C and 140 cm fabric width by 30 m/min drying speed. Desizing and washing recipes are given in Tables 4.2 and 4.3.

Table 4. 2 Desizing recipe

2,5 gr/l Torozym NT
2 gr/l Schnellnetzer KE
1 g/l R. Entlüfter BK
1g/l Emulgator BE-O

Table 4. 3 Washing recipe

2 gr/l Sevalin D
1 gr/l Schnellnetzer KE
0,6 g/l Optiderm BS-L

These samples were produced as men's shirts. Weft sett is 28 wefts/cm and warp sett is 46 warps/cm for all samples. These values were determined keeping Kipaş Textile advice in mind, according to commercial values. The component yarn used for both warp and weft is Ne 30/1, 100% cotton combed ring yarn. Detailed information about the yarns used is given in Table 4.4.

Table 4. 4 Properties of the yarn used in the experimental study

Yarn twist	919 turns/m
Yarn strength	23 Rkm
Hairness	5.67
Unevenness %	9.69
Thick +50%/km	20
Neps +200%/km	71,7
Fiber length	29,4 mm
Fiber fineness	4,25 micronaire

The properties; yarn crimp, fabric weight, fabric thickness, breaking strength and elongation, abrasion resistance, pilling resistance, dimensional stability were tested with the equipments and devices in the laboratories of Textile Engineering Department of Gaziantep University in accordance with the standards of TSE. The apparatus and devices used in the experimental studies are given below:

1. Paramount Thickness measurement apparatus
2. Sensitive scale and specimen cutter for fabric weight measurement
3. Devotrans G-21 Strength Tester
4. Martindale Abrasion Tester 2000
5. Automatic washing machine
6. Automatic tumble dryer
7. Standard reference detergent

The standards, which were followed for the experimental studies are given below;

1. TS 240 EN 20139 Textiles – Standard Atmospheres for Conditioning and Testing
2. TS 250 EN 1049-2 Textiles – Woven fabrics – Construction – Methods of analysis – Part 2: Determination of number of threads per unit length
3. TS EN 12127 Textiles – Fabrics – Determination of mass per unit area using small samples
4. TS 254 Textiles – Woven fabrics – Construction – Methods of analysis determination of yarn in fabric

5. TS 7128 EN ISO 5084 Textiles – Determination of thickness of textiles and textile products
6. TS EN ISO 13934-1 Textiles – Tensile properties of fabrics – Part 1: Determination of maximum force and elongation at maximum force using the strip method
7. TS EN ISO 12947-1 Textiles – Determination of the abrasion resistance of fabrics by the Martindale method – Part 1: Martindale abrasion testing apparatus
8. TS EN ISO 12947-3 Textiles – Determination of the abrasion resistance of fabrics by the Martindale method – Part 3: Determination of mass loss
9. TS EN ISO 12945-2 Textiles – Determination of fabric propensity to surface fuzzing and to pilling – Part 2: Modified Martindale method
10. TS 4073 EN ISO 3759 Textiles – Preparation, marking and measuring of fabric specimens and garments in tests for determination of dimensional change
11. TS 392 EN 25077 Textiles – Determination of dimensional change in washing and drying
12. TS 5720 EN ISO 6330 Textiles – Domestic washing and drying procedures for textile testing

41 sample fabrics were woven for this experimental study. These sample fabrics were considered to the same yarn setts for both weft and warp direction. But after the production it was observed that 5 fabrics were not at these yarn sett values. So those are eliminated and all the rest were used. In addition to twill weave derivatives, plain and sateen weave derivatives were produced. Sample 1 – sample 26 are twill, sample 27 – sample 33 are plain and samples 34, 35, 36 are sateen derivatives. The weave types produced to use in this experimental study is given in Table 4.5. Number of interlacings for each sample in weft and warp directions are given in Table 4.6.

Table 4. 5 Weave types used in the study

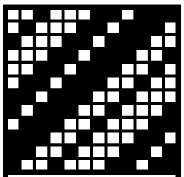
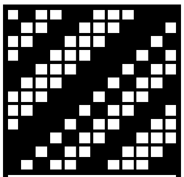
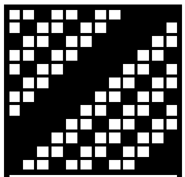
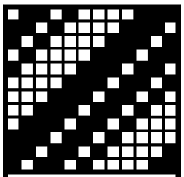
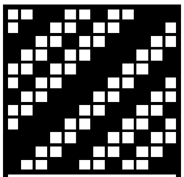
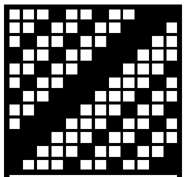
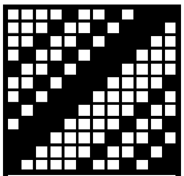
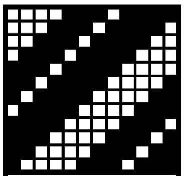
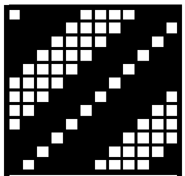
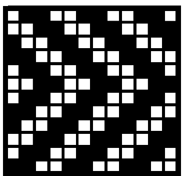
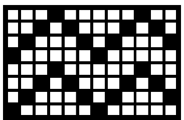
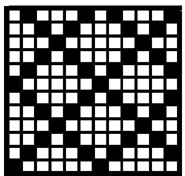
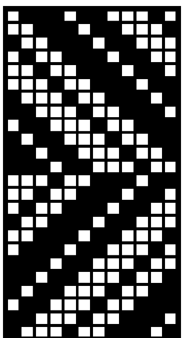
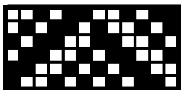
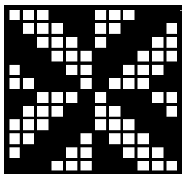
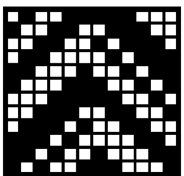
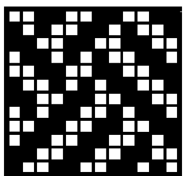
 Sample 1 Balanced twill	 Sample 2 Balanced twill	 Sample 3 Unbalanced twill
 Sample 4 Unbalanced twill	 Sample 5 Unbalanced twill	 Sample 6 Weft faced twill
 Sample 7 Weft faced twill	 Sample 8 Warp faced twill	 Sample 9 Warp faced twill
 Sample 10 Vertical waved twill	 Sample 11 Horizontal waved twill	 Sample 12 Diamond twill
 Sample 13 Horizontal herringbone	 Sample 14 Vertical herringbone	 Sample 15 Diaper twill
	 Sample 16 Broken twill	 Sample 17 Entwinned twill

Table 4.5 (cont'd)

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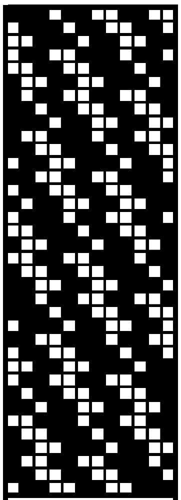
<tr><td rowspan="2">
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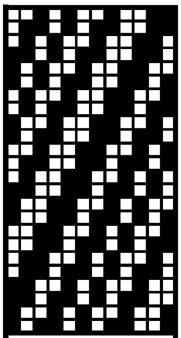
Broken twill</td><td rowspan="2">
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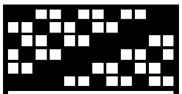
Elongated twill</td><td>
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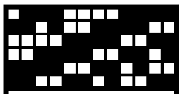
Flattened twill</td><td>
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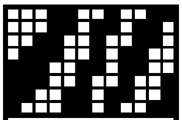
Combined twill</td></tr>
<tr><td>
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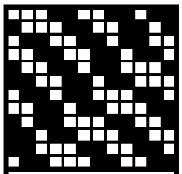
Curved twill</td><td>
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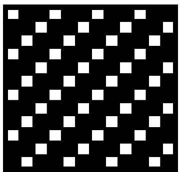
<tr><td>
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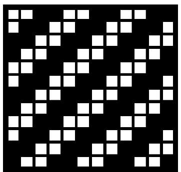
Twill</td><td>
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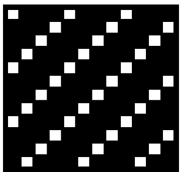
Twill</td><td>
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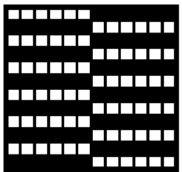
Twill</td><td>
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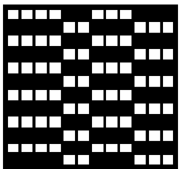
Regular weft rib</td></tr>
<tr><td>
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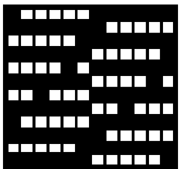
Irregular weft rib</td><td>
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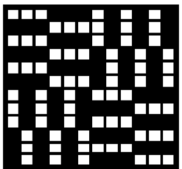
Stitched weft rib</td><td>
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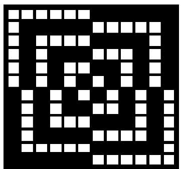
Combined rib</td><td>
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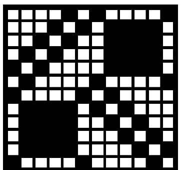
Basket weave</td></tr>
<tr><td>
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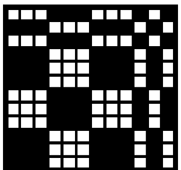
Stitched hopsack</td><td>
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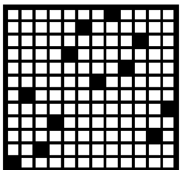
Combined hopsack</td><td>
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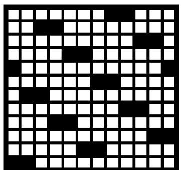
Rearranged sateen</td><td>
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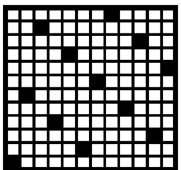
Reinforced sateen</td></tr>
<tr><td>
Sample 36
Sateen</td><td></td><td></td><td></td></tr>
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Table 4. 6 Number of interlacings for weave types

Sample	1	2	3	4	5	6	7	8	9
Weft interlacing / cm²	644	672	672	672	672	672	644	420	448
Warp interlacing / cm²	690	644	644	644	644	644	644	460	460
Sample	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Weft interlacing / cm²	672	644	728	644	952	532	644	644	644
Warp interlacing / cm²	690	644	874	690	966	552	644	736	690
Sample	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
Weft interlacing / cm²	896	621	672	672	644	868	644	644	224
Warp interlacing / cm²	460	874	368	828	644	855	690	630	1344
Sample	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
Weft interlacing / cm²	448	280	899	784	588	609	216	216	224
Warp interlacing / cm²	1316	1104	828	828	644	630	276	495	270

4.3. Warp and Weft Crimp

In Table 4.7, the yarn crimp values of warp and weft direction obtained from the crimp measurements are given.

Table 4. 7 Warp and weft crimp values of sample fabrics

Sample	1	2	3	4	5	6	7	8	9
Warp crimp (%)	5,3	5,3	4,5	4,5	4,9	4,9	5,3	4,9	4,4
Weft crimp (%)	13,6	14,6	13,2	13,6	14,8	14,3	14,9	14,0	13,8
Sample	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Warp crimp (%)	5,1	5,3	5,4	5,3	6,7	4,5	4,9	5,5	4,0
Weft crimp (%)	14,5	14,8	16,4	14,3	12,9	14,7	15,0	14,8	15,2
Sample	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
Warp crimp (%)	5,8	4,9	5,3	3,9	5,4	6,8	6,0	4,9	1,6
Weft crimp (%)	10,6	15,2	12,2	16,3	15,4	13,6	14,1	12,5	16,7
Sample	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
Warp crimp (%)	1,7	2,3	5,0	4,7	4,2	4,7	2,7	1,9	2,9
Weft crimp (%)	16,9	20,3	15,1	13,5	13,2	12,5	9,6	12,1	11,5

It is evident from Figures 4.1 and 4.2, which deal with yarn crimp, that yarn crimp values of weft direction are considerably higher than yarn crimp values of warp direction. There are two reasons for this. Firstly, weft yarns move forward more than warp yarns to pass under and above them because yarn sett values are higher in warp direction (46 yarns/cm) than weft direction (28 yarns/cm). Secondly warp yarns are exposed to more tension than weft yarns during weaving that restrict warp yarns to have more crimp than weft yarns.

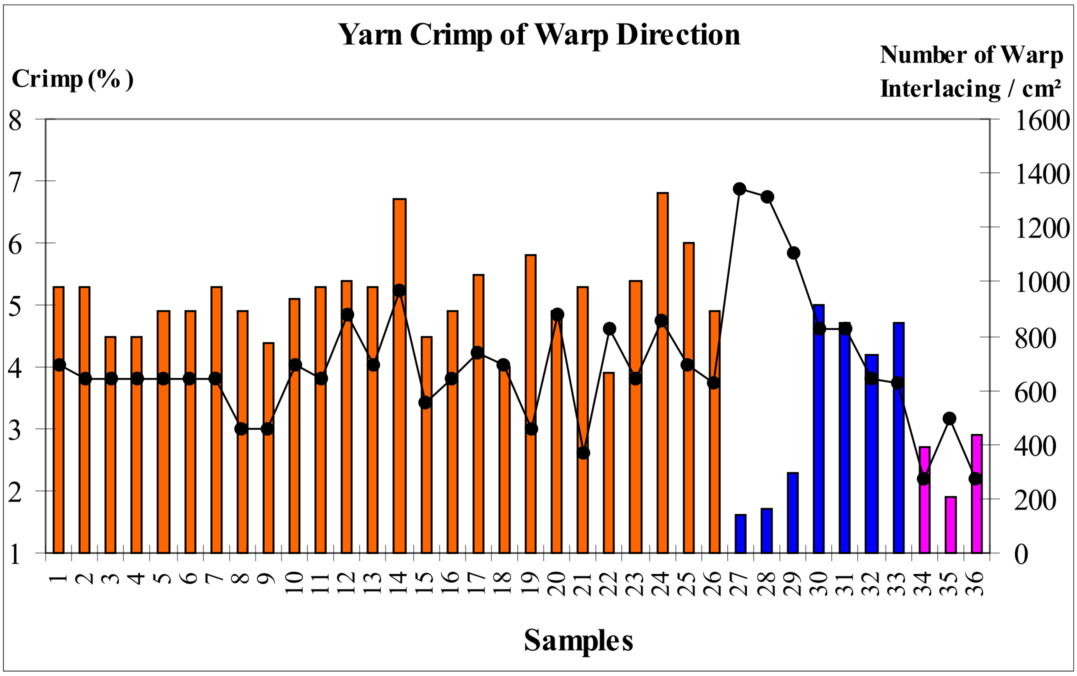

Figure 4. 1 Yarn crimp of sample fabrics in warp direction

If yarn crimp values of warp direction seen in Figure 4.1 are considered, it's observed that twill samples have the highest warp crimp values and these are followed by plain and sateen weave crimp values in warp direction respectively. Sample 27 a plain derivative with 1,6% yarn crimp has the lowest and sample 24 a twill derivative with 6,8% yarn crimp has the highest values. Figure 4.1 shows the relationship between yarn crimp and number of interlacing in warp direction. It is seen that high number of interlacing did not result an increasing yarn crimp for all samples. Especially for sample 27 similar with samples 28 and 29, it is surprising to have very low crimp values although they have the highest interlacing numbers in warp direction. In these samples with a high probability the warp yarns maintained their tensions and did not deviate from the cloth axis so much while the weft yarns moved forward by encircling the tight warp yarns. In other words stable warp yarns in these samples provides low warp crimp values while causing the weft crimp values to be increased. If Figure 4.2 is examined, it is seen that these 3 samples exhibit high weft crimp values although they have low number of interlacings.

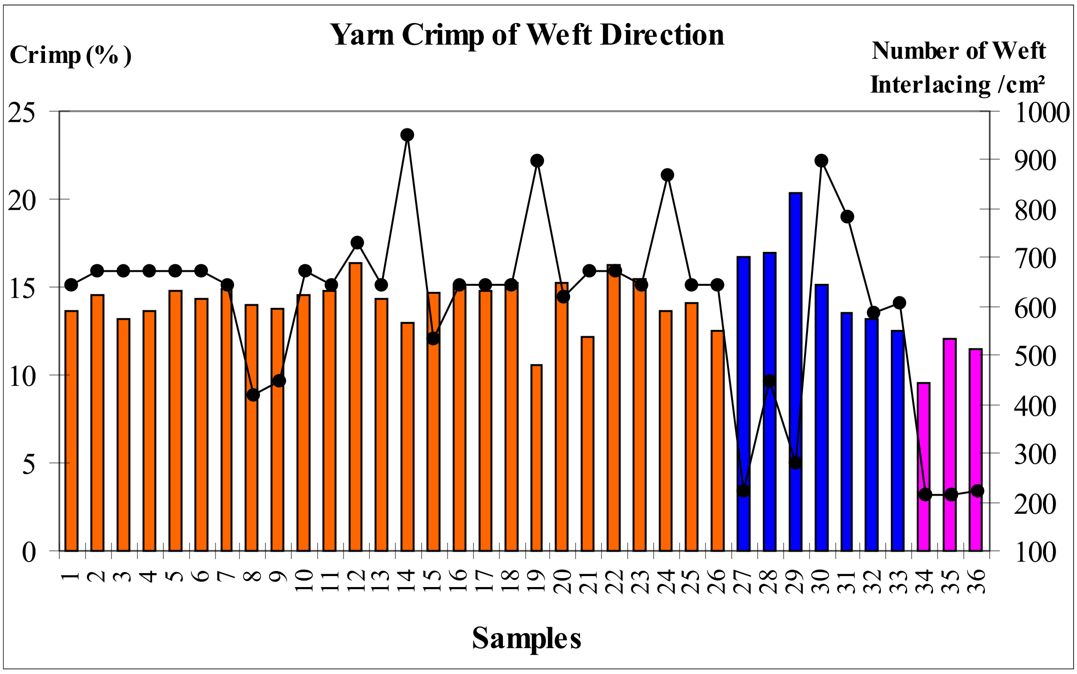

Figure 4. 2 Yarn crimp of sample fabrics in weft direction

In Figure 4.2 it is obvious that plain weave types have the highest weft crimp values. Those are followed by twill and sateen weave derivatives respectively. Sateen weave types have closer weft crimp values to each other. The lowest weft crimp value is 9,6% belongs to sample 34 a sateen derivative and the highest one is 20,3% belongs to sample 29 a plain derivative. Because sample 34 has the lowest number of interlacing. From Figure 4.2 it is seen that samples 14, 19, 24, 30 which have very high number of interlacing in weft direction in comparison to other samples have average crimp values. So it can be said that for both warp and weft direction number of interlacing is not the only effect on yarn crimp.

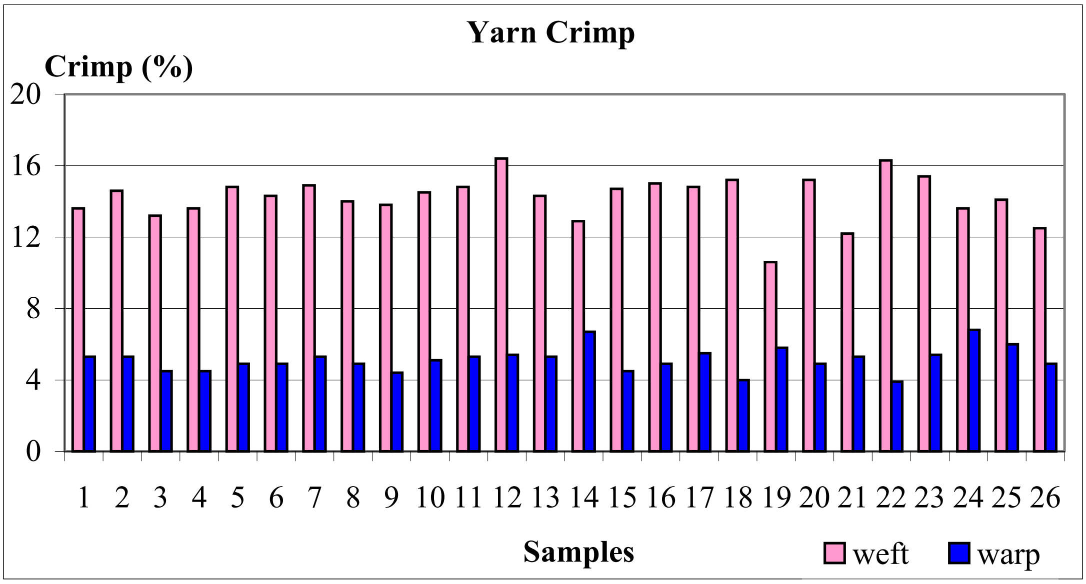

Figure 4. 3 Yarn crimp of twill weave samples

In twill weave samples seen in Figure 4.3 for warp direction sample 24 has the highest 6,8% yarn crimp while sample 22 has the lowest value of 3,9%. In weft direction sample 12 has the highest 16,4% crimp and sample 19 has the lowest 10,6% crimp values.

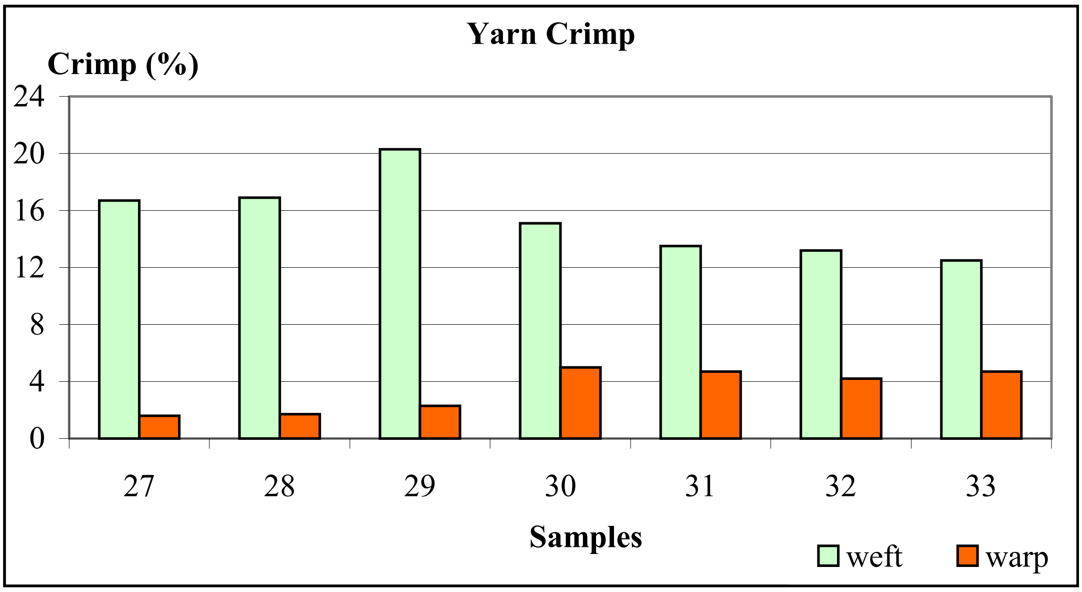

Figure 4. 4 Yarn crimp of plain weave samples

Yarn crimp values of plain weave samples are illustrated in Figure 4.4. Samples 27, 28, 29 exhibits the lowest warp crimp values versus the highest weft crimp values among plain samples as mentioned earlier. All the rest have closer yarn crimp values to each other in both warp and weft direction and the difference of crimp values between warp and weft direction lessens for these samples. This different behavior of these two groups will influence the breaking elongation property that will be discussed in the relevant section.

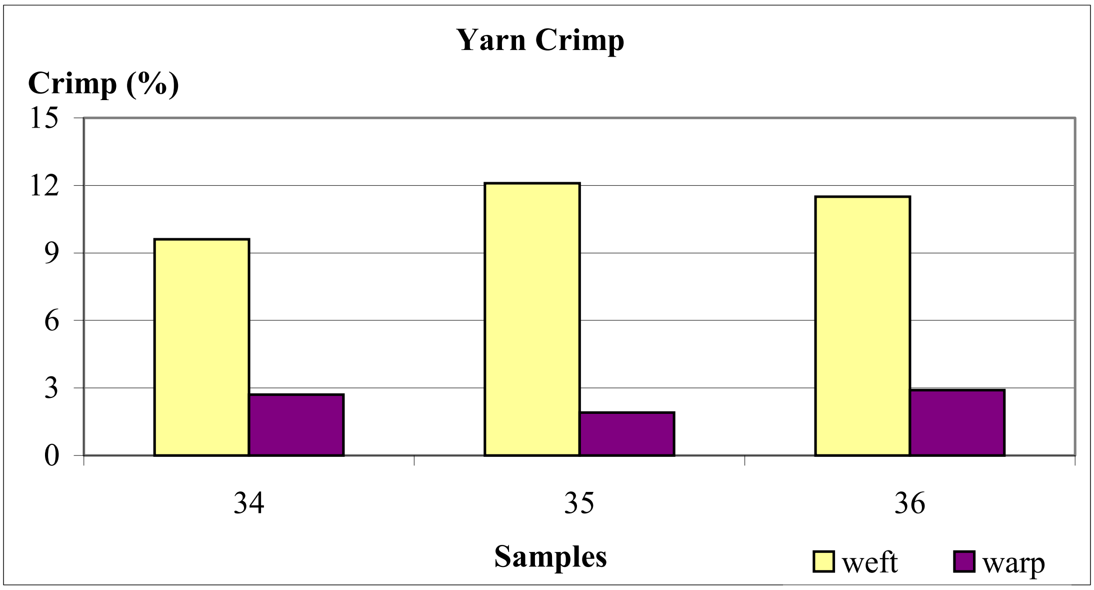

Figure 4. 5 Yarn crimp values of sateen weave samples

Figure 4.5 describes the yarn crimp values of sateen weave samples. It is obviously seen that similar with plain weave samples for sateen weave types an increasing crimp value in one direction causes the decreasing crimp value in opposite direction.

The effect of weave type on yarn crimp for both warp and weft direction is found to be significant ($P \leq 0{,}01$) at 1% significance level according to ANOVA results. Based on the statistical correlation analysis, the correlation was found to be significant and negative between warp crimp and weft crimp at 5% significance level. This negative correlation means warp crimp values increase while weft crimp values decrease. Because in woven structures, crimp does not increase continuously in both warp and weft direction. After a point, increasing crimp in one direction restricts the crimp increase in opposite direction.

4.4. Fabric Weight

Fabric weight is dependent on yarn sett, yarn count and yarn crimp. For the samples used in this study yarn sett and yarn count are same for all samples so the weight values must be evaluated in accordance with the crimp – weight relationship. Fabric weight values of sample fabrics are given in Table 4.8.

Table 4. 8 Fabric weight values of sample fabrics

Sample	1	2	3	4	5	6	7	8	9
Fabric weight (g/m²)	150	148	147	150	148	150	151	149	148
Sample	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Fabric weight (g/m²)	149	147	150	147	148	147	147	148	148
Sample	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
Fabric weight (g/m²)	145	148	145	149	149	148	149	149	150
Sample	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
Fabric weight (g/m²)	150	151	150	146	144	144	144	145	141

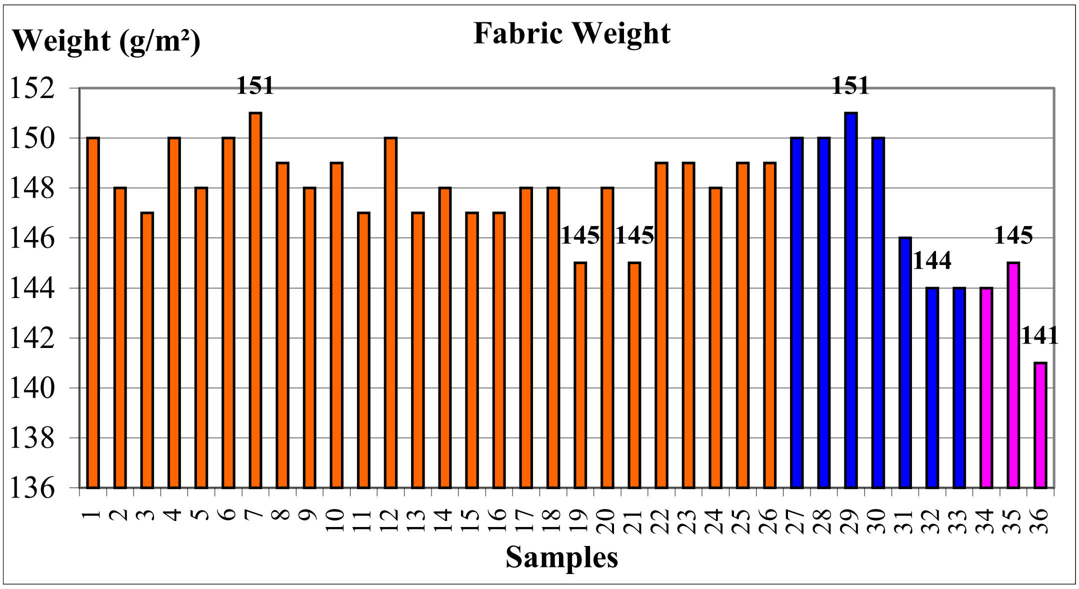

Figure 4. 6 Fabric weight values of sample fabrics

If all samples are considered in Table 4.8, sample 7 a twill derivative and sample 29 a plain derivative has the highest 151g/m² weight value while sample 36 a sateen weave sample has the lowest 141 g/m² weight value. The lowest fabric weight values are seen for sateen weave samples when Figure 4.6 is examined. It is clear from Figure 4.6, fabric weight values belong to twill weave samples vary with a wide range. If only twill weave types kept in mind, sample 7 exhibits the highest fabric weight (151 g/m²) while samples 19 and 21 have the lowest value (145 g/m²).

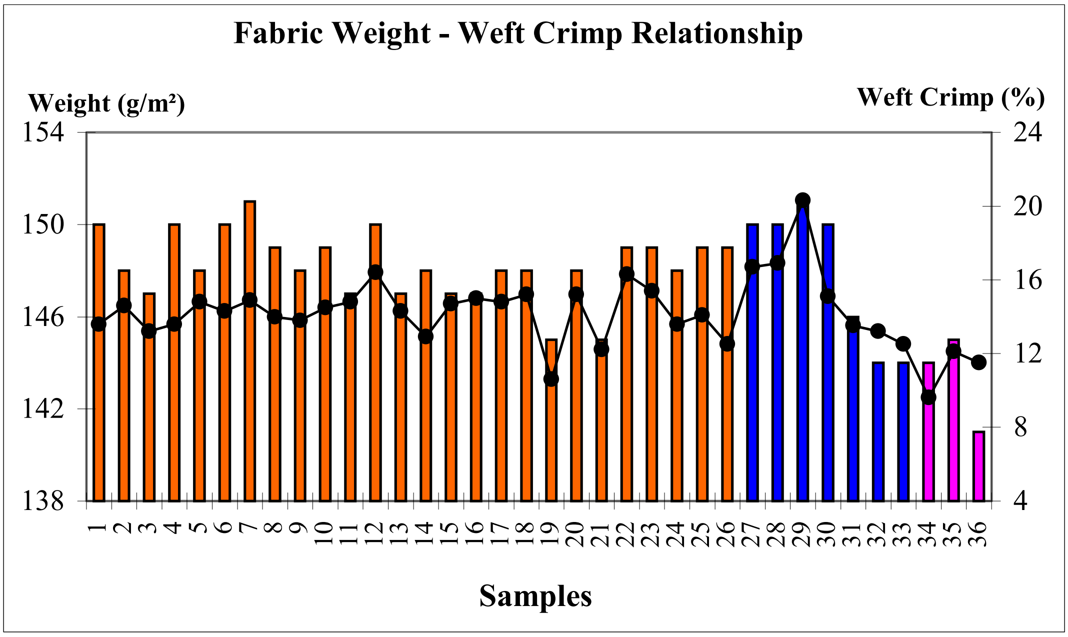

Figure 4. 7 Fabric weight – weft crimp relationship

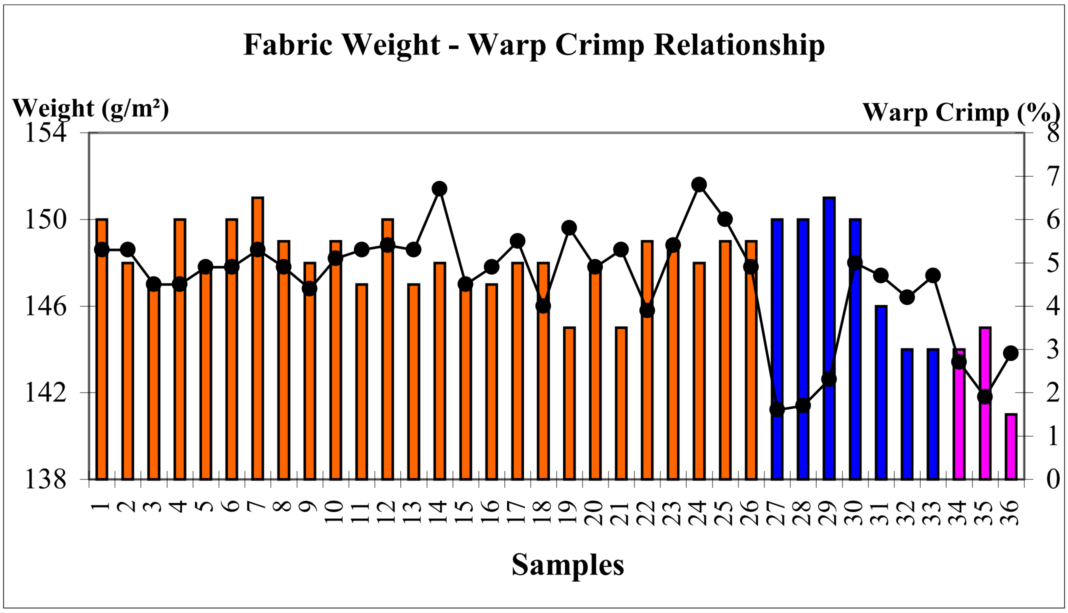

Figure 4. 8 Fabric weight – warp crimp relationship

Samples 1, 4, 6, 7 have high fabric weight values although they have average weft crimp seen in Figure 4.7. In addition to these from Figure 4.8 it is seen that samples 14, 19, 24 exhibit low fabric weight versus high warp crimp while samples 27, 28, 29 have have high fabric weight versus low warp crimp. From these situations it is seen that yarn crimp did not influence the fabric weight with an increasing effect for all samples in this study.

If the fabric weight values of sample fabrics are examined statistically according to ANOVA, it's proved that weave type has a significant ($P \leq 0,01$) effect on fabric weight at 1% significance level. And also statistical correlation analysis showed that the correlation between warp crimp and fabric weight is insignificant while the correlation between weft crimp and fabric weight is found to be significant and positive at 1% significance level. Insignificant correlation between warp crimp and fabric weight means that for this study warp direction crimp does not affect the fabric weight in accordance with statistical importance. In addition to this, positive and significant correlation between weft crimp and fabric weight can be defined as; there is a direct proportion between weft crimp and fabric weight. Although the correlation analysis done for this study found that warp crimp has no effect on fabric weight, this result can not be acceptable generally. Different experimental studies may result oppositely.

4.5. Fabric Thickness

Thickness values of all sample fabrics are shown in Table 4.9.

Table 4. 9 Thickness values of sample fabrics

Sample	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Thickness (mm)	0,31	0,31	0,3	0,31	0,29	0,3	0,31	0,33	0,33
Sample	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Thickness (mm)	0,31	0,34	0,34	0,31	0,29	0,33	0,33	0,32	0,37
Sample	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
Thickness (mm)	0,35	0,32	0,38	0,35	0,33	0,28	0,3	0,3	0,48
Sample	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
Thickness (mm)	0,38	0,5	0,44	0,42	0,34	0,34	0,39	0,4	0,41

If the thickness of twill weave samples are considered, it will be seen from Table 4.9 that the highest thickness value of 0,38 mm belongs to sample 21 and the lowest thickness value of 0,28 mm belongs to sample 24. It's clear from Figure 4.9 that sample 24 has the high number of interlacings and least number of floats for both warp and weft directions. So this sample is expected to have a tight structure causing the height of the crowns – the part of yarn that protrudes above the surface of the fabric caused by crimp – on fabric surface to be lower than other weave types. And also sample 21, which showed the highest thickness value has the opposite structural properties of sample 24. In addition to these, sample 14, which has the similar structural form with sample 24, has a low thickness value and samples 18,19,22 similar with sample 21 have high thickness values by verifying the suggestion above.

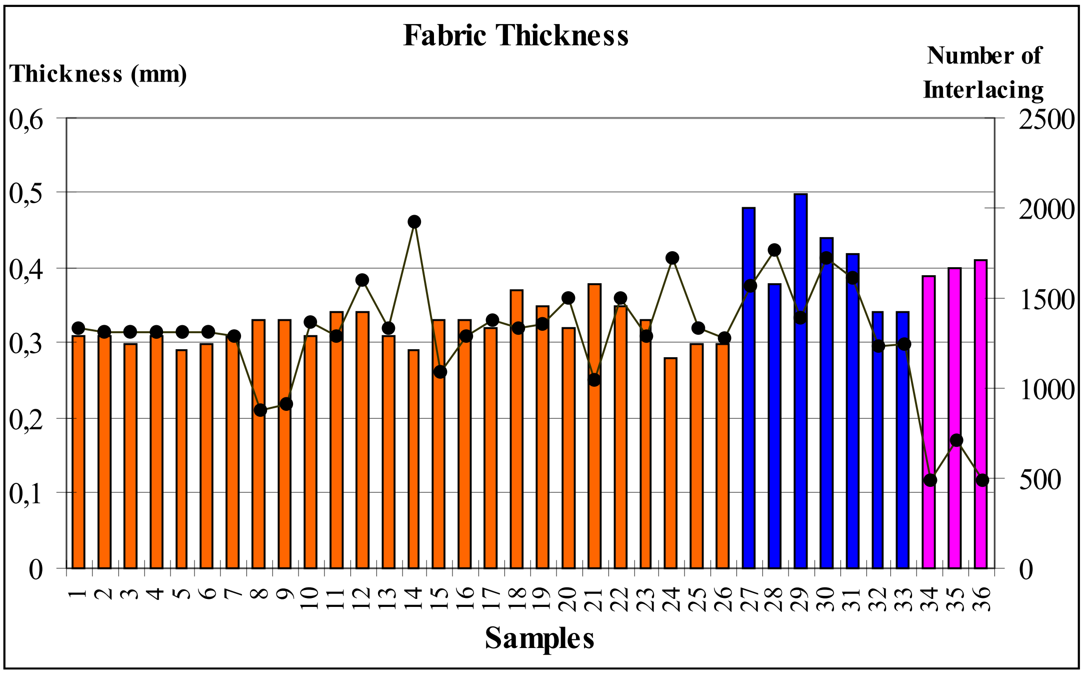

Figure 4. 9 Fabric thickness values of sample fabrics

Figure 4.9 for fabric thickness values of all samples shows that plain weave types have the higher thickness values than sateen and sateen higher than twill. The highest thickness value belongs to sample 29 a plain derivative with a value of 0,50 mm and the lowest value belongs to sample 24 a twill derivative with a value of 0,28 mm. In addition to sample 29, samples 27, 30, 31 exhibit the high values because of the results mentioned for twill weave types above. But if the thickness values of sateen weave types are evaluated by keeping the weave structure in mind, at first sight this manner seems to run counter to our assumptions. Because according to our assumptions sateen weaves might have the highest thickness values by the aid of their loose structure. But some plain weaves are thicker than sateen ones. This manner can be explained by yarn stacking on each other due to weave type especially in weft direction that is seen in these plain samples confirmed by our observations on sample fabrics.

According to ANOVA results, the effect of weave type on fabric thickness is significant ($P \leq 0,01$) at 1% significance level. According to statistical correlation analysis the correlation is found to be insignificant between thickness and weight. In addition to this we also examined significant correlations between thickness and warp crimp and between thickness and weft crimp at 1% significance level. The correlation between thickness and warp crimp is negative while the correlation was seen to be positive between thickness and weft crimp. Negative correlation means a reverse proportion, positive correlation means a direct proportion. This means increasing warp crimp has a decreasing effect while increasing weft crimp has an increasing effect on fabric thickness. The insignificant correlation between thickness and weight is surprising at first sight. Because it is expected from thick fabrics to have thick yarns by increasing fabric weight. The logical mistake at this point is to evaluate the yarn thickness related with only yarn weight. Yarn thickness is not only a result of yarn weight but also has a meaningful approach from the point of yarn bulkiness. In other words fabric thickness must be a result of yarn bulkiness that may be a result of yarn production technology, raw material type and etc.

4.6. Breaking Strength and Elongation

Table 4.10 exhibits the breaking strength and breaking elongation values of sample fabrics for both warp and weft directions.

Table 4. 10 Breaking strength and breaking elongation values of sample fabrics

Sample	**1**	**2**	**3**	**4**	**5**	**6**
Weft strength (kgf)	41,7	47,3	45	42,5	42,7	44,2
Warp strength (kgf)	79,2	80,4	85,9	82,3	85,8	81
Weft elongation	18,2%	17,9%	18,5%	18,6%	17,9%	17,7%
Warp elongation	11,4%	11,3%	10,6%	11,0%	10,8%	10,8%
Sample	**7**	**8**	**9**	**10**	**11**	**12**
Weft strength (kgf)	44,6	37	40,4	38,6	40,8	37
Warp strength (kgf)	82,5	72,1	70,3	76,4	73,4	73,4
Weft elongation	18,1%	16,9%	17,5%	17,8%	18,0%	18,7%
Warp elongation	11,1%	9,3%	8,8%	10,5%	10,5%	9,9%
Sample	**13**	**14**	**15**	**16**	**17**	**18**
Weft strength (kgf)	43,1	43,2	41,3	39,7	39	45,7
Warp strength (kgf)	80,9	75,8	75,8	70	69,3	83,7
Weft elongation	18,8%	17,8%	18,6%	18,9%	18,7%	20,6%
Warp elongation	10,7%	11,5%	9,7%	9,5%	10,6%	9,8%
Sample	**19**	**20**	**21**	**22**	**23**	**24**
Weft strength (kgf)	40,1	41,4	41,7	40,8	39,3	41,4
Warp strength (kgf)	81,4	80,7	79,6	73,6	73,5	73,9
Weft elongation	14,0%	19,8%	16,1%	21,1%	18,4%	16,8%
Warp elongation	11,2%	10,1%	10,4%	8,5%	10,4%	12,3%
Sample	**25**	**26**	**27**	**28**	**29**	**30**
Weft strength (kgf)	45,3	42,3	42	47,5	40	42
Warp strength (kgf)	76,9	78,2	74,4	72,4	72,7	75,7
Weft elongation	17,0%	16,8%	20,1%	19,7%	22,7%	18,3%
Warp elongation	11,1%	10,6%	7,9%	7,0%	7,5%	9,8%
Sample	**31**	**32**	**33**	**34**	**35**	**36**
Weft strength (kgf)	42,3	41,7	39,8	35,8	38,8	33,9
Warp strength (kgf)	77	80,3	71	69,9	69,6	66,2
Weft elongation	17,6%	16,1%	14,9%	15,1%	17,3%	14,8%
Warp elongation	8,7%	8,9%	8,2%	8,4%	8,4%	8,3%

While examining the data obtained from the breaking strength tests that are seen from Figures 4.10 and 4.11 it should be observed that there's a quite difference between warp and weft strength values. These high strength values of warp direction are caused from fairly higher yarn sett values of warp direction than weft direction.

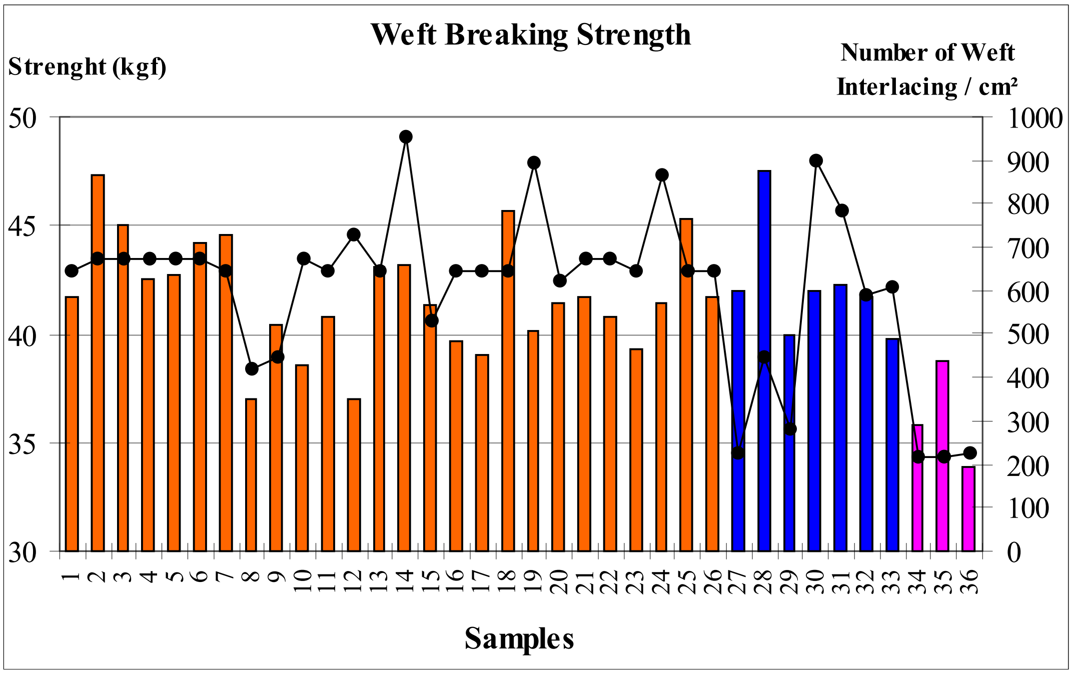

Figure 4. 10 Weft breaking strength values of sample fabrics

If the weft strength values kept in mind it is obvious from Figure 4.10 sample 28, which is a plain derivative, exhibits the highest strength value of 47,5 kgf and sample 36, which is a sateen derivative, exhibits the lowest strength value of 33,9 kgf. If Figures 4.10 and 4.11 are examined the interlacing number of sample 28 in weft direction is not very high but in warp direction it has very high interlacing number. So this highest strength value of weft direction must be a reason of the effect of warp interlacing on weft breaking strength. In other words warp interlacing number influence the weft breaking strength with an increasing effect by providing additional frictional forces between yarns. For sample 36, which has the lowest interlacing number at both weft and warp, direction was expected to have the lowest weft breaking strength values because of the least interlacing number. From Figure 4.10 it is seen that samples 14, 19, 24, and 30 did not show a direct proportion between interlacing number and breaking strength in weft direction. So interlacing number must not be evaluated as the only factor of breaking strength in a weave type, the balance in structure, yarn grouping regions and number of floats must be considered.

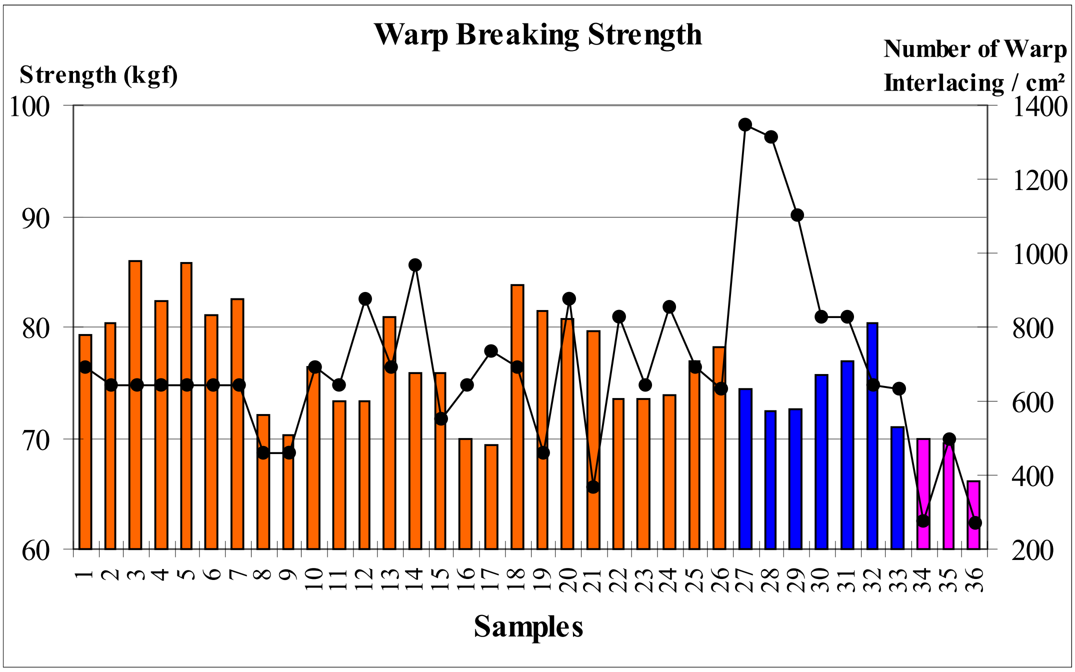

Figure 4. 11 Warp breaking strength values of sample fabrics

Figure 4.11 illustrates the warp breaking strength values of all samples. In warp direction samples 3 and 5 has the highest strength value of 85,9 kgf and 85,8 kgf respectively, while sample 36 has the lowest strength value of 66,2 kgf. Sample 36 was estimated to have the lowest strength according to probable reasons mentioned earlier. Samples 3 and 5 showed the highest warp strength values due to their low number of floats. If their similar structure with samples 1, 2, 4, 6, 7 are examined the closer strength values to samples 3 and 5 are observed. Except this manner sample 24 might have expected to have high strength value due to its balanced structure and high number of interlacings for both warp and weft direction. But its breaking strength value is closer to average values. This may be a result of yarn strength decreasing because of frictional forces during weaving due to its weave pattern obtained by a straight draft.

Weft and warp breaking elongation values of all samples are given in Figures 4.12 and 4.13 respectively. By comparing these Figures, it's seen that weft direction breaking elongations are relatively higher than warp direction breaking elongations. This behavior can be explained as a result of two possible causes. Firstly, the warp yarns in the fabric loss their stretch property during weaving preparation and weaving processes because of tensions but weft yarns doesn't have a this kind of exposure. Secondly, high weft crimps influence the weft breaking elongation with an increasing effect because as a woven fabric is stretched initially, the yarns straighten removing the crimp. If we assume the yarn crimp as a result of fabric weave type, it will be sufficient to evaluate the breaking elongation results in breaking elongation – yarn crimp relationship.

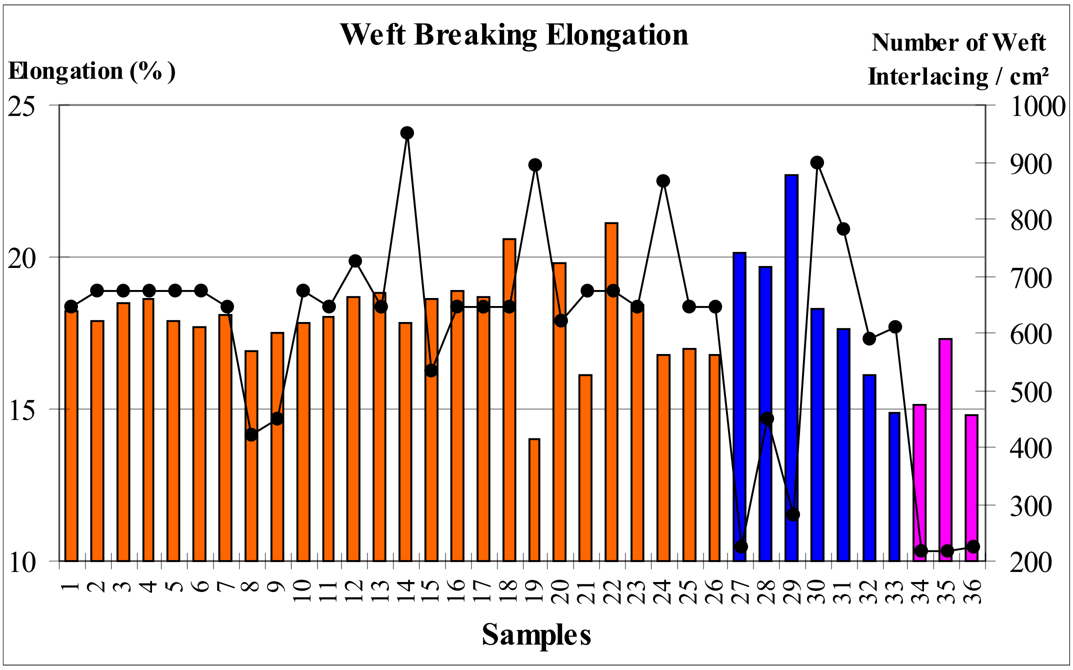

Figure 4. 12 Weft breaking elongation values of sample fabrics

In weft breaking elongation values sample 19 has the lowest and sample 29 has the highest elongations with values of 14,0% and 22,7% respectively. If the crimp values of these samples are examined from Figure 4.2 a very strong interaction will be seen between weft crimp and weft breaking elongation for these two samples as expected because of the reason mentioned above. If Figure 4.2, which is a representation of weft crimp values, is compared with Figure 4.12 a fairly uniform direct proportion between weft breaking elongation and weft crimp is also seen for all samples.

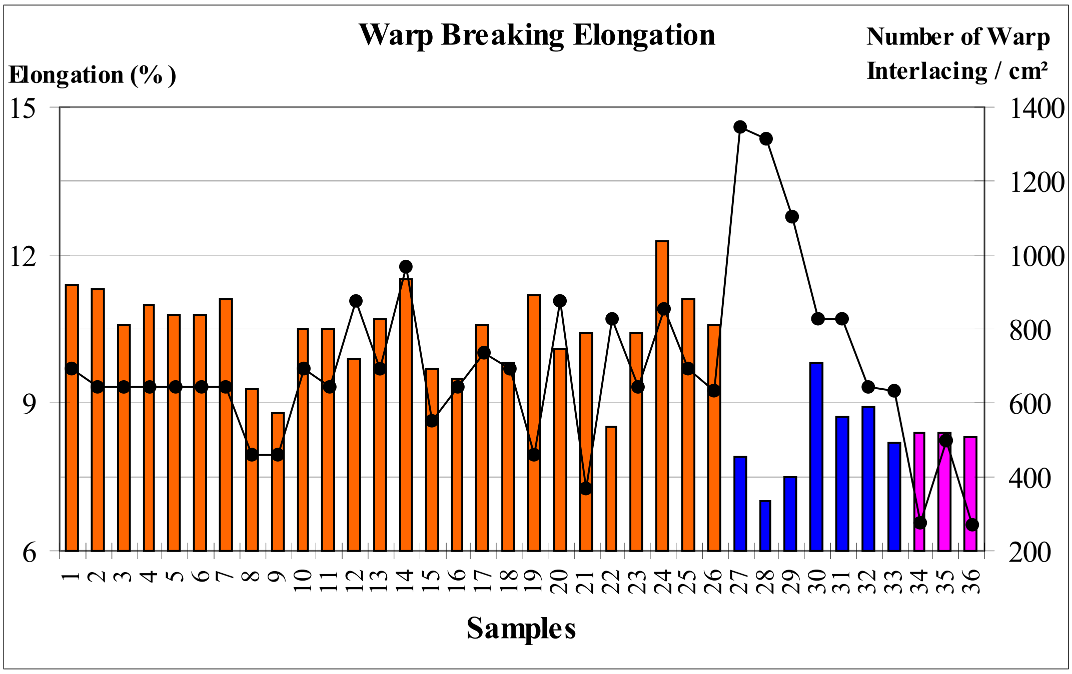

Figure 4. 13 Warp breaking elongation values of sample fabrics

If warp breaking elongation values are considered, sample 24 has the highest 12,3% and sample 28 has the lowest 7,0% breaking elongation values. Similar with the correlation between weft crimp and weft breaking elongation, by examining the Figures 4.1 and 4.13 a considerable direct proportion between warp crimp and warp breaking elongation is found.

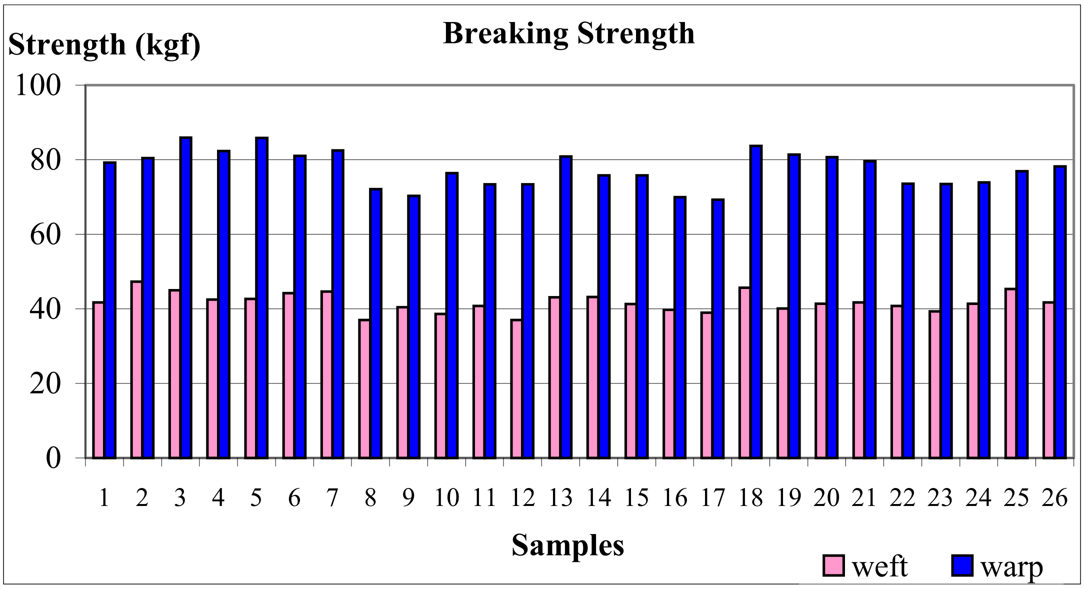

Figure 4. 14 Breaking strength values of twill weave samples

Figure 4.14 represents the breaking strength values of twill weave samples for warp and weft direction. In twill weaves a considerable difference between breaking strength values isn't available neither for weft nor for warp direction. In weft direction, sample 2 has the highest 47,3 kgf and samples 12 and 8 have the lowest 37 kgf breaking strength. In warp direction sample 3 has the highest 85,9 kgf and sample 17 has the lowest 69,3 kgf breaking strength.

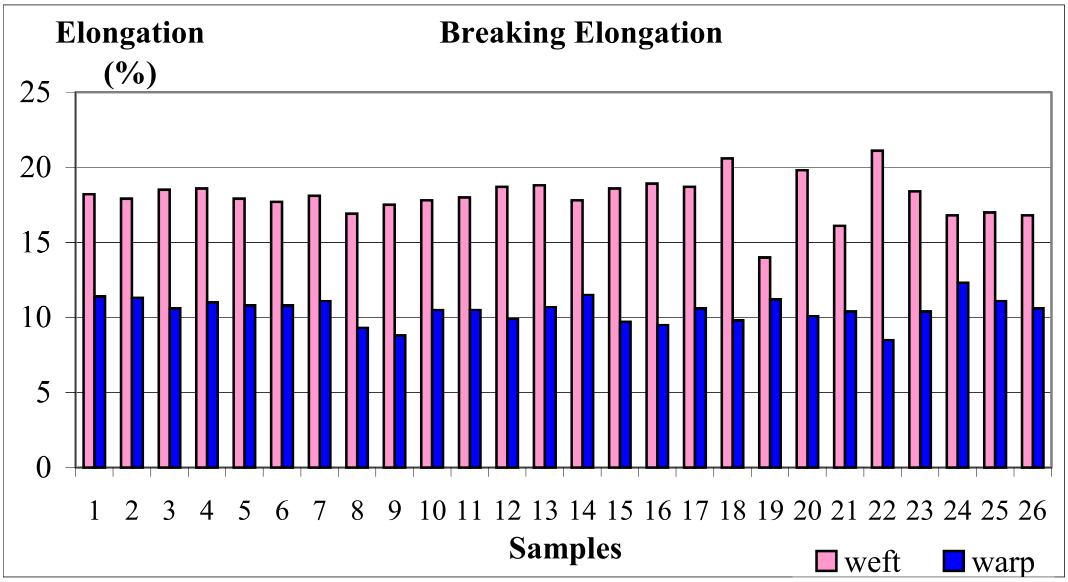

Figure 4. 15 Breaking elongation values of twill weave samples

It is clear from Figures 4.14 and 4.15, for warp and weft directions breaking strength and breaking elongation values are contrary to each other. Warp breaking strength is higher than weft breaking strength while weft breaking elongation is higher than warp breaking elongation. Among twill weave samples, for weft direction sample 22 has the highest 21,1% and sample 19 has the lowest 14,0% breaking elongations. In the other hand for warp direction, sample 24 has the highest 12,3% and sample 22 has the lowest 8,5% breaking elongations.

If Figure 4.3 is compared with Figure 4.15 in accordance with yarn crimp and fabric breaking elongation relationship, it's seen that for weft direction sample 22 has the highest yarn crimp and fabric breaking elongation while sample 19 has the lowest yarn crimp and fabric breaking elongation. In addition to this in warp direction sample 24 has the highest yarn crimp and fabric breaking elongation while sample 22 has the lowest yarn crimp and fabric breaking elongation. By this way, the direct relationship between yarn crimp and fabric breaking elongation is confirmed again by the test results.

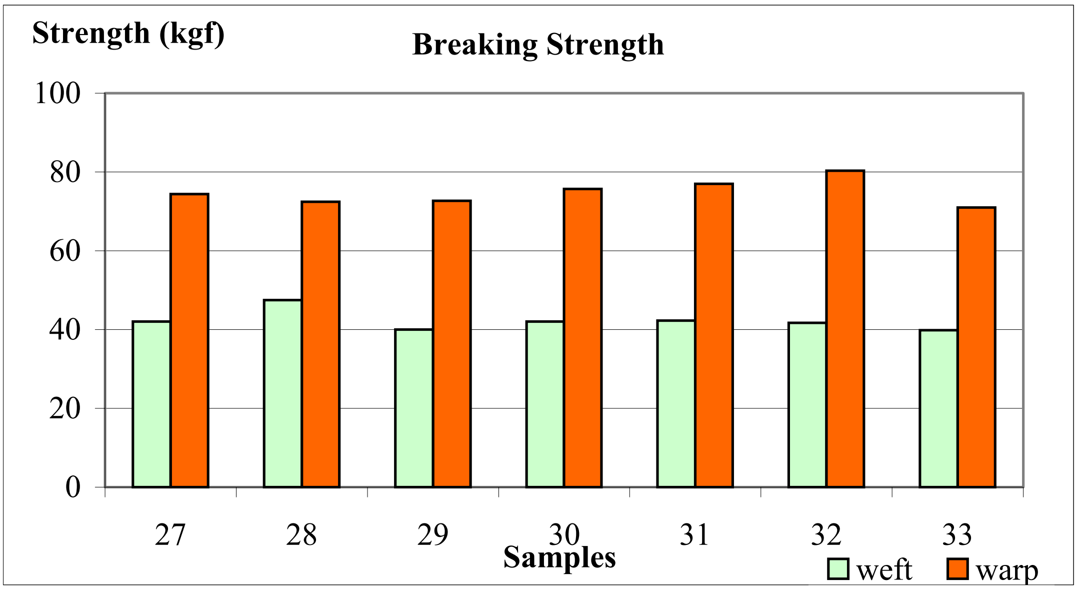

Figure 4. 16 Breaking strength values of plain weave samples

Figure 4.16 shows the breaking strength values of plain weave samples for warp and weft direction. In plain weaves a considerable difference between breaking strength values isn't available neither for weft nor for warp direction.

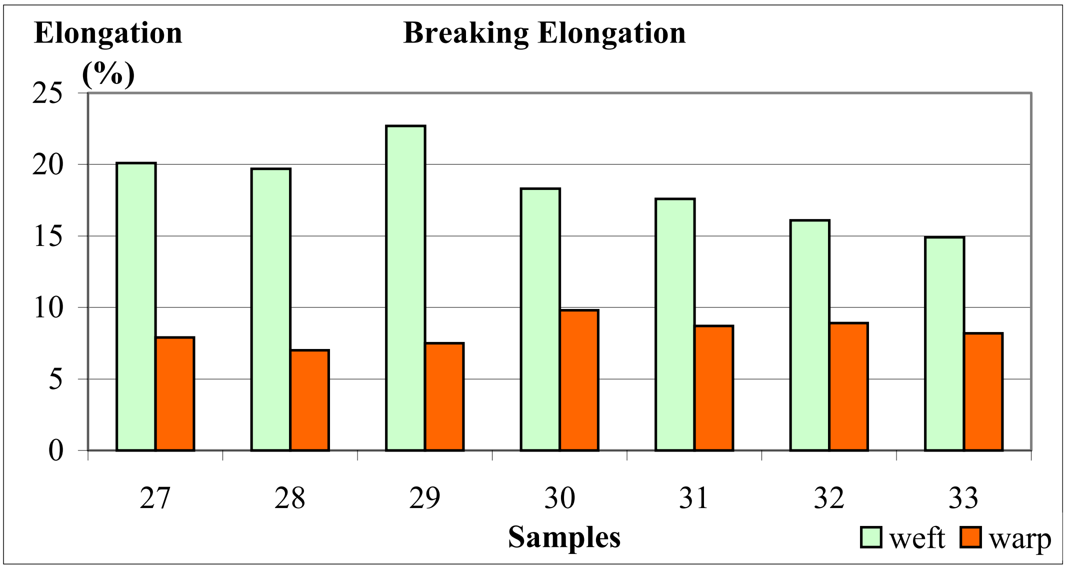

Figure 4. 17 Breaking elongation values of plain weave samples

It is clear from Figures 4.16 and 4.17, for warp and weft directions breaking strength and breaking elongation values are contrary to each other for plain weave types similarly with twill weave types. Warp breaking strength is higher than weft breaking strength while warp breaking elongation is lower than weft breaking elongation. If breaking elongations of plain weave samples are examined in comparison with crimp values from Figures 4.4 and 4.5 for warp and especially for weft direction the similarity is considerable. The highest weft breaking elongation 22,7% belongs to sample 29 that has the highest weft crimp value of 20,3% at the same time. Sample 30 has the highest warp breaking elongation 9,8% while having the highest warp crimp value of 5,0%. At the same time for weft direction the lowest yarn crimp 12,5% and the lowest breaking elongation 14,9% belong to sample 33. In the other hand sample 28 has the lowest breaking elongation and yarn crimp values in warp direction. These 4 samples verify the direct proportion between yarn crimp and fabric breaking elongation.

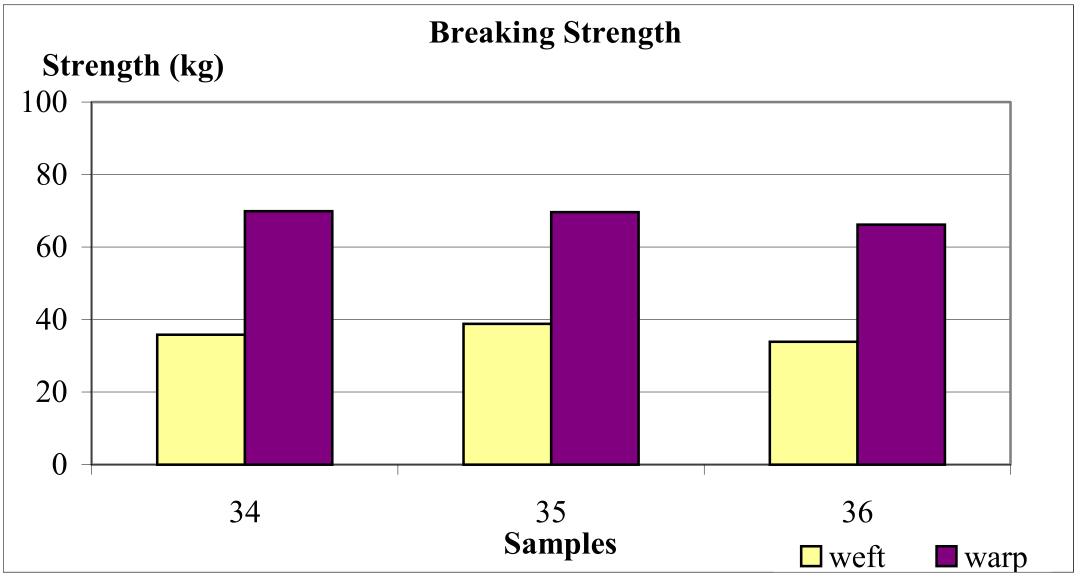

Figure 4. 18 Breaking strength values of sateen weave samples

Figure 4.18 exhibits the breaking strength for sateen weave samples. There is not a fairly important difference between values. But at the same time it should be noted that among sateen weave derivatives in weft direction sample 35, which is a reinforced form of sample 36, has the highest weft breaking strength of 38,8 kgf. And it’s followed by sample 34 with 35,8 kgf breaking strength, which is a rearranged form of sample 36. In warp direction samples 34 and 35 have nearly same (69,9 kgf, 69,6 kgf) and higher warp strength values than sample 36 (66,2 kgf). If weave types of samples 34, 35 and 36 are examined, it can be said that both changing the place of interlacings and increasing the yarn floats influence the breaking strength behavior for warp and weft direction. This two-mentioned ways influence the strength with the same proportion in warp direction while increasing the yarn floats affecting the strength more than changing the place of interlacings in weft direction.

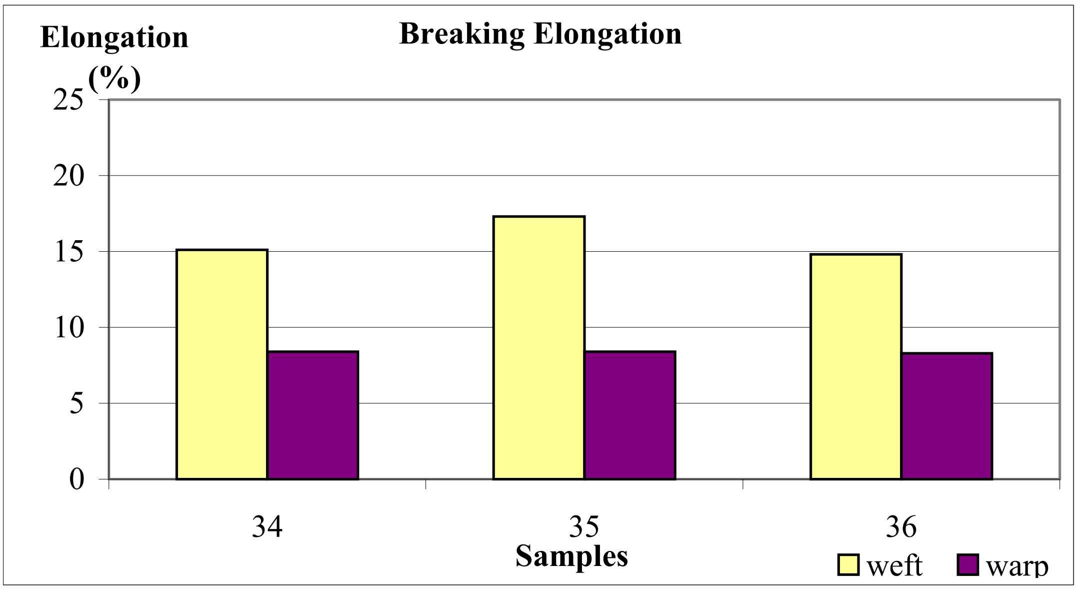

Figure 4. 19 Breaking elongation values of sateen weave samples

Three sateen weave samples have no considerable difference between warp breaking elongations as shown in Figure 4.19. In other words for sateen weaves changing the weave type has no effect on warp breaking elongations in this study. In weft direction breaking elongation sample 35 has the highest breaking elongation value of 17,3% and it is followed by sample 34 with 15,1% breaking elongation.

According to ANOVA results, the effect of weave type on breaking strength and breaking elongation values for both warp and weft direction was found to be significant ($P \leq 0,01$) at 1% significance level.

Table 4.11 was prepared by the results obtained from statistical correlation analysis done for breaking strength values for warp and weft direction.

Table 4. 11 Correlation analysis results for breaking strength

	Weft Breaking Strength	Warp Breaking Strength
Thickness	**– X**	**– XX**
Weight	**+ X**	**0**
Weft crimp	**+X**	**0**
Warp crimp	**0**	**+ XX**
Weft elongation	**+ XX**	**0**
Warp elongation	**+ X**	**+ XX**

XX : Correlation is significant at 1% significance level.
X : Correlation is significant at 5% significance level.
0 : Correlation is insignificant.
+ : Positive correlation
– : Negative correlation

According to the results of correlation analysis given in Table 4.11 we can draw the following most important conclusions. The correlation is insignificant between weft breaking strength and warp crimp and warp breaking strength and weft crimp. This means warp crimp has no effect on weft breaking strength and weft crimp has no effect on warp breaking strength. In the other hand between weft crimp and weft breaking strength and between warp crimp and warp breaking strength positive correlations were determined at 1% and 5% significance levels respectively. In other words there are direct proportions between weft crimp and weft breaking strength and warp crimp and warp breaking strength. Between weft breaking strength and weft breaking elongation and between warp breaking strength and warp breaking elongation correlations are significant and positive at 1% significance level. Weft breaking strength increases by increasing weft breaking elongation while warp breaking strength increases by increasing warp breaking elongation. Between thickness and warp breaking strength and between thickness and weft breaking strength the correlations are negative and significant at the 1% and 5% significance levels respectively. These negative proportions mean that increasing fabric thickness influence the breaking strength for both warp and weft direction with a decreasing effect. In the other hand the correlation between warp breaking strength and weft breaking strength is significant and positive at the 1% significance level.

According to Tukey tables sample 36 is the worst and sample 28 is the best samples for weft direction breaking strength while sample 36 is the worst and samples 18, 5, 3 are the best samples for warp direction breaking strength.

Table 4.12 was prepared by the results obtained from statistical correlation analysis done for breaking strength values for warp and weft direction.

Table 4. 12 Correlation analysis results for breaking elongation

	Weft Breaking Elongation	Warp Breaking Elongation
Thickness	+ **XX**	**– XX**
Weight	+ **XX**	**0**
Weft crimp	+ **XX**	**– XX**
Warp crimp	**– XX**	+ **XX**
Weft strength	+ **XX**	+ **X**
Warp strength	**0**	+ **XX**

XX : Correlation is significant at 1% significance level.
X : Correlation is significant at 5% significance level.
0 : Correlation is insignificant.
+ : Positive correlation
– : Negative correlation

According to Table 4.12 obtained from statistical correlation analysis, increasing weft crimp causes the weft breaking elongation to increase while causing the warp breaking elongation to decrease. Similarly with this manner increasing the warp crimp influence the warp breaking elongation positively while affecting the weft breaking elongation negatively. In addition to these increasing thickness value increases the weft breaking elongation while decreasing the warp breaking elongation. Fabric weight has no effect on warp breaking elongation but has a positive effect on weft breaking elongation.

According to Tukey Tables in weft direction breaking elongation sample 19 is the worst and sample 29 is the best while in warp direction breaking elongation sample 28 is the worst and sample 24 is the best samples.

4.7. Pilling Resistance

Pilling resistance property of sample fabrics are measured with the help of Martindale Abrasion Tester. The specimens are evaluated according to number of pills per square cm at different cycles of Martindale Abrasion Tester. The test strokes are 125, 500, 1000, 2000, 5000, 7000, 8000, 9000, 10000, 11000, 12000, 13000 cycles. Although TSE Standard suggest the test strokes between 125 – 7000 we wanted to follow the pilling behavior of fabrics at higher cycles so tests are continued until 13000 cycle. General assessment and comparison of all samples are done at 2000 cycle as a common suggestion of standard test methods and in the light of previous works. Table 4.13 illustrates the number of pills per square cm at 2000 cycle.

In addition to assessment at 2000 cycle we have plotted the pill numbers of sample fabrics versus cycle number of Martindale Abrasion Tester for each sample individually by giving the weave pattern of sample next to its graphical representation to understand the results of pilling tests easily in Appendix B.

Table 4. 13 Pill numbers of samples at 2000 cycle

Sample	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Number of pills	7	7	7	8	7	7	8	12	9
Sample	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Number of pills	6	6	7	8	6	6	8	7	5
Sample	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
Number of pills	6	6	8	4	6	5	4	5	11
Sample	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
Number of pills	7	8	9	12	7	6	9	8	7

Pilling tendency increases by the factors that permit the fibers protrude from the fabric surface to entangle with each other. From this point of view, if the weave type is kept in mind, the long floats and low interlacing numbers in woven fabrics will decrease the pilling resistance. The assessments will done according to this approach.

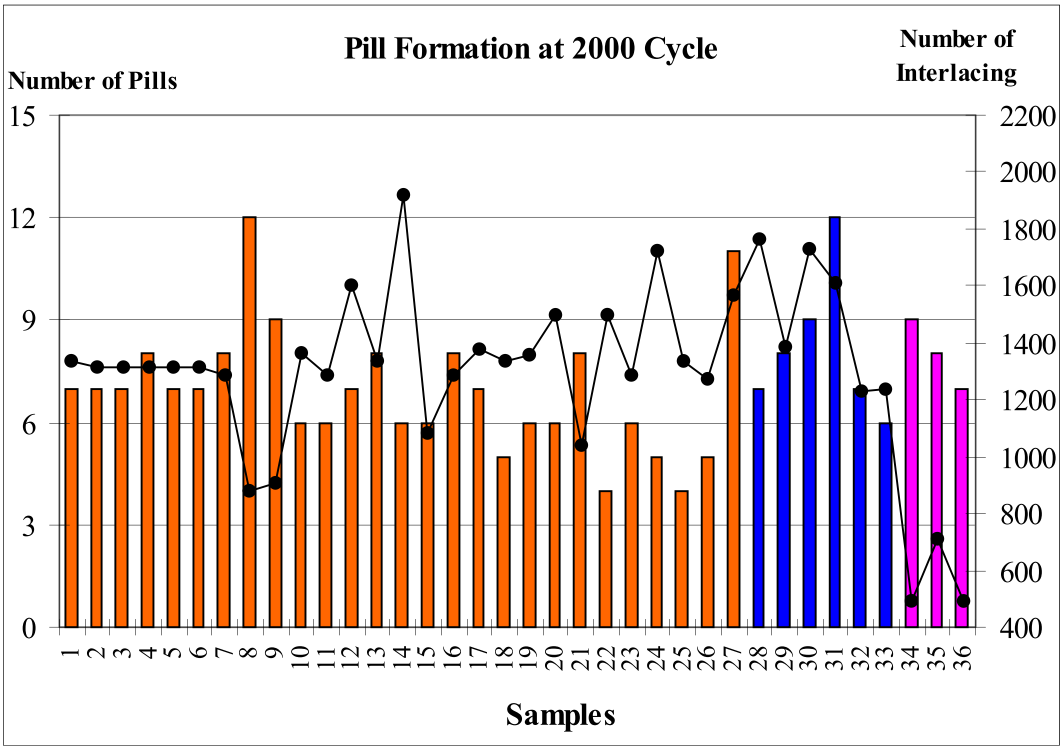

Figure 4. 20 Pill formation diagram for sample fabrics at 2000 cycle

As seen from Figure 4.20 that lowest pill numbers are generally observed at twill weave derivatives. Plain and sateen weave samples have higher pill numbers than twill. The highest number of pills belongs to samples 8 a twill derivative and 31 a plain derivative with 12 pills/cm². In the other hand samples 22 and 25 twill derivatives have the lowest pill numbers of 4 pills/cm². If Figure 4.20 is examined it is clear that for samples 8, 9, 34, 35, 36 low number of interlacing causes high pill formations and for samples 14, 22, 24 high number of interlacings cause low pill formations. But in the other hand, samples 27 and 31 have high interlacing numbers with pill formation. If these weave types are seen form Figure 4.5, it is seen that long floats cause pill formation to increase although they have high number of interlacings.

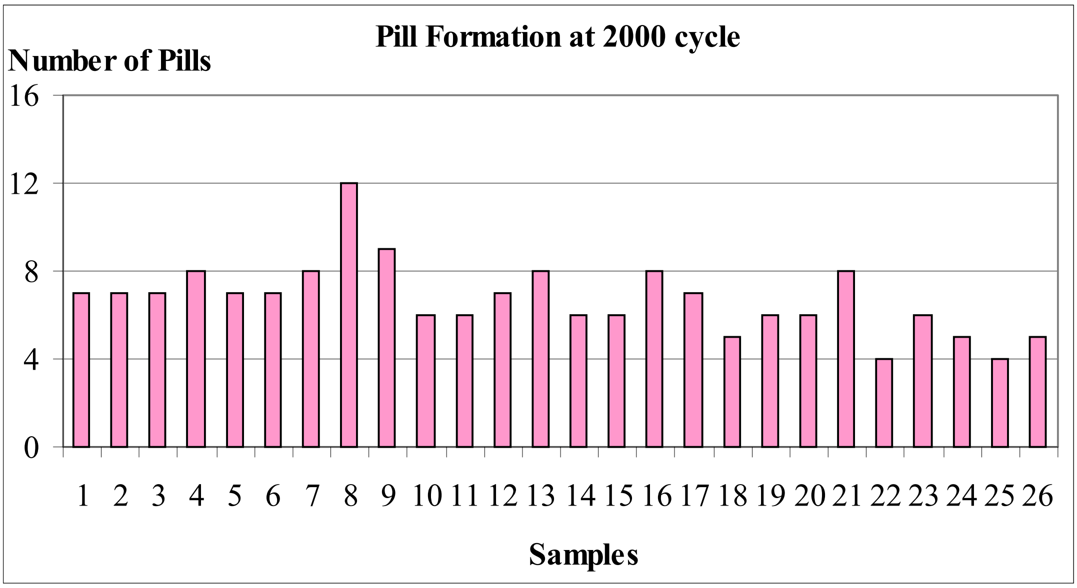

Figure 4. 21 Pill formation diagram for twill weave samples at 2000 cycle

Figure 4.21 represents the pill numbers of twill weave samples at 2000 cycle. The pilling rates are closer to each other except sample 8. As mentioned earlier sample 8 has the worst pilling resistance among twill and all other samples, while samples 22 and 25 have the best pilling resistance.

Samples 1, 2, 3, 4, 5, 6, 7 which have similar weave structures from the view of interlacing and float number have nearly same pill numbers at 2000 cycle. If samples 8 and 9 are compared from pill formation diagrams in Appendix B, it is seen that sample 9 exhibits nearly same pilling behavior with sample 8 in contrary to pill numbers in Figure 4.21. The only difference is that sample 8 reaches the maximum pill number at an earlier cycle than sample 9. Sample 22, which has the lowest pill number at 2000 cycle, reaches the maximum pill number more slowly than other twill types. It is the reason of lowest pill number at 2000 cycle. In addition to these, samples 24, 25, 26 show low and closer pill numbers due to their tight structure.

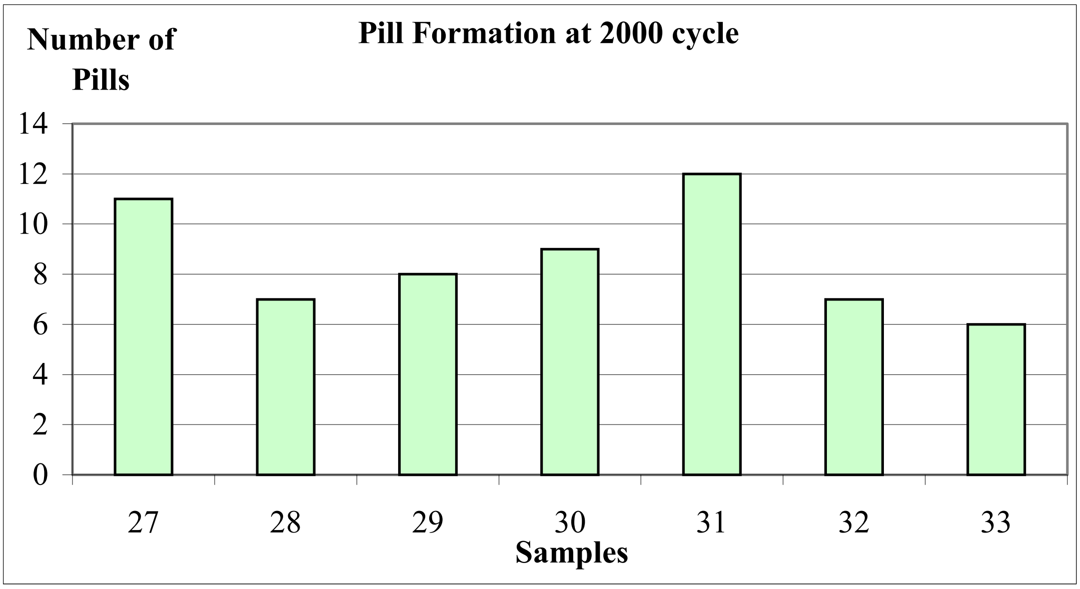

Figure 4. 22 Pill formation diagram for plain weave samples at 2000 cycle

Figure 4.22 shows the pill numbers of plain weave samples at 2000 cycle. In plain weave samples sample 33 has the lowest and sample 31 has the highest pill numbers of 6 pills/cm² and 12 pills/cm² respectively. Sample 31 that has high number of floats in both warp and weft direction exhibits the worst pilling resistance with a considerable difference from other plain weave samples. Sample 27 has a closer pill number with this sample but can't reach because of sample 27's high interlacing number in warp direction.

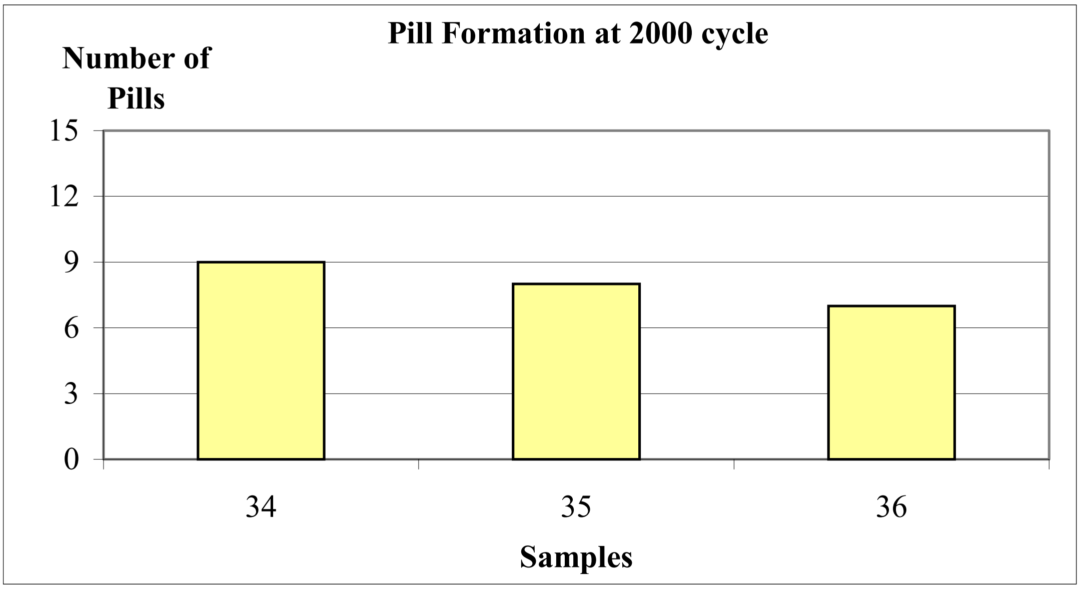

Figure 4. 23 Pill formation diagram for sateen weave samples at 2000 cycle

In sateen weave samples shown in Figure 4.23 there isn't a considerable difference of pilling resistance property.

According to ANOVA results, the effect of weave type on pilling resistance at 2000 cycle is found to be significant ($P \leq 0{,}01$) at 1% significance level. In addition to this Table 4.14 was prepared by the results obtained from statistical correlation analysis done for pilling resistance property at 2000 cycle. In this table only the necessary properties are discussed.

Table 4. 14 Correlation analysis results for pilling resistance

	Pill number per area
Warp crimp	**–XX**
Weft crimp	**0**
Fabric thickness	**+XX**
Fabric weight	**0**
Abrasion (mass loss)	**+X**

XX : Correlation is significant at 1% significance level.
X : Correlation is significant at 5% significance level.
0 : Correlation is insignificant.
+ : Positive correlation
– : Negative correlation

According to Table 4.14 there is no correlation between weft crimp and pill number and between fabric weight and pill number. Correlation analyses show that increasing fabric thickness causes the pilling resistance to deteriorate by increasing the pill number per area. Also a positive proportion is found between pilling resistance and abrasion resistance. In other words the pilling resistance deteriorate by decreasing abrasion resistance. In addition to these the negative correlation between warp crimp and pill number per area means increasing warp crimp causes the number of pill per area to decrease.

According to Tukey Tables sample 22 is the best and samples 8 and 31 are the worst samples for pill formation at 2000 cycle.

4.8. Abrasion Resistance

In abrasion resistance tests done according to mass loss evaluations a preparation test is done to determine the test strokes. This preparation test was done for a few samples and the test strokes of 5000, 7500, 10000, 15000, 25000 were decided according to TSE Standards. But when abrasion tests are performed excessive damage in some samples at 25000 cycles was observed that might cause to cancel the assessment at this test stroke. So evaluations for mass loss was done at 15000 cycle given in Table 4.15.

Table 4. 15 Mass loss values of sample fabrics after abrasion resistance tests

cycle	Mass loss (%)								
	1	2	3	4	5	6	7	8	9
5000	3,00	2,48	2,17	2,30	2,33	2,02	1,81	3,53	3,23
7500	3,93	3,64	3,12	3,30	3,63	3,03	2,40	4,62	4,22
10000	4,76	4,46	3,89	4,12	4,57	4,09	3,09	5,63	5,06
15000	6,04	6,01	5,05	5,53	6,37	5,37	4,10	7,36	6,72
25000	8,80	8,66	6,94	7,47	8,66	8,31	6,09	10,02	9,34

cycle	Mass loss (%)								
	10	11	12	13	14	15	16	17	18
5000	2,67	2,42	2,88	2,65	2,64	3,02	2,15	1,97	2,22
7500	3,84	3,32	4,65	3,90	4,02	3,99	3,12	2,90	3,13
10000	4,55	4,26	6,55	4,78	5,28	5,17	3,92	3,58	3,90
15000	6,74	5,31	11,28	6,58	7,54	7,43	5,09	5,11	5,49
25000	11,23	8,79	20,40	13,68	13,42	13,18	7,24	7,54	7,70

cycle	Mass loss (%)								
	19	20	21	22	23	24	25	26	27
5000	2,98	2,49	2,81	2,83	2,31	2,51	3,03	2,28	2,25
7500	4,25	3,41	4,51	3,62	3,29	3,45	4,00	3,14	4,26
10000	5,88	3,82	6,05	4,51	4,16	4,52	5,18	4,15	5,93
15000	8,60	5,30	8,80	6,32	5,26	6,13	6,90	5,85	8,87
25000	21,31	7,97	16,49	10,64	7,49	9,59	9,87	8,69	16,59

cycle	Mass loss (%)								
	28	29	30	31	32	33	34	35	36
5000	3,66	3,33	3,91	3,93	2,75	2,90	0,86	2,00	2,51
7500	5,02	5,23	5,31	5,90	3,62	4,15	2,58	3,78	4,70
10000	6,23	6,52	6,40	7,28	4,48	5,19	4,93	5,48	6,52
15000	9,10	9,05	7,94	9,59	5,41	6,80	7,65	8,06	9,57
25000	17,02	16,38	10,98	16,66	8,36	9,45	12,48	13,45	15,28

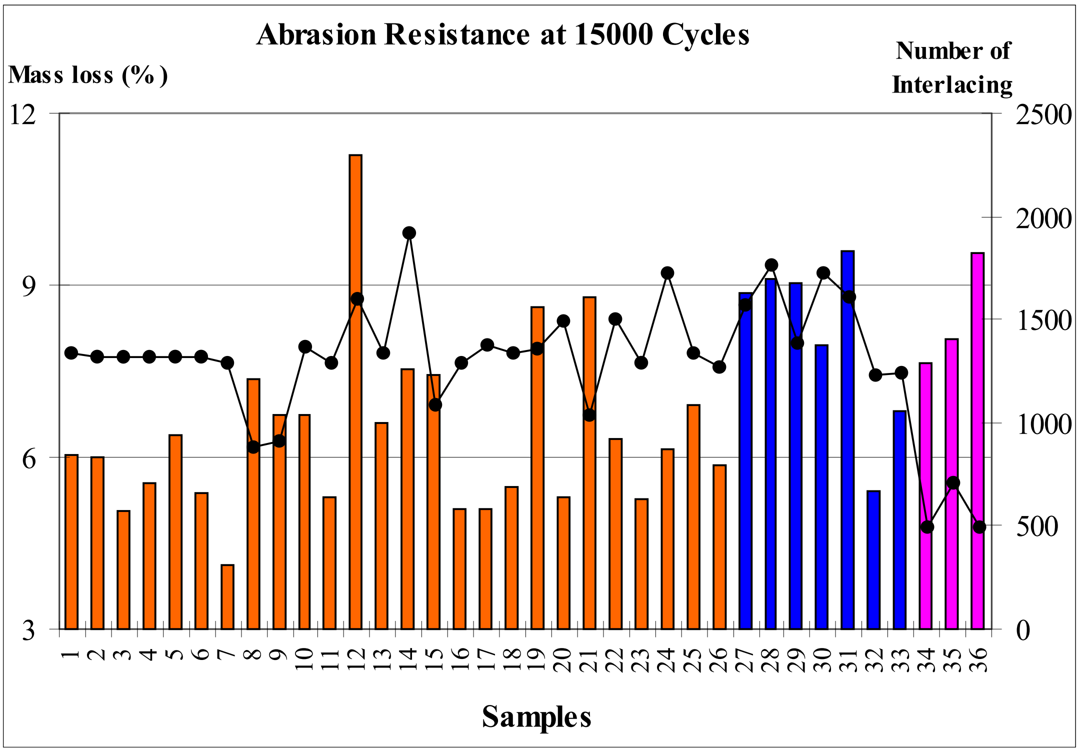

Figure 4. 24 Mass loss of sample fabrics after 15000 cycles

Figure 4.24 illustrates the mass loss values of all samples at 15000 cycles. Sample 7 a twill derivative has the mass loss of 4,1% and it's the most resistant sample to abrasion while sample 12 which is a twill derivative also has the highest mass loss of 11,28%. It is clear from Figure 4.24 that there is a considerable variation of abrasion properties of all samples. Especially for twill weaves mass loss values are very different from each other. The least variation between abrasion properties is observed for sateen weaves. From Figure 4.24 it is clear that, sateen weaves show high mass loss due to their low number of interlacing and long floats in their weave structure. If weave structure of sample 12 which has the highest mass loss is considered, its long floats and yarn grouping regions as decreasing factors on abrasion resistance are seen. Additionally samples 27, 28, 29, 30, 31 have high mass loss versus their high number of interlacing and if these weave types are examined long floats are seen as a common factor for these samples. This interaction may be explained as loose fabric form allows the fibers to leave the fabric structure more easily than tight structures. The loose forms of these fabrics are result of long floats that also cause to expand the contact area between fabric and abradant surface. Based on this result, it is clear that long floats cause the abrasion resistance to lessen.

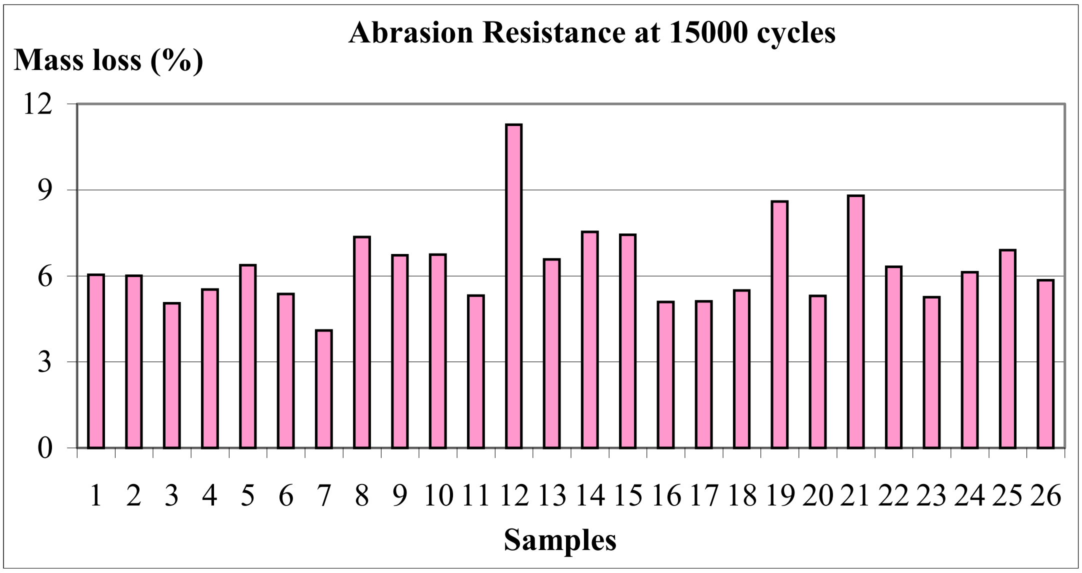

Figure 4. 25 Mass loss values of twill weave samples after 15000 cycles

In twill weave samples seen in Figure 4.25 sample 12 shows the worst abrasion resistance while sample 7 shows the best abrasion resistance. When sample 12 is examined, it is easily seen that this weave type has long floats and low number of interlacings in addition to yarn grouping regions. These manners are probable reasons for samples 19 and 21 at the same time to have high mass loss values. Except these three samples, none of twill weave types has a high mass loss value by the aid of short floats and high number of interlacings.

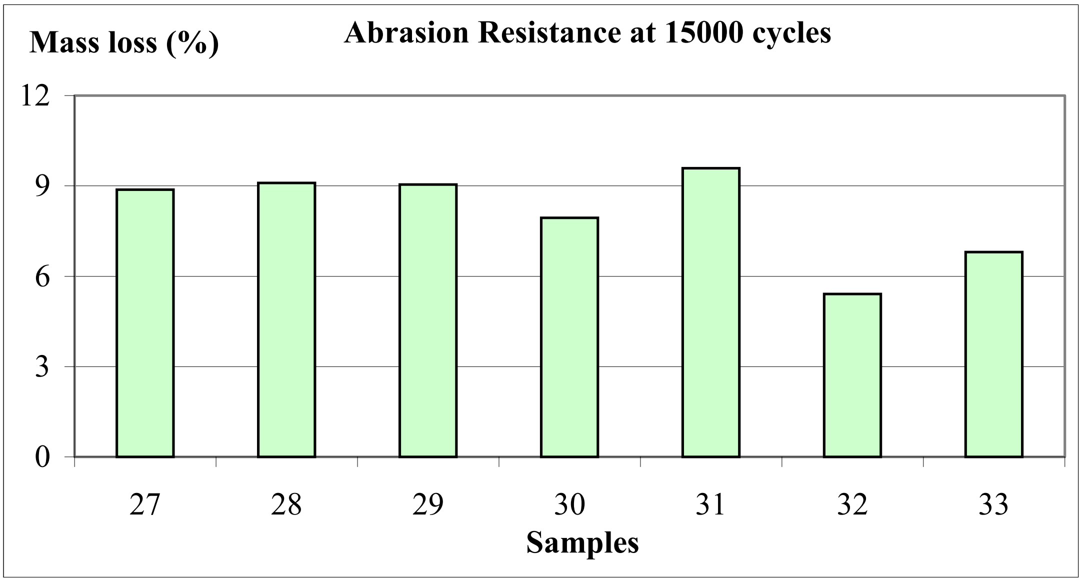

Figure 4. 26 Mass loss values of plain weave samples after 15000 cycles

It is clear from Figure 4.26 that plain weave derivatives doesn't have good abrasion resistance values except samples 32 and 33. For samples 27, 28, 29 and 31 mass loss values are high and sample 30 has a closer value to these. In these mentioned samples the reason for low abrasion resistance is long floats observed in the weaves.

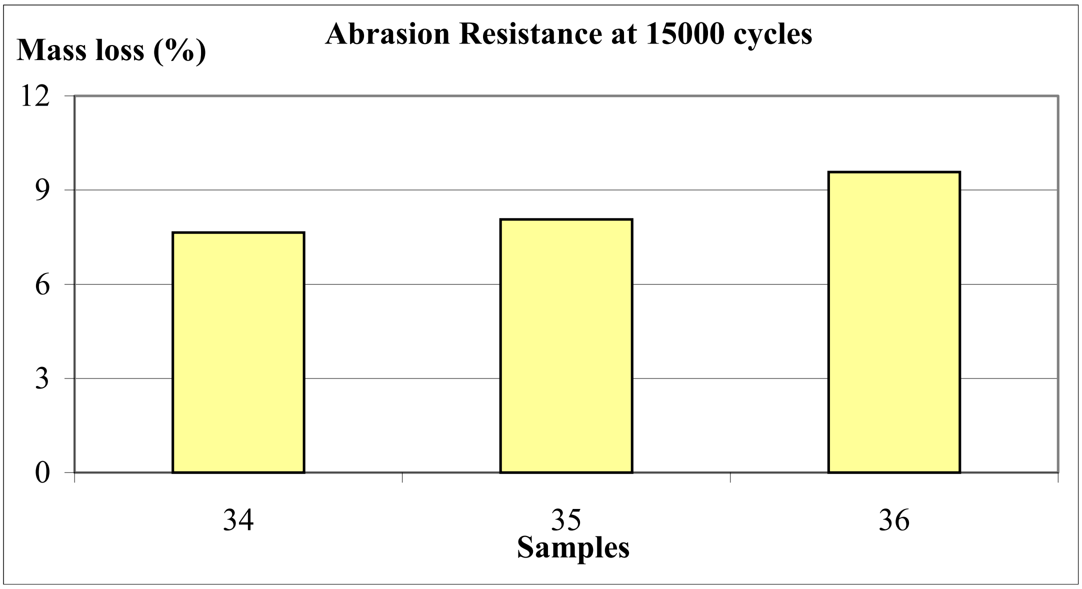

Figure 4. 27 Mass loss values of sateen weave samples after 15000 cycles

Among the sateen weave derivatives shown in Figure 4.27 it's observed that sample 36 shows the worst abrasion resistance. In samples 34 and 35 obtained by rearranging and reinforcing the sample 36 less mass loss values are observed than sample 36. In these samples mass loss values are generally higher than many of twill weave types because of long floats in the weave structure.

We have plotted the mass loss of sample fabrics versus cycle number of Martindale Abrasion Tester for each sample individually by giving the weave pattern of sample next to its graphical representation to understand the results of abrasion tests easily in Appendix C.

According to ANOVA results, the effect of weave type on abrasion resistance is found to be significant ($P \leq 0{,}01$) at 1% significance level. In addition to this Table 4.16 is prepared by the results obtained from statistical correlation analysis done for abrasion resistance property at 15000 cycles. In this table only the necessary properties are discussed.

Table 4. 16 Correlation analysis results for abrasion resistance

	Abrasion (mass loss)
Warp crimp	**–XX**
Weft crimp	**0**
Fabric thickness	**+XX**
Fabric weight	**0**
Pill number per area	**+X**

XX : Correlation is significant at 1% significance level.
X : Correlation is significant at 5% significance level.
0 : Correlation is insignificant.
+ : Positive correlation
– : Negative correlation

If Tables 4.15 and 4.16 are compared it is evident that the properties in these tables cause the same effects on mass loss and pill number properties. According to Table 4.16 there is no correlation between weft crimp and mass loss and between fabric weight and mass loss. Correlation analyses show that increasing fabric thickness causes the abrasion resistance to deteriorate by increasing the mass loss value. Also, pilling resistance deteriorate by decreasing abrasion resistance.

Tukey Tables showed that sample 7 is the best and sample 12 is the worst samples for abrasion resistance property.

4.9. Dimensional Stability

Table 4.17 shows the shrinkage values of fabrics obtained from dimensional stability tests after 10 laundering.

Table 4. 17 Shrinkage values of fabric samples after 10 laundering

Samples	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Weft Shrinkage (%)	1,6	2,3	2,6	2,8	2,3	2,1	2,9	3,3	3,4
Warp Shrinkage (%)	10,0	10,3	10,9	11,1	10,4	10,2	10,9	12,6	13,2
Samples	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Weft Shrinkage (%)	2,5	3,8	6,0	2,1	1,2	2,9	4,5	2,0	7,5
Warp Shrinkage (%)	11,3	10,2	13,8	11,1	11,2	10,9	11,0	11,3	12,5
Samples	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
Weft Shrinkage (%)	2,1	5,3	2,1	7,0	4,9	1,4	2,4	1,9	12,3
Warp Shrinkage (%)	12,9	8,9	13,3	8,5	10,3	10,1	10,3	10,8	8,0
Samples	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
Weft Shrinkage (%)	8,9	13,9	9,1	10,5	4,9	3,7	8,0	7,3	7,6
Warp Shrinkage (%)	5,1	9,9	12,3	12,5	12,8	10,7	9,8	10,5	8,8

From Figures 4.28 and 4.29 the difference between warp and weft direction shrinkage values are obvious especially for twill weave types. This difference is a result of warp and weft sett values. Low weft sett values for our samples permit the warp yarns to move and swell easily between the spaces of weft yarns and fabric to shrink easily. But high warp sett values restrict the movement of weft yarns.

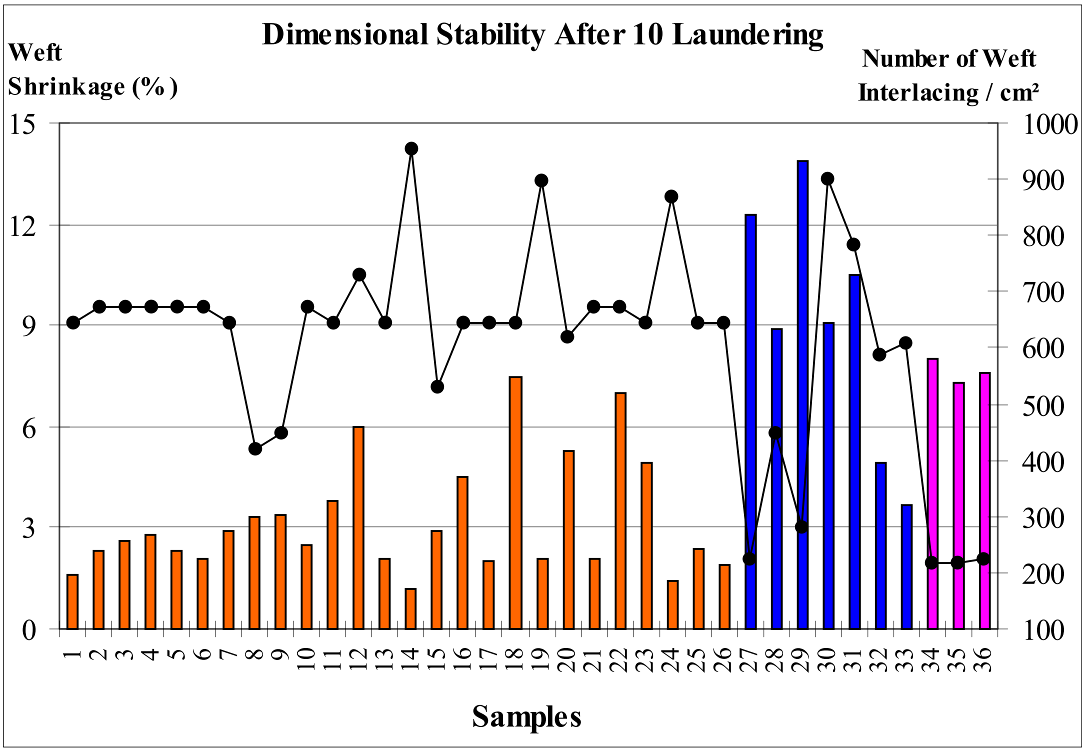

Figure 4. 28 Weft direction shrinkage values after 10 laundering process

For weft direction shrinkage plain weave types exhibit the highest shrinkage values. This weave type is followed by sateen and twill respectively. Sateen weaves does not differ from each other so much while important differences for twill and plain weaves are observed. If sateen and plain weave types except samples 32 and 33 are examined, long floats and low number of interlacings are visible in weft direction. This slack form permits them to shrink easily. The lowest shrinkage value belongs to sample 14 a twill weave derivative with a 1,2% shrinkage and the highest value belongs to sample 29, 13,9%. From Figure 4.28 it is obviously seen that samples 14, 19 and 24 have very low shrinkage versus their high number of interlacing. In addition to these, samples 27, 28, 29, 34, 35, 36 exhibit high shrinkage values because of low interlacing number in their weave structure.

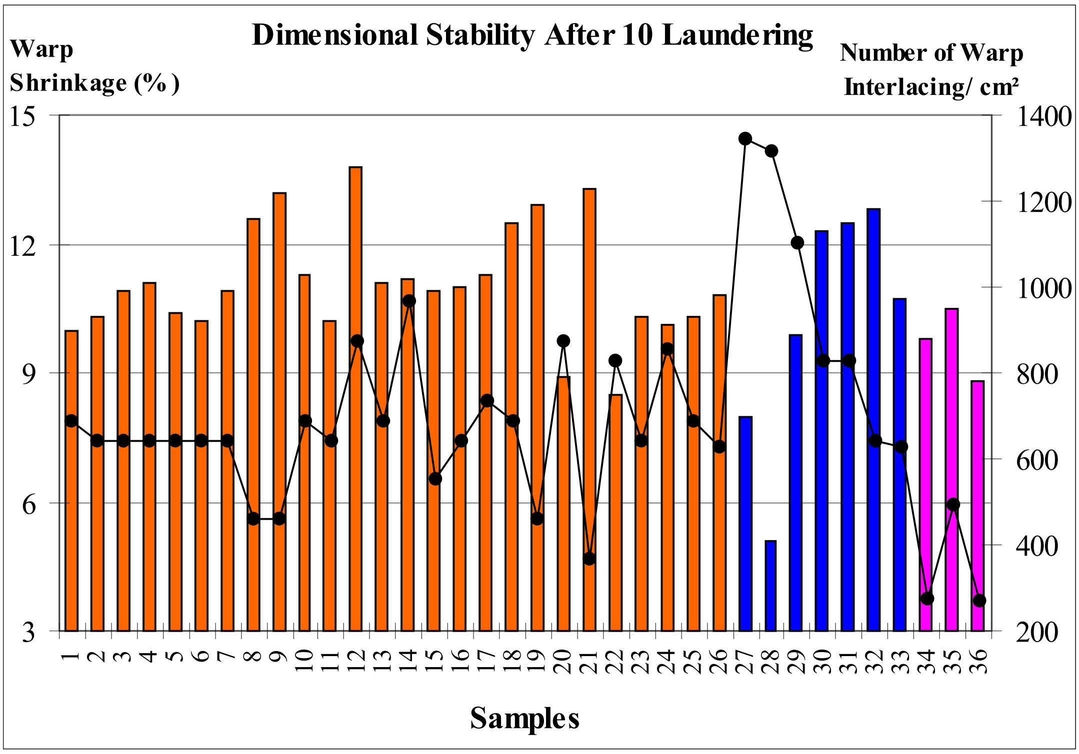

Figure 4. 29 Warp direction shrinkage values after 10 laundering process

According to Figures 4.28 and 4.29 in warp direction, shrinkage values are closer to each other than in weft direction. Sample 12 has the highest warp shrinkage value of 13,8% while sample 28 exhibits the lowest warp shrinkage value of 5,1%. The highest interlacing numbers are seen for samples 27, 28 with fairly low shrinkage values. Samples 8, 9, 19, 21 exhibit high shrinkage despite their good interlacing number but long floats that allow the yarn to move freely in the structure.

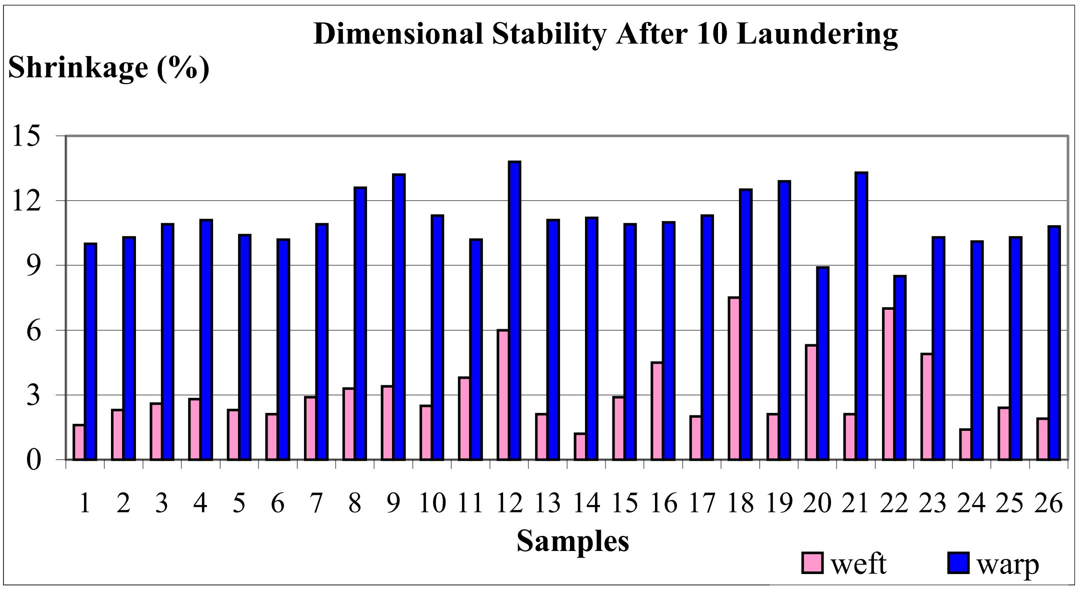

Figure 4. 30 Shrinkage values of twill weave samples after 10 laundering process

Among twill weave samples as shown in Figure 4.30 sample 14 shows the best dimensional stability with 1,2% shrinkage in weft direction because of its high number of interlacing in weft direction. Similarly, sample 22 has the best dimensional stability in warp direction with 8,5% shrinkage. Sample 12 is the worst sample for warp direction dimensional stability with a value of 13,8% while sample 18 is the worst sample for weft direction dimensional stability with 7,5% shrinkage.

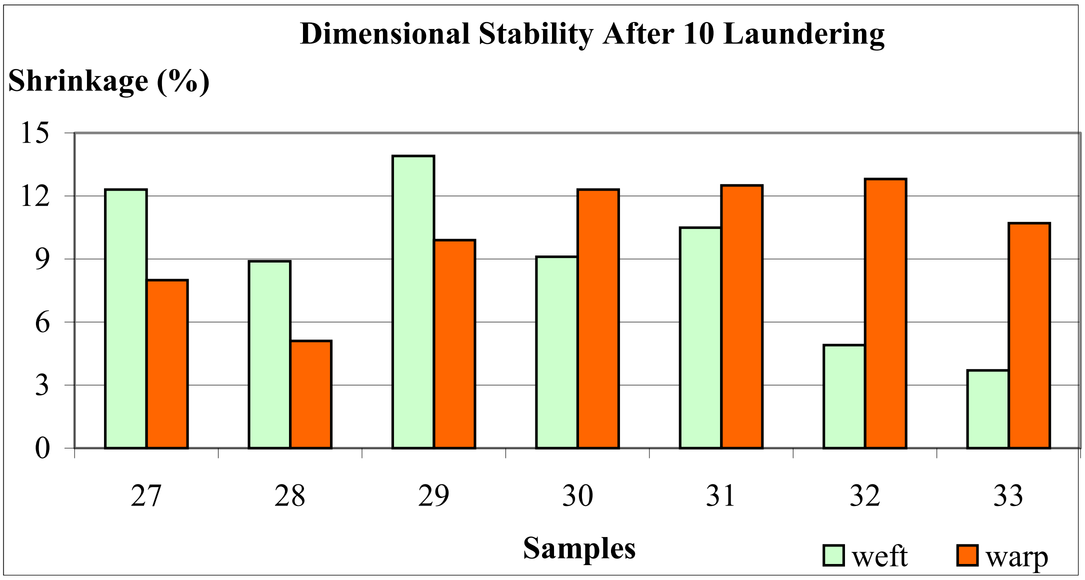

Figure 4. 31 Shrinkage values of plain weave samples after 10 laundering process

It is clear from Figure 4.31 that for plain weaves in warp direction sample 32 shows the worst and sample 28 shows the best dimensional stability with 12,8% and 5,1% shrinkages respectively. Sample 28 has the highest number of interlacing in warp direction. In weft direction sample 33 has the lowest shrinkage value 3,7% while sample 29 has the highest shrinkage 13,9%. Samples 27, 28, 29 exhibit higher shrinkage values in weft direction than warp direction in contrary to all other sample fabrics. This is a result of very low interlacing numbers in weft direction versus high interlacing numbers in warp direction.

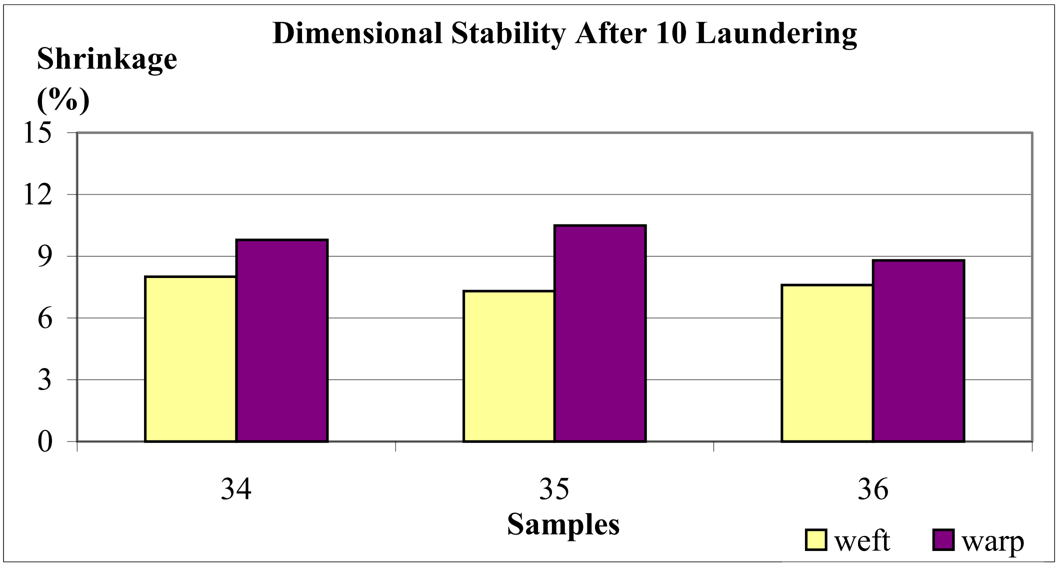

Figure 4. 32 Shrinkage values of plain weave samples after 10 laundering process

In sateen weaves shrinkage values for both warp and weft directions are closer to each other as shown in Figure 4.32. Considerable difference is not available.

We have plotted the shrinkage values of sample fabrics versus number of laundering for each sample individually by giving the weave pattern of sample next to its graphical representation to understand the results of dimensional stability tests easily in Appendix D.

According to ANOVA results, the effect of weave type on dimensional stability was found to be significant ($P \leq 0,01$) at 1% significance level. In addition to this Table 4.18 is prepared by the results obtained from statistical correlation analysis done for dimensional stability after 10 laundering.

Table 4. 18 Correlation analysis results for dimensional stability

	Shrinkage (%)	
	Weft	**Warp**
Warp crimp	**–XX**	**+XX**
Weft crimp	**+XX**	**–XX**
Fabric thickness	**+XX**	**0**
Fabric weight	**0**	**–XX**
Pill number per area	**+XX**	**0**
Abrasion (mass loss)	**+XX**	**0**

XX : Correlation is significant at 1% significance level.
X : Correlation is significant at 5% significance level.
0 : Correlation is insignificant.
+ : Positive correlation
– : Negative correlation

According to Table 4.18 increasing weft crimp increases the weft shrinkage by decreasing the warp shrinkage while increasing warp crimp increases the warp shrinkage by decreasing the weft shrinkage. Because when yarns shrink they swell by increasing their diameter via shortening their length simultaneously. So increasing yarn length by crimp helps to shrink more easily. At the same time the correlation between fabric thickness and weft shrinkage is important with a direct proportion while the correlation between fabric weight and warp shrinkage is found to be important with a reverse proportion from the view of statistical approach. In addition to these dimensional stability in weft direction, abrasion resistance and pilling resistance deteriorates simultaneously. According to statistical correlation analyses between weft direction and warp direction shrinkage the correlation is significant and negative at 1% significance level. Increasing the shrinkage in one direction causes decreasing in opposite direction. Because after laundering process it is expected from fabrics to arrive a stability in dimensions by balancing their length and width. So increasing a dimension in one direction will cause to lessen the dimension in opposite direction.

According to Tukey Tables in weft direction sample 14 is the best and sample 29 is the worst, while in warp direction sample 28 is the best and sample 12 is the worst sample for dimensional stability.

Photographic views of samples in comparison between before and after tests are given in Appendix E.

CHAPTER 5

CONCLUSION

The utility functions, which fabrics should fulfill, first of all depend on their destination. Woven fabrics have a very wide range of applications, starting from underwear and everyday clothing, through protective and work clothing, decorative and furniture fabrics, up to technical textiles. Such a wide range of application means that during their lifetime fabrics undergo actions from different forces and strains depending on their destination and working conditions. They can be stretched, in one direction for example safety and transportation belts or in many directions for example furniture fabrics, torn for example elements of sleeves and trousers or compressed for example rigid interlining. In most of the mentioned cases fabrics are used at least a few times, and sometimes the number of work cycles can total many thousands of repetitions. In each work cycle, the total deformations are significant, and users expect that, after removing the forces, the fabric will return its primary state [31].

Fabric design is a major component of the field of textile engineering. In many cases the desired fabric properties are known or specified by the end user, but the yarn and needed to obtain these properties are not known. Furthermore, the properties of the yarn do not directly correlate the fabric behavior. For example, the strength of a fabric depends not only on the strength of the constituent yarns but also on the yarn structure as influenced by the spinning system, yarn bending behavior, fabric geometry, weaving conditions, fabric finishing treatments and many other parameters [32].

Different fabric weaves differentiate the structure of fabrics and these different structural properties of fabrics will cause the fabrics to behave differently from each other. The aim of this study was to investigate the influence of weave patterns on fabric physical properties for twill weaves and elaborations of twill weaves. The effect of weave type on fabric properties were investigated not only for twill weave types but also sateen and plain weave derivatives are included additionally. 36 sample fabrics with different weave structures were tested according to TSE standards.

The properties of fabrics that will be discussed are;

- Warp and weft crimp
- Fabric weight
- Fabric thickness
- Breaking strength and breaking elongation
- Abrasion resistance
- Pilling resistance
- Dimensional stability

Analyses of variance (ANOVA) was performed in order to understand the statistical importance of weave type on fabric properties and Tukey Tables were used to determine the best and worst weave types for breaking strength and elongation, pilling resistance, abrasion resistance and dimensional stability properties. In addition to these, correlation analysis was done to show the relationship between fabric properties from statistical approach. For this aim the statistical software package SPSS 8.0 was used to interpret the experimental data. All test results were assessed at significance levels of $\alpha \leq 0,05$ and $\alpha \leq 0,01$.

The results show that weave type effects the structural properties of yarn crimp, fabric thickness, fabric weight and mechanical properties of breaking strength and elongation, pilling resistance, abrasion resistance and dimensional stability with a wide range. The effect of weave type on all these mentioned properties is found to be significant at 1% significance level according to ANOVA results.

It is evident from the test results that increasing the number of interlacing in a weave pattern influence the yarn crimp with an increasing effect. In warp direction the highest crimp was 6,8% while the lowest value is 1,6%. In the other hand in weft direction 9,6% was the minimum crimp value and 20,3% was the maximum. And also, correlation analysis showed that there’s a reverse proportion between warp and weft crimp values.

Fabric weight is affected by the weave types used in this study. The fabric weight values are evaluated in accordance with the yarn crimp – fabric weight relationship. Weft direction crimp values affected the fabric weight in a more considerable manner than warp direction crimp values. The samples, which have high weft, crimp values showed higher fabric weight results. Sample 29 a plain derivative which has the highest weft crimp value was most heavy fabric with 151 g/m² fabric weight at the same time. Sample 36 a sateen derivative was the most light fabric with 141 g/m² fabric weight by having a low weft crimp value. From the point of statistical approach, it is found that weft crimp influence the fabric weight with an increasing effect while warp crimp has no effect on fabric weight.

Our findings indicated that the fabrics which have tight structures causing the height of crowns – the part of yarn that protrudes above the surface of the fabric caused by yarn crimp – on fabric surface to be lower than other weave types have lower fabric thickness values. In addition to this the weave types, which allow the yarns to stack on each other in fabric structure, caused high fabric thickness. The highest thickness value belongs to sample 29 a plain derivative with a value of 0,50 mm and the lowest value belongs to sample 24 a twill derivative with a value of 0,28 mm. The difference caused by the weave type is considerable. According to correlation analysis between thickness and weft crimp there's a direct proportion while the warp crimp effect on fabric thickness isn't important. In addition to these the correlation has no statistical importance between fabric thickness and fabric weight.

Based on breaking strength test results, it's clear that breaking strength and breaking elongation values are influenced by the weave type. The low interlacing numbers in weave types caused low breaking strength values in both warp and weft direction. In addition to this it is observed for some weave types that increasing the interlacing number in one direction caused to increase the breaking strength in opposite direction. The highest and the lowest strength values in weft direction were 47,5 kgf and 33,9 kgf respectively. In warp direction, the highest value is 85,9 kgf and the lowest value is 66,2 kgf. The average increase in breaking strength result due to increasing the number of interlacing is 30% in warp direction and 40% in weft direction. If breaking strength values are kept in mind sample 36 a sateen derivative has the lowest interlacing number in warp and weft directions has the lowest breaking strength values in two directions. According to correlation analysis between weft crimp and weft breaking strength and warp crimp and warp breaking strength the correlations were significant and positive. And also there's a direct proportion between breaking strength and breaking elongation in warp direction similar with weft direction.

In the observation of breaking elongation values it is seen that there's a direct proportion in breaking elongation and yarn crimp values. In weft direction sample 29, which has the highest weft crimp, exhibited the highest breaking elongation of 22,7%, while sample 19 has the lowest breaking elongation of 14,0% versus low yarn crimp value in weft direction. In warp direction the highest breaking elongation 12,3% belongs to sample 24 and the lowest breaking elongation 7,0% belongs to sample 28. A considerable direct proportion between warp crimp and warp breaking elongation was found, similar with weft direction. For breaking elongation correlation analysis the most important manners are; the positive correlations between crimp and breaking elongation in same directions and negative correlations between these values in opposite directions.

The pilling resistance test results showed that long floats and low interlacing numbers in woven fabric decrease the pilling resistance. According to the assessments done at 2000 cycle, the slack form of samples 8, 9, 27, 29, 31 caused a fairly important increase of pill number per area than other weave types. In contrary to these, samples 24, 25 and 26 showed good pilling resistance at 2000 cycle and other cycles. Statistical correlation analysis showed that increasing fabric thickness caused the pilling resistance to deteriorate. In the other hand pilling resistance deteriorates by decreasing abrasion resistance.

According to abrasion test, the loose structures as a result of long floats and low interlacing numbers in weave types caused higher mass loss values. The loose forms of these fabrics caused to expand the contact area between fabric and abradant surface in addition to allowing the fibers to leave the fabric surface more easily than tight structures. The most resistant fabric to abrasion was sample 7 with a 4,1% mass loss while sample 12 showed the worst abrasion resistance with 11,8% mass loss. It must be emphasized that the highest mass loss value is nearly three times bigger than the lowest mass loss value. By this way obvious influence of weave type on abrasion resistance is seen clearly. As a result of statistical correlation analysis the correlation between fabric thickness and abrasion is significant and positive. This means increasing fabric thickness increases the mass loss and vice versa.

The shrinkage results obtained form the dimensional stability tests were very different between warp and weft directions. Increasing number of interlacing in weave types caused the shrinkage values to decrease in both warp and weft directions. In weft direction the highest shrinkage 13,9% belongs to sample 29 and the lowest shrinkage 1,2% belongs to sample 14. In warp direction sample 12 exhibited the worst dimensional stability with 13,8% shrinkage while sample 28 showed the best dimensional stability with 5,1% shrinkage. Although the difference between the maximum and minimum shrinkages in weft direction is higher than in warp direction, in both directions the difference is fairly high. According to correlation analysis, increasing weft crimp increases the weft shrinkage by decreasing the warp shrinkage while increasing warp crimp increases the warp shrinkage by decreasing the weft shrinkage. In addition to this correlation analysis showed that between weft and warp direction shrinkages correlation is significant and negative. This means increasing the shrinkage in one direction caused the shrinkage to decrease in opposite direction.

Recommendations

The further study on this subject may be structured as follows:

- These tests may also be done on fabrics, which are produced by the yarns of different spinning systems like friction, air-jet, and air-vortex.
- It could be useful that during the experimental studies use of fabrics, which are undertaken, finishing process and compare the results.
- It could be useful that use of different raw materials and properties like (silk, wool, viscose) and determine dimensional changes.

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