SEPTEMBER 2014 M. Sc. THESIS IN TEXTILE ENGINEERING GÖKBEN ZOR


**UNIVERSITY OF GAZİANTEP**

**GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES**


# INVESTIGATION OF EFFECT OF WOVEN STRUCTURE CHARACTERISTIC ON BRIGHTNESS OF FABRIC FOR AUTOMATIC DEFECT DETECTION APPLICATION

**M. Sc. THESIS**

**IN**

**TEXTILE ENGINEERING**


**BY**

**GÖKBEN ZOR**


**SEPTEMBER 2014**

# Investigation of Effect of Woven Structure Characteristic on Brightness of Fabric for Automatic Defect Detection Application

**M. Sc. Thesis**

**in**

**Textile Engineering**

**University of Gaziantep**

**Supervisor: Prof. Dr. Mehmet TOPALBEKİROĞLU**

**by**

**Gökben ZOR**

**September 2014**

T. C.
UNIVERSITY OF GAZİANTEP
GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES
TEXTILE ENGINEERING

Name of the thesis: Investigation of effect of woven structure characteristic on brightness of fabric for automatic defect detection application

Name of the student: Gökben ZOR

Exam date: 15.09.2014

Approval of the Graduate School of Natural and Applied Sciences

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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**I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct.**

**Gökben ZOR**

# ABSTRACT

## INVESTIGATION OF EFFECT OF WOVEN STRUCTURE CHARACTERISTIC ON BRIGHTNESS OF FABRIC FOR AUTOMATIC DEFECT DETECTION APPLICATION

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**M.Sc. in Textile Eng.**
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**September 2014**
**118 pages**

The quality of a finished textile product depends on the processes of yarn, fabric, finishing and ready-made with starting from fiber properties. The defects on the textile products can be tested with different ways by laboratory test equipment. The detection of defects which are on the raw fabric or finished fabric is done manually in the quality control machines. The new systems have been developed automatically to perform quality controls of the fabric with image analysis. In these systems, the image frame acquired by camera is transferred to the computer and then the defect analysis is done by computer with passing the various algorithm processes. Structural characteristics of the fabric affects brightness of fabrics, thus the detectability of defects varies according to the type of fabric.

In this study, the effects of fabric structural parameters on the brightness of the fabric and also, the effects of the brightness of the fabric on the defect detection were investigated at the automatic control systems. Three main parameters were investigated; weave pattern type (plain, twill, saten), weft sett (17, 22 and 27 weft/cm) and fiber type (cotton, poliester, linen and lyocell). Ten different fabric samples were woven. Same size mispick defects were formed at the fabric samples. The brightness of these samples was measured by using spectrometer and image analysis (MATLAB® and Photoshop®). A coefficient was calculated based on the standard deviation values of Photoshop® program. The defect detection performance was determined by using this coefficient at different constructions of the fabric.



**Key Words**: Woven structure, defect detection, fabric brightness, image analysis.

# ÖZET

**OTOMATİK HATA TESPİT UYGULAMALARINDA DOKUMA YAPISAL KARAKTERİSTİKLERİNİN KUMAŞ PARLAKLIĞINA ETKİSİNİN İNCELENMESİ**

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**Eylül 2014**
**118 Sayfa**

Bir tekstil ürününün kalitesi elyaf özelliklerinden başlayarak iplik, kumaş, terbiye işlemleri ve hazır giyim işlemlerinin tümüne bağlıdır. Elyaf, iplik ve kumaşlar da bulunan hatalar laboratuvar test cihazları ve değişik yöntemlerle test edilebilmektedir. Ham ya da terbiye işlemi görmüş kumaşlarda bulunan hataların tespiti genellikle kalite kontrol makinelerinde manüel olarak yapılır. Kumaşların görüntü analizi yöntemiyle otomatik olarak kalite kontrollerinin yapılabilmesi için yeni sistemler geliştirilmiştir. Bu tür sistemlerde kalite kontrolü yapılacak kumaşın görüntüsü bir kamera ile alınarak bilgisayara aktarılır ve bilgisayar tarafından çeşitli algoritma işlemlerinden geçirilerek kumaşın hata analizi yapılmaktadır. Kumaş yapısal özelliklerinin değişmesi kumaş parlaklığını etkilemektedir, dolayısıyla hataların tespit edilebilirliği kumaş cinsine göre değişiklik göstermektedir.

Bu çalışmada bazı kumaş yapısal parametrelerinin kumaş parlaklığına olan etkileri ve ayrıca otomatik kontrol sistemlerinde kumaş parlaklığının hata tespitine etkileri incelenmiştir. Kumaş yapısal parametreleri olarak kumaş örgü çeşidi (bezayağı, dimi ve saten), atkı sıklığı (17,22 ve 27 atkı/cm) ve elyaf çeşidi (pamuk, polyester, keten ve lyocel) olmak üzere üç ana parametre üzerinde durulmuştur. Bu numunelerde aynı büyüklükte atkı kaçığı hatası oluşturulmuştur. Bu numunelerin parlaklıkları spektrometre ve görüntü analizi yöntemleri (MATLAB® ve Photoshop®) kullanılarak ölçülmüştür. Photoshop® programının standart sapma ölçümlerinden bir katsayı hesaplanmıştır. Bu katsayı ile farklı yapıdaki kumaşlarda bulunan hataların tespit edilebilirliğinin kumaş parametrelerine göre değişim miktarı bulunmuştur.



**Anahtar Kelimeler**: Dokuma yapısı, hata tespiti, kumaş parlaklığı, görüntü analizi.

***To my wife***

***Neslihan ZOR***

***And***

***To my daughters***

***Eylül ZOR***
***Ezgi ZOR***

## ACKNOWLEDGMENTS

I would like to express my gratitude thanks to my supervisor, Prof. Dr. Mehmet TOPALBEKIROĞLU for him guidance, many insightful conversations, and helpful comments during development of the ideas in this thesis.

I would like to express my deepest appreciation and special thanks to Asst. Prof. Dr. H. İbrahim ÇELİK for supporting me in every part of my study.

I would like to thank my thesis committee Prof. Dr. L. Canan DÜLGER, Assoc. Prof. Dr. Cem GÜNEŞOĞLU, and Asst. Prof. Dr. Mehmet Erdem İNCE.

I am grateful to Research Asst. H. İbrahim İÇOĞLU for all their support and help.

I am grateful to Kipaş Textile to supply the fabric samples for this study especially to Mr. Selahattin Türkyılmaz, Mr. Ejder Vursavuş, Mr. Mustafa SUNA and the team of product development department of Kipaş Denim.

I would like to thank to technical staff of Textile Engineering Department Mr. Halil AKARDENİZ and Mr. Süleyman ŞENER for support and help during the laboratory studies.

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| | |
|---|---|
| AFIS | Advanced Fiber Information System |
| ASTM | American Society for Testing and Materials |
| FMT | Fineness and Maturity Tester |
| FOV | Field of View |
| HVI | High Volume Instrument |
| ITMF | International Textile Manufacturers Federation |
| MVI | Medium Volume Instrument |
| NIR | Near Infrared |
| NIRS | Near Infrared Spectroscopy |
| SD index | The Coefficient of Standard Deviation Index |

# CHAPTER 1

# INTRODUCTION

## 1.1. INTRODUCTION

In the textile manufacturing process, the quality is the most important parameter despite the increase in one or both of the other parameters that are the cost and just-in-time delivery. The quality control means conducting observations, tests and inspections and thereby improving its performance. Because there is no production process with 100% defect-free, the success of a weaving mill is significantly highlighted by its success in reducing fabric defects [1].

Quality is the ability of a product to perform its properties and is a function of several factors including reliability and ease of use. Quality control is a very important issue to apply the not receive the defective products to customer at manufacturing sector. The technological developments that reduce the human factor will help to companies dramatically to reach the desired excellence. Image processing is a very sensitive and cheap technology in quality control process. The automation is useful at fabric control in long run for economy and quality.

Fabric inspection is vital to assure the fabric quality in the textile industry. Many different defects occur in textile products. These defects can have various reasons that can be caused by fiber, yarn and fabric properties sources. Fiber defects can be evaluated as the fiber fineness, fiber length, fiber strength, the amount of foreign substances, color characteristics, etc. Yarn defects can be evaluated as yarn evenness, yarn hairiness, yarn strength properties, etc. Fabric defects can be evaluated as pattern defects, thin-thick yarns, yarn holes, tears, double yarns, hairiness effects, fly yarn, slub defects, yarn sett defects, etc. Observance of these defects to determine which procedures and methods will be examined. Also, these defects will be examined by using inspection process.

Inspection process is generally performed by human experts or different methods. Fabrics under inspection are generally 1-3 m wide. It is stated that the identification rate is about 60% for human visual inspection on the condition that the fabric moves 30 m/min. Large amount of losses are occurred due to faulty fabrics in textile industry.

Some studies have been made for detection of fabric defects by using image processing methods. In these studies, some defects detected but fabric properties were not been regarded. Especially fabric reflectivity (fiber cross section, fiber thickness, fiber type, fiber length…) may have important effect on image acquisition.

In a weaving plant, first quality fabric generally has not had major defects and minor defects. Second quality fabric is the fabric that contains a few major defects and several minor defects. The non-detected fabric defects are responsible for minimum 50% of the second quality in ready-made clothing industry because the product only will sell for 40%-70% first quality product's price [1].

Quality level greatly improved with the continuous improvement of materials and technologies, though it is necessary to perform 100% inspection for most weavers because customer expectations have risen and the delivering risk of low-quality fabrics is not acceptable without inspection. We have to distinguish between offline and online inspection systems. Online system supplies the figures from production, and it is located directly on the production line. Offline system is placed after the production line. Until recently, the fabric quality control is performed manually and offline with a maximum precision 65%-75% [1].

Weaving sector has a lot of difficulties to create a high productivity with high quality. Production speeds happened faster than ever, producers need to identify defects, place their sources, correct the faults in low time to decrease second quality fabric amount. The boredom, tiredness, inattentiveness are important factors for inspector performances. This generates a big strain on the quality control departments. Inspectors can determine the level of acceptable defects. The comparing of these levels is impossible between other inspectors. Therefore, automatic inspection systems are the best choice for objective and consistent evaluation [1].

The producers are trying to improve the production techniques to obtain high quality, low cost, high comfort, high accuracy and high speed. The technology was needed to simulate of inspector functions from manual to mechanical and from mechanical to automatic. The applications of automated fabric quality control would seem to offer a number of potential advantages, for example safety, low labour costs, the elimination of worker fault and the creation of timely statistical product data. Therefore, automated visual inspection is gaining rising importance in weaving industry [1].

An automated inspection system uses a computer-based vision system. Because this system is computer-based system and they don't enable to the drawbacks of human manual visual inspection. Automated inspection systems are able to inspect fabric in a continuous processing without pause. The inspection systems must be applied online or on-loom to be more efficient. The application of digital image-processing is useful in textile manufacturing and inspection [1].

The fabric defect is defined as a flaw at the fabric construction or surface, in other words, it is any abnormality in the fabric that hinders its acceptability by consumer. Weaving defects are created along to weaving process. These defects are generally seen at warp direction (longitudinal direction) or at weft direction (width direction) [1].

Other defects are due to fiber defects and yarn defects such as slubs, thin-thick places, waste or contaminations, flaw sat the fabric construction or surface during weaving process. Additional defects are mostly machine related, and appear as structural failures (tears or holes) or machine residue (oil spots or dirt). Because of the wide variety of defects as mentioned previously, it will be gainful to apply the study on the most major fabric defects. The chosen main defects are: double-pick, hole, float, broken end, coarse-pick, coarse-end, double-end, oil stain, broken pick, irregular weft sett [1].

The denim woven fabric was selected as a material. The name of denim comes from a strong fabric called serge, originally made in Nimes, France. Nimes is then shortened to denim. Denim fabric is first produced as “working cloths”. Since the denim fabric is strong and durable, it was used as working cloth in 18th century and as mineworker cloth in 19th century. The mass production of the denim fabrics was begun in 1853 by Levi Strauss [2].

Overtime, the denim fabric was used in the production of different cloth types such as; short, shirt, skirt, jacket and different products such as hat, bag. It is estimated that 85% of the produced denim fabric is used in production of trousers.

Denim is a strong and heavy warp faced cotton cloth. The classical denim is made from 100% cotton and woven from coarse indigo dyed warp and grey undyed weft yarn. Weft yarn passes under two or more warp yarns and 3 and 1 twill construction is obtained. Generally, brown or blue colored yarns are used in warp and bleached yarns are used in weft [2, 3].

The warp and weft yarns make connections by passing over and under each other according to the weave pattern. There are very types of weaves that can be used in the weaving process. The basic weaves are plain, twill and satin weaves.

The factors which determine the structural properties of woven fabrics are as follows:

- The way of the weft and warp yarns is interlaced with each other, i.e. the weave of the woven fabric.
- Structural properties of the weft and warp yarns, i.e. fiber type, yarn counts, yarn twist.
- The number of weft and warp yarns per cm, i.e. density of the yarns.
- Finishing processes such as dyeing, finishing, printing.

These structural properties of woven fabrics change the optical properties of fabrics such as brightness, lightness, and reflectance properties.

Ala, D.M., was studied numerating woven fabric defects with image analysis and Photoshop histogram analysis was used to analyze the fabric defects [4]. The composition of the reflected part of the incident light depends on the properties of the surface and detected in terms of lightness and saturation. The perception of the color of fabric surfaces are affected by constructional properties including the properties of fibers (origin), yarns (spinning process, count, yarn twist, number of filaments) and fabrics (yarn density, weave pattern, etc.). Assessment of the effects of constructional properties on the reflectance properties of fabric surfaces will allow obtaining the required reflectance of proposed fabric construction in the stage of design.

Akgün, M., Alpay, H.R. and Becerir, B. were investigated about the relations between fabric constructional parameters and fabric reflectance [5].Also, Akgün et al has studied about investigation of the changes in reflectance properties of warp and weft yarns before and after weaving of some polyester woven fabrics [6].Huang, C.C., was studied about woven fabric analysis by image processing and identification of weave patterns which are plain, twill and sateen [7].

Çelik H.I. has proposed a machine vision system to achieve the fabric inspection and defect classification processes automatically. The system consists of image acquisition hardware and image processing software. A simple and portable system was designed so that it can be adapted easily to all types of fabric inspection machines. The software of the system consists of defect detection and classification algorithms. The defect detection algorithm is based on wavelet transform, double thresholding binarization and morphological operations. It was applied real-time via a user interface prepared by using MATLAB® program [8].

## 1.2. PURPOSE OF THE THESIS

At the present time, the quality control of fabrics is made by inspector. The eye and brain of inspectors has the ability to distinguish any defect from fabric construction. The human brain can adapt itself to the alterations on the surface of the fabric and can change the parameters which are to detect and evaluate the fabric defects in accordance with conditions whether the structure, color, brightness of fabrics vary. Whereas in automatic fabric defect detection methods, the defects are tried to be identified by a standard program and so it is hard to detect the defects by working with same parameters regarding different fabric constructions or brightness. Therefore, it should be provided that the parameters of the system must be selected in accordance with the properties of the fabric which is subject to quality control.

The aim of this study is to investigate the effects of fabric construction on brightness of fabric for automatic defect detection application. A coefficient is to be obtained according to fabric properties and providing recommendations for further studies. In the first section of the study, the defect types and their detection methods will be searched in textiles. These defect types and their detection methods are classified in subheadings that are fibers, yarns and fabrics. In the second section, the brightness (reflectance) property, that is the most important woven fabric parameter for image processing, will be inquired image analysis method. Thus, fabric defect detection using image processing technique will be made with regard to the fabric properties. With examining the fiber, yarn, woven fabric properties (denim fabric), some programs will be used to find uncovered effects of these properties in image analyzing method. In this thesis, MATLAB® and Photoshop® CS4 programs were used for image processing.

According to quality control of textile products, this study is important to investigate the defect detection method for fiber, yarn, fabric and their properties like as brightness (reflectivity) in image processing for textile industry.

## 1.3. STRUCTURE OF THESIS

Chapter 2 includes a review on textile defect (fault) types which were classified at three subheadings. These subheadings are fiber defects, yarn defects and fabric defects. Additionally, the detection methods of these defects were explained in this chapter.

Chapter 3 includes information about optical properties of textiles and the relationship between optical properties and textile constructions (fiber cross sectional shape, raw material of fiber, yarn twist, fabric pattern, etc).

Chapter 4 includes the experimental studies, preparing of the fabric samples, the properties of the fabric samples, test procedures.

Chapter 5 includes the test results, graphical representations and tables of spectrometer measurements (brightness values, reflection values, lightness values, and whiteness index values), image analysis measurements (mean values, standard deviation values and SD index values).

Chapter 6 includes the conclusion about this study and recommendations to further studies.

# CHAPTER 2

# TEXTILE DEFECTS AND DEFECT DETECTION METHODS

## 2.1. INTRODUCTION

Textile defect is defined as an injury caused to a textile material. The defect may be caused in the form of braded portions, cuts, holes, change in color, pitting, tears, scratches, nicks, stains, soiling, etc., which lower the value of an item.

Textile defect analysis is a special area in testing of textiles and has significant practical relevance as textiles can be defected at various stages during their processing, manufacture, distribution; usage and transportation. Defect analysis demands a wide knowledge of textile fibers, the processes of yarn and fabric production, garment production, chemical treatment and typical application of textiles. In addition, it also requires the knowledge of methods of analysis using image analysis, microscopy, infrared spectroscopy, chromatography, thermal analysis, etc. Additional requirements for successful defect analysis is information regarding the processes and machines used transportation, stages in storage, conditions of usage, etc [9].

**Types of defects**

In general, defects in textiles can be classified into six different groups namely;

a. Chemical defect
b. Mechanical defect
c. Thermal defect
d. Biological defect
e. Defect by light
f. Defect due to presence of defects and contaminants [9]

In general, textile defects and detection methods shown in Figure 2.1 are categorized mainly into three groups.

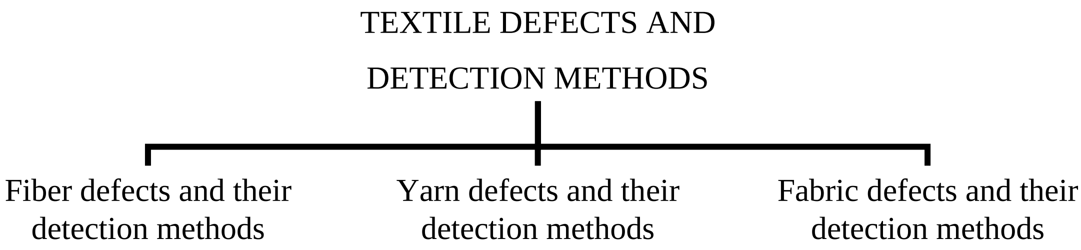



Figure 2.1 Classification of textile defects and detection methods

## 2.2. FIBER DEFECTS AND DETECTION METHODS

The raw materials should be sampled regularly but the schedule depends on the fiber. Sampling and labeling varies with the type of fiber. Every cotton bale is labeled with the normal fiber parameters. Yarn producers use HVI or other mass testing lines to measure every bale. With wool, the fibers may be in bulk, and sampling might require core-boring tools. Composite samples of both tip and root are tested. Even man-made fibers are tested by some with the dividing and doubling techniques [10].

### 2.2.1 Fiber Defects

There is not any study about what fiber defects are. The immaturity can be said as fiber fault whereas the yellowness, stickiness, trash content, fiber fineness, fiber length can classified as fiber properties.

In the fiber properties, length is generally most important. Fiber fineness is second property, yellowness is third one, trash content is fourth one, nep and short fiber content are following them.

#### 2.2.1.1 Fiber Immaturity

The cotton fiber consists of lumen and cell wall. The maturity index is dependent upon the thickness of this cell wall. A fiber is to be considered as mature when the cell wall of the moisture-swollen fiber represents 50-80% of the round cross-section, as immature when it represents 30-45%, and as dead when it represents less than 25%. Since some 5% immature fibers are present even in a fully matured boll, cotton stock without immature fibers is unimaginable: the quantity is the issue. Immature fibers have neither adequate longitudinal stiffness nor adequate strength, they therefore lead to:

- Loss of yarn strength;
- Neppiness;
- A high proportion of short fibers;
- Varying dye ability;
- Processing difficulties [11].

Fiber maturity is related to the amount of cellulose deposited during boll development. It is primarily a function of weather variety and culture. Maturity is not affected by gin operation but there is some evidence that dye uptake is reduced in fiber [12].

The effect of fiber maturity or immaturity on fiber bundle strength tests is also sometimes a point of contention. Whilst a single mature fiber is inherently stronger than a single immature fiber by virtue of its crystalline cellulose structure, this relativity is often not clearly seen in HVI bundle strength tests. Research has shown that reasonably immature fiber can still produce good fiber bundle tenacity values and corresponding yarn tenacity values. The effects seen in this circumstance can probably be attributed to one or a combination of the following factors. One is inaccurate assessment of fiber linear density and bundle weight by the HVI and therefore improper adjustment of the fiber bundle/yarn strength value, and the other is the positive effect of immature fiber having more fiber ends and surface area contributing to the bundle strength result.

### 2.2.2 Fiber Defect Detection Methods

#### 2.2.2.1 The Detection Methods of Fiber Immaturity

The following are the most important methodologies available at present for measuring cotton fiber maturity. There are several methods for determining the maturity of fibers. They are classified as direct and indirect methods.

a) Direct methods:

i. Caustic soda swelling method
ii. Polarized light method

b) Indirect methods:

i. Differential dyeing test

ii. Air Flow Method (Micronaire / Shirley fineness & maturity tester)
iii. Advanced Fiber Information System
iv. Medium Volume Instrument STATEX MVI
v. Near Infrared (NIR) Measurement
vi. Fiber Maturity Measurement by Image Analysis [13].

**a) Direct Method of Measurement**

Direct measurement involves direct estimation of cotton maturity, In case of sodium hydroxide swelling technique, the cotton fibers are immersed in NaOH and the appearance of fibers are analyzed. Ribbon like fibers and convoluted fibers are treated as immature fibers and rod like fibers are treated as matured fibers. In India, three methods have been recognized as standard for the determination of Maturity using of cotton fibers by caustic soda technique. Method I is followed at CIRCOT. Method II is based on the ASTM and Method III on the British standards. In case of polarized light technique, the classification of maturity is made depending upon the interference colors produced by the fibers. Image based maturity is the globally accepted methodology of measuring maturity since it is most accurate and free from human errors. In image based maturity measurement, the cross section of the fiber is analyzed to determine maturity values [14].

**i. Caustic soda swelling method**

In this method; a thin fiber tuft is drawn from silver with a comb sorter. This tuft is laid on a microscope slide, the fibers separated and parallel. A cover slip is put over the middle. Likewise four to eight slides are prepared. There are two steps involved in this method.

1. Treatment with 18% caustic soda.
2. Examination under a microscope

On the microscope slide, the fibers are irrigated with 18% caustic soda solution, which has the effect of swelling. Then, the slide is placed on the stage of a microscope. The absence or presence of the convolution is observed and the fibers are classified into three groups; mature, half mature and immature fibers. [15]

### ii. Polarized Light Microscopy Technique (SiroMat)

Color digital cameras, image analysis software and high power computers allow shortening the test time to two minutes per sample. Moreover, a sample taken from raw or processed cotton does not require conditioning before testing. The SiroMat™ method determines fiber maturity based on the colors of fibers under a polarized light microscope set up according to the ASTM standard. Cotton fibers are automatically scanned and analyzed so that a selection of fibers or fiber sections and the interpretation of their color is no longer subject to operator interpretation. Additionally, the method is also able to measure the distribution of mature and immature fibers in the sample.

The SiroMat™ instrument is calibrated in terms of the maturity ratio. The current calibration equation is a two term multiple linear regression with the independent variables being the areas of yellow and green color measured in the fiber snippet images. These color area percentages are correlated with the maturity ratio data measured by 'Shirley' Fineness and Maturity Tester (FMT) for a calibration set of Australian Upland cottons [16].

### b) Indirect Method of Measurement

Double compression methods used in High Volume Instruments manufactured by reputed firms are one of the indirect methods of measuring maturity. In spite of the importance of maturity, there is no indirect or direct measurement method that is both reliable and fast. The lack of standards of reference for maturity has made it impossible to calibrate the existing instruments, further it can't be refined without the reference standard for Maturity. In the present study, the PREMIER ART-2, Instrument has been tested with reference samples supplied by the instrument manufacturer, whose maturity values are determined by image analysis technology at Bremen Institute [14].

### i. Dyeing Methods

Immature and mature fibers differ in their behavior towards various dyes. Certain dyes are preferentially taken up by the mature fibers while some dyes are preferentially absorbed by the immature fibers. In this method, the fibers are dyed in a bath which contains a mixture of two dyes, namely Chlorantine Fast Green BLL and Diphenyl Fast Red 5 BL. The mature fibers take up the red dye and the thin walled immature fibers take up the green dye. An estimate of the average of the sample can be visually assessed by the amount of green and red fibers [17].

**ii. Air Flow Method for Measuring Maturity**

Air permeability is most acceptable, and two airflow instruments are commonly used to measure relative maturity. Arealometer measures air permeability of fibers at two different levels of air compression. The percentage of mature fibers can also be measured by the Shirley I.I.C. Fineness/Maturity Tester (FMT) [18]. Micronaire is a measure of the cotton fiber’s resistance to air flow per unit mass, and its primary components are the fiber’s maturity and fineness [19]. The arealometer is responsive to two of these properties: specific area (A), defined as the ratio of the external surface of the fibers to the volume of fibrous material; and immaturity ratio (I), defined as the ratio of the area of a circle having the same perimeter as an average fiber to the actual cross-sectional area of the fiber.

A primary cause of resistance to the flow of air is the amount of external fiber surface exposed to the air flow, and this resistance is used as a measure of specific area. The resistance, however, is modified by the distribution and orientation of these surfaces ; hence, on suitably compressing the sample, that change in resistance which is essentially due to reorientation of flattened fibers becomes a measure of the immaturity ratio [20].

FMT is an instrument for measuring resistance to airflow through cotton samples of standard weight at two levels of compression. In principle the method is similar to that used in the Arealometer but employs a different measuring technique [21].

The micronaire module of HVI 9000 and the low volume fineness tester use the airflow method to estimate the fineness value of cotton. A sample known weight is compressed in a cylinder to known volume and subjected to an air current at a known pressure. The rate of airflow through this porous plug of fiber is taken to be a measure of the fineness of cotton. The number of fibers in a given weight of cotton will be more in the case of finer fibers than in the case of finer fibers than in the case of coarser fibers. If air is blown through these samples, the plug containing finer fibers will be found to offer a greater resistance than the plug with coarser fibers. This is due to the fact that the total surface area in the case of the former will be greater than the latter and hence the drag on the air flowing past will be more. This differentiating factor is made use of indirectly measure the fineness of cotton.

The instrument operates as follows. The chamber lid is closed; a piston at the chamber bottom compresses the fiber to a fixed and known volume. A regulated stream of air is then forced through the sample and the pressure drop across the sample is applied to a differential pressure transducer. The transducer outputs an analog signal voltage proportional to the pressure drop. This analogue voltage is applied to an analogue to digital converter, which outputs a digital signal representing the voltage. Cotton with known fineness values is tested and the voltages obtained are used to obtain the calibration curve, which is used for all subsequent testing to display the cotton fineness.

The fineness is expressed in the form of a parameter called the micronaire value, which is defined as the weight of one inch of the fiber in micrograms. Maturity of cotton also influences the micronaire value [22].

**iii. Advanced Fiber Information System (AFIS)**

The AFIS method is based on aeromechanical fiber processing, similar to opening and carding, followed by electro-optical sensing and then by high speed microprocessor based computing and data reporting [23].

A fiber sample is introduced into the system and is processed through a fiber individualizer, which aero mechanically separates the sample into three components consisting of cleaned fiber, micro dust and trash. Each of these components is transported in a separate pneumatic path and may be analyzed electro-optically or by other means. The data processing and reporting are handled by an industrial PC.

AFIS provides basic single fiber information and is distinguished from earlier and existing methods by providing distributions of the basic fiber properties. These distribution measurements provide more accurate, precise and basic information about fiber. The fiber individualizer uses unique cleaning and separating techniques to present the fibers pneumatically to the electro-optical sensor. The fibers are opened and cleaned using specially designed, pinned and perforated cylinders, which are similar to open end spinning beaters and stationary carding flats. Airflow into the perforations of the cylinder allows for thorough engagement and efficient dust and trash removal [23].

**iv. Statex MVI**

Medium Volume Instrument (MVI) is a new system for fiber. The Statex Electronic estimates the linear density of fiber in terms of micronaire value and the results will be displayed in the Computer interfaced with this instrument. The air at known pressure is forced through the plug and the difference in pressure is measured by the electronic sensor and is converted to micronaire value by the microprocessor unit.

In order to measure maturity, MVI developed by Statex measures the resistance to air flow through the cotton plug at two different air flows at two different compression rates. The pressure differences are used to provide independent estimates of fiber maturity and fineness. The maturity ratio estimated by MVI matches well with the maturity estimated by single fiber by AFIS [24].

**v. Near Infrared (NIR) Measurement**

Near-infrared spectroscopy (NIRS) is a spectroscopic method and this instrument uses the near-infrared zone of the electromagnetic spectrum. The use of NIR spectroscopy and applications for agriculture, fiber, and textile products are many, and the use of NIR spectroscopy in these areas continues to grow [25].

**vi. Fiber Maturity Measurement by Image Analysis**

The image analysis method involves a rapid and simple embedding procedure under controlled conditions to obtain 1-2 μm thick sections and analysis of thin fiber cross sections using a CCD camera attached to an Olympus microscope. The statistical software computes perimeter, area of the secondary wall, and computes circularity or $\theta$ (the ratio of the wall area, excluding lumen, to the area of a perfect circle having perimeter P). It is optimized various steps involving sampling, embedding and cross sectioning of fiber tuft to minimize faults and to develop accuracy, speed and reproducibility. Maturity ratios ($M = \theta/0.577$) from the current image analysis results for the nine fiber samples from International Textile Manufacturers Federation

(ITMF) Round Test cottons representing different maturity ratios showed excellent correlation ($R_2$ = 0.88) to previously published maturity ratios as determined by FMT. In summary, image analysis can serve as a reference standard for other indirect methods that are currently employed for determining fiber quality [26].

## 2.3. YARN DEFECTS AND DETECTION METHODS

Yarn defects are usually defined as random and single deviations from the normal yarn properties. For example, a single fairly slub can be called a defect, but a series of thin and thick places can be classified as unevenness or irregularity.

Yarn defects can take place in either filament or staple yarns. The defects derive from differences in linear density and morphology of the polymer (molecular structure of polymers) in filament yarns. The dye affinity of filament yarns changes with morphology alterations and dye affinity has a powerful effect at fabric and yarn appearance. However, drips, debris, married fibers cause problems. The staple yarn defects derive from processing the fibers and coactions between the fibers and processing. In staple yarns, the unacceptable yarn production has higher possibility than filament yarns. Because staple yarns include a high percentage of natural fibers that have variable characteristics and non-fibrous materials.

Yarn defects can be caused by a variety of conditions. Some machine errors can cause to these faults such as drafting waves and machine eccentricities. Many of the defect types are caused by drafting system. Static electricity can be generated by fiber sliding with drafting under dry conditions. On the ring traveler, the lint accumulations causes to fiber balls on the yarn. In staple spinning, the machine settings, improper maintenance and raw material supply cause to irregular faults. Slub creation, fiber breakage and derivative faults can be formed by drafting unit of machine that has very close roll settings. In carding and opening, the un-success at removing trash can cause to production of faulty yarn. Defective yarns are produced by wearing of machine parts that derives with a period using of parts. Additionally, the problems can occur with improperly conditioned or an unclean atmosphere. Neps is defined as a small defect of more than 200% of the yarn diameter and the neps vary from stage to stage at yarn production.

### 2.3.1 Yarn Defects

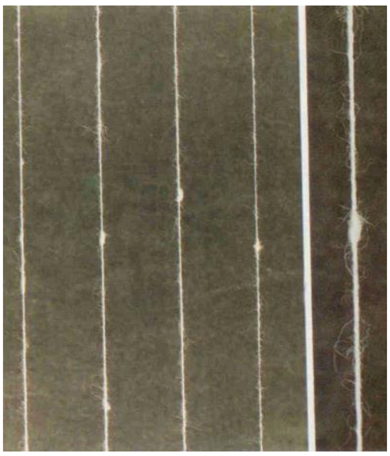
This section describes yarn faults, their origins and solutions. This information is used in the design of the expert system.

#### 2.3.1.1 Group 1- Faults with a characteristic length

**a) Class A faults - Length about 4 mm**

**(i) Nep:** A nep (Figure 2.2a) is a small accumulation of entangled fibers with a well-defined core. The diameter of the core is generally of the order of 0.8 mm to 1.5 mm. In general the total length of the nep is from 1.5 mm to 3 mm, and the local count 2 to 5 times that of the average yarn count. The origin of a nep is in the preparation stages, that is, at the top. It can be formed during the scouring of wool, opening and carding processes, and can be removed during combing. The problem could be that the roller beater in the blow-room may not be opening the fibers well enough to remove coils. During carding, 85% of neps should be removed under normal circumstances [27].

**(ii) Short fly:** The short fly (Figure 2.2 b) is a mass of fiber of rather loose structure, generally loosely adhering to the yarn. The fault is most often shorter than 4 mm. The length of these short fibers does not fall within the range of the fibers being processed. It is easily distinguished from a nep by having a very loose structure, and by the fact that it has no compact core. They are loose because air suction and currents cause them to fly around. The solution is to improve the efficiency of such systems [27].



(a) Neps

(b) Short fly

Figure 2.32 Class A faults - length about 4 mm [28]

A powerful extraction system must be kept in place to remove these fibers, ensuring minimal amounts of short fibers in the spinning area. Suction fans should be placed around the spinning area to remove such short fibers.

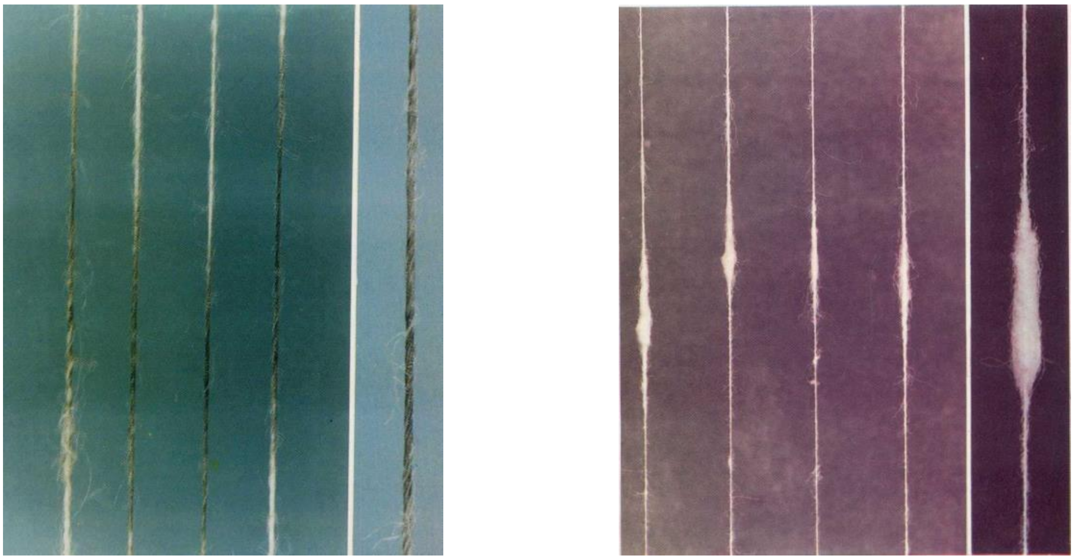
**(iii) Knot:** A knot can occur in the singles yarn, and also in the folded yarn. If the quality of the yarn as a result of preparation is poor, then knots may derive. Fibers must be straight. Drafting rollers need straight fibers, otherwise the front rollers result in a coiled fiber. If there is unevenness of sliver coming from the card and a variation in the evenness in spinning, thin zones as a result of short fibers occur [27].

**b) Class B faults - Lengths between 4 mm and 40 mm**

**(i) Waste:** Waste (Figure 2.3a) is a compact mass of fibers analogous to a nep but distinctly larger in size having average adhesion to the yarn. The length of the fault is between 4 mm and 15 mm (more rarely up to 20 mm). The fault in the yarn originates from waste in the top. The faults are formed in the first stages of preparation and may disappear in drawing. Just like neps, the system must be able to extract unnecessary material such as short fibers, twigs, and seeds. Fibers would certainly form around any of these materials.

**(ii) Fly:** A fly is a mass of fiber of rather loose structure, generally loosely adhering to the yarn. The fault is more often between 4 mm and 20 mm long but may reach 70 mm. The increase in local count, and particularly apparent diameter, may sometimes be very large, e.g. 2 to 20 times the average yarn. The increases and decreases in thickness at the beginning and end of the fault are not always abrupt. This fault is often formed by bundles of fiber drawn into the yarn during its passage to the winding machine / spinning frame. A powerful extraction system to remove these fibers must be kept in place to ensure minimal amounts of short fibers in the spinning area. Suction fans should be placed around the spinning area to remove these [27].

**(iii) Slub:** A slub (Figure 2.3b) is part of a yarn with a thickness appreciably greater than the average over a fairly short length, of the order of 10 mm to 40 mm, and characterized by a fairly gradual appearance and disappearance of the thickened place. The local count will be between about 2 and 6 times the average. The corresponding part of the yarn is generally less or much less twisted. The fault is generally produced at the spinning frame by a faulty drafting action at certain times. The sliver then experiences a reduced amount of draft due to poor fiber control, releasing fiber bundles. The solution lies in how efficient the preparation has been, how well the system eliminates dust, and how well the fibers are paralleled [27].



(a) Waste (b) Slub

Figure 2.3 Class B faults - Lengths between 4 mm and 40 mm [28]

**c) Class C fault – Length between 40 and 160 mm**

**(i) Long slub:** It is a part of the yarn with a thickness appreciably greater than the average over a fairly long length ranging from 40 mm to 160 mm. The emergences and disappearances of the thickness are generally very gradual. The local count may be up to about 6 times the average. The corresponding part of the yarn has generally very little twist. The fault is produced in the spinning frame by a faulty drafting action, but is in general caused by more pronounced mechanical defects, or more pronounced faults in the roving [27].

**(ii) Pieceing up:** Every time an end breaks during spinning, the yarn end of the bobbin is located, withdrawn and rethreaded, bringing it into close proximity with the yarn of fibers being delivered from the drafting zone, so that the twist binds the two ends of the yarn together where they overlap. This is called piecing up. Faults derive due to careless piecing at the spinning frame. When the yarn is pulled from the bobbin back to between the drafting rollers, it meets new fibers. The length is between 40 mm and 60 mm (exceptionally up to 200 mm), and the local count between 2 and 6 times greater [27].

**(iii) Cracker:** Refers to parts of yarn with a thickness clearly greater than the average, over a length most often between 40 mm and 60 mm, but different from the long slub fault by having a characteristic spiral appearance, some of the fibers comprising the yarn being wrapped around the other part in a corkscrew fashion. The local count is generally about 2 to 6 times the average; the emergence and disappearance of the thick part are fairly gradual. The fault occurs at the spinning frame as a consequence of the formation in the drafting zone of two parts of the roving which were drafted differently. The part drafted most winds itself round the part drafted least in the manner of a corkscrew. As in the slub, the problem could be that the covering rollers are be worn out at the spinning phase. This problem appears during roving and in the spinning system [27] (Figure 2.4).

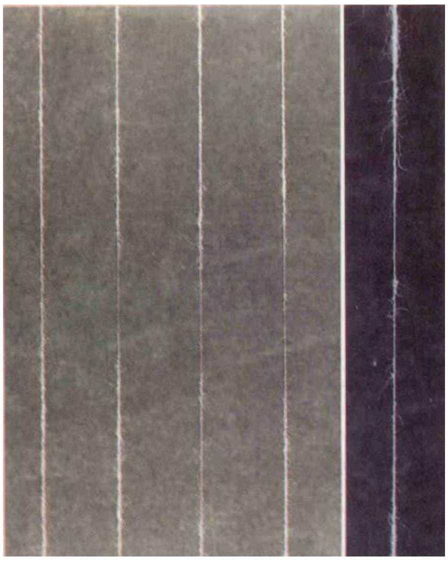


Figure 2.34 Cracker defect [28]

**d) Class D faults– Length above 160 mm**

**(i) Thick yarn:** This refers to part of the yarn with a thickness appreciably greater than the average (as in the slub), of the order of 160 mm to 1 meter in length (in rare cases up to 2 meters or more), for which the emergence and disappearance of the fault are generally very gradual. The local count is generally between 1.5 and 4 times the average. This fault is generally caused by a thickening similar to a slub present in the finisher roving, where it appears for reasons analogous to those indicated for yarn. Drafted from about 10 to 25 times at the spinning frame, this ‘slub’ produces long thick places in the yarn, at times up to about 2 meters in length (Figure 2.5).

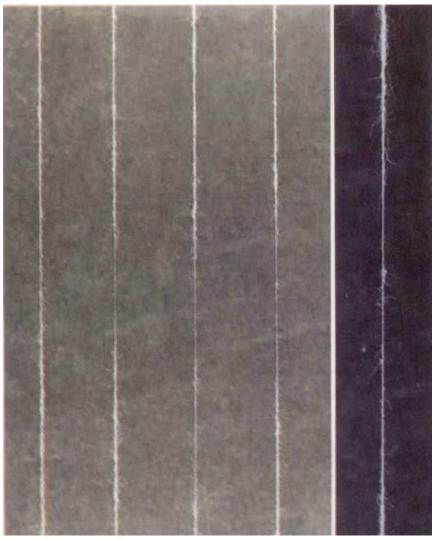


Figure 2.35 Thick-thin defect [28]

**(ii) Spinners double:** Where an end breaks and piecing occurs, a fault is produced by the total or partial fusion of two ends at the spinning frame. Once inside the rollers and joining new fibers, the redundant fiber has to be cut out. If it is left too long, it doubles up because of new roving coming in the ring system. Local count is about 1.5 to 2 times greater than the average. The fault is often quite long, up to several meters.

**(iii) Twisting double or twisting lash-in:** Accidental fusion of two ends in twisting. This fault is caused by the winders. For twisting to take place, some winding should be done first. Instead of a single yarn in the bobbin going in after joining, the loose end may not be located. When it gets to the winder, it comes together with the other loose end, and they come together. Winding should ensure that this fault is eliminated as soon as it is detected. Local count is generally twice the average. The fault is often rather long [27].

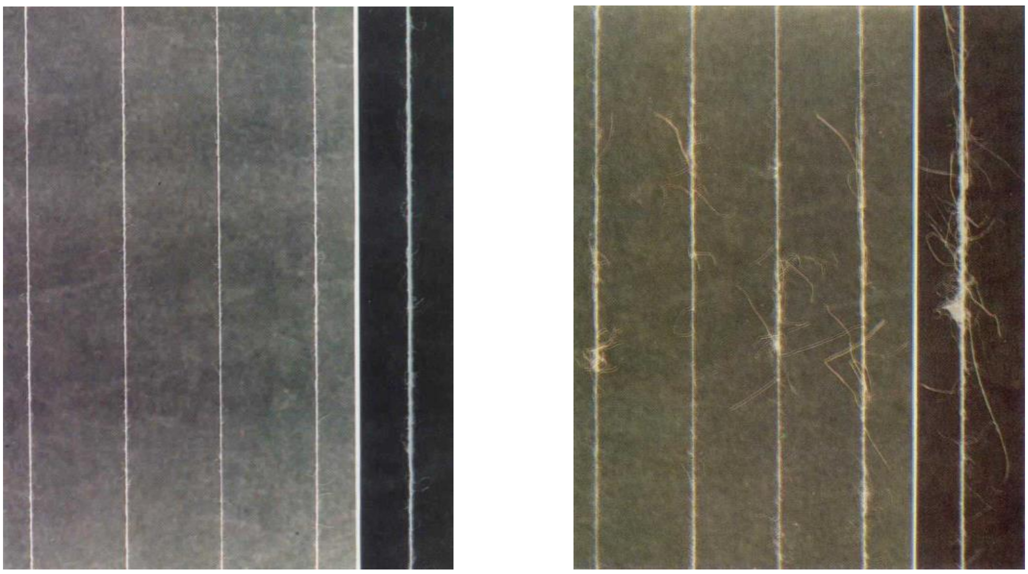
#### 2.3.1.2 GROUP 2 - Faults of variable length

**(i) Double thread or winding lash-in:** This is the length of yarn which escapes from the hand of the spinning operative (and is then spun by the twist in the yarn), or the winding operative (resting nearly freely on the yarn, with little binding twist), and proceeds to get entangled with the main part of the yarn. Local count is about double the average. The length generally is from 2 cm to 20 cm. The length of yarn which escapes from the hand of the spinning operative gets entangled with the main part of the yarn [27].

**(ii) Snarl:** Snarl occurs on yarns which are badly set and have a high twist. In folded yarn, it sometimes causes quite a bad fault by twisting itself around the yarn. Twist liveliness is the degree to which the yarn coils around itself. If the twist is too high, then twist liveliness is increased in an effort to improve the strength of the yarn (Figure 2.6a).

**(iii) Loop:** The fault occurs at a time of a sharp breakage in winding due to insufficiently tensioning the yarn held in the hand when restarting after a breakage. The fault occurs predominantly with yarns which have a tendency to snarl.

**(iv) Foreign matter:** These are faults deriving in general from the top in the case of the wool (Figure 2.6b).



(a) Snarl (b) Foreign matter

Figure 2.36 Snarl and Foreign matter defects [28]

**(v) Fiber ring or rub-up:** Fiber ring is an accumulation of fibers surrounding the yarn, forming a ring of greater or lesser length. This fault most often has a length from 4 mm to 10 mm, but may reach 20mm or more. The ring of fibers is distinguished from WASTE and SLUB faults by the fact that it is only lightly attached or is not attached at all to the yarn, and by the fact that it encircles the yarn. It can easily be made to slide along the yarn. The fiber can be produced at the traveler of a ring frame, or on various yarn guides during spinning and winding. The solution is to ensure that the system is efficient enough to get rid of excess matter. Suction units should be in place around the traveler to remove dirt [27].

**(vi) Pote:** It can be defined as undrafted and untwisted roving present in the yarn. This fault is generally caused by broken gear tooth, damaged cots of top roller or insufficient pressure on the top roller.

**(vii) Moore:** It can be defined as improperly joined broken ends. This fault is generally caused by improper piecing present in sliver or roving, improper piecing by the charkha operator.

**(viii) Bakar:** It can be defined as trash present in the yarn structure. This fault is generally caused by improper ginning i.e. seeds broken during ginning, presence of too much trash in cotton fiber or insufficient cleaning in blow room.

**(ix) Daghi:** It can be defined as oil or stain marks present on the yarn. This fault is generally caused by over flowing of oil from spindle bolster, excessive oil on ring with the intention of running the traveler smoothly, improper storage of material or improper material handling [27].

**(x) Hairiness:** Fibers protruding out from the main body of the yarn are called hairiness. The hair numbers exceeding 3mm in length as a percentage of the total hair numbers are found to be linearly related to the yarn count, for example, there are more hairs in a fine yarn than a coarse yarn (Figure 2.7).

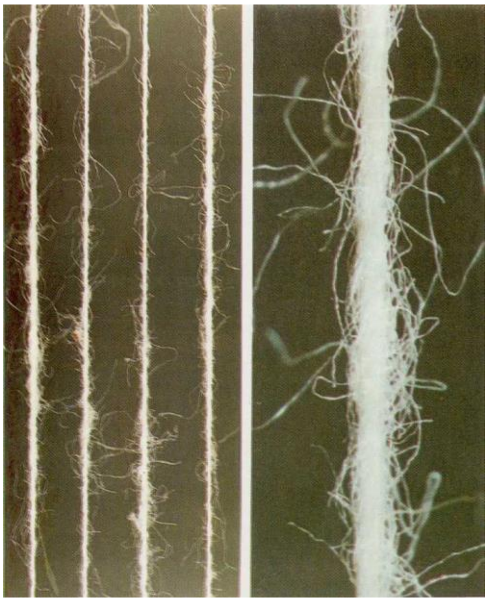


Figure 2.37 Hairiness defect [28]

### 2.3.2 Yarn Defect Detection Methods

Yarn defect detection methods are examined at two subheadings that are;

- Yarn Evenness,
- Yarn Hairiness.

#### 2.3.2.1. The Detection Methods of Yarn Evenness

The evenness is a measure of the extent of sameness in the yarn density along its length. The defects represent unusual incidents exceeding in their forms the expected variation in the density of a fiber yarn. These involve neps, thick places and thin places shown in Figure 2.8.

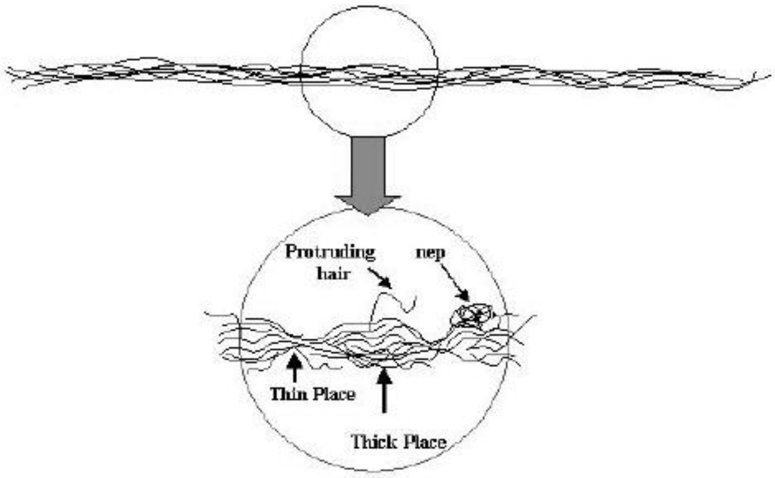



Figure 2.8 Different imperfections in a spun yarn [29]

The reference practice of evenness and defect test is clearly a microscopic practice. On the other hand, the large number of yarn required to attain credible microscopic data makes this practice time-consuming, especially in a practical atmosphere. Alternatively, we can take a long fiber yarn, cut it into sections of equal length, and weigh each section. The thickness variation can be decided from the variation in the weight per unit length given in Figure 2.9. The name of this practice is “cut and weight” practice and it is used as the principle for the more developed capacitive practice usually used by textile factories [29].

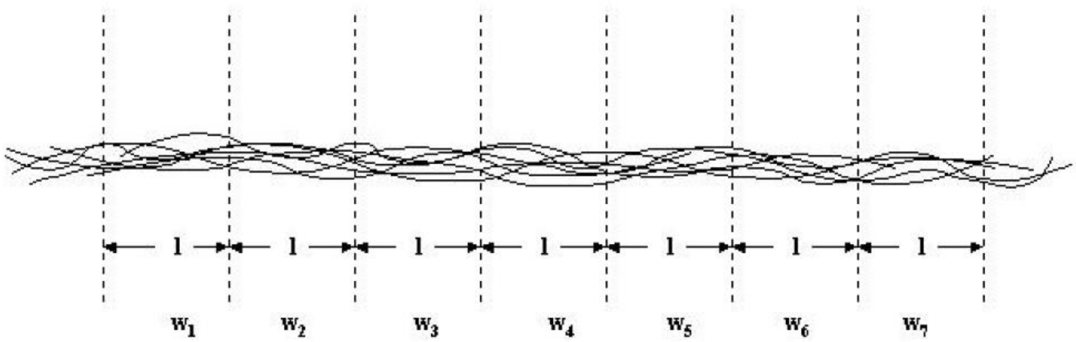



Figure 2.39 The cut and weight method [29]

Eqn 2.1 represents ratio of mean value of mass to unit length ($\overline{W}$)

$$\overline{W} = \sum w_i / n = [w_1 + w_2 + w_3 + ...........W_n] / n \tag{2.1}$$

Eqn 2.2 illustrates ratio of standart deviation of weight to unit length ($\sigma$)

$$\sigma = \sqrt{\sum (w_i - \overline{w})^2 / n} \tag{2.2}$$

$C.V(\%)$ denotes the coefficient of variation of yarn evenness (Eqn 2.3)

$$C.V(\%) = \frac{\sigma}{\overline{W}} \times 100 \tag{2.3}$$

Irregularity is defined as the mass per unit length variation due to variation in fiber combination. The diagram can show a true reflection of the volume or weight per unit length variation in a fiber combination.

Types of Irregularity:

- Weight per unit length,
- Diameter,
- Twist,

- Strength,
- Hairiness,
- Color.

Two mathematical statistics are offered:

a. The irregularity $U\%$: It is the percentage mass deviation of unit length of material.

b. The coefficient of variation $C.V(\%)$: The parameter of variation is usually used to define variability and is thus fit to the problem of expressing yarn evenness (Eqn 2.3). It is presently maybe the most widely accepted way of measuring irregularity.

The irregularity ($U\%$) is proportional to the density of the mass changes around the mean rate. If the fiber combination needed to be tested is normally distributed with regard to its mass variation, a transformation probability is present between the two types of calculations (Eqn 2.4) [30].

$$C.V(\%) = 1.25 \times U\% \tag{2.4}$$

There are many methods used for testing the evenness of a yarn. These are:

a. Visual examination method
b. Gravimetric method (Cut end weigh method)
c. Capacitive method
d. Mechanical method
e. Optical method
f. Pneumatic method
g. Acoustic method

**a. Visual examination (Seri Plan Method)**

Yarn to be examined is wrapped onto a matt black surface in equally spaced turns. The black boards are then examined under good lightening conditions using uniform non-directional light. ASTM has series of Cotton Yarn Appearance Standards which are photographs of different counts with the appearance classified in four grades. The test yarn is then wound on a blackboard approximately 9.5 x 5.5 inches with the correct spacing and compared directly with the corresponding standard.

Motorized wrapping machines are available: the yarn is made to traverse steadily along the board as it is rotated, thus giving a more even spacing. It is preferable to use tapered boards for wrapping the yarn if periodic faults are likely to be present. This is because the yarn may have a repeating fault of a similar spacing to that of one wrap of yarn. By chance it may be hidden behind the board on every turn with a parallel-sided board whereas with a tapered board it will at some point appear on the face [30].

**b. Gravimetric Method (Cut and weigh method)**

This is the simplest way of measuring in mass per unit length of a yarn. The method consists of cutting consecutive lengths of the yarn and weighing them. For the method to succeed, however, an accurate way of cutting the yarn to exactly the same length is required. This is because a small error in measuring the length will cause an equal error in the measured weight in addition to any errors in weighing operations. One way of achieving accurate cutting to length is to wrap the yarn in around a grooved rod which has a circumference of exactly 2.5 cm and then to run a razor blade along the groove, leaving the yarn in equal 2.5 cm lengths. The lengths so produced can then be weighed on a suitable sensitive balance. If the mass of each consecutive length of yarn is plotted on a graph, a line showing the mean value can then is drawn on the plot. The scatter of the points about this line will then give a visual indication of the unevenness of the yarn [30].

**c. Capacitive method**

The measuring device of an electronic capacitance tester is a parallel plate capacitor represented in Figure 2.10. Under certain conditions, the effect of introducing a non-conducting material such as a sliver or yarn into the space between the plates is to change the capacity of the capacitor, the change being proportional to the weight of material present. If, therefore, the material is drawn through the capacitor continuously, the changes in the capacity will follow the variation in the weight per unit length of the yarn, the unit length being the length of the capacitor. If is necessary to detect the changes in capacity and to translate them electronically into meter readings which indicate the coefficient of variation. At the same time a trace of the variation should be made on a pen recorder if required [30].

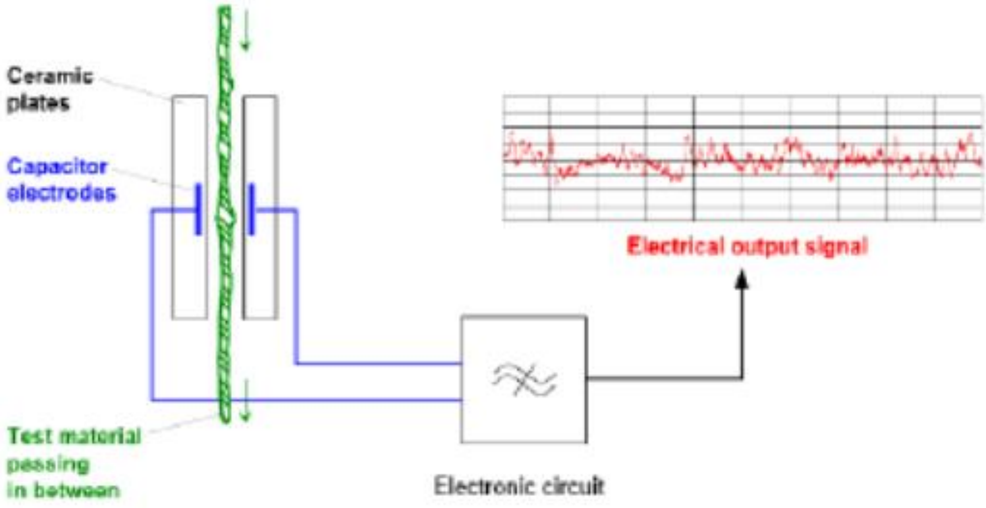



Figure 2.10 Capacitive measuring system [30]

Figure 2.11 shows capacitive sensor. The electrical measuring condenser (1) forms the sensor for the capacitive monitoring of the yarn mass. This is done by two parallel metal plates, the electrodes. In the space in between (2), the two electrodes build an electrical field when putting on an electrical alternating voltage (3). If a yarn (4) is electrical signal, the yarn signal (5) is derived. The change n the capacitance depends, besides the mass of the yarn and of the dielectric constant of the fiber material used, on the moisture content of the yarn. With the capacitive measuring principle, the yarn signal corresponds to the yarn cross-section yarn mass, respectively, which is located in the measuring field. Changes of the yarn mass cause a portional change of the yarn signal [31].

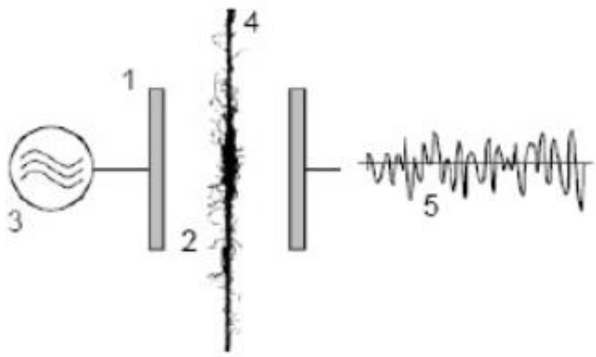



Figure 2.11 Capacitive sensor [31]

Schematic diagram of Uster evenness tester is shown in Figure 2.12. Two oscillators A & B have equal frequencies when there is no material in the measuring capacitor C. When the two frequencies are superimposed the difference in frequency is zero. The presence of material (yarn) in the capacitor causes its capacity to change and so alter the frequency of the oscillator A. There will then be a difference between the two frequencies which varies according to the material (yarn thickness) between the capacitor plates. Suitable circuits D translate these frequency differences into signals which (1) are indicated on the meter M, (2) drive the pen of the recorder, and (3) are fed into the integrator which indicates the average irregularity either as PMD or CV% according to the model used [30].

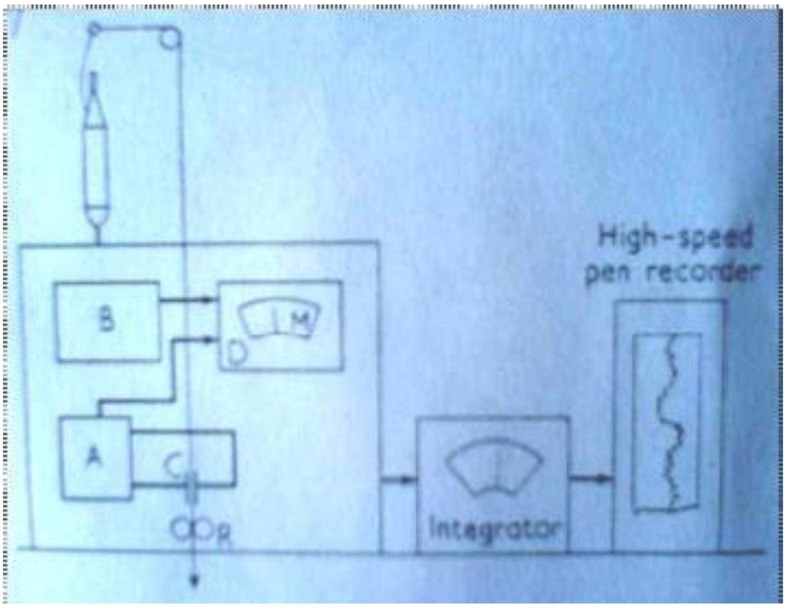



Figure 2.12 Uster evenness tester [30]

**d. Mechanical method**

Principle of mechanical method of evenness testing is compression of fibrous yarn. Wool Industries Research Association has developed W.I.R.A sliver, roving levelness tester. It can provide a continuous record of the test performed [30].

In the mechanical practice, the irregularity of a yarn is detected using a mechanical feeler that senses the yarn mass variation as it passes through a pair of drafting cylinder (Figure 2.13). It is used correctively with auto leveling systems [29].

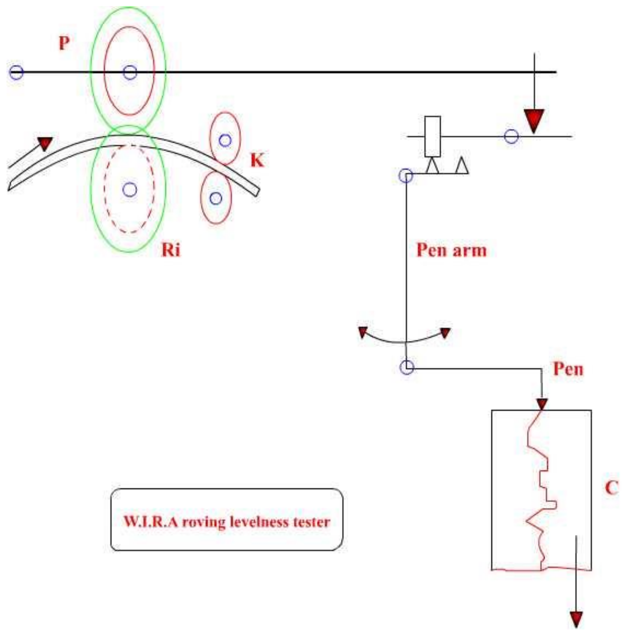



Figure 2.13 Principle of mechanical method of evenness testing [29]

Main features of the tester:

•Positively driven roller R1, with a rectangular groove

•Negatively driven top roller which has flange type shape and can be positioned into the groove of roller R1

•R2 is mounted on an arm (lever) which is pivoted at P

•Recording pen and graph paper [30].

**e. Optical method (Zweigle G580)**

This instrument uses optical method of determining the yarn diameter and its variation. In the instrument an infra-red transmitter and two identical receivers are arranged as shown in Figure 2.14. The yarn passes at speed through one of the beams, blocking a portion of the light to the measuring receiver. The intensity of this beam is compared with that measured by the reference receiver and from the difference in intensities a measure of yarn diameter is obtained. The optical method measures the variations in diameter of a yarn and not in its mass.

However, in practice the twist level throughout a yarn is not constant. Therefore the imperfections recorded by this instrument differ in nature from those recorded by instruments that measure mass variation [30].

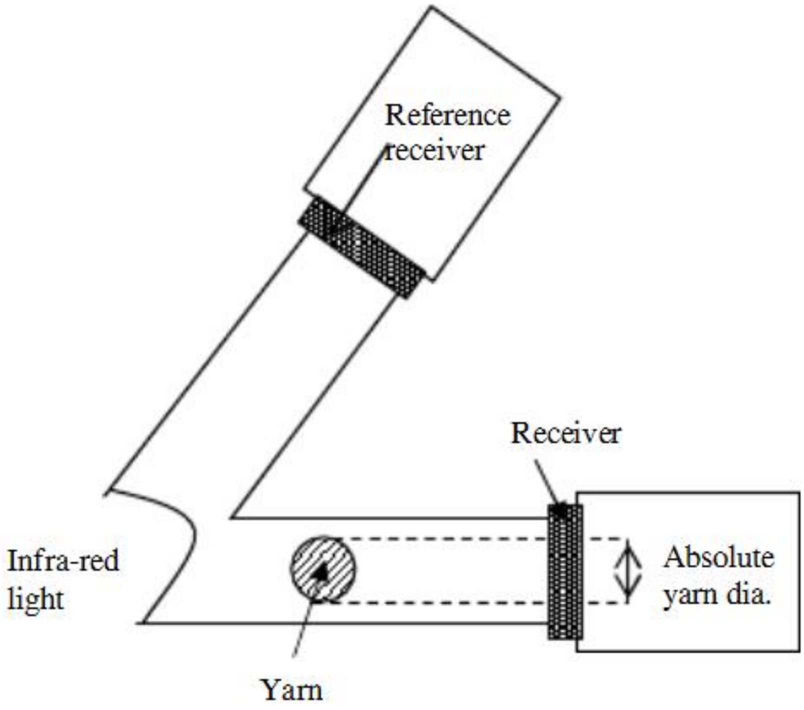



Figure 2.14 Principle of optical method of evenness testing [30]

Zewigle optical evenness: Optical methods are used in the Zewigle EIB system and the Uster® tester. In measuring the evenness of a yarn, the main limiting factor of the optical method is its sensitivity to the geometrical profile of the yarn. Irregular cross units are probably be presented to the light source in primary direction of line [29].

Optical sensor is shown in Figure 2.15. The infrared light source (1) and the photocell (3) represent the sensor for the optical monitoring of the yarn thickness. The infrared light is scattered by a diffuser (2) in the light field and reaches the photocell (3). The photocell emits a tension, which is proportional to the amount of light. If a yarn (4) is brought in the light field, parts of the light will be absorbed by the yarn. The amount of light, which hits the photocell, is smaller. From this change, an electrical signal, the yarn signal (5) is deriver. With the optical measuring principle the yarn signal corresponds to the diameter of the usually round yarn, which is located inside the measuring field. Changes of the yarn diameter cause a proportional change of the yarn signal [31].

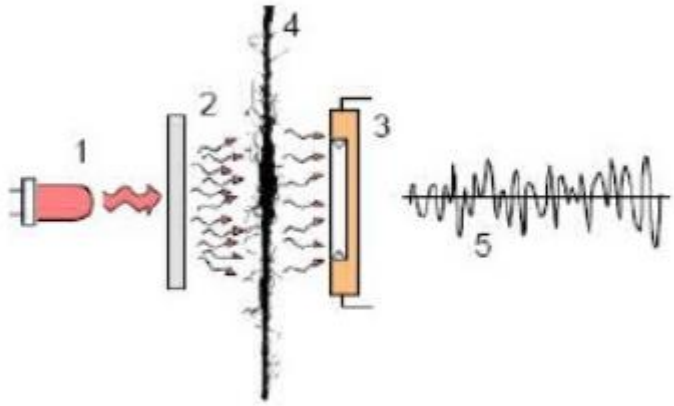



Figure 2.15 Optical sensor [31]

**f. Pneumatic Method**

In this practice, the yarn is run out through an eyehole or a narrow pipe and the air stream is forced. The evenness of the yarn is measured by the changes in the value of airflow. Limiting agents of this technique involve the non-linear relationship between the mass of yarn and the airflow rate, and the high sensitivity to atmospheric conditions (temperature and humidity). This practice has been utilized in connection with auto leveling systems of yarns during carding [29].

Two air streams are pushed towards each other, and a bunch of filaments is directed to meet the resulting jet at right angles. The filaments are pushed towards the stream of higher density, which thus causes pressure weavings in both, and these variations are measured in the stream of lower intensity to create a signal proportional to the mass of yarn meeting with air-flow. The practice is still relatively untested and out of favor [30].

**g. Acoustic Method**

In this practice, the yarn is directed through a sound field between a pick-up device and a generator. The time is measured electronically. The change in the transit time is believed to correspond to the change in the cross-sectional sizes of the yarn. The advantage of this practice is the being insensitive to moisture change. This practice has been used by some instrument developers for measuring the uniformity of sliver during drawing and carding [29].

Impulse acoustic method is elaborated to determine the inner (transversal) unevenness of multifilament chemical yarns and its defectiveness in the yarn's cross-section by means of the impulse-acoustic spectrograms, both separately and in combination with an analysis of the full stretching diagram. This method is applied for different chemical yarns. There are no other methods for obtaining such information, including all the standard testing methods currently used [30].

#### 2.3.2.2. The Detection Methods of Yarn Hairiness

Yarn hairiness is an unwanted condition and it causes problem to in production. So it is significant to be able to measure it in order to control it. Also, it is very difficult to represent hairiness with a parameter since the hair lengths and the hair numbers both vary autonomously. In theory, a yarn may have a combination of large number of short hairs or a small number of long hairs [32].

Fiber ends protrude from the yarn body or fabric causes hairiness, some knotted fibers arch out from the yarn core and some wild fibers in the yarn. The number of prominent fibers is the main criteria for the definition of yarn hairiness [33].

Yarn hairiness is a complicated term, which usually cannot be totally explained by a single figure. Spinning, especially weaving and knitting are very important in the effect of yarn hairiness on the textile operations, because of the some fabric flaws the measurement of hairiness started.

Some parameters are used in textile mills to define the quality of a yarn but there are basically two measures. One of them is mass variation along the length and the other one is yarn strength. Yarn hairiness as a quality parameter has been used by many factories but it hasn't gained a universal popularity.

Many methods can be used for testing the hairiness of a yarn. These involve:

a. Subjective method
b. Microscopic method
c. Photoelectric Method
    i. Shirley-Atlas Hairiness Tester
    ii. Zweigle Hairiness Tester
    iii. Uster Tester
    iv. Changling Hairiness Tester
    v. Premier Electronic Tester

**a. Subjective Methods**

Comparison of appearance is important for grading for hairiness. The levels of hairiness in two yarns can be evaluated by comparison of full bobbins. For evaluating the hairiness also covering the yarn on a blackboard and comparing them can be employed. Yarn hairiness grade standard boards have been developed by Uster. This will assist in evaluating of yarns. Objective observers can determine statistically significant differences in hairiness through estimation of parameter of consistency.

**b. Microscopic Methods**

The hairiness of a yarn was measured under the microscope before the devices were developed. The image yarn is reflected on a screen and number of protruding hairs and knots are captured and counted. Length of protruding hairs is measured with micrometer eyepiece scale. Length of hairs per unit length is measured with the help of this. Hairiness is measured by the number of intersections the fiber makes with the lines marking the zone on either side. This method is important and gives the hairiness length of the hairs.

**c. Photoelectric Method**

Many devices are present for measurement of hairiness depending on photoelectric method.

i. Shirley-Atlas Hairiness Tester
ii. Zweigle Hairiness Tester
iii. Uster Tester
iv. Changling Hairiness Tester
v. Premier Electronic Tester

**(i) Shirley-Atlas Hairiness Tester**

In the Shirley yarn hairiness tester there is a light beam shining on a small diameter photoreceptor in front of it. This test is held between the light and the receptor at a continuous speed. While a hair runs between the light and receptor the light beam is instantly broken and an electronic circuit counts the pause as one hair. In Figure 2.16, two sets of yarn can be seen in the device. The lower set directs the yarn on a guide at a fixed distance of 3 mm from the receptor. The top set leads the yarn on a movable guide that can be set at a distance of between 1 and 10mm from the receptor. The complete number of hairs in a fixed length of yarn is counted by counting for a given time, the yarn passing at a known speed [32].

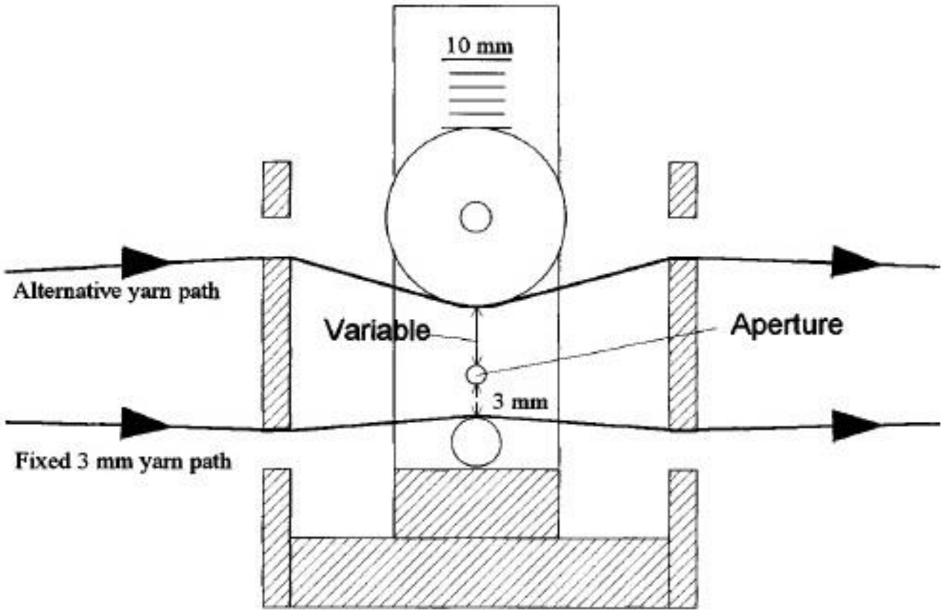



Figure 2.16 Shirley yarn hairiness [32]

**(ii) Zweigle Hairiness Tester**

The Zweigle hairiness tester operating on the photometric principle is used to determine yarn hairiness. It counts the number of hairs at certain distances. The yarn is illuminated from the opposite side from the photocells. In the illumination only the fibers sticking out of the yarn body are visible, and the yarn body is dark. The received light is converted into an electrical signal. The values are read from the counters upon completion of the determination of hairiness. The instrument calculates the total number of hairs [33].

This apparatus counts the number of hairs at distances from 1 to 25mm from the yarn edge. The hairs are counted simultaneously by a set of photocells which are arranged at 1, 2, 3, 4, 6, 8, 10, 12, 15, 18, 21 and 25mm from the yarn as is shown diagrammatically in Figure 2.17. The yarn is illuminated from the opposite side from the photocells and as the yarn runs past the measuring station the hairs cut the light off momentarily from the photocells, which causes the electrical circuits to count in a similar manner to that of the Shirley instrument.

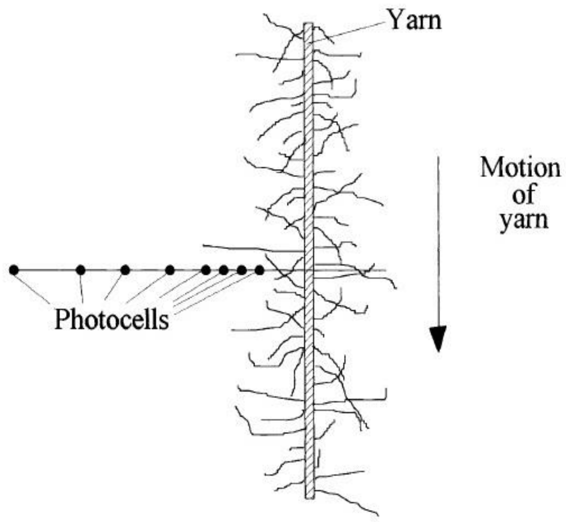



Figure 2.17 Zweigle yarn hairiness [32]

The instrument measures the total number of hairs in each length category for the set test length. The yarn speed is fixed at 50m/min but the length of yarn tested may be varied. The zero point, that is the position of the yarn edge relative to the photocells, is adjusted while the yarn is running by moving the yarn guides relative to the photocells. A further set of photocells is used to locate the edge of the yarn during the setting up procedure. The instrument calculates the total number of hairs above 3 mm. It also computes a hairiness index which has been especially devised for this instrument and which is intended to combine all of the information measured by it [32].

**(iii) Uster Tester**

This device is produced as an attachment for the Uster evenness tester and is connected in place of the normal measuring capacitor. However, it makes use of the full statistical result collection capabilities of the evenness instrument. The principle of the measurement is quite different from the above instruments. Therefore the results from the two types of instrument are not comparable. In this instrument the yarn is illuminated by a parallel beam of infra-red light as it runs through the measuring head. Only the light that is scattered by fibers protruding from the main body of the yarn reaches the detector as is shown in Figure 2.18. The direct light is blocked from reaching the detector by an opaque stop. The amount of scattered light is then a measure of hairiness and it is converted to an electrical signal by the apparatus [32].

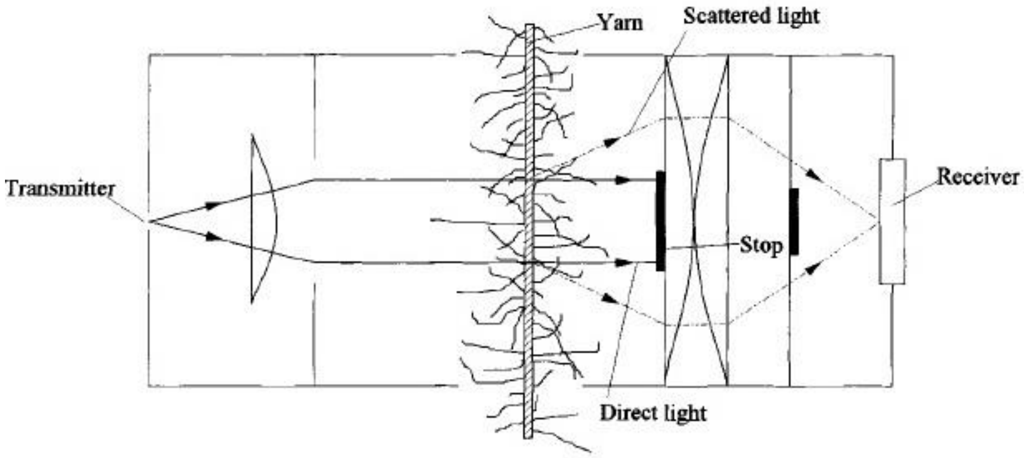



Figure 2.18 The measurement of hairiness by scattered light [32]

**(iv) Changling Hairiness Tester**

In this method a sensitive integrated photocell and a laser light source are used for measuring number of reflecting hairs. It is possible to measure hair number for lengths from 1 to 9 mm. Besides the estimates of number of hairs, length-wise, S3 value is another parameter that is mostly used, that defines the number of fibers that protrude beyond 3 mm length [34].

**(v) Premier Electronic Tester**

Premier Qualicenter measures hairiness with a supplement by hair count as well as Hairiness index practice. One of the factors that affect the result of hairiness is testing speed. It is found that hairiness reduce with test speed in SDL tester. Other factors that affect the hairiness results are direction of hairs, air drag and rubbing. That is why different results are attained from the different devices. Conditioning time and humidity conditions are the other factors that affect hairiness [34].

## 2.4. FABRIC DEFECTS AND DETECTION METHODS

Inefficiencies in industrial process cause costs in the sense of time, money and consumer delight. To become more competitive the business should ask of itself also the economic pressure force business to do this. So that, smart visual supervision systems appear to ensure high quality of products in production lines and in this way the products are in increasing demand. For many of the completed consumer products, the raw materials are present in the form of web1 materials. Even though industrial web materials take many forms still there is a spectacular similarity in automation needs for visual supervision of these materials. As it is shown in Figure 2.19, automation problems for web supervision divides into two general categories depended on the types of web materials which are used. In the first category the problems are related with uniform web supplies such as metals, film, paper, etc [35].

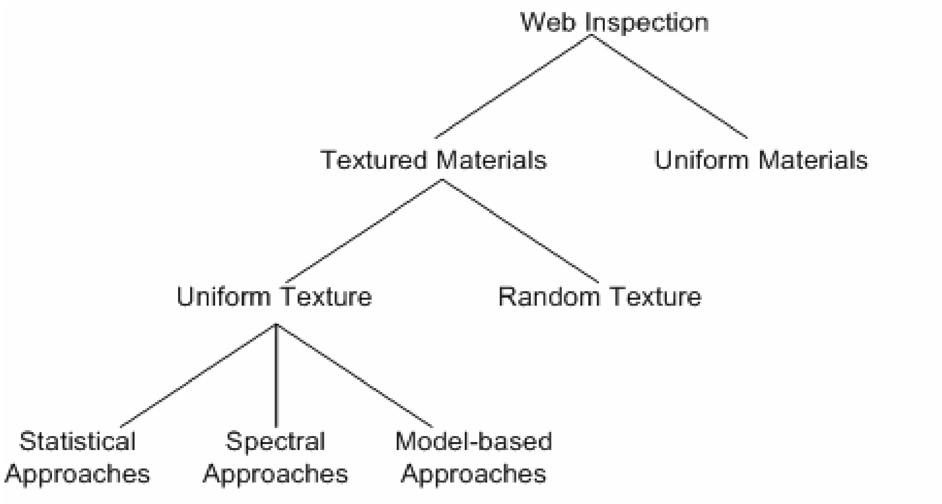



Figure 2.19 Classification of inspection problem based on material types [35]

Defect detection in these web materials normally based on characterization of zones that differ from a uniform background. In the second category of web inspection problems are related with fabric supplies such as textile, ceramics, plastics, etc.. The sense of what makes to be a fabric defect changes from person to person. One person may have separate sensibility from time to time. The definition of defects in textured materials is generally not clearly determined. So that, the visual supervision of textured supplies composed of evaluating the supplies depending on the total fabric specialties such as material isotropy, homogeneity and fabric thickness. The fabric supplies can be then separated into uniform, random, or patterned fabrics. Brazakovic et al. have detailed a model-based approach for the supervision of random fabric supplies. The problem in the printed fabrics such as printed fabrics, printed currency, wall paper needs assessment of color sameness and stability of printed materials, also any unconformity in the background fabric, however it has attracted little attention of researchers. The supervision of real fabric defects is especially difficult because of the stochastic changes in scale, stretch and skew of fabric texture/defects predominantly because of the environment and the nature of weaving process [35].

### 2.4.1 Fabric Defects

It has been thought that with the help of the presence of defects the price of fabrics is cut down by 45%-65%. Yarn quality and weaving defects affect the fabric quality. The bad quality of raw materials and inappropriate conditioning of yarn causes yarn quality defects (Figure 2.20) and also it causes the color or slubs, width inconsistencies, broken ends, hairiness, etc. There are so many quality tests for yarns, for estimating the quality of fabric. The quality tests of the yarns are mostly carried out at the output of yarn spinning-mills.

In order to perform the quality test the looms or knitting machines should stop. This pause is not practically applicable for the machines which are in the intention of production large quantity of products. So that the quality is held on the worn, older, or obsolete model looms which generally produce undesirable results [35].

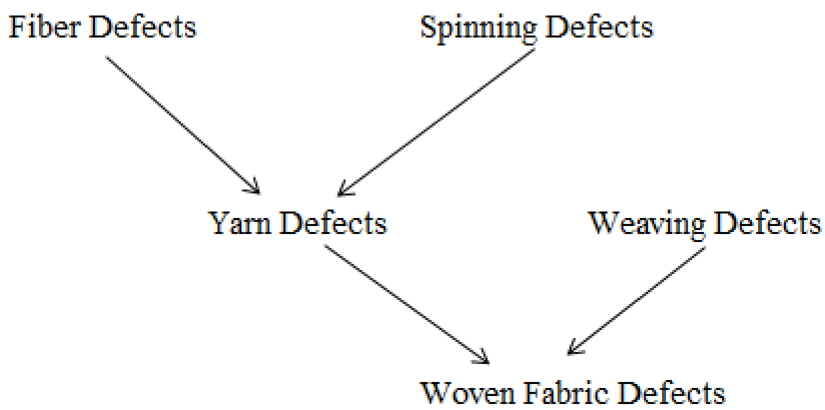



Figure 2.20 Flowchart of woven fabric defects based on its source

The fabric defects caused by changes in the tension of one or more yarn yarns are usually misinterpret as the defects caused by bad yarn quality. The weaving irregularities produced in the weaving machines because of the variation in operating situations (humidity, temperature, etc.) also cause various fabric defects independent from yarn quality. The number of fabric defects may change dynamically as small variations in the weaving process can cause completely new type of fabric defects [35].

The different types of defects detected while quality controls are broadly categorized as below.

a. **Critical Defects** - Defects that are probably result in damage to the health of people who are using it.
b. **Major Defects -**More significant defects that are probably influence the purchase of the product.
c. **Minor Defects -**Involve small defects that have no influences on the purchase of the product [36].

**Names of Woven Fabrics Defects or Faults:**

**Drawbacks**

It is caused by excessive weaving machine tension gradually applied by some abnormal restriction. When the restriction is removed the excess slack is woven into the fabric. Usually the ends are broken (Figure 2.21a).

**Doublepick**

This is the result of one filling feed on a four-feed weaving machine picking up the end from the reserve supply package and pulling in a double filling on every fourth pick (Figure 2.21b ).

**Burl Mark**

When a slub is woven into the fabric, it is generally removed by a "burling tool" (Figure 2.21c ).

**Broken Pattern**

A broken pattern is the result of non-continuity of the pattern/design in the pile fabric (Figure 2.21d ).

**Thick place**

This defect is the result of picks being forced closer together than normal for this construction [37] (Figure 2.21e ).

**Soiled Filling or End**

Causes: Dirty, oil looking spots on the wrap or weft yarns, or on package- dyed yarn (Figure 2.21f ).

**Smash**

Causes: It is caused by a number of ruptured wrap ends that have been repaired (Figure 2.21g ).

**Slub**

Causes: It is caused by an extra piece of yarn that is woven into fabric. It can also be caused by thick places in the yarn (Figure 2.21h ).

**Open Reed**

Causes: Results from a bent reed wire causing wrap ends to be held apart, exposing the filling yarn (Figure 2.21i ).

**Oil Spot**

Oil spots are deposits of oil that have fallen onto the fabric from some processing step (Figure 2.21j ).

**Mixed Yarn**

Causes: Yarn of a different fiber blend used on the wrap frame, resulting in a streak in the fabric (Figure 2.21k ).

**Knots**

Causes: It is caused by tying spools of yarn together (Figure 2.21 l ).

**Jerk-in**

Causes: It is caused by an extra piece of weft yarn being jerked part way into the fabric by the shuttle (Figure 2.21m ).

**End Out**

Causes: It is caused by yarn breaking and weaving machine runs with missing end [37] (Figure 2.21n ).

**Dropped Pick**

Causes: It is caused by the weft insertion mechanism on a shuttle-less loom not holding the weft yarn, causing the weft yarn to be woven without tension. The weft yarn appears as "kinky" (Figure 2.21o).

**Thin Place**

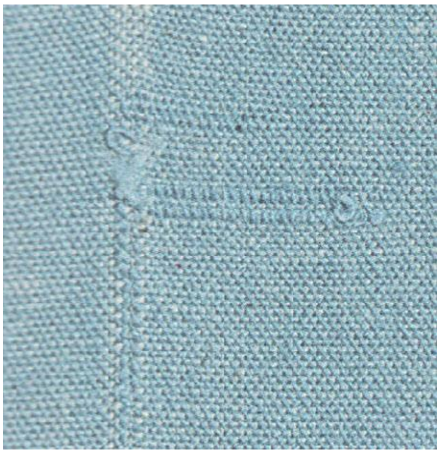
Causes: It is caused by the weft yarn breaking and the weaving machine continuing to run until the operator notices the problem (Figure 2.21p ).

**Bad Selvedge**

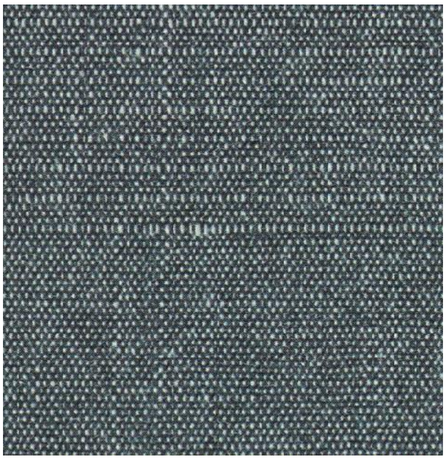
Causes: A defect in a fabric because of faulty weaving, warp ends being set too far apart for the thickness of the yarn or in finished fabric, an appearance in which the underlying structures is not connected to the degree required (Figure 2.21r ).

**Stop Mark**

Causes: When the machine is stopped, the yarn elongates under tension; when machine starts again' the slackness is woven into the fabric (Figure 2.21s ) [37].

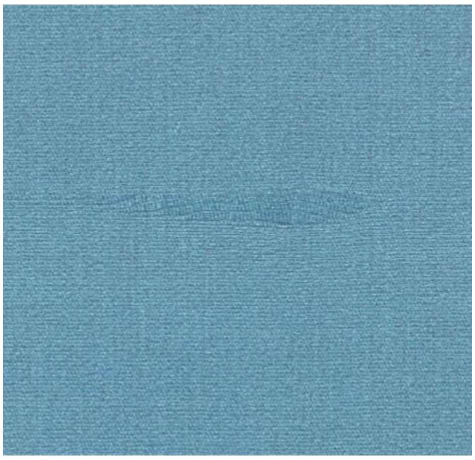


a) Drawback

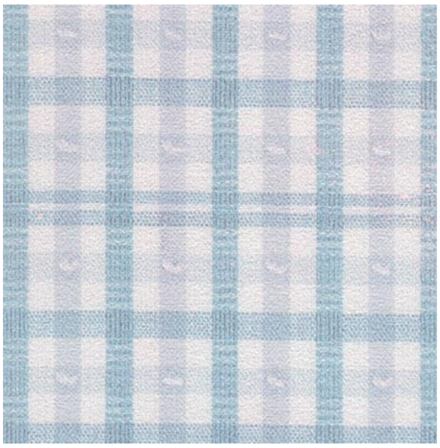


b) Double pick

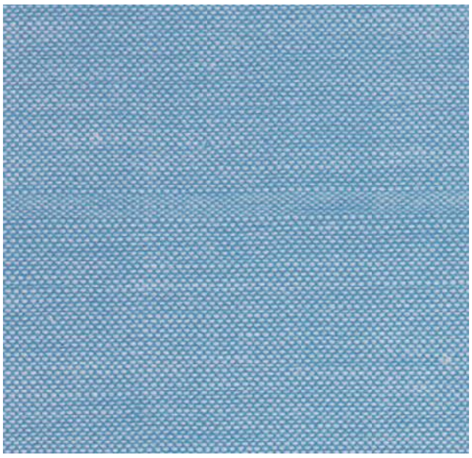
Figure 2.21 Common fabric defects [38]



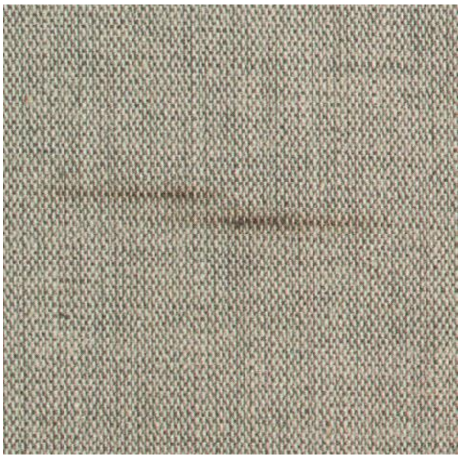
c) Burl mark



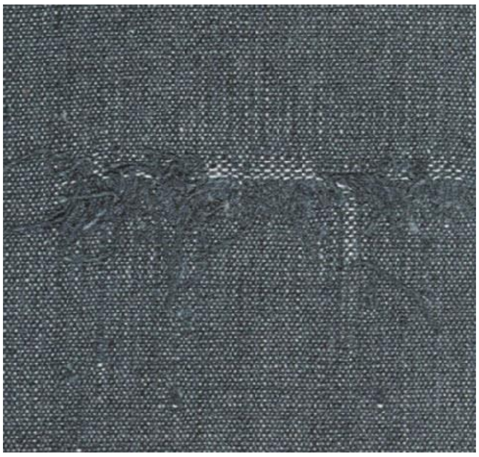
d) Broken pattern



e) Thick place



f) Soiled filling

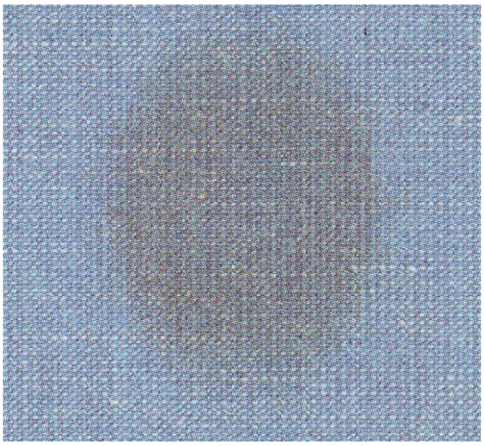


g) Smash

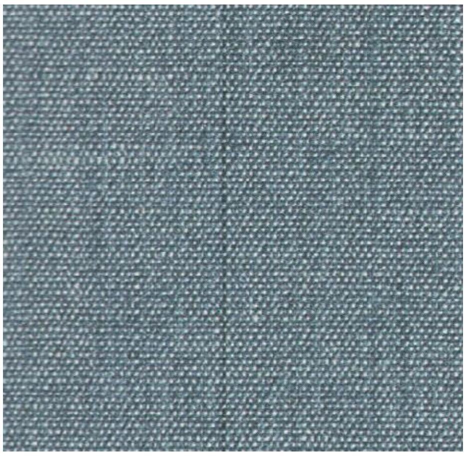
h) Slub

Figure 2.21 Common fabric defects (continued) [38]

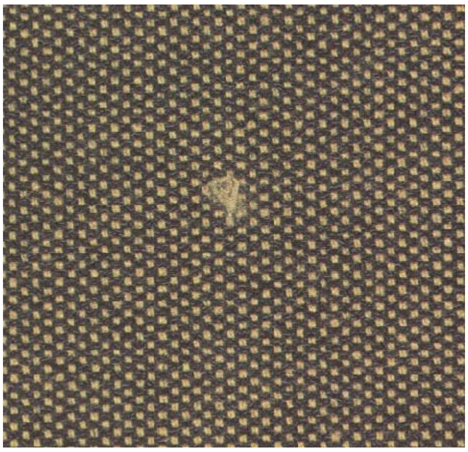
i) Open reed



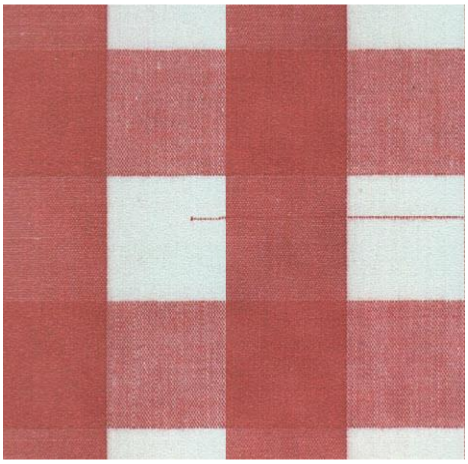
j) Oil spot



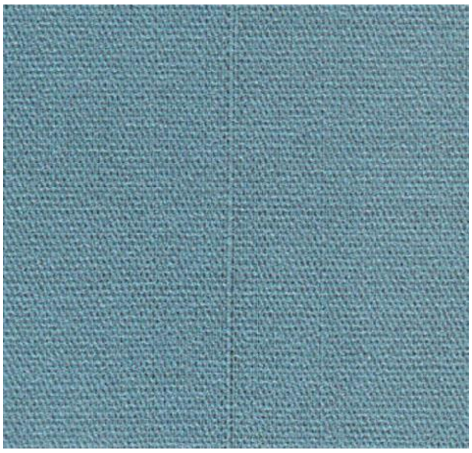
k) Mixed yarn



l) Knot

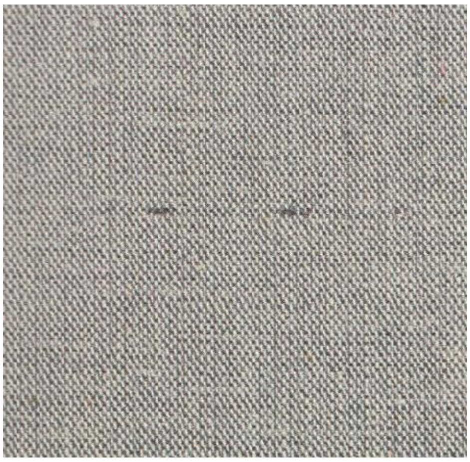


m) Jerk in

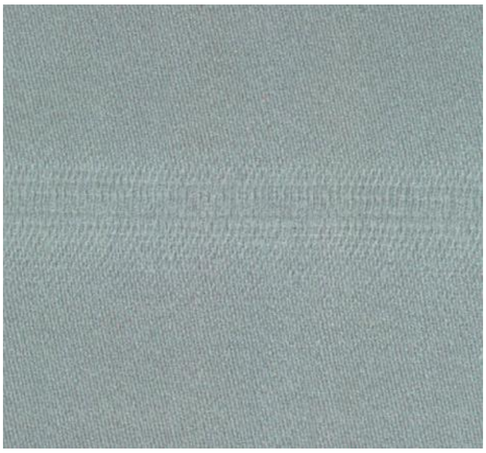


n) End out

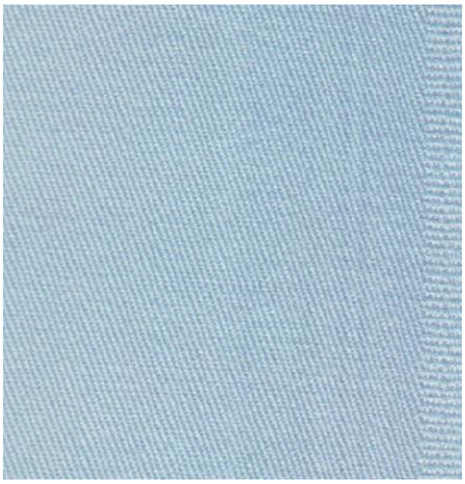
Figure 2.21 Common fabric defects (continued) [38]



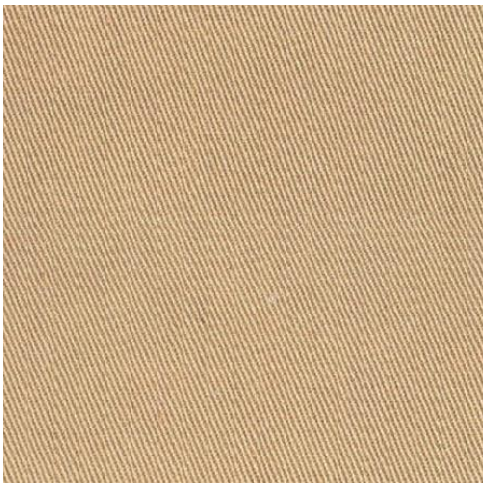
o) Dropped pick



p) Thin place



r) Bad selvedge



s) Stop mark

Figure 2.21 Common fabric defects (continued) [38]

### 2.4.2 Fabric Defect Detection Methods

There are many methods that can be used for detecting the defects of fabric. These include:

1-Traditional inspection (Manual defect detection)

2-Automatic Fabric Inspection (Automation for inspection)

a. BarcoVision's Cyclops,
b. Elbit Vision System's I-Tex
c. ZellwegerUster'sFabriscan and MQT.

#### 2.4.2.1. Traditional Inspection (Manual Defect Detection)

There are two apparent means for fabric defect detection. The first of them is the process supervision in which the weaving process can be continuously observed in case any defect occurs. Since process supervision is disincentive supervision, and is usually not carried out in the textile mills because the weaving process is very complex. The second mean is the product supervision in this supervision the produced fabric has to be supervised for the defects. The available study is focused on product supervision.

The fabric manufactured from the weaving machines has the width of 1.5-2 meters, and rolls out at the speed of 0.3-0.5 meters per minute. The product supervision in the textile factories is not carried out simultaneously with the manufacture. The slow speed of manufactured fabric is inadequate to continue a human supervisor busy therefore human supervision is not economical. Besides, the comparatively hostile working atmosphere near the weaving machines is not convenient for human supervision. The traditional supervision procedure is to take the produced fabric rolls from the looms and lay them on the supervision. When a human supervisor realizes a defect on the moving fabric, he stops the control machine, records the defect and its place, and then he starts the engine again. The early detection of recurring defects and abnormal defect rate is left to the operators or so called roving supervisors. These roving supervisors will warn the manufacture department therefore suitable measures can be taken to reduce the defect rate [35].

In the textile industry, supervision is done to assure the quality of fabric because fabric defects can reduce the product price by 45% to 65%. The quality assurance of web processing is mainly performed by manual supervision. However, the reliability of manual supervision is confined by following exhaustion and carelessness. In fact, only about 70% of defects can be detected by the most highly educated supervisors [36].

Fabric like many intermediate products is available in a web form (continuous rolls) where a typical fabric web is 1.5-2 meter wide. In addition, defects to be detected by inspection are numerous and present complex appearance.

Traditionally, this procedure must performed by well-trained human inspectors. The existing methods of fabric inspection vary from mill to mill. In few mills, trained labors pull the fabric over a table by hand [39]. As shown in Figure 2.22, most mills have power driven inspection machines where the manufactured fabric rolls are removed from the weaving machines and unrolled on an inspection table at a relatively higher speed of 8-20 meters per minute.

Figure 2.22 Traditional (manuel) fabric inspection

**2.4.2.2. Automatic Fabric Inspection (Automation for Inspection)**

Textile industries are facing with rising pressure to be more competitive and influential by decreasing costs. So that, automatic defect detection in textile fabrics provides high quality production and high speed manufacture and it is really required.

There are some advantages of automated detection of defects:

1. 100% supervision can be carried out
2. It is more steady process when compared with manual supervision
3. It is non-contact supervision, so avoiding problems that happen because of using some contact supervision instruments
4. It can usually give result:

- Lower labor costs
- Improved quality
- Faster supervision
- Increased reliability [36].

All textile industries aim at manufacturing competitive products. The competition recruitment is mainly subject to productivity and quality of the fabrics manufactured by each industry. In the textile industry, there have been a great amount of losses because of the imperfect fabrics. In the developing countries, most defects happening in the production phase of a textile material are still detected by human supervision. The job of supervisors is very boring and time taking. They must find small details that can be placed in broad area which is moving along their visual field. The definition rate is almost 70%. Also, the influence of visual supervision reduces quickly with exhaustion. Over the last ten years, digital image processing techniques have been increasingly applied and used to textured examples analysis.

• Wastage decrease through complete and early stage detection of defects in fabrics is also an significant regard of quality development..
• Summarize the comparison between human visual supervision and automated supervision.
• Price of the fabric is decreased by 45% to 65% because of the defects [40].

**Components of Automatic Fabric Defect Detection System**

The automation of visual supervision process is an all-round problem and needs complicated interactivity among different system constituents. The investment in the automated fabric supervision system is economically charming when there is a decrease in personnel cost and integrated advantages are thought. The architecture of a specifically automated textile web supervision system is can be seen in Figure 2.23.

There are group of cameras which are settled in parallel across the web to be scanned in the system: There are also a computer console hosting processors, a lighting system, the frame grabber and the supporting mechanical and electrical interfaces for the supervision machine. The supervision system adopts great parallelism in image achievement with a front-end algorithm that decreases the information flow to the zone of interest only.

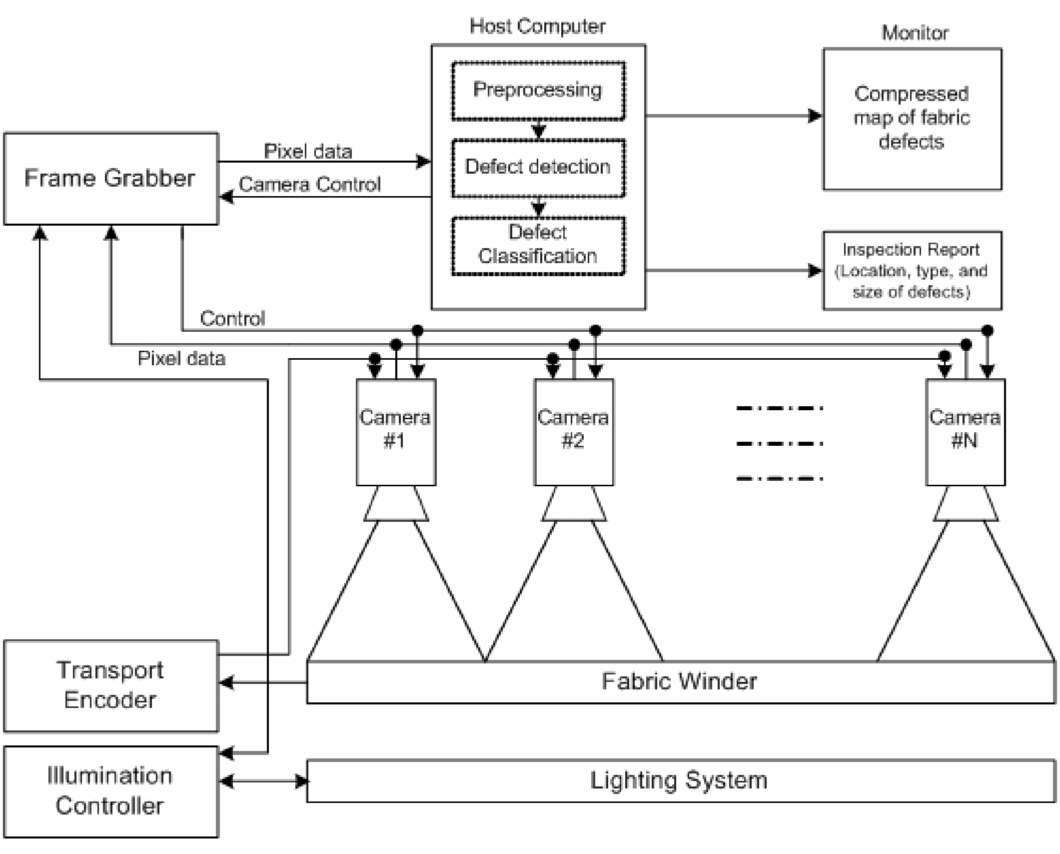



Figure 2.23 Architecture of a typical automated visual inspection system [35]

**(i) Lighting system:**

The quality of gained images plays a very important role in simplifying a supervision problem. The image quality is severely influenced by the level and the type of clarification. There are four main types of lighting diagram utilized for visual supervision i.e. back, front, structured and fiber-optic. The backlighting cut off the shadow and dazzles influences, and is utilized for fabric supervision. It is also possible to adopt fiber optic lightening for the fabric supervision, as it ensure uniform lightening of products without any shadow or dazzle problem.

**(ii) Camera:**

A great sort of cameras with enormous variation in sensor types, read out speed, resolution, precision and other specialties find their implementations in the machine vision. The resolution of a camera is confined to the number of pixels in the camera photo sensor and the object Field of View (FOV).

**(iii) Transport encoder:**

The transport encoder is used to supply master timing pulses for the camera. Fabric Winder is in direct contact with the wheel of the transport. In case of line scan cameras, the resolution of the transport encoder decides the pixel resolution.

**(iv) Frame grabbers:**

The pixel information is transformed into a digital image by the frame grabber. All web supervision systems have to cope with the multiple camera inputs. The output from the frame holder is moved to the host computer in any of the industrial bus formats (PC100, PICMG, VME, etc.) or popular PC formats (PCI, VESA, ISA, etc.).

**(v) Host computer:**

Host computer’s functions can be categorized in three main groups.

- Defect detection and categorization,
- Control and camera lightening,
- System control [35].

#### 2.4.2.2.1 Automated Fabric Inspection Systems

State-of the-art fabric inspection systems are;

a. BarcoVision's Cyclops,
b. Elbit Vision System's I-Tex
c. ZellwegerUster'sFabriscan and MQT [40].

**a. Barco Vision’s Cyclops**

The Cyclops inspection unit uses one or two moving image acquisition heads. The heads consist of a camera and an illumination unit. They are installed on the off-loom take up unit (Figure 2.24). As the woven fabric is wound on the cloth beam, images are taken and transferred to the image processing unit. Any detected defect is being sent signal to the loom. The automatic fabric edge detection unit adjusts the scanning range according to the fabric position and width. The system optimizes the illumination and camera settings in relation to the optical characteristics of the fabric. The algorithm parameters for optimal defect detection are calculated according to the fabric structure. The structure of the fabric is identified automatically. Maximum available scan width is 560 cm. Single camera scanners are used for single panel looms and double camera scanner is used for multi panel looms. Standard illumination is infrared led. Scanning resolution is reported as 10 pixels/mm [41].

Figure 2.24 Barco Vision's Cyclops [41]

**b. Elbit Vision System**

I-TEX system is capable of inspection speeds up to 300 meters per minute and can handle fabric widths up to 5 meters. Elbit Vision system combines image processing software and camera system hardware for fabric defect detection (Figure 2.25). IQ-Tex system learns the pattern of the defect-free fabric. Since the same pattern is repeated during the whole fabric weaving, the changes from the standard pattern are detected. The variations over a threshold level are evaluated as the defective part. Multiple image processing algorithms are used for the defect detection. The location and the size of the defects are memorized in a defect map. The image of the defective area is then saved for the further analyses. The detected defects are also classified according to their type. Typical detectable defects are; nap, knot, foreign material, eye brow, dirt spot, strip contamination, oil stain and hole. The system is adaptable to the applications such as grey, dyed and finished fabrics, car seat, air-bag, roofing, glass fabric, composites, carbon webs, non-woven, plastic films, coated textile, glass fabric, laminates and tire cords. IQ-Tex can detect the defects as small as 0.1 mm. The operation speed of the system is up to 800 m/min [41].

Figure 2.25 Elbit Vision System [41]

**c. Zellweger Uster Fabriscan**

The ZellwegerUster's present system, Fabriscan, is able to supervise fabric at speeds up to 120 m/min and can detect defects down to a resolution of 0.3 mm. It can conduct fabric widths from 110 to 440 cm. ZellwegerUster has many mills in Europe including a range uncolored fabrics including clothes, industrial fabrics and denim.

Fabriscan categorizes defects in a matrix named Uster Fabriclass, which resembles to the well-recognized Uster Classimat system for yarns. Fabriclass has two axes. Y-axis symbolizes the contrast of the defect and x-axis symbolizes the length of the defect. This lets the system to reveal the variations between disturbing defects versus non-disturbing defects so that this makes over- detection virtually nonexistent, according to the company. Information on defects is also able to be stored in an associated database, lets users to produce any type of report that they require. Cut optimization software is added to develop first quality fabric product. The revolutionary Uster® Fabriscan on-loom supervises every single millimeter of the fabric and controls it for defects. The fabric has direct contact with the scanner sensors and distributes high-quality images for credible detection of defects. The Uster® Fabriscan on-loom avoids imperfect manufacture since, through immediate detection of defects; it makes instant correction (Figure 2.26) [40].

Figure 2.26 Zellweger Uster Fabriscan [40]

The system called Zellweger Uster Fabriscan was shown at CITME 2004, Beijing in China. The fabric passes over two parts of illumination module. It is designed for an inspection in either reflected or transmitted light. The system has different illumination types depends on fabric density and the defect types. The system has 3-6 high resolution CCD line scan cameras above the illumination module. The number of the cameras can be increased up to 8 depending on the inspection width. The system performs a neural network based algorithm for defect detection and classification. It can inspect fabric with a minimum 0.3 mm defect size and at speed up to 120 meters per minute. The system can memorize the images of defective areas. Fabriscan project has been finished since it has resulted in poor results and it couldn’t manage the fabric inspection successfully. It was installed in some denim fabrics in Turkey, but the required fabric inspection success rate was not obtained. It is informed that this product is removed from USTER product list [41].

#### 2.4.2.2.2 Algorithms Used in Automated Fabric Defect Detection

**a. Structural approaches**

Structural approaches say that the textures are made up of primitives and these primitives can be so simple as individual pixels, a place with uniform gray levels, or line sectors. As a result, the essential aims of these approaches are mainly to extract texture primitives, and secondly to model or generalize the areal placement norms. The placement rules can be getting by modeling geometric associations among primitives or learning statistical specialties from texture primitives. But, these approaches were not accomplished on fabric defect detection, primarily due to the stochastic changes in the fabric structure which poses serious problems in the extraction of texture primitives from the real fabric examples [1].

**b. Statistical approaches**

They measure the areal delivery of pixel rates as their main aim is to split the image of the supervised fabric into the areas of different statistical manners. A significant presumption in this process is that the statistics of defect-free zones are constant, and that these zones extend over a important sector of supervision images. Depended on the number of pixels identifying the local specialties, Mahajan categorized these approaches into first order, second order and higher order statistics. The first order statistics estimate properties like the average and change of individual pixel rates, ignoring the areal interaction between image pixels, second and higher order statistics on the other hand estimate specialties of two or more pixel rates happening at specific locations associated with each other. Apparently, the use of statistical approaches is well distinguished in the field of computer vision and has been extensively applied to various services [1]. The most used approaches are:

i. Gray level thresholding approach
ii. Normalized cross-correlation approach
iii. Statistical moments approach
iv. Multilevel thresholding approach
v. Histogram properties approach

vi. Rank-order functions approach
vii. Fractal dimension approach
viii. Edge detection approach
ix. Morphological operations approach
x. Eigenfilters or Independent Component Analysis approach
xi. Gray level co-occurrence matrix approach
xii. Local linear transforms approach
xiii. Artificial neural-networks approach
xiv. Autocorrelation function (ACF) approach
xv. Local binary patterns (LBP) approach
xvi. Optimal filter design approach

**c. Spectral approaches**

Depended on areal-frequency domain specialties that are less sensitive to noise and density changes than the specialties extracted from areal domain, spectral approaches take part a big part of the latest computer vision study work. It simulates the human vision system where the psychophysical research has indicated that human visual system tests the textured images in the area frequency domain. Spectral approach needs a high degree of periodicity, so that it is suggested to be implemented only for computer vision of uniform textured staff like fabrics. Such approaches are developed to cope with the efficiency drawbacks of many low-level statistical practices for automated defect detection. The main aims of these approaches are primarily to extract texture primitives, and secondly to model or generalize the areal placement rules [42]. The most used approaches are:

i. Fourier analysis (transforms) approach
ii. Gabor filters approach
iii. Optimized Finite Impulse Response (FIR) filters approach
iv. Wigner distributions approach
v. Wavelet analysis (transform) approach

**d. Model-based approaches**

Model-based texture analysis methods try to capture the process that generated the texture. They try to model the texture by determining the parameters of a pre-defined model. Particularly, model-based approaches are suitable for fabric inspection when the statistical and spectral approaches have not yet shown their utility].These approaches often require that the image features at different levels of specificity or detail match one of possible many models of different image classes. The mostly used three models will be discussed in the following part.

i. Gauss Markov Random Field (GMRF) model approach
ii. Poisson's model approach
iii. Model-based clustering approach [1]

**e. Combination of computational methods**

From the previous survey, one may conclude that it is rather difficult to perform a robust individual approach that detects all fabric defects with high accuracy. It is mainly due to the fact that each technique has some advantages but, in the same time its drawbacks. Therefore, many researchers combined two or more different approaches to give better results, than either one individual one. The main object is to minimize the computational complexity and enhance the detection capability.

**f. Comparative studies for different approaches**

Due to the huge number of fabric defect detection algorithms and techniques, the need for effective methods to compare between these approaches is very important than before. The comparative studies have a vital importance and may be considered as a research guide. This guide enables the researchers to learn and understand the differences between the various used algorithms or approaches based on its feasibility and reliability [1].

# CHAPTER 3
# OPTICAL PROPERTIES OF TEXTILES

## 3.1. INTRODUCTION

Fabrics differ by weave pattern, raw material, application, constructional parameters and visual characteristics. Appearance and application of a fabric were determined by the fabric constructional parameters and their values. The properties of a fabric (such as design, texture, color, and pattern) create the overall visual image of this fabric. Textile material's color is attributed to the colors of constituent yarns, fibers and fabrics as well as to certain complex phenomena that occur at the same time. The parameters and phenomena (influencing the textile colors) and consequently, optical phenomena (occurring on the untreated surface of textile) are fully natural origin, for example texture, natural color and surface parameters that are yarn parameters. Additionally, chemical and mechanical (printing, dyeing, mechanical finishes) processes influence the optical and spectral phenomena in textiles.

## 3.2. OPTICAL BEHAVIORS ON FABRIC

The appearance and perception of a woven product's color are affected by three factors:

– The light source transmitting rays onto the observed surface,
– The optical-reflective properties of material,
– The responsiveness and observer of the eye.

The color of a textile material (fabric, yarn, fiber) depends on its structure and its physical and chemical composition. When light touches to the surface of a fabric, a portion of light is absorbed from the surface, and a portion is reflected by the surface. The color of the fabric depends on the relation between these two portions. Figure 3.1 shows the phenomenon of absorption, reflection, scattering and refraction of the light in a fabric. In the light, point A, that is surface contact point, a portion of light $I_0$

is reflected as $I_r$, and a portion passes through the fiber of the fabric and refracts as $I_l$ (ray B) [43].

$$I_0 = I_r + I_a + I_s + I_t$$

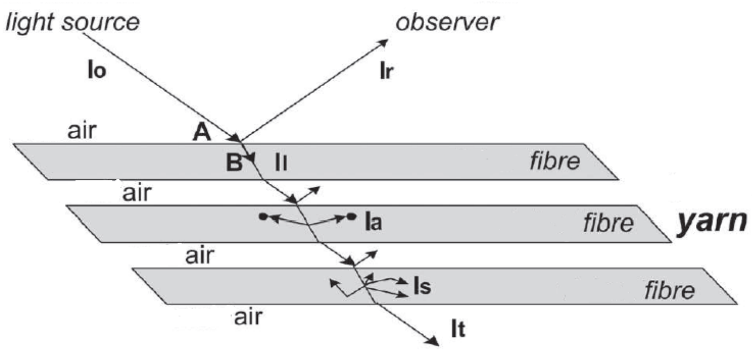



Figure 3.21 Reflection, refraction, absorption, transmittance, scattering of light [43]

Fabric is denser than air therefore the ray changes the angle of its travel in view of the normal. When the ray leaves in point B and goes through the air, the slope of its travel again changes and happens parallel to the incident light ray. At the through following fibers, the light ray refraction processes are repeated. As a result of the light absorption, the light intensity is decreasing on scattering structural parts-$I_s$ and into the dyestuff-$I_a$.

Incident light $I_0$ is a total of absorbed light $I_a$, reflected light $I_r$, transmitted light $I_t$ and scattered light $I_s$.

### 3.2.1 Reflection

Reflection is the portion of the light that doesn’t refract inside the material and reflects from its surface and arrives to the eye. In the smooth surface, the reflection angle is the same as the incidence angle. In the unsmooth surface, the reflection angle is different from the incidence angle [44].

The textile material surface influences the light reflection and the perception of the color saturation and lightness of the material. The reflection is generally affected by three surface parameters: luster, brilliance and texture. The luster characterizes the reflection of the light like a selective mirror. Brilliance has influence on color saturation and lightness. The appearance of high brilliance surface is darker than a mat surface. A surface texture is related with brilliance and a more evident texture shows less brilliance. When the light contacts with the surface, a part of the light reflects from particles that are randomly distributed. The properties and type of the particles affects the spectral composition of the reflected light. The non-reflected light from the surface penetrates into the material where it is partly reflected and selectively absorbed back towards the observer.

Perception of the color depends on the angle of viewing; the light, which reaches the eye, changes when the position of the observed object is changed [44].

Four types of the light reflection are shown in Figure 3.2 according to the surface smoothness. In case A, diffusive reflection of the light is presented; in that case the appearance of the surface is independent of the angle of viewing. In cases B and C, the increased smoothness of the surface results in the orientation of the reflected light in a particular direction [45].

As the angle of light reflection is identical to that of light incidence, material D is perfectly totally with. The surface is shining, and its appearance relies upon the angle of viewing.

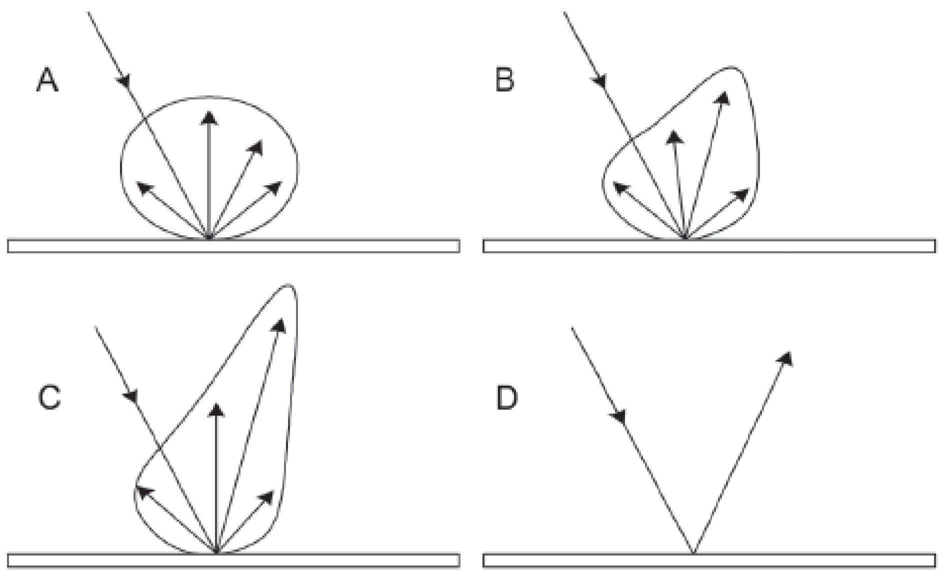



Figure 3.2 Reflected light orientations at different surfaces [45]

A larger fragment of the light reflects diffusively from textile fibers– from natural fibers as a result of scattering on the surface of microfilaments, and from synthetic fibers as a result of the particles of titanium dioxide [45].

### 3.2.2 Light refraction

The incident light refracts and changes the angle of its travel during penetration into material. This phenomenon occurs because of different densities of materials and, therefore, different indexes of refraction [45].

### 3.2.3 Light absorption

Light absorption is the capability of a material to absorb the light of certain wavelengths. All materials can absorb the waves of ultraviolet, visible or infrared spectrum of electromagnetic radiation. But only the materials which absorb the waves within visible light spectrum could be recognized by the eye as colored.

### 3.2.4 Scattering

A portion of the light striking textile material passes through it because of the spaces existing between weft and warp yarns, and between fibers. The scattering happens only if the particles that the light hits against are small enough compared to the incident light wavelength [46].

## 3.3. CONSTRUCTIONAL PARAMETERS AND COLOR OF FABRIC

The phenomenon of color on a woven fabric cannot be featured completely to the above optical phenomena. There are a lot of other parameters which affect the general understanding of color. The complete color phenomenon of a woven fabric can be perceived only if we have all constructional parameters of fabric and yarn, together with color design parameters of fabric which define:

– Relationship between the incident light and the material: scattering, reflection, and absorption (hairiness or smoothness of the surface, material and type of yarns or fibers, texture and relief),
– Size and proportion of individual colored surfaces (yarn spacing, weave, linear density),

– Arrangement of color surfaces (warping, weave, weaving pattern),
– General effect of a single-color or multicolor fabric (color designing parameters of a fabric). [43]

### 3.3.1 Constructional parameters of yarn

The parameters which determine the properties, construction and appearance of yarns, are:
– Raw material,
– Cross-section and type of fibers,
– Shape, type, diameter and linear density of yarn.

#### 3.3.1.1. Raw material, shape and type of fibers

We have to give particular attention to the properties imparted by the used raw material at colorimetric investigation of fibers. Light reflection and refraction on a fiber are defined by crystallinity, surface, shape of cross-section and dimensions.

Few parameters which considerably influence the color of a woven product has to be indicated when the fiber-light relationship is analyzed [47]:

– Fibers surface,
– Linear density,
– Cross section,
– Fibrous structure orientation,
– After-treatment by calendaring or by finish,
– Matting agent.

Natural fibers mostly have rough surface and unequal dimensions produced by lumen at cotton, scales at wool, and by longitudinal furrows at stem fibers. The fiber lengths differ from 11 to 50 mm with cotton, and from 50 to 400 mm with wool. The cross-section of these fibers also differs lengthwise the fibers, and hasn't got a regular shape: such as furrowed, flattened, kidney-shaped. As a result of the light scattering in all directions from uneven texture the light reflection from natural fibrous structures is therefore diffusive. The only exception is silk, which has rather smooth surface and oval cross-section. The luster of these fibers is lower and it is less dependent on the angle of viewing. Larger quantity of dyestuff is necessary to achieve the same color effect as with the fibers with round cross-section. Figure 3.3 shows the contact of the light with a cotton fiber (a) and a wool fiber (b) [43].

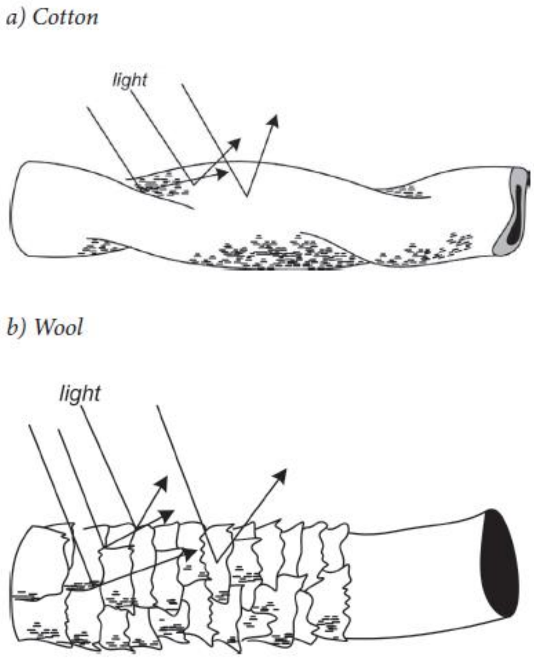



Figure 3.3 Cross-section and surface of natural fibers with light reflection [43]

The cross-section shape of synthetic fibers and their diameter's size are identified during their extrusion through nozzles with enough shaped openings. Meanwhile, the fibers properties are adjusted for further usage. Their relations with light could be pre-identified as well because it is possible to plan the three mentioned parameters of synthetic fibers.

Synthetic fibers' surface is totally smooth; therefore, the light reflection from such surface would be rather specular and mirror-like due to the pushing of spinning blend through nozzles that could be controlled with the nozzle shape which identifies the dimensions of the fibers cross-section (oval, trilobal, tubular, multilobal, triangular, convex or of any other shape). Same as the natural fibers; diffusive light reflection affects visually lighter colors that might look less saturated as well [48].

The size of fiber cross-section is also important. Fibers with lower linear density generally have smaller cross-section. Consequently, these fibers absorb less light, but are because of larger specific surface of fibers more scattering active. Finer fibers look lighter than thicker fibers.

Orientation of fibers and contact of fibers: The appearance of color of textile materials is considerably influenced by randomness of fibers orientation. When staple fibers with more or less random arrangement and filament fibers are in comparison, the role of orientation is noticed. As the light reflects from their surface specularly, color appearance of lament fibers highly relies on the angle of viewing. The opposite is the case with staple fibers, in which the observer's perception of color is less dependent on the angle of viewing because of random light reflection from staple fibers.

Optical contact of fibers increases by enlarging the contact surface of fibers. This reduces the scattering power of the colored fabric surface. Such phenomenon is achieved with after-treatments, like calendaring and application of colorless finishing agents [48].

Light reflection and scattering in dependence of the shape of fibers cross-section, fibers length and orientation, and fibers contact surface are presented in Figure 3.4.

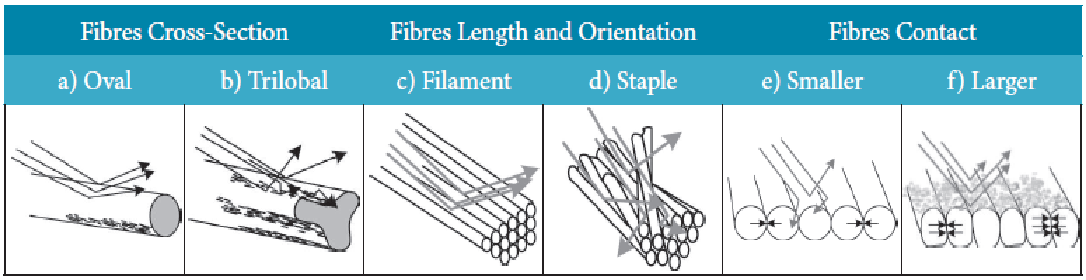



Figure 3.4 Scattering and reflection on the surface of fibers [48]

### 3.3.1.2. Type and shape of yarn

Yarn is a textile product which consists of a multitude of fibers which means that all properties of fibers defined above are indirectly transferred to the yarn. Additionally, the constructional parameters of yarn establish new relationships between fibers that define the light yarn relationship.

The parameters of yarn, which would be considered while the color of a fabric is designed, are as follows [49]:

– Type,
– Linear density,
– Yarn twisting,
– Diameter,
– Color parameters,
– Hairiness,
– Structural parameters,
– Compactness and rigidity,
– Absorption of chemical agents and humidity.

**a) Type of yarn**

The type of constituent fibers, their arrangement and orientation determines the type of yarn. The yarn groups by types are as follows: spinning, .lament, twisted, fancy, and textured yarns. The incident light reflection is different because of the different shape and relief of yarn groups. Filament yarn consists of one or more filaments of infinite length. The light reflection direction and the light scattering intensity mostly rely on the type and shape of fibers as fibers are oriented lengthwise the yarn axis. Fibers are partly oriented lengthwise the yarn axis while spinning and twisting as to spinning and twisted yarns.

Orientation relies on the type and sequence of spinning phases and also on the intensity of twists or torques. Two cotton yarns produced on ring and rotor spinning machines may be given as an example. Ring spun yarn has higher number of twists and its appearance is therefore glossier with higher luster. Rotor spun yarn has more random position and direction of fibers by length, which results in more unequal light reflection.

**b) Yarn twist**

The direction of twists defines the orientation of fibers in yarn and, consequently, the direction of the incident light reflection. In the case of yarn with shorter fibers, as a result of the orientation of fibers in the direction of the yarn longitudinal axis, luster increases with the increase of the number of twists.

### 3.3.2 Constructional parameters of fabric

Some of the most significant parameters of a fabric which also affect its color appearance are:

– Weave,
– Types of pores,
– Cover factor,
– Warping and weaving pattern,
– Finishing processes [49].

#### 3.3.2.1. Weave

Weave shows the way of weft and warp yarns interlacing which affects the color and relief structure of a fabric by the following parameters [49]:

– Weave repeat size,
–Number and ratio of interlacing points,
– Distribution of individual weft and warp interlacing points and their assemblies,
– Length of floating and special texturing effects,
– Size and arrangement of color surfaces.

**Size of weave repeat:** The size of the weave repeat identifies the smallest sequence of interlacing points of a set of weft and warp yarns. The smallest size of such recurring structural pattern is 2 × 2 (plain weave); the highest size is the size equaling the number of all warp yarns on a weaving machine.

**Number and ratio of weft to warp interlacing points:** The effect of the yarns of each system on overall color influence is determined by the ratio of the weft to warp interlacing points.

In warp effect, the texture and color of warp yarns is exposed on surface because of the higher number of warp interlacing points. Similarly, weaves in weft influence have the texture and color of weft yarns exposed on surface. The examples are satins, weft and warp twills and other more complex weaves.

**Distribution of weft and warp interlacing points and their assemblies:** Distribution of weft and warp interlacing points affects the shape, sequence, size and orientation of the surfaces differing in color and relief in a weave repeat. Weft and warp yarns impart color and relief characteristics to the weave. Figure 3.5 represents the groups of weaves with variously distributed interlacing. The given weaves have weft and warp yarns of the same yarn spacing and linear density [43].

Different patterns on weave are produced with different shapes of color and relief surfaces in weave repeat. In dependence of the agglomeration of the weft and warp interlacing points, these patterns may be more/less geometrical, regular/irregular,

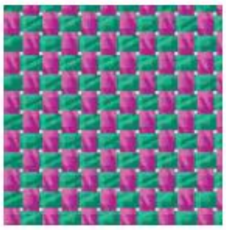
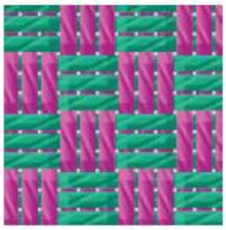
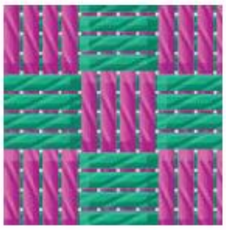
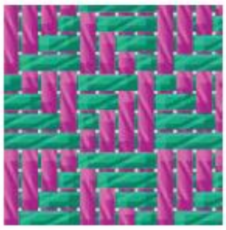
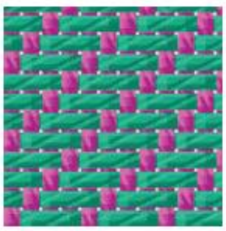
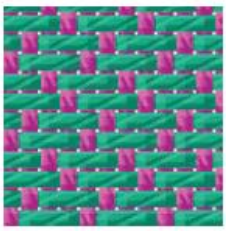
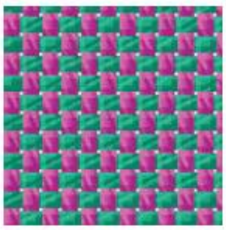
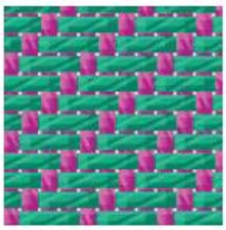
| Parameter | Weaves | |
|---|---|---|
| Size |  |  |
| Shape |  |  |
| Sequence |  |  |
| Orientation |  |  |

Figure 3.5 Distribution of interlacing points in a weave repeat [43]

larger/smaller etc. As the eye is able to perceive faster and easier the uniform, regular and larger shapes, the shape of the surfaces affects optical perception of what is going on in the weave.

As the perception of their color depends on the angle of observation, these weaves are accepted special from optical viewpoint. Particularly, the incident light reflects specularly relying on the yarns orientation in the weave which is perceived in dependence of the angle of viewing as different luster of the fabric. The examples are twill and satin weave. The light reflection is diffusive in non-oriented weaves because of the granular texture, and independent of the direction of viewing such as plain weave and Panama weave.  [43].

**Length of floating:** The length of yarn floating affects the color and relief influence area from the color and optical viewpoint. Longer is the floating of a yarn on the face or back side of the fabric, more exposed is the effect of such yarn. The examples are plain and satin weave. Plain weave is characterized by low luster because of most frequent interchanging of weft and warp interlacing points and, consequently, high floating of weft and warp yarns. The light reflects diffusively from granular surface of the fabric, i.e. in all directions. With satin weave, more luster is produced; particularly because of the specific distribution of interlacing points on the surface, and higher floating of weft and warp yarns, the light reflects specularly from parallel oriented yarns in a defined direction (Figure 3.6) [48].

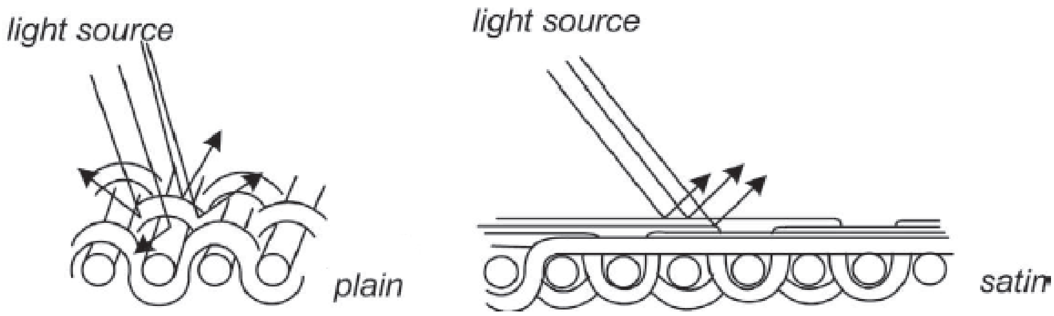



Figure 3.6 Reflection on fabric in plain and satin weave [48]

#### 3.3.2.2. Cover factor

Cover factor is determined as the area of a fabric, which is covered by weft and warp yarns. Indirectly, it presents the information about compactness and transparency of a fabric. The calculation scheme of cover factor is illustrated in Figure 3.7 [50].

The cover degree cover of a fabric depends directly on the yarn constructional parameters (diameter and yarn spacing) and the weave, which defines, in dependence of the type, the boundary values of yarn spacing.

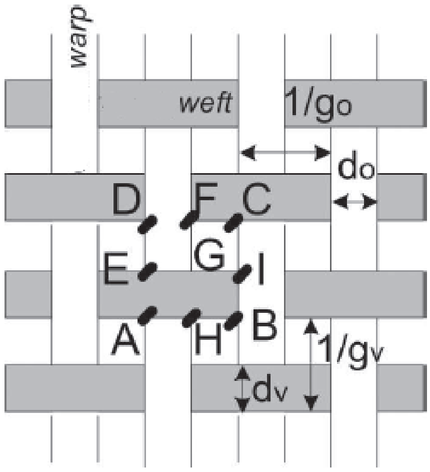



Figure 3.7 Calculation scheme of cover factor [50]

Plain weave is schematically shown in Figure 3.7 and it may be accepted that there is a great interdependence of the degree of cover of a particular yarn system and its effect on overall color influence of a fabric. On the basis of the area of weft and warp yarns, their constructional parameters and the spaces between yarns, the degree of fullness of individual elements may be calculated by using some equations.

The satin weave higher fullness of weft and warp may be supposed as yarns may approach considerably. It may cover each other at higher yarn spacing too.

Pores between yarns take the inclined position preventing because of the spatial position of yarns, thus direct effect of foundation on the fabric surface. Such yarn displacements are not frequent in plain weave; the position of pores is vertical, which admits a direct insight into the spaces between yarns at vertical observation. It is required to point out that the extent of the foundation color influence on the fabric surface also relies on the degree of fullness. The fullness of usual fabrics is 80 to 90%. No effect of the foundation reflectance may be seen because of the yarn interlacing when such fabrics lie on a particular foundation, but when such fabrics are looked towards the light, transparency of the fabric is disclosed because of the light rays passing through pores. At lower values of fullness, the influence of the underlying foundation may be already visually perceived.

Besides theoretical methods by calculating, the degree of fabric fullness and, consequently, the effect of an individual yarn system may be defined microscopically by using the image analysis. This process is based on acquiring image data of a fabric and their processing in digital form at particular magnification by using programming tools for image analysis. The advantage of this method are precise numerical data about the size of the areas of weft and warp yarns on the fabric surface, about particularities at yarns interlacing and weave arrangement, and also about the extent and effect of reflectance (pores) on overall color influence. However, this method is very time-consuming and due to this, theoretical calculations of fabric fullness are generally used in practice. The results of some researches prove that theoretical calculations are suitable despite certain simplifications. In simpler weaves, the results are highly comparable with the results gained by the more precise method of image analysis [43].

# CHAPTER 4

# MATERIALS AND METHODS

## 4.1. INTRODUCTION

The production information of denim fabric samples, the structural properties of samples, the test methods to measure the brightness of samples, the calculating principles to evaluate the visibility of fault at image processing were explained in this section.

## 4.2. MATERIALS

For this experimental study, ten denim fabric samples were produced at Kipaş Denim Mills. These denim raw fabric samples were formed by three different weaving pattern samples, three different weft sett samples and four different fiber type samples. In these denim fabric samples, the fiber type and number of the warp yarns were constant as 100% cotton ring carded and Ne 20/1, respectively. The warp sett was 32 warps/cm.

At weave pattern samples and at weft sett samples, the same weft yarns were used at same properties (Ne 20/1 yarn count and 100% cotton ring carded yarn). At fiber type samples, different weft yarns that were formed cotton, linen, poliester, lyocell were used at same yarn count number. The construction information of samples was given in Table 4.1. Test samples were weaved at Picanol optimax loom having rapier weft insertion system and dobby shedding mechanism. They were produced at same weaving loom and at the same conditions. The weaving process was carried out with 70 numbered reed and 180 cm in width.

The investigated parameters are;

- Weaving patterns: Plain, twill and sateen patterns,
- Weft densities: 17 yarn/cm, 22 yarn/cm, 27 yarn/cm,
- Fiber types: Cotton, poliester, lyocell, linen

**Table 4.1** Construction properties of fabric samples

| | Fabric Code | Warp Yarn Number | Warp Yarn Type | Warp Sett | Weft Yarn Number | Weft Yarn Type | Weft sett | Weave Pattern |
|---|---|---|---|---|---|---|---|---|
| **Weave Pattern Samples** | **1** | 20/1 Ne | %100 Cotton Ring | 32 | 20/1 Ne | %100 Cotton Ring | 22 | **1/1 Plain** |
| | **2** | 20/1 Ne | %100 Cotton Ring | 32 | 20/1 Ne | %100 Cotton Ring | 22 | **1/3 S Twill** |
| | **3** | 20/1 Ne | %100 Cotton Ring | 32 | 20/1 Ne | %100 Cotton Ring | 22 | **1/7 Sateen** |
| | | | | | | | | - |
| **Weft sett Samples** | **4** | 20/1 Ne | %100 Cotton Ring | 32 | 20/1 Ne | %100 Cotton Ring | **17** | 1/3 S Twill |
| | **5** | 20/1 Ne | %100 Cotton Ring | 32 | 20/1 Ne | %100 Cotton Ring | **22** | 1/3 S Twill |
| | **6** | 20/1 Ne | %100 Cotton Ring | 32 | 20/1 Ne | %100 Cotton Ring | **27** | 1/3 S Twill |
| | | | | | | | - | |
| **Fiber Type Samples** | **7** | 20/1 Ne | %100 Cotton Ring | 32 | **20/1 Ne** | **%100 Ring Carded** | 22 | 1/3 S Twill |
| | **8** | 20/1 Ne | %100 Cotton Ring | 32 | **33/1 NM** | **%100 Linen** | 22 | 1/3 S Twill |
| | **9** | 20/1 Ne | %100 Cotton Ring | 32 | **300 denier** | **%100 Poliester** | 22 | 1/3 S Twill |
| | **10** | 20/1 Ne | %100 Cotton Ring | 32 | **20/1 Ne** | **%100 Lyocell Ring** | 22 | 1/3 S Twill |

At weaving pattern samples, all production conditions and all properties of fabric samples were left unchanged, only the weave patterns were changed. Similarly, only weft sett numbers were changed at weft sett samples and only the fiber types of weft yarns were changed at fiber type samples.

## 4.3. METHOD

The aim of this study is to investigate firstly the effect of different fabric constructions (different weaving pattern, different weft sett and different fiber type) on the fabric brightness and secondly the effect of this brightness on detecting of the fabric faults by image analysis process. As fabric fault, the mispick fault was chosen because it is the most common fault that is seen at weaving processes. The same fabric fault was formed at all fabric samples. All measurements and analysis of samples were made from back side of the fabrics; this side is dominated by weft yarns.

Two methods were used in the measurement of the brightness values of fabric samples. Then, the effect of the brightness on fault detection was investigated with image analysis.

a) Determination of Fabric brightness

-Method 1: Determination of brightness with spectrometer

-Method 2: Determination of brightness with image analysis (with MATLAB® and Photoshop® programs)

b) Determination of the effect of brightness on fault detection at image analysis with calculating “standard deviation index” values.

The brief explanation;

a) Three different categories were selected as weave type, weft sett and fiber type.

b) Ten different fabric samples were prepared according to these three different categories at Kipaş factory.

c) Two methods were selected to determine brightness values which are spectrometer method and image analysis method.

d) The brightness values of these 10 fabric samples were measured by spectrometer method under three different parameters which are lightness, reflectance and whiteness index.

e) The brightness values of these ten fabric samples were measured at image analysis method with using MATLAB® program to convert the pictures to 0.04 threshold format and Photoshop® CS4 histogram program to calculate mean values and standard deviation values.

f) Lastly, the effects of brightness values were analyzed by image analysis and defect detection analysis. In other words, the SD index values were analyzed to understand the visibility of fabric faults at different brightness of fabrics.

### 4.3.1 Determination of Brightness with Spectrometer

In the first method, the spectrometer device was used to determine the brightness values of fabric samples (Figure 4.1). The measurements were made for faulty zones and fabric zones of the fabric samples.

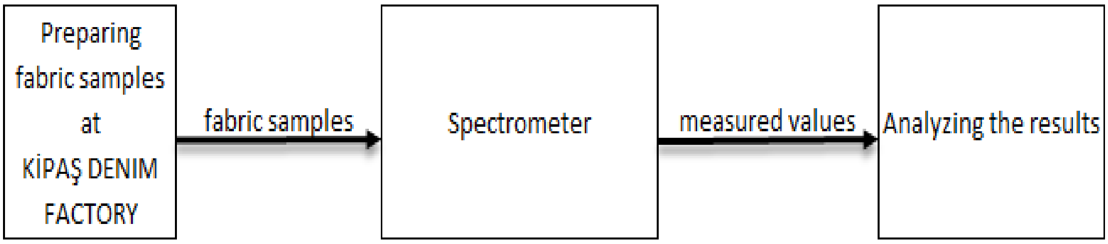



Figure 4.1 Flowchart for Method 1

#### 4.3.1.1. Spectrometer

The spectrophotometer is the integral part of a system and it has components of a computer and its metric programs. Spectrometer measures spectral reflectance of fabric samples at 16 wavelengths at visible spectrum range 400-700 nm. As a monochromator, a holographic net is used with a diode cell. The illuminant is xenon flash bulb. The computer may be used as a system with one place or a system with more places [51].

Brightness values were measured according to standards by Datacolor 650 spectrometer (Figure 4.2) at D65/$10^0$ lighting settings, at position of specular component included (SCI), at 400 to 700nm wavelength range, at wavelength of maximum absorbance. The measurement results were obtained by using the CIELAB formula.

Figure 4.2 Datacolor 650 spectrometer device

Reflectance spectra, whiteness indices, tristimulus values and CIELAB coordinates were recorded. These values were measured on daylight. The measurement geometry was d / 10º [51].

A color is determined by three coordinates: L*, a*, b* (Figure 4.3).

L* is the vertical coordinate (three-dimensional color system) and it has values between 0 (black) and 100 (for white);

a* is the horizontal coordinate and it has values at range between –80 (green) and +80 (red);

b* is the horizontal coordinate and it has values at range between –80 (blue) and +80 (yellow).

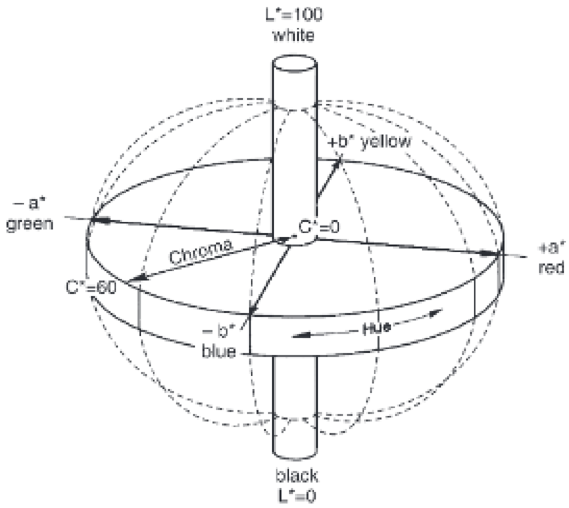



Figure 4.3 Three dimensional colour coordinate system [51].

***Lightness*** is perception by which white objects are distinguished from gray and light-colored objects from dark-colored (Figure 4.4). Colors are classified as dark or light to compare their value.

***Reflectance*** is the ratio of the intensity of reflected radiant energy to that reflected from a defined reference standard.

***Specular reflectance included (SCI)*** is the measurement of the total reflectance from a surf ace, including the specular and diffuse reflectance.

***Whiteness index assessment (W)*** is an attribute by which an object is judged to approach the preferred white. Different whiteness assessment formulations are used by Berger, Stensby and Hunter [51].

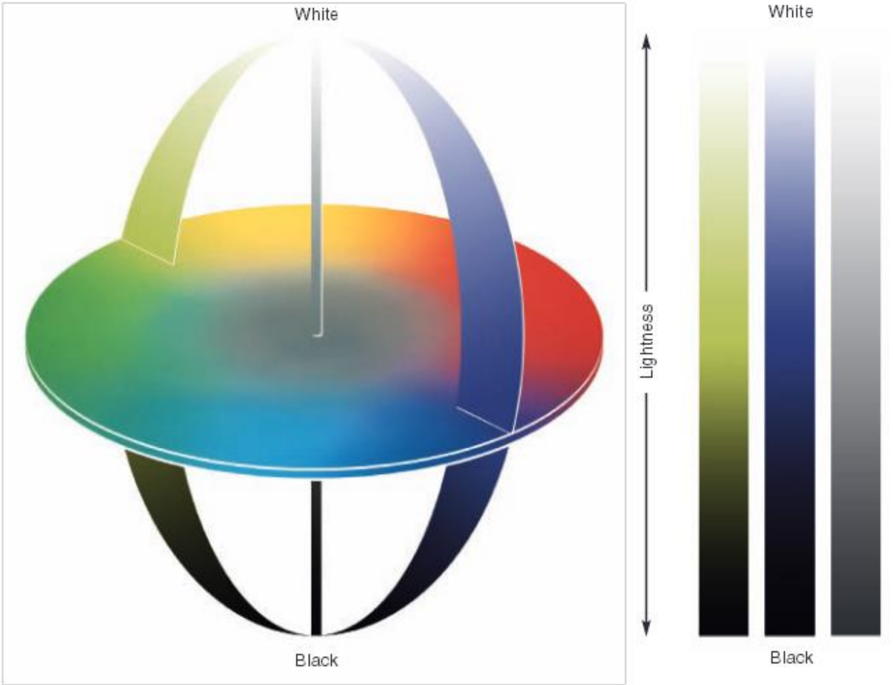



Figure 4.4 Three-dimensional color system with lightness [51]

### 4.3.2 Determination of Brightness with Image Analysis

In this method, an experimental set-up mechanism, MATLAB® program and Photoshop® CS4 histogram panel were used to obtain brightness values of samples. The flow chart of this process is shown in Figure 4.5.

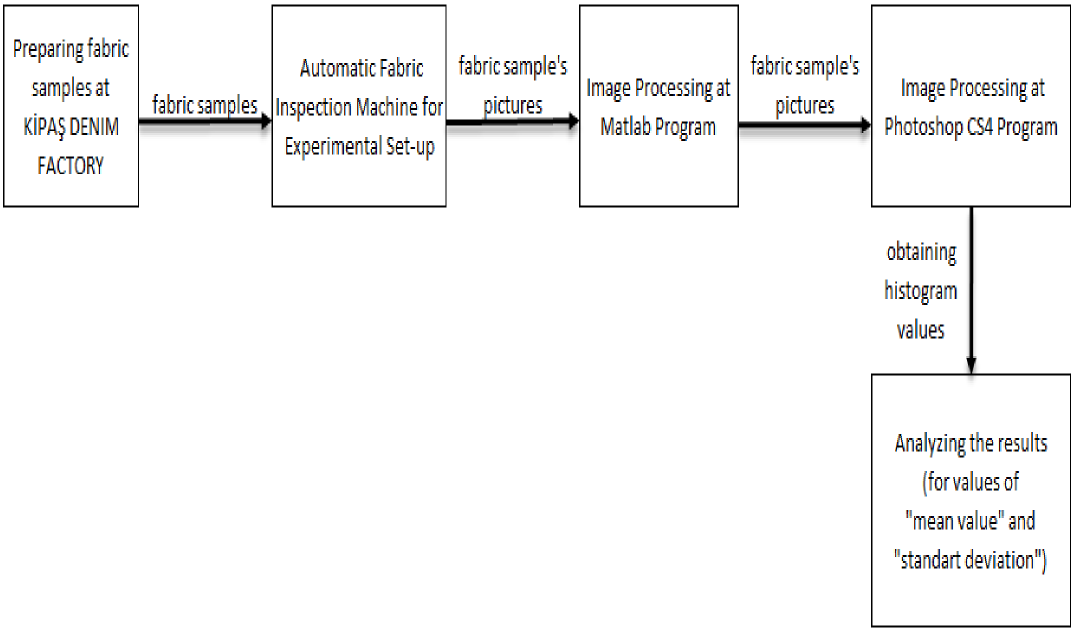
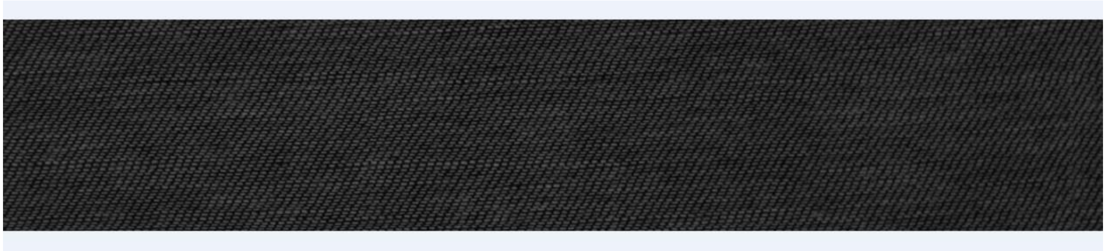
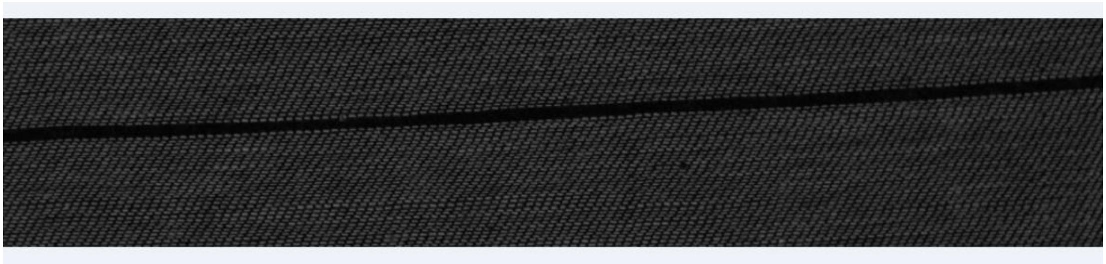



Figure 4.5 Flowchart for Method 2

A video output of the fabric samples were obtained by an experimental setup mechanism which is developed from fabric inspection machine, camera and computer. The fabric samples were wound adjacent on same fabric roll because these samples were woven in same weaving machine consecutively. The images of fabric samples were taken by a camera which is attached to experimental setup mechanism.



(a)



(b)

Figure 4.6 The photos of one sample with faultless zone (a) and faulty zone (b)

This video was converted to jpeg pictures (Figure 4.6), and then these jpeg pictures were converted to new format at two different threshold values of 0.03 and 0.04 with processing by MATLAB® program. At different fabric constructions, different threshold pictures have been obtained with processing at suitable threshold values. The pictures of faulty zone and fabric zone (faultless zones) of fabric photos were analyzed separately in MATLAB® program.

In MATLAB® program, the threshold values of the images were converted to different values which are 0.01, 0.02, 0.03, 0.04, 0.05, 0.08 and 0.10. The images of 0.03 and 0.04 threshold values were the most suitable. They were shown in Figure 4.7 and Figure 4.8. In this study, 0.04 threshold pictures were selected for Photoshop® CS4 histogram analyzes.

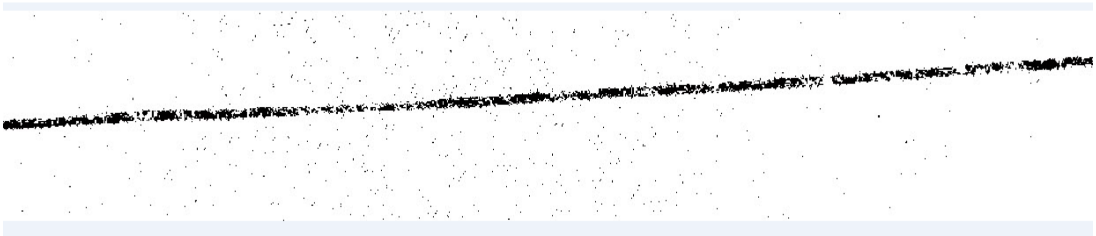


Figure 4.7 The picture of one sample converted format to 0.03 threshold at MATLAB®

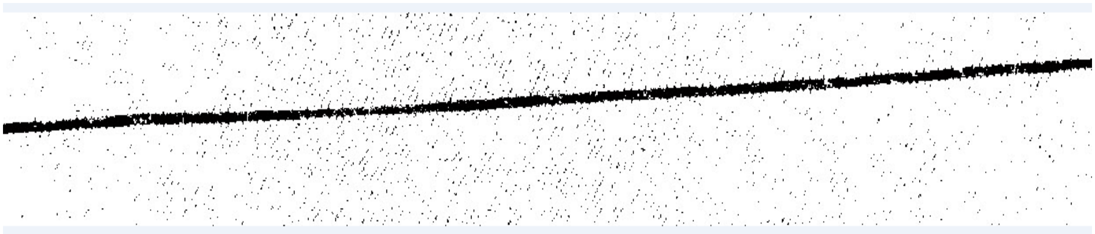


Figure 4.8 The picture of one sample converted format to 0.04 threshold at MATLAB®

And then, these MATLAB® pictures were analyzed to determine histogram values at Photoshop® CS4 histogram panel. These measurements were made separately for fabric zone (faultless zones) and faulty zones of samples similarly with MATLAB® processing. In histogram analysis, two parameters were considered “mean value” and “standard deviation values” and they were measured separately for each sample.

The images of these ten fabric samples at 0.04 threshold format are processed at Photoshop® CS4. Same size zones were processed at all fabric samples and the sizes of this zone are 718 x 64 pixels.

Firstly, the faultless zone of a fabric sample was processed as shown in Figure 4.9. Mean value and standard deviation value of faultless zone were measured as a result of this analysis and this faultless zone was showed with a selected rectangle area. Then, the mean value and standard deviation value were found from the histogram panel. The values of selected zone are;

Mean value 249.97,

Standard deviation value 32.60

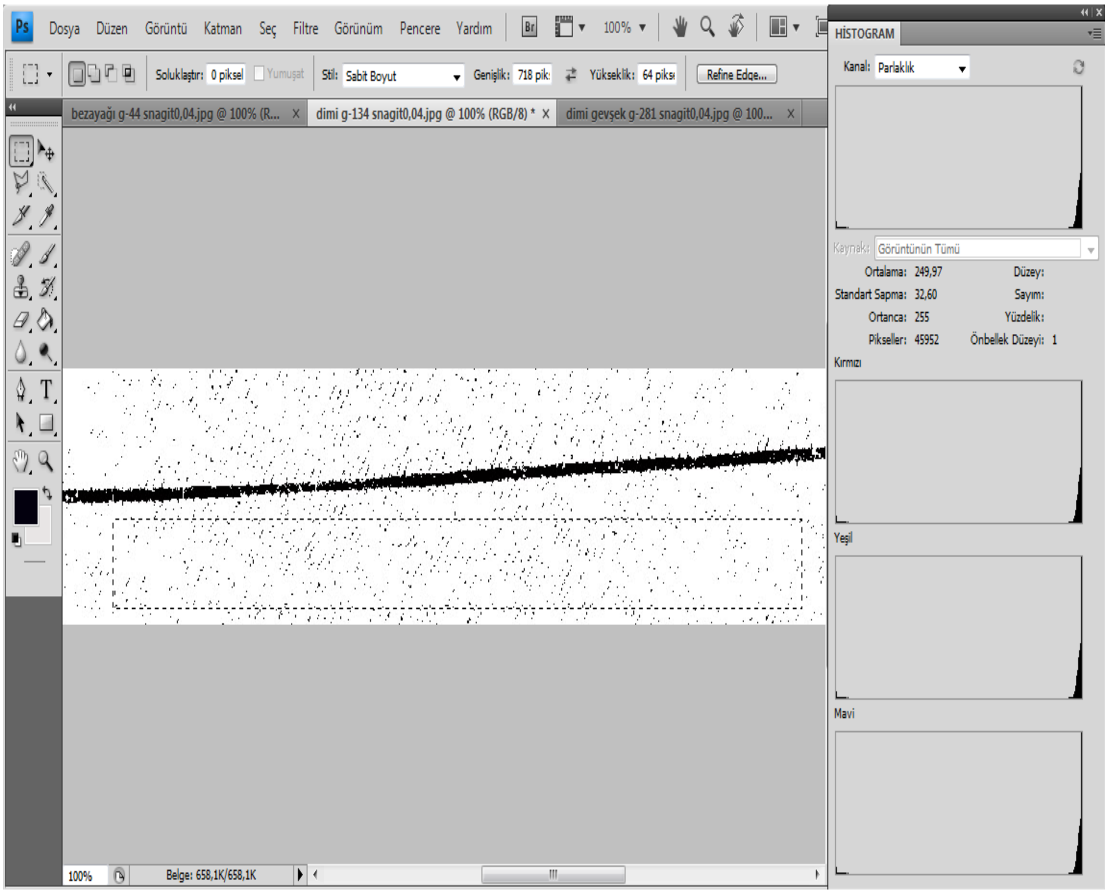



Figure 4.9 The view of processing images at Photoshop® CS4 when measuring the values of faultless zone of sample

Secondly, the faulty zones of same fabric sample were selected with a same size of rectangle zone as shown in Figure 4.10. Mean value and standard deviation values of faulty zones were found as a result of this analysis and they are;

Mean value 219.06,

Standard deviation value 87.34.

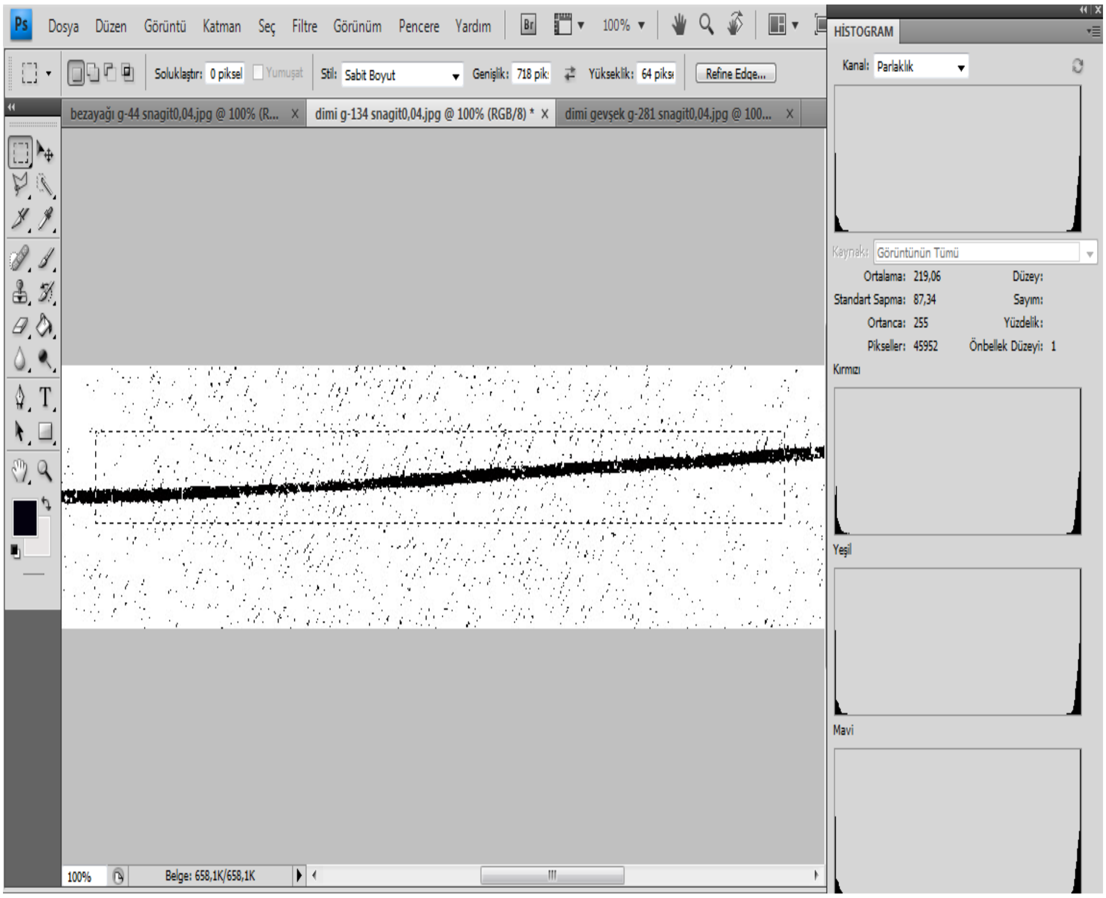



Figure 4.10 The view of processing pictures at Photoshop® CS4 when measuring the values of faulty zone of sample

#### 4.3.2.1. Experimental Set-Up

Çelik (2013) [41] studied the development of an intelligent fabric defect inspection system. At this study, an experimental set-up was built by Çelik and we have used this set-up mechanism to analyze our samples.

The experimental set-up for automatic fabric inspection consists of an industrial fabric inspection machine, a camera system, camera attachment equipment, an additional lightening unit, a rotary encoder and host computer. The camera system includes CCD line-scan camera, frame grabber card, lens and camera link cable. The connection of the equipment is made as in Figure 4.11. The fabric inspection machine adjustments are carried out using its control panel. The camera settings and the image analysis processes are performed by using computer (PC). As the fabric sample is wound from back to the front cloth roller, CCD line-scan camera captures the image frames line by line. The frame grabber transmits the digital image data to the computer. A camera attachment unit is designed to place the line-scan camera properly in front of the fabric inspection machine. The additional illumination unit is installed to provide required light intensity for high quality image frames. The rotary encoder is then used to synchronize the fabric motion and image acquisition [41].

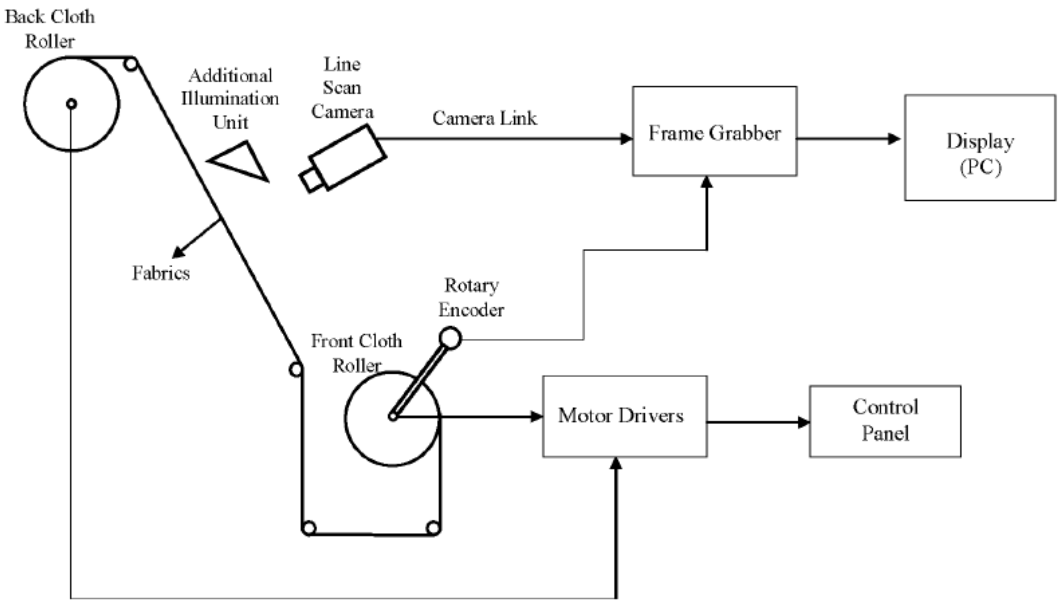



Figure 4.11 Experimental set-up architecture [41]

They are available at Gaziantep University, Textile Engineering Department Laboratory, Turkey. The automatic system is installed in the weaving laboratory. The specification and the functions of the set-up equipment are explained in the following [41].

**a. Fabric Inspection Machine**

The fabric inspection machine is a Concorde CDK2 Model made by Cihansan Company in Turkey (Figure 4.12). It is used for the fabric winding ensuring a smooth and uniform movement. The machine allows the adjustment of the fabric tension so that appropriate tension can be introduced along the fabric. The fabric winding speed and the tension of the fabric can be controlled by means of a control panel [41].

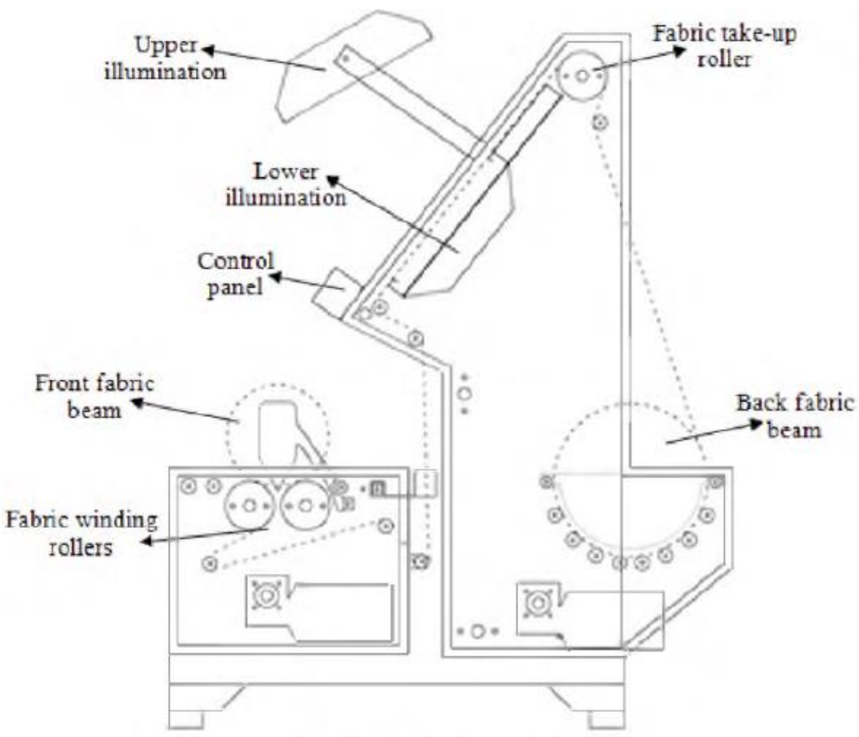



Figure 4.12 Concorde CDK2 inspection machine [41]

**b. Camera System**

The image acquisition process is achieved by using different types of devices; Flatbed scanner, slide scanner, X-ray scanner, digital camera, CCD line-scan camera, CMOS area scan camera and microscope video attachment. These devices are compared in terms of their advantages and disadvantages in the available references. The line scan camera is suitable for the inspection of continuous stream of objects, such as paper, fiber, web, plywood or iron plates [41].

**c. Rotary Encoder**

The rotary encoder is used as an external camera trigger device. The function of the encoder is to provide the synchronization between the fabric motion and the image capturing. As the motor shaft rotates, the encoder sends triggering signal to the camera via the frame grabber (Figure 4.13). Thus, the image frames are captured depending on the fabric winding speed [41].

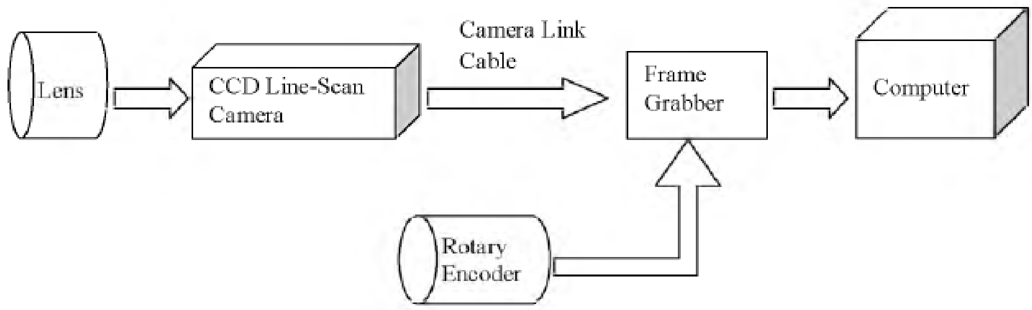



Figure 4.13 Connection of rotary encoder to camera system [41]

**4.3.2.2. MATLAB®® Program**

MATLAB®® is a program at high level language and interactive environment for visualization, programming and numerical computation. MATLAB® can develop algorithms, analyze data and create applications and models. MATLAB® program can be used for a range of signal processing, applications and communications, video and image processing, measurement and test, control systems, computational biology and computational finance. MATLAB® is used by more than a million scientists in academic and engineers in industry.

**a. Image Processing Toolbox**

Image Processing Toolbox™ supplies a comprehensive set of applications and functions for image processing, reference standard algorithms, visualization, analysis and algorithm development. You can perform image segmentation, image analysis, image registration, noise reduction, image enhancement, geometric transformations. The toolbox functions support GPUs, multicore processors, C-code generation.

**b. Analyzing images using image thresholding techniques**

Image thresholding is a simple way of partitioning an image into a background and foreground. This image analysis technique is an image segmentation type which isolates materials by converting grayscale images into binary images (white / black). Image thresholding is most effective in images with high levels of contrast. Common image thresholding algorithms include histogram and multi-level thresholding [52].

**The functions used at thresholding:**

**Reading image (imread):** A = imread (filename, fmt) reads a grayscale or color image from the file specified by the string filename.

A = imread (filename, fmt)

I = imread (filename)

**Graythresh:** The graythresh function uses Otsu's method, which chooses the threshold to minimize the intra class variance of the white and black pixels.

Level = graythresh (I)

**Converting to Binary Image (im2bw):** BW = im2bw(I, level) function converts the grayscale image to a binary image.

BW = im2bw(I, level)

#### 4.3.2.3. Photoshop®® CS4 Histogram Panel

Histogram is a simple graph of bar that shows the brightness levels range that make up an image and the prevalence of each of these shades and a graphical representation of the pixels exposed in the image. The left side of the graph shows the shadows or blacks, the right side shows the bright or highlights areas and the middle section shows middle tones (18% grey). Each tone between 0-255 (0is black and 255 is white) is one pixel wide on the graph, so imagine the histogram as a bar graph all squished together with no spaces between each bar (Figure 4.14) [53].

Statistical information about the intensity values of the pixels appears below the histogram:

- ***Mean:*** This represents the average intensity value.
- ***Standard deviation:*** This represents how widely intensity values vary.
- ***Median:*** This shows the middle value in the range of intensity values.
- ***Pixels:*** This represents the total number of pixels.
- ***Level:*** This displays the intensity level of the area underneath the pointer.

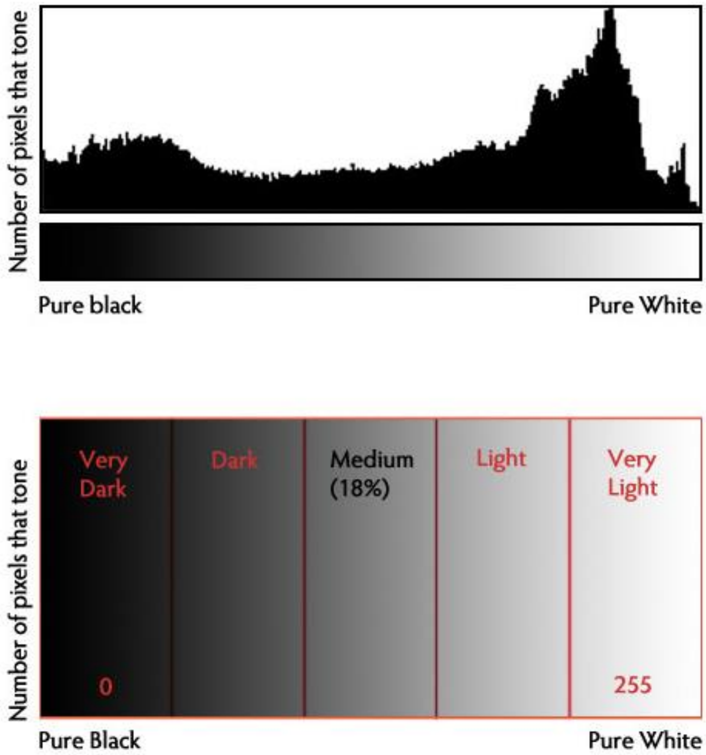



Figure 4.14 Mean value diagram for 0-255 black white tones [53]

### 4.3.3 Determination the Effect of Brightness to Fabric Defect Detection at Image Analysis

In this section, the standard deviation values that were obtained from Photoshop® histogram analysis were used to determine the effect of fabric brightness to the fabric faults detection at image analysis. The standard deviation index values were found by comparing the standard deviation values of faulty and fabric zone (faultless zones) of fabrics. By this way, comparable results were obtained about the evidence of fabric faults (detect ability of faults by image analysis) between samples.

The effect of the brightness measurement values that were obtained with two different methods were analyzed on the invisibility of fabric faults. The standard deviation values were obtained with analyzing the picture at Photoshop® CS4 histogram panel after this picture was converted to 0.04 threshold format by processing the samples in MATLAB® program. These standard deviation measurements were done separately for faulty zones and fabric zones (faultless zones) of fabrics and these values were based on a fixed area (718 pixels x 64 pixels) at every measurement.

The amount of change in the standard deviation values in fabrics will give information about the visibility of fabric fault. Thus the fabric faults at same features and same size were determined the visibility on different fabric constructions. As a result, the effect of fabric construction was determined over the image analysis at fault detections.

All samples were examined at same threshold value, and then the standard deviation values of the faultless zone of fabrics caused to differ from each other. For example, when the standard deviation value of plain weave sample is 97.17 at faultless zone, the other sample that is sateen weave sample has 14.38 standard deviation values at same threshold value. The standard deviation values of fabric zone (faultless zones) at samples should be set to same numerical value to measure correctly the visibility of fabric fault but this could not be done therefore “standard deviation index” value will be used to eliminate the effect of standard deviation values at fabric zone (faultless zones) of samples to fault detection. Standard deviation index value is a coefficient that is calculated with dividing the standard deviation value at faulty zone of sample to standard deviation value at faultless zone of same sample (Eqn 4.1).

$$SD\,index = SD_{faulty} / SD_{fabric} \qquad (4.1)$$

If a sample has high SD index value, the visibility of this sample is lower than others and in same way, if a sample has low SD index value, the visibility of this sample is higher than others. In other words, if a fabric has a high degree of brightness level, this fabric has a low level of visibility of fabric faults. For this reason, the detection faults on bright fabrics are difficult in the image analysis.

When a fabric fault is determined with image analyzing method, the effect of fabric construction is examined with using histogram standard deviation values of samples.

# CHAPTER 5
# RESULTS

## 5.1. THE EFFECT OF BRIGHTNESS TO FABRIC DEFECT DETECTING ACCORDING TO WEAVING PATTERN

### 5.1.1. Measuring of Brightness by Spectrometer for Weave Pattern Samples

The lightness values, the reflectance values and the whiteness values (calculated according to the formula Berger) were examined as the brightness values of fabrics.

At this part of the study, lightness (L), reflectance (% R) and whiteness index (Berger) values were determined. While looking up the brightness values of the fabrics, the average values of three different zones were calculated for each sample. These values are given in Table 5.1. Thus, three measurements were performed from different places for each sample. A total of nine measurements were made for three different samples. The reflectance values were measured at 620 nm wavelength because the maximum absorbance was formed at this value.

**Table 5.1** Spectrometer brightness values for weave pattern samples

| Sample Number | Weave Pattern Types | LIGHTNESS (L) | | REFLECTANCE (%R) | | WHITENESS INDEX (WI) (Berger) | | L max wavelength |
|---|---|---|---|---|---|---|---|---|
| | | FABRIC ZONE | FAULTY ZONE | FABRIC ZONE | FAULTY ZONE | FABRIC ZONE | FAULTY ZONE | |
| **1** | 1/1 Plain | 45.67 | 44.02 | 14.8 | 13.66 | 16.21 | 14.8 | 620 nm |
| **2** | 1/3 S Twill | 59.78 | 58.36 | 28.05 | 26.51 | 23.88 | 22.55 | 620 nm |
| **3** | 1/7 sateen | 64.2 | 62.48 | 33.32 | 31.15 | 27.44 | 26.08 | 620 nm |

Three fabric samples consist of weave pattern studies and the effect of weave pattern type was examined on fabric brightness. The types and codes of fabric weave samples;

Sample 1 has plain weave,
Sample 2 has twill weave,
Sample 3 has sateen weave.

Three different spectrometer parameters have been examined for each sample. These are;

- Lightness
- Reflectance (%R)
- Whiteness Index

***Lightness values of weave pattern samples:*** **L**ightness values, that were measured for faulty and fabric zone (faultless zones) of weave pattern samples, are shown in Figure 5.1.

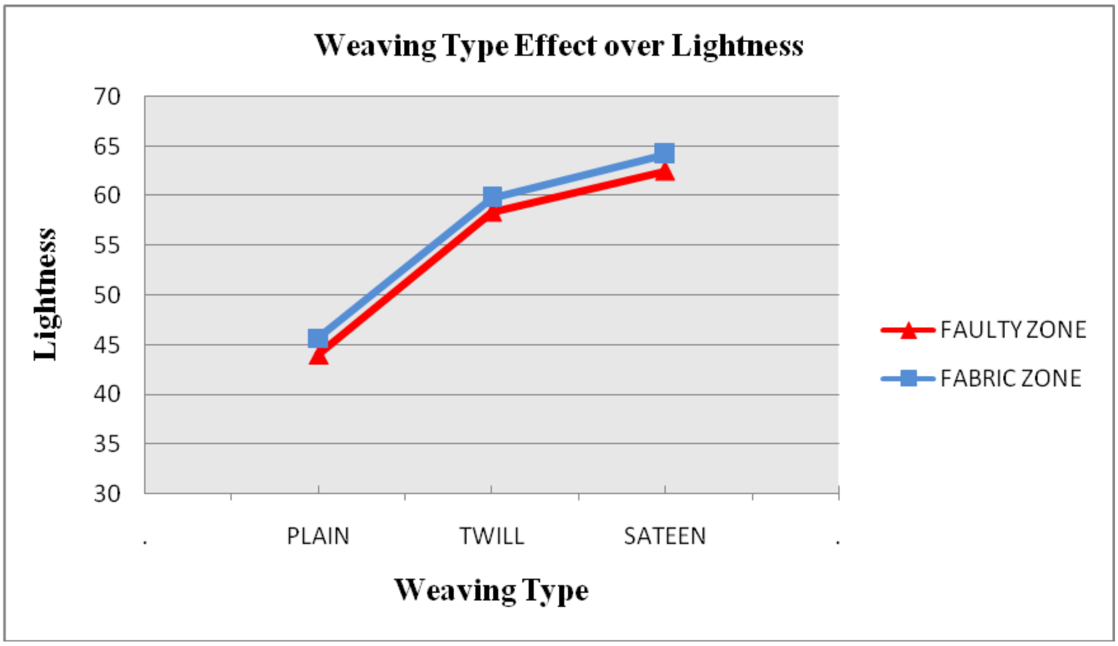



Figure 5.1 Spectrometer lightness values of weaving type samples

For fabric zones (faultless zones) of fabric samples, the smallest lightness value that is 45.67 was measured at plain weave and the biggest lightness value that is 64.2 was measured at sateen weave. The lightness value of twill weave fabric was measured 59.78 and it was found a place between plain weave and sateen weave.

For faulty zones of these fabric samples, the lightness values were measured and found in the same parallelism. The lightness values were measured 44.02 for plain weave sample, 58.36 for twill weave sample, 62.48 for sateen weave sample.

***Reflectance values of weave pattern samples:*** When the reflectance (%R) values were compared for fabric zone (faultless zones) of fabric samples, the smallest value is 14.8 that was measured at plain weave, the median value is 28.05 that was measured at twill weave, the biggest value is 33.32 that was measured at sateen weave.

For faulty zones of these fabric samples, the reflectance (%R) values were measured 13.66 at plain weave, 26.51 at twill weave and 31.15 at sateen weave. Reflectance (%R) values that were measured for faulty zones and fabric zones (faultless zones) of weave pattern samples are shown in Figure 5.2.

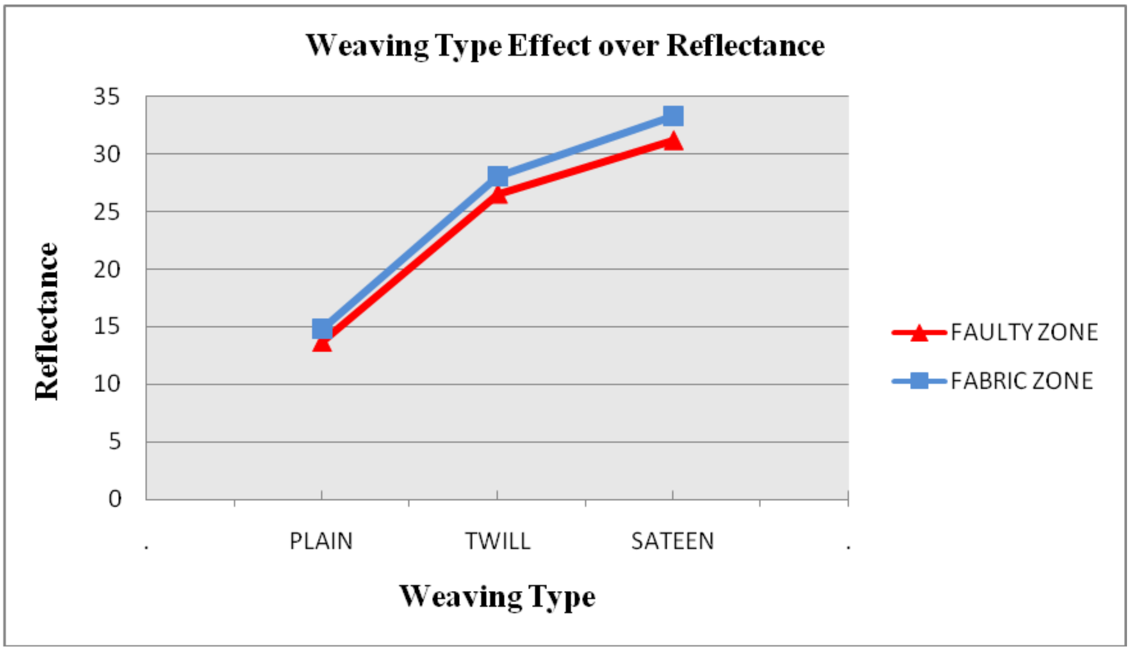



Figure5.2 Spectrometer reflectance values of weaving type samples

***Whiteness index values of weave pattern samples:*** When whiteness index values were examined for fabric zone (faultless zones) of fabrics, the values were seen as similar parallelism with other parameters. Whiteness index at plain weave were measured 16.21 that is smallest value, 23.88 at twill weave and 27.44 at sateen weave.

For faulty zones of these fabric samples, the whiteness index values were measured 14.8 at plain weave, 22.55 at twill weave and 26.08 at sateen weave.

Whiteness index values, that were measured for faulty and fabric zone (faultless zones) of weave pattern samples, are given in Figure 5.3.


Figure 5.3 Spectrometer whiteness index values of weaving type samples

As a result;

The brightness degrees are directly related to fabric weave pattern. The brightness values that are lightness, reflectance and whiteness index are taken the smallest values at plain weave, medium values at twill weave and biggest values at sateen weave.

### 5.1.2. Measuring of Brightness by Image Analysis for Weave Pattern Samples

The histogram values of these three different weave pattern samples were measured at Photoshop® CS4 and the mean values are given in Table 5.2.

As seen in Table 5.2, if the mean values of three different fabric pattern samples were examined at 0.04 threshold value, the spectrometer values and these mean values were measured at same parallelism. In this context mean values can be given an idea for fabric brightness.

**Table 5.2** The mean values of weave pattern samples measured at Photoshop® CS4

| Sample Number | Weave Pattern Types | MEAN VALUE (0.04 Threshold Value) | |
|---|---|---|---|
| | | FABRIC ZONE | FAULTY ZONE |
| **1** | 1/1 Plain | 207.86 | 172.1 |
| **2** | 1/3 S Twill | 250.04 | 219.26 |
| **3** | 1/7 sateen | 253.99 | 228.41 |

Among three different weave pattern samples, the mean value of sateen weave sample has the highest value and the mean value of plain weave sample has the lowest value. The same rank was seen at the mean values that were measured on faulty zones. The brightness degree of fabric weave samples is arranged from the highest to the lowest as sateen, twill and plain samples (Figure 5.4).

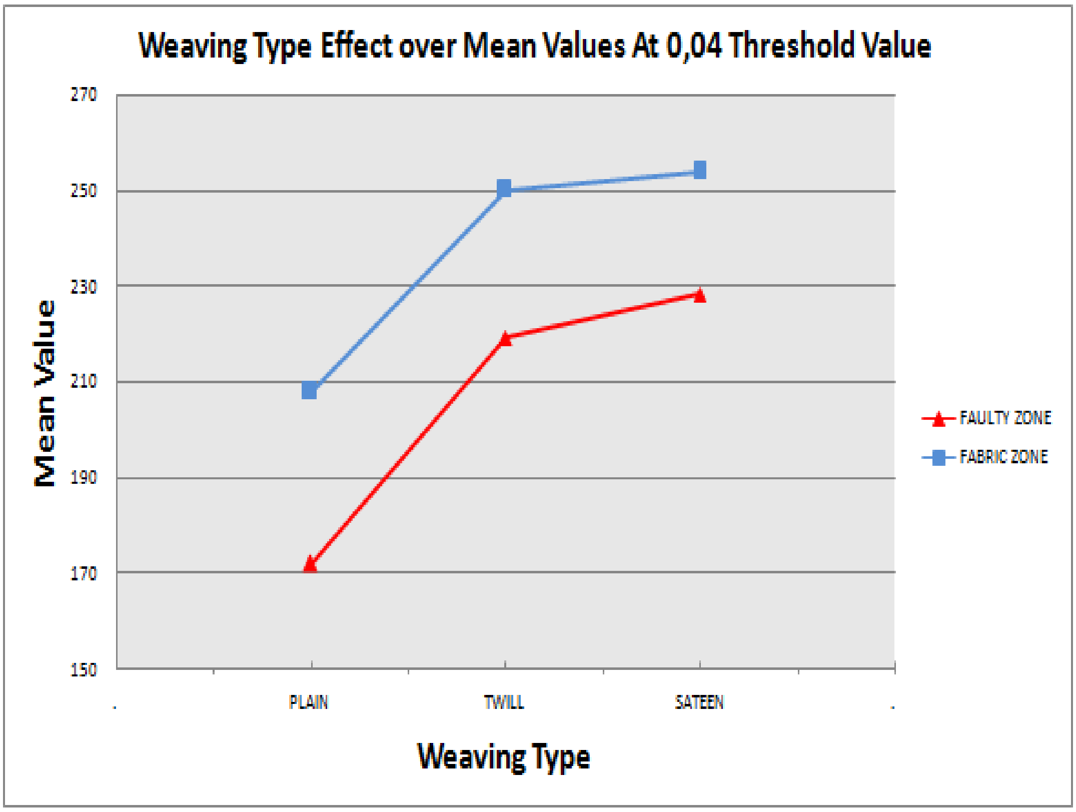



Figure 5.4 Mean values of weaving type samples

### 5.1.3. Determination of the Effect of Brightness to Fabric Defect Detection at Image Analysis for Weave Pattern Samples

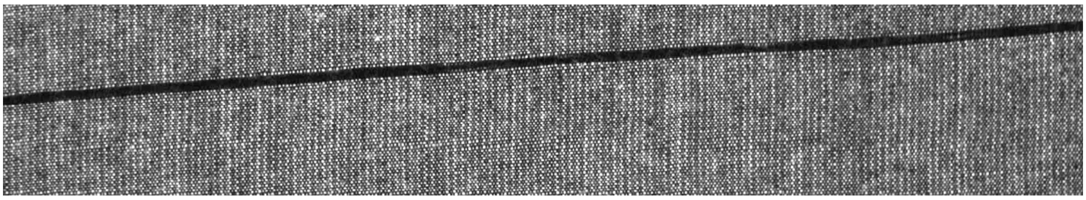
In histogram analysis, how to finding the standard deviation values of sample pictures was described at mean value analyzing section. These standard deviation values were measured simultaneously at histogram analysis of Photoshop® CS4 program when analyzing the mean values. Therefore, the standard deviation values were measured firstly for fabric zone (faultless zones) then faulty zones of samples.

Standard deviation values and SD index values that were measured at histogram panel were listed in Table 5.3.

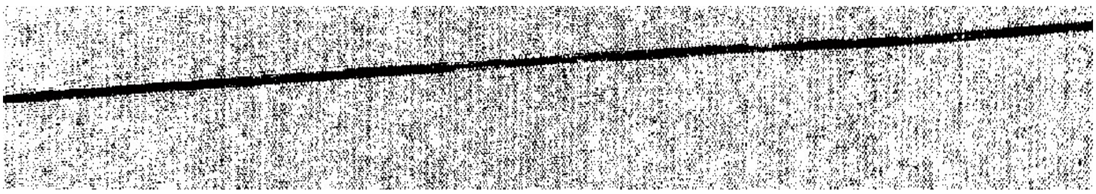
**Table 5.3** Standard deviation values and SD index values of samples

| Sample Number | Weave Pattern Types | STANDARD DEVIATION VALUES | | SD INDEX ($SD_{faulty}$ / $SD_{fabric}$) |
|---|---|---|---|---|
| | | FABRIC ZONE | FAULTY ZONE | |
| **1** | 1/1 Plain | 97.17 | 117.92 | 1.21 |
| **2** | 1/3 S Twill | 32.43 | 87.11 | 2.69 |
| **3** | 1/7 sateen | 14.38 | 76.94 | 5.35 |

The photos of three different weave pattern samples (plain, twill and sateen weaves) (Figures 5.5.a, 5.6.a and 5.7.a) and the sample pictures that are converted to 0.04 threshold form at MATLAB® program are shown in Figures 5.5.b, 5.6.b and 5.7.b.

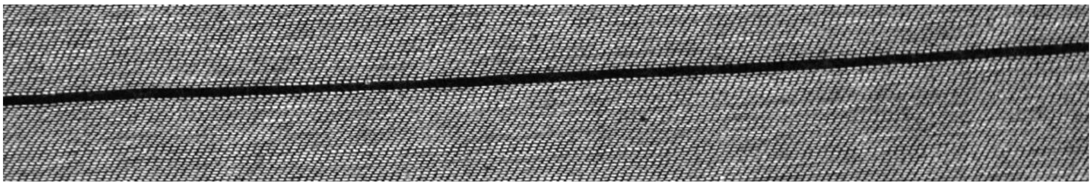


(a)

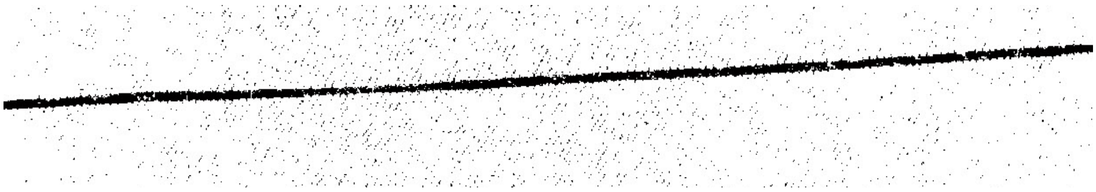


(b)

Figure 5.5 The picture of plain weave sample (a) and 0.04 threshold picture of same photo (b)

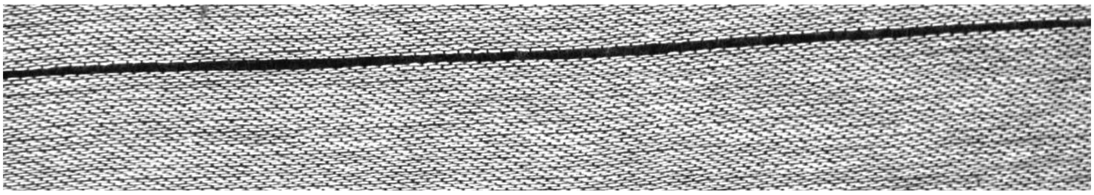


(a)

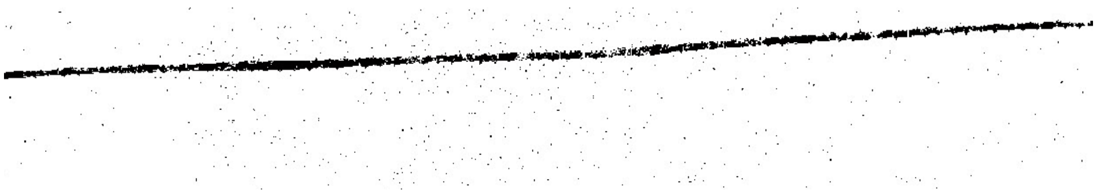


(b)

Figure5.6 The picture of twill weave sample (a) and 0.04 threshold picture of same photo (b)



(a)



(b)

Figure 5.7 The picture of sateen weave sample (a) and 0.04 threshold picture of same photo (b)

For these three different weave pattern samples, the standard deviation index values were determined as;

Plain weave sample SD index value is 1.21,
Twill weave sample SD index value is 2.69,
Sateen weave sample SD index value is 5.35.

If these results are analyzed, minimum value is seen at plain weave sample and this minimum value says that the mispick fault at this fabric is more visible and clearer to identify at image analyzing. Similarly, maximum value is 5.35 and it was measured at sateen weave sample, therefore the visibility of fault is lower than other samples for sateen weaves.

The rank of fabric brightness from the highest to the lowest; sateen, twill and plain weaves. The rank of fabric fault visibility from the highest to the lowest; sateen, twill and plain weaves.

## 5.2. THE EFFECT OF BRIGHTNESS TO FABRIC DEFECT DETECTING ACCORDING TO WEFT SETT

### 5.2.1. Measuring of Brightness by Spectrometer for Weft Sett Samples

The weft densities of fabrics were changed at subsequent samples that have sample 4, sample 5 and sample 6, the all other properties of fabrics were remained as constant. In this way, it was investigated the effect of the brightness to the weft sett. In these samples, three different fabrics were weaved at different weft setts that are 17 weft/cm, 22 weft/cm and 27 weft/cm. If a fabric has a high weft sett, this fabric must have a high weft sett. As seen in the measured value, the brightness values (lightness, reflectance and whiteness index values) were measured high at fabrics having high weft sett value.

The types and codes of fabric weave samples;

Sample 4 was woven at 17 weft/cm,
Sample 5 was woven at 22 weft/cm,
Sample 6 was woven at 27 weft/cm

Lightness, reflectance and whiteness index measurements of weft sett samples were performed for faulty and faultless zones and the results are given in Table 5.4.

**Table 5.2** Spectrometer brightness values for weft sett samples

| Sample Number | Weft Sett Numbers | LIGHTNESS (L) | | REFLECTANCE (%R) | | WHITENESS INDEX (WI) (Berger) | | L max wavelength |
|---|---|---|---|---|---|---|---|---|
| | | Fabric Zone | Faulty Zone | Fabric Zone | Faulty Zone | Fabric Zone | Faulty Zone | |
| **4** | 17 weft/cm | 54.98 | 53.52 | 23.01 | 21.6 | 20.38 | 19.24 | 620 nm |
| **5** | 22 weft/cm | 59.78 | 58.36 | 28.05 | 26.51 | 23.88 | 22.55 | 620 nm |
| **6** | 27 weft/cm | 63.77 | 62.88 | 32.69 | 31.68 | 27.64 | 26.28 | 620 nm |

***Lightness values of weft sett samples:*** The lightness values for fabric zone (faultless zones) of fabrics were measured as 54.98 for sample 4, 59.78 for sample 5 and 63.77 for sample 6. The lightness values for faulty zones of fabrics were measured as 53.52 for sample 4, 58.36 for sample 5 and 62.88 for sample 6. The graphic of lightness values, that were measured for faulty and fabric zone (faultless zones) of weft sett samples, is shown in Figure 5.8.

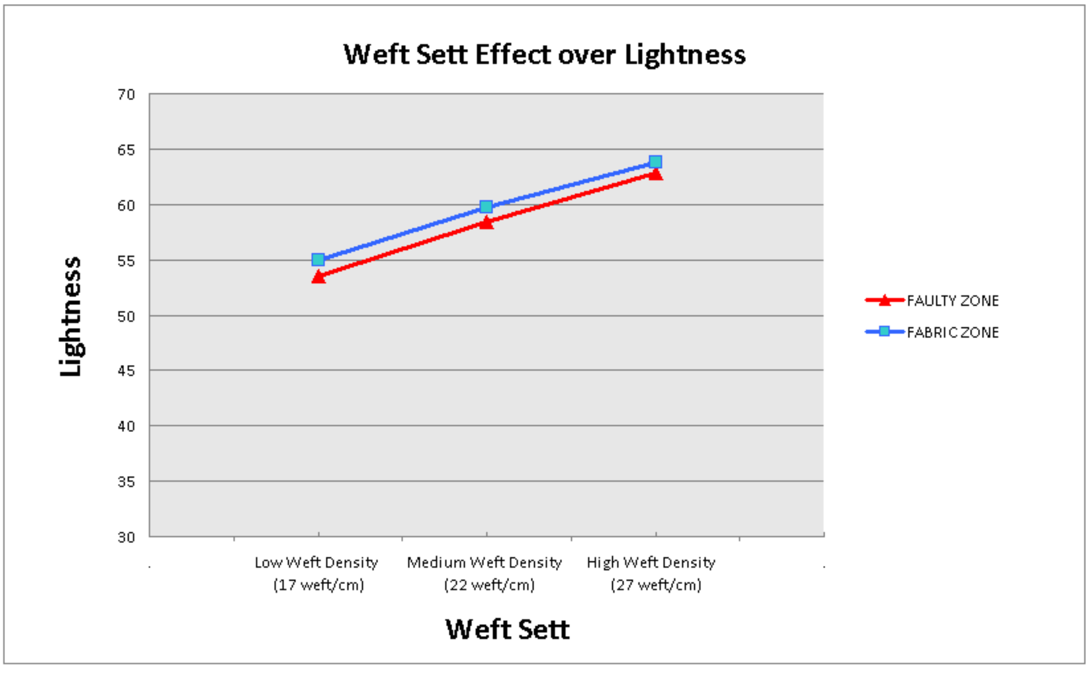



Figure 5.8 Spectrometer lightness values of weft sett samples

***Reflectance values of weft sett samples:*** The reflectance (%R) values for fabric zone (faultless zones) of fabrics were measured as 23.01 for sample 4, 28.05 for sample 5 and 32.69 for sample 6. The reflectance (%R) values for faulty zones of fabrics were measured as 21.60 for sample 4, 26.51 for sample 5 and 31.68 for sample 6.

The graphic of reflectance (%R) values, that were measured for faulty and fabric zone (faultless zones) of weft sett samples, is shown in Figure 5.9.

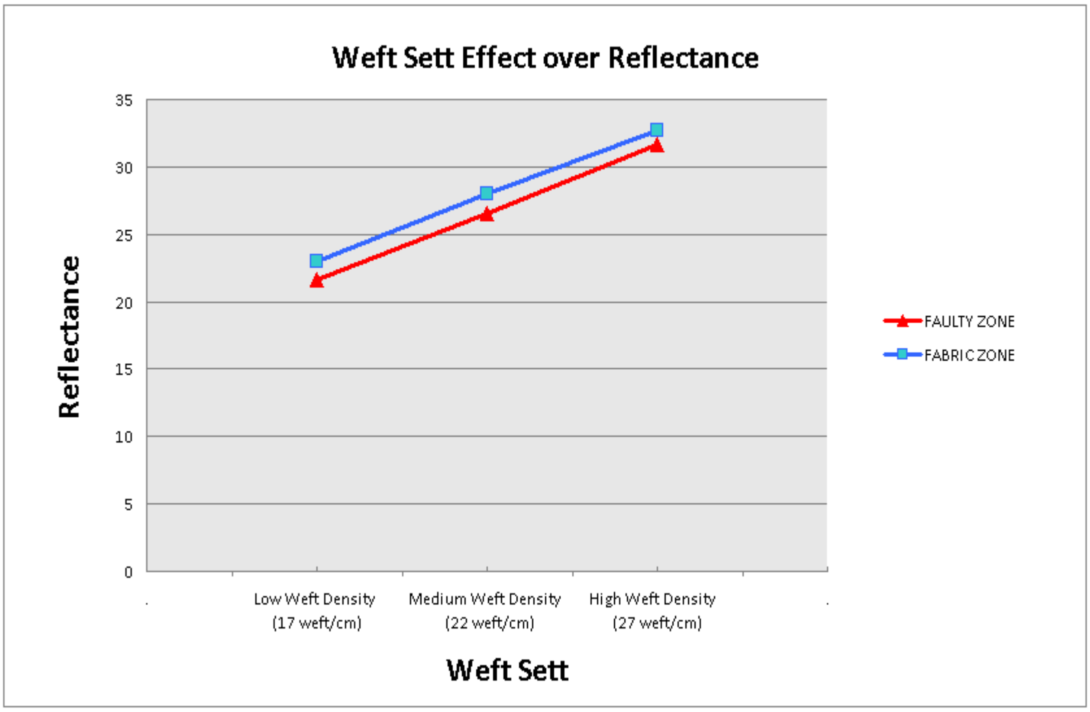



Figure 5.9 Spectrometer reflectance values of weft sett samples

***Whiteness index values of weft sett samples:*** The whiteness index values for fabric zone (faultless zones) of fabrics were measured as 20.38 for sample 4, 23.88 for sample 5 and 27.64 for sample 6. The whiteness index values for faulty zones of fabrics were measured as 19.24 for sample 4, 22.55 for sample 5 and 26.28 for sample 6.

The graphic of whiteness index values, that were measured for faulty and fabric zone (faultless zones) of weft sett samples, is shown in Figure 5.10.

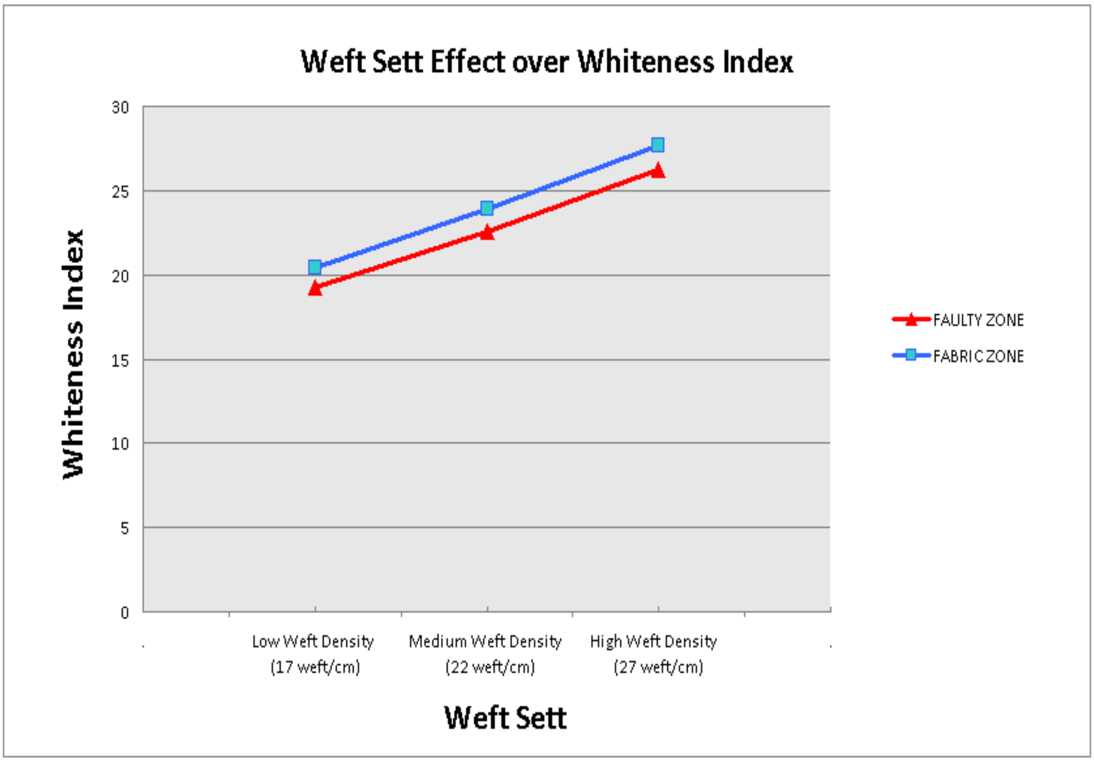



Figure 5.10 Spectrometer whiteness index values of weft sett samples

As a result;

The brightness degrees are directly related to fabric weft sett. The brightness values are taken the smallest values at low weft sett sample (17 weft/cm), medium values at medium weft sett sample (22 weft/cm), and biggest values at high weft sett sample (27 weft/cm).

### 5.2.2. Measuring of Brightness by Image Analysis for Weft Sett Samples

Among three different weft sett samples, the fabric sample that has the highest weft sett takes the highest mean value and the other fabric sample that has the lowest weft sett takes the lowest mean value. The measuring results are given in Table 5.5.

**Table 5.5** The mean values of weft sett samples measured at Photoshop® CS4

| Sample Number | Weft Sett Numbers | MEAN VALUE (0.04 Threshold Value) | |
|---|---|---|---|
| | | FABRIC ZONE | FAULTY ZONE |
| 4 | 17weft/cm | 237.8 | 192.27 |
| 5 | 22 weft/cm | 250.04 | 219.26 |
| 6 | 27 weft/cm | 254.47 | 235.69 |

The same rank was seen at the mean values that were measured on faulty zones. The brightness degree of weft sett samples is arranged from the highest to the lowest as 27 weft/cm, 22 weft/cm and 17 weft/cm samples. The brightness values of fabrics are increasing with rising weft sett (Figure 5.11).

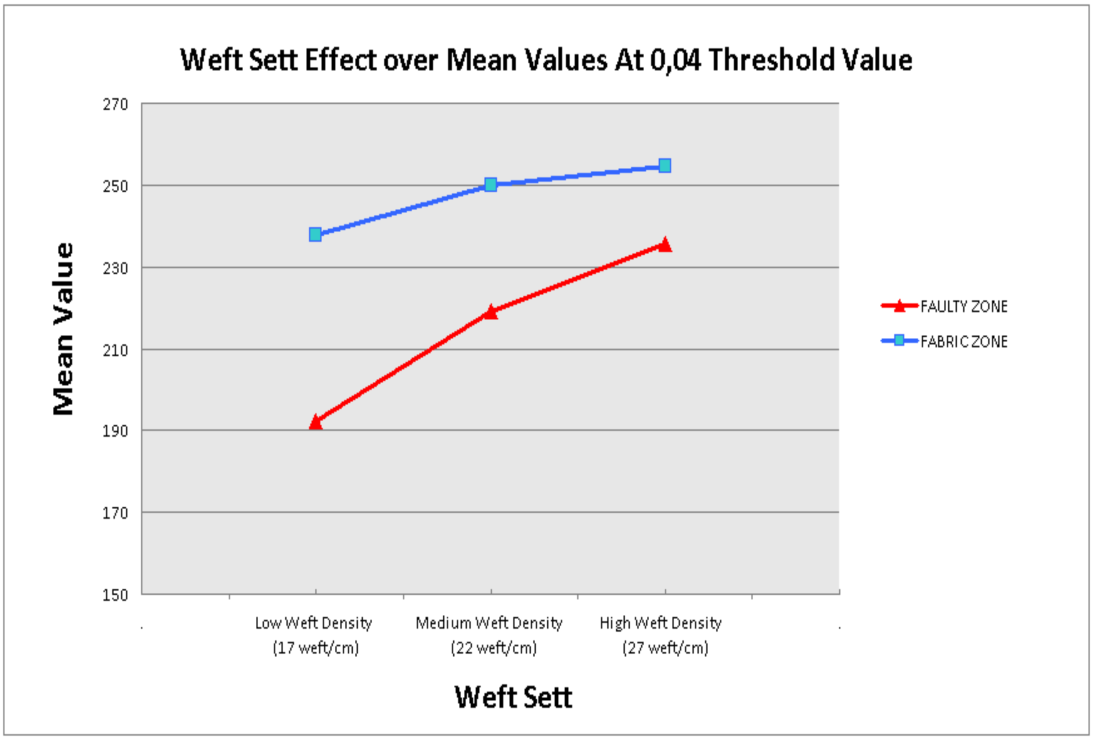
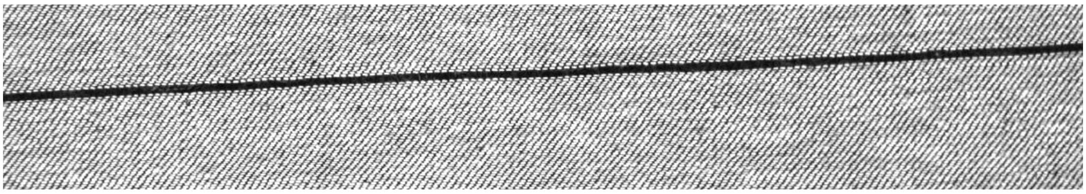


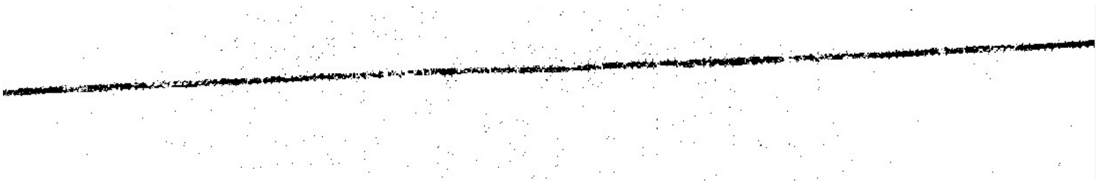

Figure 5.11 Mean values of weft sett samples

### 5.2.3. Determination the Effect of Brightness to Fabric Defect Detection at Image Analysis for Weft Sett Samples

The photos of three different weft sett samples that are 17 weft/cm, 22 weft/cm and 27 weft/cm (Figures 5.12.a, 5.13.a and 5.14.a). The sample pictures that are converted to 0.04 threshold forms at MATLAB® program are shown in Figures 5.12.b, 5.13.b and 5.14.b.

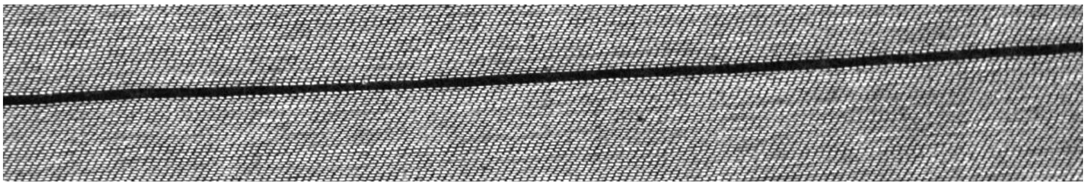


(a)



(b)

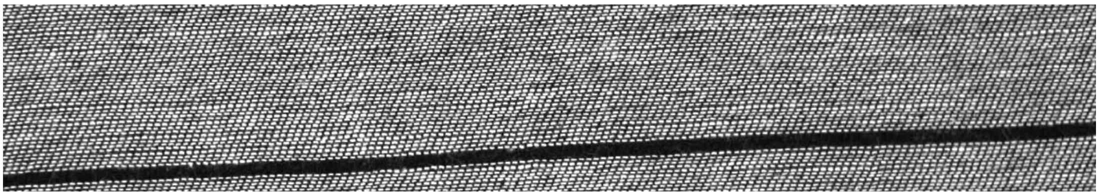
Figure 5.12 The picture of 17 weft/cm weft sett sample (a) and 0.04 threshold picture of same photo (b)



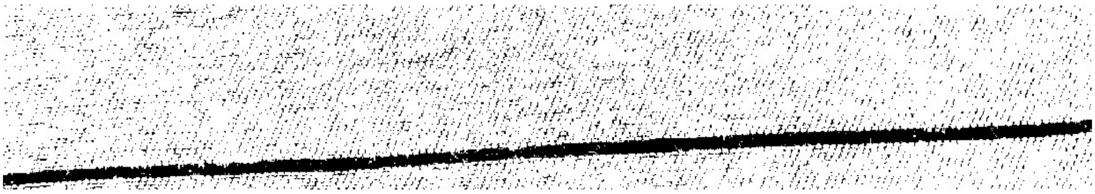
(a)

(b)

Figure 5.13 The picture of 22 weft/cm weft sett sample (a) and 0.04 threshold picture of same photo (b)



(a)



(b)

Figure 5.14 The picture of 27 weft/cm weft sett sample (a) and 0.04 threshold picture of same photo (b)

For these three different weft sett samples, the standard deviation index values were determined as;

SD index value of 17 weft/cm weft sett sample is 1.76,
SD index value of 22 weft/cm weft sett sample is 2.69,
SD index value of 27 weft/cm weft sett sample is 6.51.

Standard deviation values and SD index values that are measured at histogram panel were listed in Table 5.6.

**Table 5.6** Standard deviation values and SD index values of weft sett samples

| Sample Number | Weft Sett Numbers | STANDARD DEVIATION VALUES | | SD INDEX ($SD_{faulty}$ / $SD_{fabric}$) |
|---|---|---|---|---|
| | | FABRIC ZONE | FAULTY ZONE | |
| 4 | 17weft/cm | 61.53 | 108.36 | 1.76 |
| 5 | 22weft/cm | 32.43 | 87.11 | 2.69 |
| 6 | 27weft/cm | 10.24 | 66.62 | 6.51 |

If these results are analyzed, the minimum value is seen at 17 weft/cm weft sett sample and this minimum value says that the mispick fault at this fabric is more visible and clearer to identify at image analyzing.

The rank of fabric brightness from the highest to the lowest is 27 weft/cm weft sett samples, 22 weft/cm weft sett samples and 17 weft/cm weft sett samples. The rank of fabric fault visibility from the highest to the lowest is 27 weft/cm weft sett samples, 22 weft/cm weft sett samples and 17 weft/cm weft sett samples.

## 5.3. THE EFFECT OF BRIGHTNESS TO FABRIC DEFECT DETECTING ACCORDING TO FIBER TYPE

### 5.3.1. Measuring of Brightness by Spectrometer for Fiber Type Samples

In this last sample group that have four different fabrics, the effect of weft fiber type was examined on fabric brightness by changing only fiber types of weft yarns at same yarn counts. The fibers used at weft yarn are cotton, poliester, linen and lyocell. If the brightness values are compared, the brightness values of woven fabric with poliester were seen higher than the other fabrics that were woven by cotton, linen and lyocell fibers. The fabric woven by cotton weft yarn follows to the fabric woven by poliester weft yarn. The brightness values of linen and lyocell samples were very near to each other and their values were smaller than cotton and poliester samples. These results show us the effect of fiber type to fabric brightness.

The types of fiber type samples;

Sample 7 was woven by cotton weft yarn,
Sample 8 was woven by linen weft yarn,
Sample 9 was woven by poliester weft yarn,
Sample 10 was woven by lyocell weft yarn.

The measurements of lightness, reflectance and whiteness index values were performed at faulty and fabric zone (faultless zones) of these samples that were woven with different fiber weft yarns and the results are given in Table 5.7.

**Table 5.7** Spectrometer brightness values for fiber type samples

| Sample Number | Fiber Types | LIGHTNESS (L) | | REFLECTANCE (%R) | | WHITENESS INDEX (WI) (Berger) | | L max wavelength |
|---|---|---|---|---|---|---|---|---|
| | | FABRIC ZONE | FAULTY ZONE | FABRIC ZONE | FAULTY ZONE | FABRIC ZONE | FAULTY ZONE | |
| **7** | %100 Cotton | 59.78 | 58.36 | 28.05 | 26.51 | 23.88 | 22.55 | 620 nm |
| **8** | %100 Linen | 54.86 | 53.37 | 22.61 | 21.16 | 22.46 | 21.48 | 620 nm |
| **9** | %100 Poliester | 62.91 | 61.44 | 30.6 | 28.87 | 37.02 | 35.34 | 620 nm |
| **10** | %100 Lyocell | 55.98 | 53.8 | 23.78 | 21.62 | 23.56 | 22.08 | 620 nm |

***Lightness values of fiber type samples:*** The graphic of lightness values, that were measured for faulty and fabric zone (faultless zones) of different weft fiber samples, is shown in Figure 5.15.

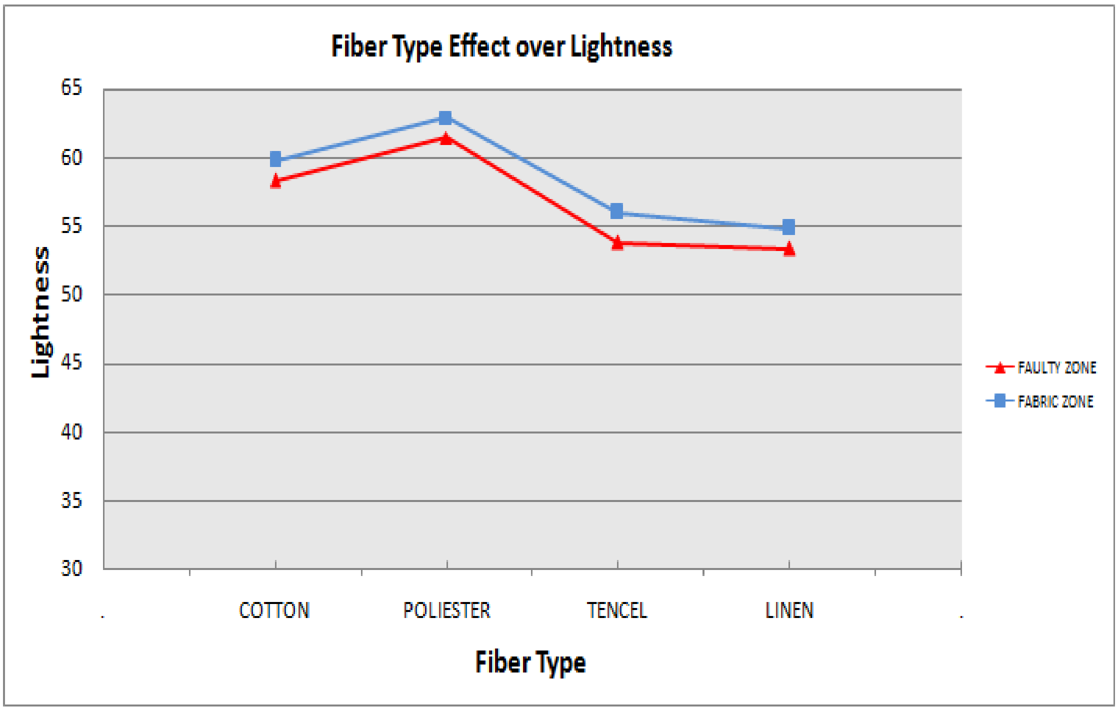



Figure 5.15 Spectrometer lightness values of fiber type samples

The lightness values for fabric zone (faultless zones) of fabrics were measured as 59.78 for sample 7, 54.86 for sample 8, 62.91 for sample 9 and 55.98 for sample 10.

The lightness values for faulty zones of fabrics were measured as 58.36 for sample 7, 53.37 for sample 8, 61.44 for sample 9 and 53.80 for sample 10.

***Reflectance values of fiber type samples:*** The reflectance (%R) values for fabric zone (faultless zones) of fabrics were measured as 28.05 for sample 7, 22.61 for sample 8, 30.60 for sample 9 and 23.78 for sample 10.

The reflectance (%R) values for faulty zones of fabrics were measured as 26.51 for sample 7, 21.16 for sample 8, 28.87 for sample 9 and 21.62 for sample 10. The graphic of reflectance (%R) values, that were measured for faulty and fabric zone (faultless zones) of different weft fiber samples, is shown in Figure 5.16

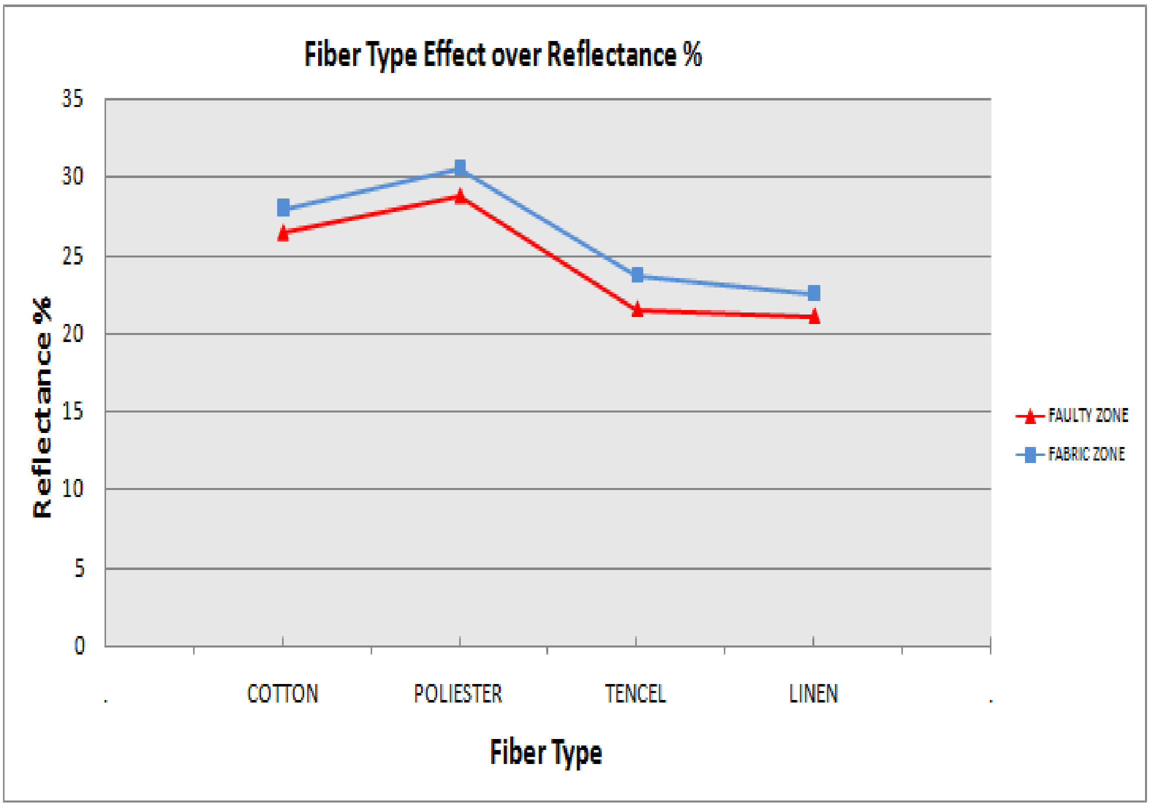



Figure 5.16 Spectrometer reflectance values of fiber type samples

***Whiteness index values of fiber type samples:*** The whiteness index values for fabric zone (faultless zones) of fabrics were measured as 23.88 for sample 7, 22.46 for sample 8, 37.02 for sample 9 and 23.56 for sample 10.

The whiteness index values for faulty zones of fabrics were measured as 22.55 for sample 7, 21.48 for sample 8, 35.34 for sample 9 and 22.08 for sample 10. The graphic of whiteness index values, that were measured for faulty and fabric zone (faultless zones) of different weft fiber samples, is shown in Figure 5.17.

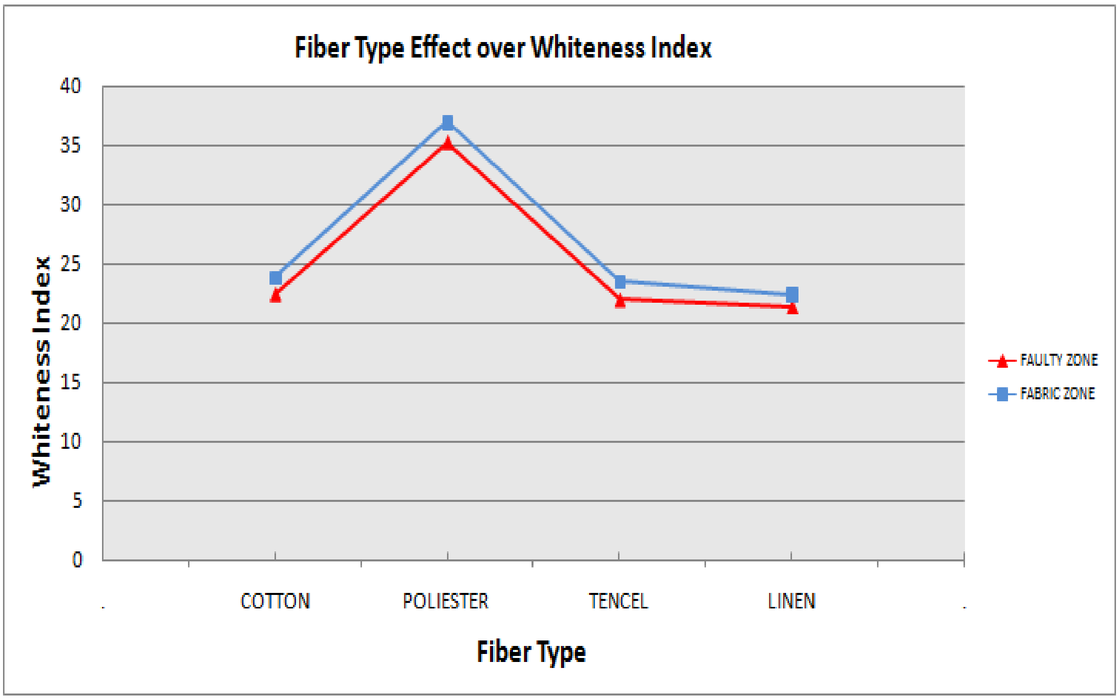



Figure 5.17 Spectrometer whiteness index values of fiber type samples

As a result;

The brightness degrees are directly related to fiber types. The brightness values were obtained as the smallest for linen fiber sample, the values of cotton and lyocell samples were similar to each other. They have medium brightness values and the biggest values at poliester sample.

### 5.3.2. Measuring of Brightness by Image Analysis for Fiber Type Samples

Among four different weft fiber type samples, poliester fiber type sample takes the highest mean value and linen fiber type sample takes the lowest mean value. The measuring results are given in Table 5.8.

**Table 5.8** The mean values of fiber type samples measured at Photoshop® CS4

| Sample Number | Fiber Types | MEAN VALUE (0.04 Threshold Value) | |
|---|---|---|---|
| | | FABRIC ZONE | FAULTY ZONE |
| 7 | %100 Ring Carded | 250.04 | 219.26 |
| 8 | %100 Linen | 228.25 | 196.88 |
| 9 | %100 Poliester | 255.45 | 223.66 |
| 10 | %100 Lyocell Ring | 239.64 | 208.23 |

The same rank was seen at the mean values that were measured on faulty zones. The brightness degree of fiber type samples is arranged from the highest to the lowest as poliester, cotton, lyocell and linen samples (Figure 5.18).

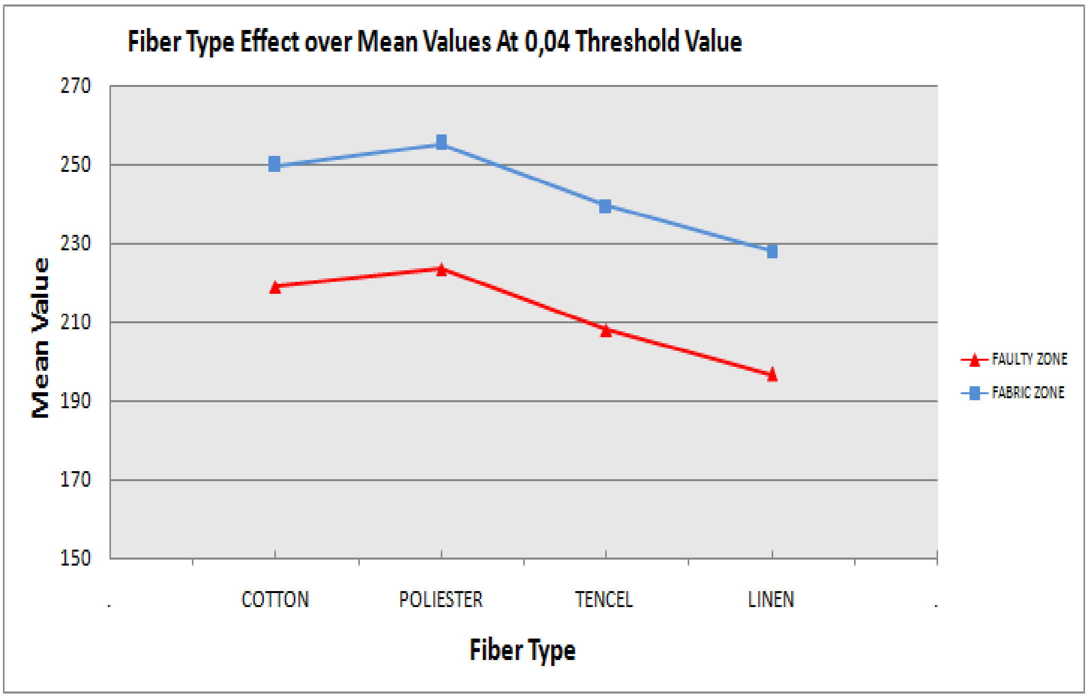
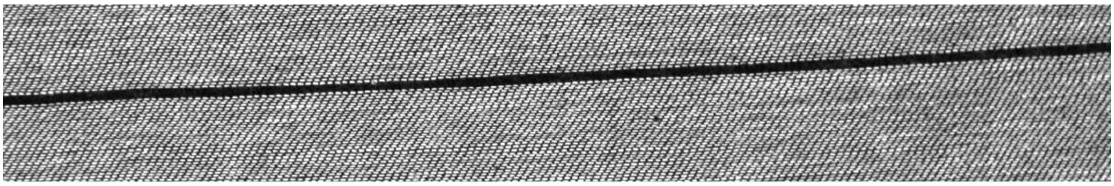


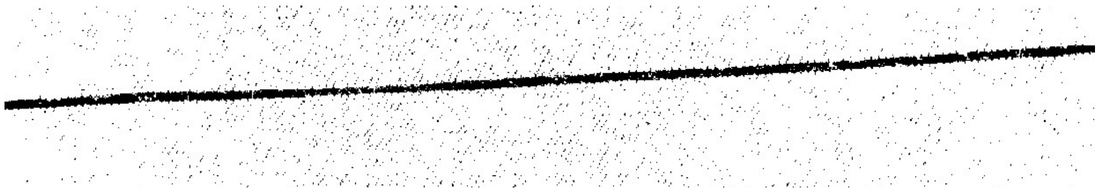

Figure 5.18 Mean values of fiber type samples

### 5.3.3. Determination the Effect of Brightness to Fabric Defect Detection at Image Analysis for Fiber Type Samples

The photos of four different samples that are weaved with four different weft yarns (cotton, poliester, lyocell and linen). The sample pictures that are converted to 0.04 threshold formed by MATLAB® program are shown in below.

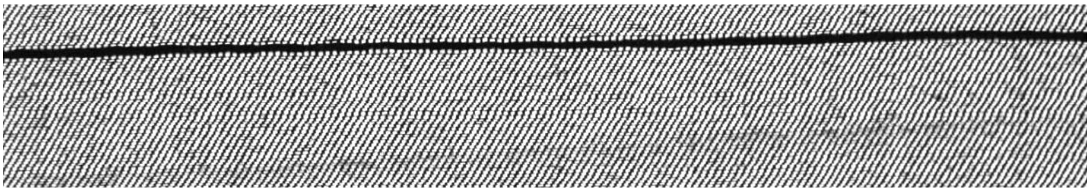


(a)

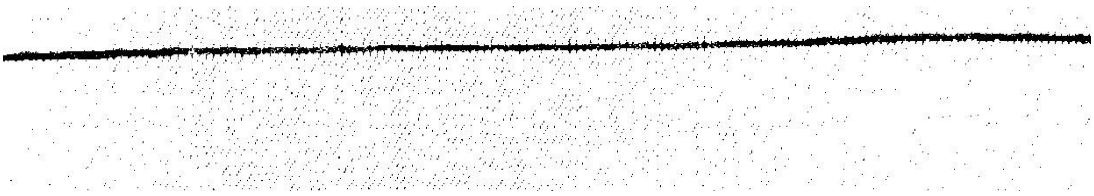


(b)

Figure 5.19 The picture of sample that is weaved cotton weft yarn (a) and 0.04 threshold picture of same photo (b)

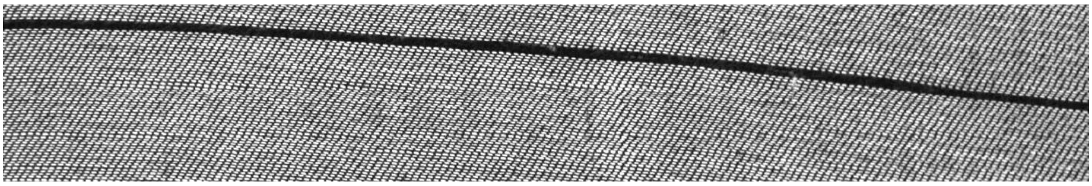


(a)

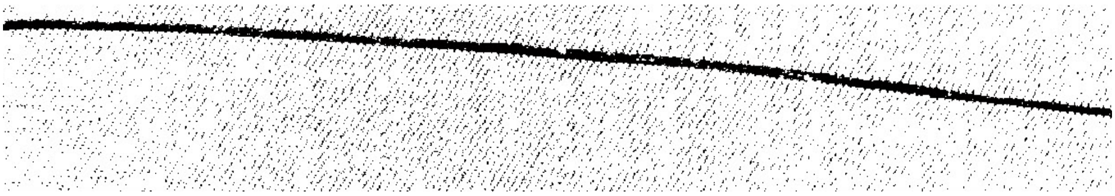


(b)

Figure 5.20 The picture of sample that is weaved poliester weft yarn (a) and 0.04 threshold picture of same photo (b)

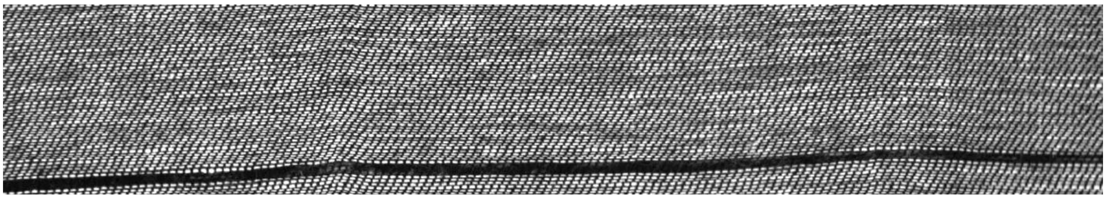


(a)

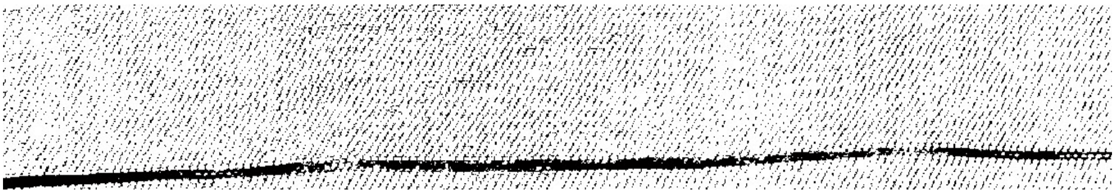


(b)

Figure 5.21 The picture of sample that is weaved lyocell weft (a) and 0.04 threshold picture of same photo (b)



(a)



(b)

Figure 5.22 The picture of sample that is weaved linen weft (a) and 0.04 threshold picture of same photo (b)

The standard deviation index values were determined for four different weft fiber type samples as;

SD index value of cotton weft yarn sample is 2.69,

SD index value of linen weft yarn sample is 1.39,

SD index value of poliester weft yarn sample is 2.72,

SD index value of lyocell weft yarn sample is 1.67.

If these results are analyzed, the minimum value is seen at linen weft yarn sample and this minimum value says that the mispick fault at this fabric is more visible and clearer to identify at image analyzing. The visibility of faults at image analyzing was arranged from the highest to the lowest as linen, lyocell, cotton and poliester samples. Standard deviation values and SD index values that are measured at histogram panel were listed in Table 5.9.

**Table 5.9** Standard deviation values and SD index values of weft sett samples

| Fabric Code | Samples | STANDARD DEVIATION VALUES | | SD INDEX ($SD_{faulty}$ / $SD_{fabric}$) |
|---|---|---|---|---|
| | | FABRIC ZONE | FAULTY ZONE | |
| 7 | %100 Cotton | 32.43 | 87.11 | 2.69 |
| 8 | %100 Linen | 75.86 | 105.31 | 1.39 |
| 9 | %100 Poliester | 37.96 | 103.12 | 2.72 |
| 10 | %100 Lyocell | 58.01 | 96.99 | 1.67 |

As a result;

If the results of spectrometer analysis and Photoshop® CS4 histogram analysis;

For weave pattern samples; the brightness degree is arranged from the highest to the lowest as sateen, twill, plain samples at histogram analysis and spectrometer analysis.

For weft sett (weft sett) samples; the brightness degree is arranged from the highest to the lowest as 27 weft/cm, 22 weft/cm, 17 weft/cm samples at histogram analysis and spectrometer analysis.

For fiber type samples; the brightness degree is arranged from the highest to the lowest as poliester, cotton, lyocell and linen samples at histogram analysis and spectrometer analysis.

## 5.4. CORRELATION ANALYSIS

Correlation analysis is used to measure strength of the association (linear relationship) between two variables and correlation analysis is done to show the relationship between fabric properties from statistical approach. For this aim the statistical property of excel program is used to interpret the experimental data.

One of the most widely used statistics is the coefficient of correlation 'r' which measures the degree of association between the two values of related variables given in the data set. It takes values from + 1 to – 1. If two sets or data have r = +1, they are said to be perfectly correlated positively if r = -1 they are said to be perfectly correlated negatively; and if r = 0 they are uncorrelated (Figure 5.23).

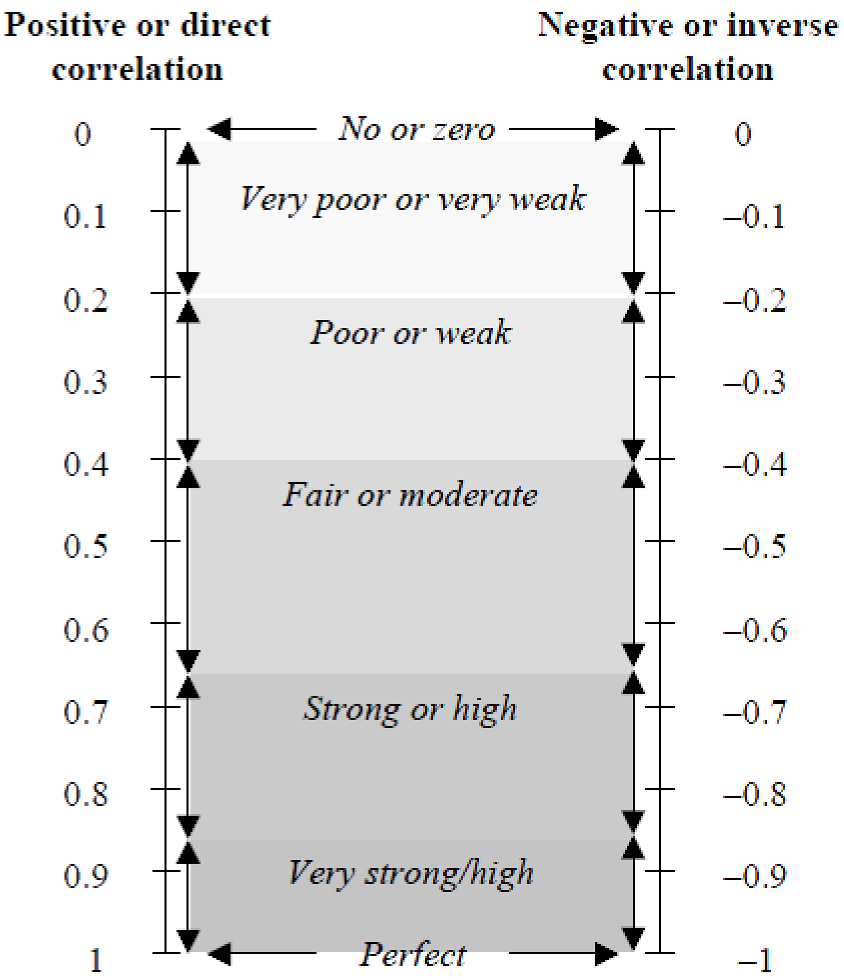



Figure 5.23 Interpretation of correlation coefficient

In this study, spectrometer measurements, image analysis measurements and standard deviation index calculations were obtained with experimental works. Correlation analysis was used to see the relationship between these values and the results of correlation analysis was shown in Table 5.10.

**Table 5.10** Correlation analysis between the parameters
(White section is the correlation analysis result of faulty zones,
Gray section is the correlation analysis result of faultless zones)

| | SPECTROMETER MEASUREMENTS | | | IMAGE ANALYSE MEASUREMENTS | | |
|---|---|---|---|---|---|---|
| | Lightness (L) | Reflectance (%R) | Whiteness index (WI) | Mean Values | Standard Deviation | SD Index |
| Lightness (L) | 1 | 0.9945 | 0.7955 | 0.9724 | -0.8190 | 0.7646 |
| Reflectance (%R) | 0.9951 | 1 | 0.7645 | 0.9744 | -0.8562 | 0.8222 |
| Whiteness index (WI) | 0.7944 | 0.7668 | 1 | 0.7460 | -0.3870 | 0.4679 |
| Mean Values | 0.9715 | 0.9577 | 0.7541 | 1 | -0.8860 | 0.7830 |
| Standard Deviation | -0.9493 | -0.9676 | -0.6241 | -0.9410 | 1 | -0.8860 |
| SD Index | 0.7514 | 0.8053 | 0.4653 | 0.6500 | -0.8400 | 1 |

Based on the statistical correlation analysis, the correlation was found very strong between spectrometer values and image analysis values. This very strong correlation means that spectrometer measurements of brightness and image analysis measurements of brightness verify each other.

Especially, there is a very strong positive correlation between the parameters of lightness, reflectance, mean value and this positive correlation means lightness values increase while mean values increase.

Similarly, there is a very strong negative correlation between the parameter of standard deviation and all other parameters. This negative correlation means standard deviation values increase while the values of other parameters decrease.

The parameter of whiteness index has lower correlation with other parameters, for example, strong correlation between the parameter of whiteness index and the parameters of lightness, reflectance, mean value. There is moderate correlation between the parameter of whiteness index and the parameter of SD index and also poor correlation between the parameter of whiteness index and the parameter of standard deviation.

The parameter of SD index has got strong correlation with the parameters of brightness (mean value, lightness, and reflectance). This means that the coefficient of SD index has harmonious relations with the measured brightness values and verifies each other.

# CHAPTER 6
# CONCLUSIONS AND RECOMMENDATIONS

## 6.1. CONCLUSIONS

This study consists of two parts. First part is a review study about textile defects and detection methods. Second part is an experimental study to investigate the effect of fabric structure for automatic detection applications.

In the first section, the defects that are seen at textile products were examined for the materials of fiber, yarn and fabric. As fiber defect, the immaturity defect was examined and the immaturity defect detection methods explained with details. Similarly, yarn defects and detection methods were available in details. And lastly, fabric defects were classified with their pictures. As fabric detection methods, the manual inspection and automatic control systems were explained. The second section starts with a review study was based on the optical behaviors of textiles. Fabrics differ by weave pattern, raw material, application, constructional parameters, and visual characteristics. The brightness properties of a fabric are changed by these parameters. Appearance and application of a fabric are determined by the fabric constructional parameters and their values.

In experimental study, three fabric parameters were investigated to understand the effect of brightness on automatic fabric defect detection. These parameters were weave pattern, raw material and weft sett (weft sett). The mispick defect has been made at fabric samples and they were processed at the experimental set-up mechanism which has been built by Çelik [30]. The pictures of fabric samples were taken and processed at MATLAB® and Photoshop® programs. The brightness values of fabric samples were measured. Similarly, the brightness values of the samples were measured with spectrometer as a second measuring method. A coefficient named as SD index was calculated to understand the detectability of fabric defects at different fabric structures on automatic detection methods.

As shown in results; brightness values are changing according to fabric structure. The brightness values affect the ability of defect detection on automatic fabric detection applications.

At weave pattern samples; the brightness values are sequenced from lowest to highest; plain, twill, and sateen.

At weft sett samples; brightness values from lowest to highest has a ranking such as; low yarn sett (17 weft/cm), medium yarn sett (22 weft/cm), high yarn sett (27 weft/cm).

At raw material samples; brightness values from lowest to highest has a ranking such as; poliester, cotton, lyocell, linen.

The fabrics, that have high brightness values such as sateen fabric, high yarn sett fabric or poliester fabric, have high brightness values and the detecting defects of these fabrics is more difficult on automatic detection methods with comparing other fabrics. SD index coefficient was created to understand the amount of detectability of fabrics on automatic detection applications.

## 6.2. RECOMMENDATIONS

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

• The effect of fabric brightness can be decrease with entering the values that are created by SD index values. With this way, the quality control of different fabrics can be done at same conditions and defect detection can be occurred more efficiency.

• There are automatic control systems which were Barco Vision's Cyclops, Elbit Vision System's I-Tex and Zellweger Uster's Fabriscan. These systems have difficulties at factory applications. This study can guide to these systems to change their parameters at different fabrics.

• Automatic quality control system that is effective for all weave types and fiber content can be developed.

## REFERENCES

[1] Malek, A. S. (2012). Online Fabric Inspection by Image Processing Technology *Haute Alsace University, A thesis in Mechanical Engineering.*

[2] Wikipedia the free encyclopedia. (2001). Available at: http://en.wikipedia.org/wiki/Denim. Accessed (2014).

[3] Gokarneshan., N. (2004). Fabric structure and design. *New Delhi: New Age International (P) Ltd.*

[4] Ala, D. M. (2008). Numerating woven fabric defects with image analysis. *Pamukkale University, Master thesis.*

[5] Akgün, M., Alpay, H.R. and Becerir, B. (2012). Review of the relations between fabric constructional parameters and fabric reflectance. *Uludağ Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi,* **17** (1): 93-106.

[6] Akgün, M., Alpay, H.R. and Becerir, B. (2012). Investigation of the changes in reflectance properties of warp and weft yarns before and after weaving of some polyester woven fabrics. *Uludağ Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi,* **17 (2):** 91–104.

[7] Huang, C. C., Liu, S. C., Yu, W. H. (2000). Woven Fabric Analysis by Image Processing: Part I: Identification of Weave Patterns. *Textile Research Journal,* **70**: 481-485.

[8] Çelik, H. İ., Dülger, L. C., Topalbekiroğlu, M. (2014). Development of a machine vision system: real-time fabric defect detection and classification with neural networks. *The Journal of The Textile Institute,* **105** (6): 575–585.

[9] Gowda, R. V. M., Babu, K. M. (2008). Key issues in testing damaged textile samples. Fabric Testing. *Woodhead Publishing*. 309-338.

[10] Lord, P. R. (2003). Quality and quality control. Handbook of Yarn Production. *Woodhead Publishing*. 276-300.

[11] Rieter Textile systems. (1795). Available at: http://www.rieter.com/en/rikipedia/articles/technology-ofshort-staple-spinning/raw-material-as-a-factor-influencing-spinning/fiber-fineness/fiber-maturity/. Accessed (2013).

[12] Valco, T. D. (2002). Fiber quality aspects of cotton ginning. Handout in Level III Cotton Ginners Short Course text. *Cotton Technology Transfer.* Available at: https://www.extension.org/mediawiki/files/5/5f/Ginning_Quality_Aspects.pdf

[13] Available at: http://tr.scribd.com/doc/15569730/Fibre-Testing Accessed (2012).

[14] Venkatakrishnan, S., R.P. Nachane. (2011). The Impact of Cotton Fibre Maturity on Dye Uptake & Low Stress Mechanical. *World Cotton Research Conference on Technologies for Prosperity*. 553-560.

[15] Available at: http://www.thesmarttime.com/testing/maturity-determination-methods.htm Accessed (2011).

[16] Frydrch, I., Raczynska. M., Cekus, Z. (2010). Measurement of Cotton Fineness and Maturity by Different Methods. *Fibres & Textiles in Eastern Europe*, **18**(6) (83). 54-59.

[17] Available at: http://textiletesting.blogspot.com.tr/2009_07_01_archive.html Accessed (2012).

[18] Xu, B., Pourdeyhimi, B. (1994). Evaluating Maturity of Cotton Fibers Using Image Analysis: Definition and Algorithm. *Textile Research Journal*. **64.** 330-335.

[19] Rodgers, J., Montalvo, J., Davidonis, G.,VonHoven, T. (2009). Near Infrared Measurement of Cotton Fiber Micronaire, Maturity and Fineness – a Comparative Investigation. *Textile Research Journal.* **80**(9). 780–793.

[20] Hertel, K.L. (1951) Cotton Fineness and Immaturity as Measured by the Arealometer *Textile Research Journal.* **21** (11). 765-774.

[21] Stephens, S. G. (1977) Estimation of Cotton Fiber Dimensions from Shirley I.I.C. Fineness/Maturity Tester Readings. *Textile Research Journal* . **47**(8). 526-530.

[22] Parthasarathi, V. (2008) Evolution in cotton testing instruments. *The Indian Textile Journal*. April 2008.

[23] Akola, T. Advance Fiber Information. Available at: http://tr.scribd.com /doc/7314236/advance-fibre-information. Accessed (2011).

[24] Mukuntharajan, S. (2000) Application Of Statex MVI- Technology For Cotton Quality Measurement And Comparısıon With HVI. *Textile Trends*. June 2000. 35-37.

[25] Rodgers, J., Fortier, C., Montalvo, J. (2010) Near Infrared Measurement of Cotton Fiber Micronaire by Portable Near Infrared Instrumentation. *Textile Research Journal.* **80**(15). 1503–1515.

[26] Rajasekaran, K., Thibodeaux, D. (2002) Fidelity of Cotton Fiber Maturity Measurement by Image Analysis. *Journal of New Seeds,* **4**(3), 25-36.

[27] Dlodlo, N., Hunter, L., Cele, C. (2007) A Hybrid Expert Systems Architecture for Yarn Fault Diagnosis. *Fibres & Textiles in Eastern Europe*. **15**(2)(61), 43-49.

[28] Available at: http://textilelearner.blogspot.com.tr/2013/07/different-types-of-yarn-defectsfaults.html Accessed (2014).

[29] Mogahzy, Y.E. Fiber to Yarn Conversion System – Yarn Characteristics. Available at: http://textile2technology.com/2009/07/fiber-2-yarn-conversion-system-yarn-characteristics.html? Accessed (2012).

[30] Marwat, A.B. Yarn Evenness. Available at: http://tr.scribd.com/doc/18583083/ Yarn-Evenness-Testing-By-AbuBakkar-MarWat Accessed (2012).

[31] Umer, R. Uster Quantum Clearer. Available at: http://tr.scribd.com/doc /23665185/Uster-Quantum-Clearer Accessed (2012).

[32] Measurement of yarn hairiness Shirley. Available at: http://textilelearner. blogspot.com.tr/2012/05/measurement-of-yarn-hairiness-shirley.html Accessed (2012).

[33] Yarn hairiness tester. Available at: http://www.ts-rc.eu/index.php? option=com_content&view=article&id=138%3Ahairness&catid=45%3Aequipment&Itemid=76&lang=en Accessed (2012).

[34] Chauhan, R.S. (2009). Yarn hairiness: Measurement, effect & consequences. The Indian Textile Journal. Available at: http://www.indiantextilejournal. com/articles/fadetails.asp?id=1927 Accessed (2012).

[35] Kumar, A. (2008). Computer-Vision-Based Fabric Defect Detection: A Survey. *IEEE Transactions on Industrial Electronics*. **55** (1). 348-363.

[36] Sabeenian, R.S., Paramasivam, M.E. (2010). Defect detection and Identification in Textile Fabrics using Multi Resolution Combined Statistical and spatial Frequency Method. *IEEE 2nd International Advance Computing Conference*. 162-166.

[37] Fabric Faults, Causes of Woven Fabrics Defects or Faults. Available at: http://textilelearner.blogspot.com/2012/04/fabric-faults-causes-of-woven-fabrics.html Accessed (2012).

[38] Standard Fabric Defect Glossary. Available at: http://www.cottoninc.com /product/Tech-Assistance-Training/StandardFabricDefectGlossary/ Accessed (2012).

[39] Behera, B.K. (2009). Image Processing In Textiles. *Textile Progress*. **35** (2-4). 1-193.

[40] Kothari, V. (2010). Automatic Fabric Inspection. Textile review. Available at: http://tr.scribd.com/doc/43266269/Automatic-Fabric-Inspection Accessed (2012).

[41] Çelik, H.İ. (2013). Development of an Intelligent Fabric Defect Inspection System. *Ph.D Thesis in Mechanical Engineering, University of Gaziantep.*

[42] Kadkol, R.J., Rai, H.M., Kulkarni, A.H. (2013). Textile Defect Detection for Reflective Material using Spectral Transform. *International Journal of Latest Trends in Engineering and Technology (IJLTET).* **2** (2). 177-180.

[43] Helena, G. (2007). Colour and Optical Phenomena on Fabric. *Textilec.* **50** (4-6). 93-132.

[44] Field, G. G. (1999). Color and Its Reproduction. (2nd ed.). *Pitsburg: GAFTPress*, 1-113.

[45] Donald, R. (1997). Colour Physic for Industry. (2nd ed.). *Brad-ford, England: Society of Dyers and Colourists.*

[46] Tilley, R. (2010). Colour and optical properties of materials: an exploration of the relationship between light, the optical properties of materials and colour. *Wiley.*

[47] Etters J. N. (1997). Infuence Of Fabric Surface Effect On Color Depth And Hue Of Garment-Dyed Textile. *American Dyestuff. Reporter.* **86**(5). 15–18.

[48] Morton, T. H. (1976). Apparent Color Yield in Dyed Textiles. *Journal of the Society of Dyers and Colorists*. **92** (4). 149–157.

[49] Adanur, S. (2001). Handbook of weaving. *Sultzer, A technical Publishing book ompany, Technomic.*

[50] Newton, A. (1995). The Comparison of Woven Fabrics by Reference to Their Tightness. *Journal of Textile Institute,* **86** (2). 232–239.

[51] Zarubica1, A., Miljković1, M. (2005). Colour Parameters, Whiteness Indices and Physical Features of Marking Paints for Horizontal Signalization. *Physics, Chemistry and Technology*. **3**(2). 205-216.

[52] Analyzing images using image thresholding techniques. Available at: http://www.mathworks.com/discovery/image-thresholding.html Accessed (2013).

[53] Available at: http://fcvphotography.com/tutorials/external-tutorials?open=82 Accessed (2013).