İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

AN INVESTIGATION ON THE MECHANIC AND PERFORMANCE ANALYSIS OF WOVEN FABRICS BY USING OBJECTIVE EVALUATION TECHNIQUES

Master Thesis by
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Programme: Textile Engineering

Supervisor : Assoc. Prof. Dr. Ömer Berk BERKALP

JANUARY 2008

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OCAK 2008

FOREWORD

I wish to express my sincere thanks to my supervisor Assoc.Prof.Dr.Ömer Berk BERKALP for his encouragement, support, patience and guidance in this long term of my study, and for encouraging me to go to abroad for my study.

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January, 2008 **Özge TOKMAK**

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ABBREVIATIONS

HESC	: Hand Evaluation and Standardization Committee
FAST	: Fabric Assurance by Simple Testing
KES-F	: Kawabata Evaluation System For Fabrics
HV	: Hand Value
THV	: Total Hand Value
TAV	: Total Appearance Value
BS	: British Standards
AATCC	: American Society for Testing and Materials
ASTM	: American Association of Textile Chemists & Colorists
ISO	: International Standardization Organization
TS	: Turkish Standards
R.S.	: Relaxation Shrinkage
H.E.	: Hygral Expansion
B.R.	: Bending Rigidity
B.L.	: Bending Length
W	: Weight
S.R.	: Shear Rigidity
B.E.	: Bias Extension
S.T.	: Surface Thickness
F	: Formability

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d	: Yarn diameter
N_t	: Yarn linear density
φ	: Yarn packing factor
ρ_f	: Fiber density
$\overline{\rho_f}$	: Average fiber density
ρ_i	: Weight fraction of the *i*th component
ρ_{fi}	: Fiber density of the *i*th component
M_1, M_2	: Warp and weft weave factors
N_1, N_2	: Numbers of warp ends and filling treads per weave repeat
i_1, i_2	: Numbers of filling and warp intersections per weave repeat
$t_{1\max}, t_{2\max}$	: Maximum numbers of warp ends and picks per unit area
d_1, d_2	: Warp and weft treads diameters
m	: A constant dependent on the weave type
C_f	: Construction factor
T_f	: Tightness factor
c_1, c_2	: Warp and weft cover factors
S_1, S_2	: Warp and weft density

ÖZET

Bu çalışmada, dokuma kumaşların performans ve mekanik özellikleri, objektif kumaş ölçüm teknikleriyle elde edilerek, analiz edilmiştir. Objektif ölçüm sistemi, özellikle yün kumaş endüstrisi için önemli bir sistemdir. Bu sistem yeni kumaşların geliştirilmesinde, üretim öncesi tasarımında ve kumaş proses işlemlerinden önce zorlukların tespit edilerek proses işlemlerinden önce bu zorlukların giderilerek daha dikkat edilmesini sağlar. Kumaşların düşük gerilim altındaki mekanik özelliklerin ölçülmesinde kullanılan iki sistem vardır. Bunlar KES-F ve FAST sistemleridir. FAST sistemi yünlü kumaş endüstrisinde kullanılmasına rağmen, KES-F sistemi sadece laboratuar çalışmalarında kullanılmaktadır. Cusick Dökümlülük Test Cihazı da bu çalışmada kumaş dökümlülüğün ölçümünde kullanılmıştır.

Bu çalışmanın amacı, yün ve yün karımı kumaşların mekanik ve performans özelliklerinin objektif ölçüm sistemleriyle analiz edilesi, ve bu kumaşların fiziksel ve mekanik özellikleri arasında güvenilir bir ilişki kuma araştırmasıdır.

Kumaş mekanik özellikleri KES-F sistemi, FAST sistemi ve Cusick Dökümlülük Cihazı kullanılarak elde edilmiştir. Kesilme, eğilme, uzama ve basınç özellikleri KES-F ve FAST cihazları kullanılarak, dökümlülük katsayısı da Cusick Dökümlülük Cihazı kullanılarak elde edilmiştir. KES-F ve FAST sistemleri, farklı ölçüm prensipleri kullanmalarına rağmen, her bir parametre için iyi bir korelasyon göstermiştir. Bu çalışmadan elde edilen başka bir sonuç da dökümlülüğün eğilme ve kesilme özelliklerine bağlı olup olmamasıyla ilgilidir. Dökümlülüğün kumaşın eğilme ve kesilme özelliklerine birinci derecede bağlı olduğu bulunmuştur. Ayrıca; kumaş örgüsünün, iplik numarasının ve kullanılan materyalin dökümlülük katsayısının, FAST eğilme rijitliği, FAST kesilme rijitliği ve FAST uzama yüzdesi üzerindeki etkileri incelenmiştir. Kumaşın örgü tipinin dökümlülük üzerinde bir fark yaratmadığı, ancak eğilme, kesme ve uzama parametreleri için kumaşın diğer fiziksel özelliklerine bağlı olduğu görülmüştür. İplik numarasının da kumaşın diğer fiziksel özelliklerine bağlı olduğu görülmüştür. Kumaşta elastan kullanımı dökümlülük, kesilme ve uzama üzerinde belirgin bir fark yaratmasına rağmen, eğilme özelliği üzerinde herhangi bir fark yaratmamıştır.

SUMMARY

In this study mechanic and performance analyses of woven fabrics by using objective evaluation techniques was investigated. Objective evaluation system is a very important system especially for wool fabric industry. This system enables the development of new fabrics, designing before production and to find out the difficulties before clothing processes so that the processes can be arranged according to difficulties and can be taken more care about the clothing processes. There are two fabric objective evaluation systems which measure the fabric low stress mechanical properties. These are KES-F and FAST systems. FAST system is being used in wool fabric industry but KES-F system is being used only for laboratory studies. Cusick Drape Meter was also used to measure the drape property of the fabric.

The aim of this study is to analyze the mechanical and performance characteristics of wool and wool-blended fabrics with objective evaluation systems, and to search for a reliable relationship between physical and mechanical properties of these fabrics

KES-F system, FAST system and Cusick Drape Meter were used to evaluate fabric mechanical properties. Shear, bending, extension, and compression parameters were measured by using KES-F and FAST instruments, and drape coefficient by using Cusick Drape Meter. It is found that, KES-F system and FAST system have a good correlation between each parameter, although they use different measurement principles. Another conclusion, obtained from this work is about the dependence of bending and shear parameters on fabric drape property. It is found that drape of a fabric is primarily dependent on fabric's bending and shear properties. Besides, the effects of weave, yarn count and material are investigated on drape coefficient, FAST bending rigidity, FAST shear rigidity and FAST extension values. It is found that, the effect of weave for drape is not significant, but it depends to other physical parameters of fabrics for bending, shear and extension properties. The effect of yarn count also depends on other physical properties of fabrics. The effect of elastane was significant for drape, shear and extension parameters, but bending does not affected by the usage of elastane fiber.

1. INTRODUCTION

Humans have dressed, since before the old historical ages. The basic reason of the need for clothing were protecting and covering their bodies from external effects, such as hot and cold weather. They used animal skins for this purpose at first, but by the developing of agriculture and stockbreeding, people have formed new structures called ‘fabrics’ as clothing materials.

Fabrics are defined as the structure of assembling of the textile fibers in a smooth surface with a thin layer and sufficient strength. This definition includes the fabric’s geometrical and mechanical properties. In terms of geometrical property point of view, a fabric is a structure which has a covering property, and in terms of mechanical property point of view, a fabric is an elastic material. The fabrics, especially used as clothing materials, should be fit for body, and have sufficient smooth surface that enables stretchiness and fineness.

Textile fabrics made from natural fibers have been used as the most suitable materials for clothing for a long time, and, more recently, man-made fiber fabrics are also being used for clothing as textile materials. There are several reasons for the use of such materials. The low weight and high ratio of strength/weight of these fibers are suitable for achieving the primary functions of clothing. Secondly, fiber assemblies, such as woven fabrics, are flexible and deformable, and have desirable surface properties [1]. Human have accepted these materials as clothing materials, because of these fabric attributes.

Fabric has some important properties that determine its function and application as a textile material. The basic properties are smooth surface, thin layer, stretchiness, strength and covering properties, and besides, there are lots of important properties that determine its surface appearance, using conditions, behaviors and etc. These properties are obtained from the fabric’s raw material and complex functions of fabric structures.

Fabric properties are generally divided in three important parameters;

1. Chemical Properties of Fabrics

2. Physical Properties of Fabrics
3. Appearance Properties of Fabrics

The relationship between the fabric and dying material is related to fabric's chemical properties. The absorption of fabric is very important in finishing stage and the chemical structure of fibers provides to make a bond between the fabric and the finishing material. The appearance properties are also as important as the chemical properties. Because, as an end-use product, the production should appear good to the consumer as they use it. The weave construction of the fabric affects the appearance of the fabric. By the change of construction, the light reflection from the fabric will change and the surface appearance will be shiny or dull. This reflection is also affected by the characteristics of raw material.

The physical properties of fabrics are very important and related to our study. These properties are a set of complex properties that are affected from fiber and yarn properties and also from fabric structural parameters. Fabric physical properties can be divided in four groups:

1. Structural Parameters
2. Mechanical Parameters
3. Permeability and Conductivity Parameters
4. Sensory Parameters

Structural parameters include fabric width and length; weave design, the fineness and densities of fibers and yarns, and fabric thickness. These parameters affect other physical parameters markedly.

Mechanical parameters are the behaviors that are affected in perpendicular direction of fabric width, length and fabric plane that are under the force. These are elongation at breaking point, tensile resistance, rupture resistance, tearing resistance, bursting resistance, bending resistance, friction resistance and creasing resistance. The mechanical properties of a fabric are the performance characteristics of yarn stretchability properties on fabric structure and yarn densities. The fabric thickness and weight is determined from fabric structure, and yarn diameter and density. Tensile resistance is directly affected from these parameters. Elongation at breaking point, stretchability and tearing resistance properties are closely related to fabric design while the tensile resistance have a close result with the summation of the yarn tensile resistance at the same direction.

Permeability and conductivity properties are water permeability, air permeability, heat conductivity, and electrical properties. Air and water permeability properties are directly related to fabric thickness, and at the same time, water permeability is related to surface structure because of surface stress, and air permeability is related to quantity and dispersion of porous in fabric. Heat conductivity is related to fabric thickness and thermal properties of fibers. Electrical properties are important because of insulation and static electricity, and are related directly to fiber properties.

Sensory properties, as indicated in the outline, are the feelings while the fabric is touched, like stiffness and hardness, handle and drape properties. These properties are based on mechanical parameters and these are complex parameters that are formed with the effects of various factors and assessed by touching the fabric. This is a subjective evaluation technique and in last decades new technique is being developed to assess fabric sensory properties. This new technique is called fabric objective evaluation system.

The oldest fabric formation technique is woven fabric formation technique. Woven structure, shown in Figure 1.1, is basically, formed as the interlacing of two sets of yarns, and disposed at the right angle. Thin layer, stability, strength, smooth surface, covering properties, and the variety of weave constructions make woven fabrics to be different from other structures. By the industrial revolution, the development in woven industry was accelerated. However, in Renaissance period, the formation techniques of fabric designing were developed and reached nearly today's techniques. Today, lots of new fabric formation techniques are developed but, woven structure is still very important for textile industry. Woven fabrics are used for apparel fabrics, such as shirts, blouses, trousers, jackets, suits, costumes, pullovers, etc.; household textiles, such as blankets, carpets, furnishing, bed cloths, drapes, etc.; accessories etc. Raw materials, yarn types, weave designs are chosen, due to fabric's desired end-use properties. Raw materials are selected according to the end-use properties of the product. Sometimes, pure raw materials are used but sometimes, these materials are blended due to some reasons. Blended fibers are used for quality improvements, for appearance and profitability. For suiting apparels, mostly wool and wool blended fibers are used. Wool is excellent for blending with other fibers, especially with synthetic fibers, such as polyamide and polyester. These mixtures are used for the reducing of felting and improving the aftercare characteristics. Wool is also blended with fine hair fibers, such as mohair to have softer structure, and with elastane to have more elastic structure. Yarn formation technique also has an important effect on woven fabrics. Ring spun yarns are used for woven fabrics mostly, because of its strength to friction. But more recently, a new qualified ring spinning technology, SiroSpun yarn spinning technology, is developed, especially for worsted system. In this system, the spinning and doubling are combined in one operation in ring spinning technology. SiroSpun is suited to the production of lightweight transseasonal fabrics. Yarns produced by sirospun spinning process are fine, even and less hairy than conventional yarns. The fabrics produced from this yarns have a smooth feel.

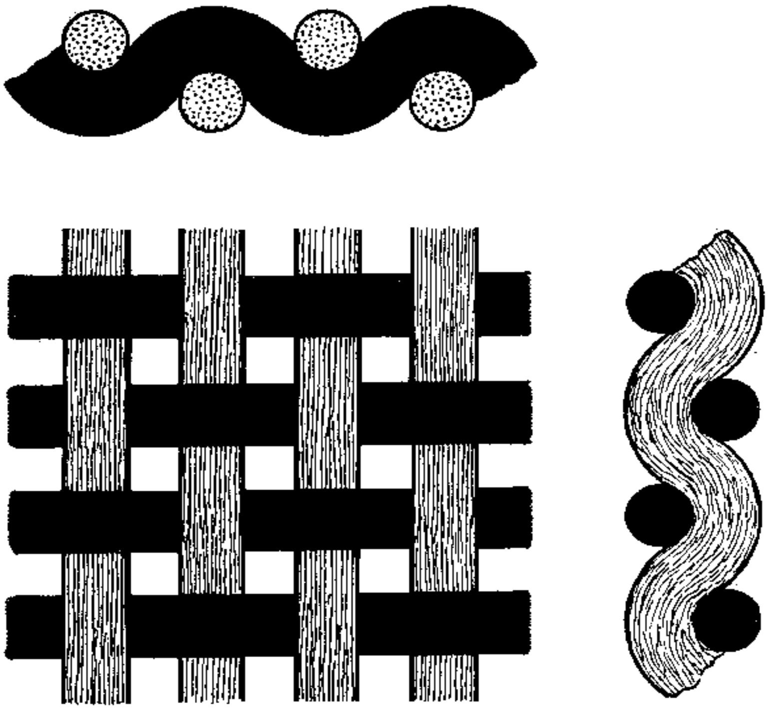


Figure 1.1: The Basic Structure of Woven Fabrics

During the production stages and after production of a textile material, various kinds of tests are applied to fabric. These materials are being tested to control the properties based on the end-use properties of fabrics and apparels. The tests are made to provide feedback to the quality assurance system and to be sure that the system of production of textile material work correctly. All these are being done for the quality control of the textile materials. Quality control is a set of test methods, inspection and analytical procedures which are applied to raw materials, intermediate products and final products. In the inspection stage, the material is checked with eyes on the control desks, and in this control the weaving faults, printing faults, correct width, distortion, etc. are controlled. These tests are being done according to some national and international standards such as ASTM (American Society for Testing and

Materials), AATCC (American Association of Textile Chemists&Colorists), ISO (International Standards Organization), BS (British Standards), and etc. Textile fabrics and apparel are being tested according to the test methods based on these standards. These tests are physical tests. Some of these test methods used for yarns, woven fabrics and apparels are [2];

- Strength properties for apparels
- Fabric stretch properties
- Dimensional changes in apparel due to laundering, dry-cleaning, steaming and pressing
- Sewability of fabrics
- Bow and skewness (bias) in woven fabrics
- Distortion of yarn in woven fabrics
- Wrinkle recovery
- Stiffness and drape
- Fabric thickness
- Thermal properties
- Air permeability
- Water resistance and water repellency
- Pilling
- Snagging
- Abrasion resistance
- Colorfastness
- Yarn strength and elongation
- Yarn number
- Yarn twist

- Wear testing

Characterizing of textile materials is not only knowledge of technical specification, but also sensory evaluation of these materials. By touching, it is not possible to get technical information that is felt with senses. Very important criterions of fabrics are the comfort, aesthetics and physiological sense, while evaluating the textiles in traditional uses. The comfort sensation of a fabric has multi-dimensional attributes and it can not be assessed as a numerical value as an individual property. 'Fabric hand' is commonly used to assess fabrics for the comfort evaluation of textile materials.

Quality is a very important feature for a fabric, and hence apparel and it can be briefly defined as "fitness for purpose". The basic components of quality are price, technical performance and aesthetics of apparel. As a textile engineer, we always seek ways to manufacture fabrics and apparels at the best quality. For this purpose, we have to control the quality which is known as "Quality Control" and defined as: "A set of test methods, inspection and analytical procedures which are applied to raw materials, intermediate products, and final products, to provide feedback to the quality assurance system and to be sure that the system of production is working correctly" [3]. The applied test methods are physical tests that measure the physical properties of textile materials. In textile industry it's very difficult to measure all quality attributes by these test methods.

In clothing industry a very important quality attribute is handling. Handle is explained as the aesthetic quality of a fabric. For a long time, handle had been evaluated by a system called subjective evaluation system. According to this system, fabric was touched by fabric experts and then these experts were expressing their feelings. It was a common quality assessment. In the last decades, many researches have been attracted to the subject of objective evaluation of fabric handle. Everyone who is in the textile industry accepted that handle is one of the most important quality attribute. Subjective system was a common assessment technique but development of new production technologies, new yarns, increasing in automation, the retirement of experienced experts and changes in education made people to think more about objective evaluation systems. Objective evaluation system enables the development of new fabrics, designing before production and to find out the difficulties before clothing processes so that the processes can be arranged according to difficulties and can be taken more care about the clothing processes. In objective evaluation system, numerical values are obtained from the measurements and these values are not dependable on humans. In subjective evaluation system, the evaluation was changing from person to person so there was not a precise result for one fabric. Now, objective evaluation systems are more popular in textile industry but subjective evaluation system is still being used. But in time, all manufacturers will understand the importance of objective evaluation system and thus the textile industry will offer more new developments and higher quality products.

In Turkey, woven industry has an important part in the production and exportation of the textile industry. According to the statistical analyses of Turkish Exporters' Association [4] exported amount and cost of woven fabrics have an increasing level year by year. In the first period of 2007 (January-June) there is a 15% increase from the first period of 2006 (January-June) in the exported amount of woven fabrics. These fabrics include woven fabrics made from cotton yarns, from synthetic filament yarns, from synthetic staple fibers, and from wool yarns. The most amount of exportation is made to EU (European Union) countries in 2006 and 2007. In Table1.1. the exportations in the first period of 2006-2007 to each group of countries and costs in 1000 $ was shown. In Table 1.2 the variance, cost and amount of exportation of Turkey, in the first period of 2006-2007 and in the first period of 2005-2006 was shown.

Table 1.1: Exportation of Woven Fabrics of Turkey in the First Period of 2006-2007 [4]

Country group	2006 (January-June)	2006-Total amount in textile industry (%)	2007 (January-June)	2007-Total amount in textile industry (%)
EU countries	1.486.770	55,6	1.759.026	55,3
Other OECD countries	136.258	5,1	156.702	4,9
Other European countries	52.272	2,0	79.586	2,5
Old Soviet Union countries	273.524	10,2	377.352	11,9
Middle East Countries	193.743	7,2	186.570	5,9
Africa countries	162.938	6,1	200.114	6,3
Other Asia countries	107.106	4,9	122.764	3,9
Other countries and areas	262.911	9,8	297.697	9,4

Table 1.2: The Exportation Amount, Cost and Variance of Woven Fabrics of Turkey in the First Period of 2006-2007 (January-July) [4]

	2006		**2007**		**Variance (%)**	
Fabric Type	**Amount of Exportation (kg)**	**Cost ($)**	**Amount of Exportation (kg)**	**Cost ($)**	**Amount**	**Cost**
Woven fabrics made of cotton yarns	25.407.252	234.929.452	29.755.813	293.243.951	17,1	24,8
Woven fabrics made of synthetic filament yarns	13.942.673	170.049.324	16.964.079	222.358.487	21,7	30,8
Woven fabrics made of staple synthetic yarns	8.150.106	96.608.497	7.997.959	92.189.174	-1,9	-4,6
Woven fabrics made of wool yarns	1.098.330	38.802.517	1.235.534	45.175.550	12,5	16,4

Generally the exportation of woven fabrics are increased year by year. If we look individually according to different types of fabrics, the wool fabrics and fabrics made of synthetic filament yarns show better increase. The cotton fabrics however shows a decrease in 2006, but in 2007 it shows a good increase and a better amount and cost when compared with 2005.

2. AN OVERVIEW OF FABRIC OBJECTIVE MEASUREMENT SYSTEM

2.1 The Need for Objective Measurement Technology

Textile and clothing industry have produced fabrics and garments in needed qualities for all types of end-use characteristics, and consumer requests like price, durability, fashion, and comfort. By years, all these kinds of such products has been improved. This improvement is achieved due to the introduction and continual renovating of nationally and internationally recognized performance standards and test methods. In more recent years, with the application of standards, and rivalry of companies, improvements in quality have been achieved. All these improvements are achieved in the absence of any system of subjective and objective criteria, relating to the handle of fabrics, and so, since the handle is accepted as the most essential characteristic to determine the given fabric's end-use purpose of a particular fabric, whether it is suitable or not, handle assessment is being used for the success or failure of textile manufacturing process or products [5].

The technological developments and sociological changes over the last 60-70 years have effected textile and clothing industries. The invention of synthetic fibers, the developments in spinning process, weaving, and knitted technologies, and many developments in finishing processes have changed lots of properties of fabrics. Some of these changes have improved cost-effectiveness of production, and other has been made for the changing needs in the marketplace. By sociological changes, like the changing life-style, the growing wealth of consumers, these changes brought another direction. During this period, there has been a continual change in the style and handle of fabrics. With the increase in change, in textile and clothing industry, the assessment of fabric handle became more difficult, and the quality as measured in terms of fabric handle became poorer.

Around 1969, Kawabata's observation about subjective evaluation of fabric handle was the first step of the development of the first objective evaluation system. He mentioned that the quality related to fabric handle was becoming poorer, in spite of the progress in technology and engineering, and the quality of the fabrics produced in modern systems with the help of advanced technology had not always been improved from the point of view of fabric handle. It was not possible to quantitative the fabric handle in the absence of accepted methodology for hand evaluation, but, this observation was enough strong to establish the cooperation of the Hand Evaluation and Standardization Committee (HESC), under the sponsorship of Textile Machinery and Society of Japan in 1972.

By the end of the 1970s it had become possible to apply the essential physical properties to predict the basic mechanical properties of extension, shear, bending and compression for all kinds of interlaced fabrics. The results of the analyses led the development of instrumentation for the experimental measurement of fabric low stress mechanical properties, and then, the new technology of fabric objective measurement was established in the end of 1970s.

The presence of fabric low stress mechanical and surface properties, such as extension, bending, shear and surface smoothness in studies of the fabric mechanics, handle, thermal insulation, comfort and tailorability demonstrates the importance of these properties for the specification, prediction and control of fabric quality and performance.

The main concept of fabric objective measurement technology is to specify and control the quality, tailorability and performance of an apparel fabric with a necessary and sufficient set of instrumental measurements made on fabrics.

The relationship between fabric mechanical and surface properties on one hand, and fabric quality and performance characteristics, such as fabric handle, tailorability or making-up properties and garment appearance is apparent in more recent years. Fabric mechanical properties are the critical properties in the determination of the quality, and performance of fabrics and garments. Fabric mechanical properties are critical also from the point of view of fabric tailorability. There is an optimum combination of these fabric mechanical properties which enables wool fabrics to be tailored successfully into high quality without any unsightly features in the seam regions of the garment [6].

The application of fabric objective measurement technology is very important due to some important factors [7];

- The increasing level of automation in both textile and clothing manufacture,
- The gradual loss of personnel with traditional textile knowledge based on many years of experience and at the same time appearance of trained

engineers to carry out the production, research, development and quality control functions,

- The widespread use of internet and all kinds of digital communication tools, as well as the large number of product varieties due to shorter terms of seasonal products and the need for quick response to maintain competitiveness in business.

These are the some of the main factors on which the argument of fabric objective measurement has been argued.

Postle [8], has identified the six main ways in which fabric and garment objective measurement technology is being used in different countries and by various companies depending on nature, priorities and aims that are reported at Australia-Japan Science and Technology Symposia. These are;

- Objective measurement of fabric quality and handle, and their primary components for various textile products,
- Design and production of a diverse range of high quality yarns and fabrics using objective mechanical and surface property data.
- Objective evaluation and control of textile processing and finishing sequences for the production of high quality yarns and fabrics.
- Objective evaluation of fabric tailorability and finished garment quality and appearance.
- Objective specifications by tailoring companies for fabric selection, production planning, process control and quality assurance using fabric mechanical and dimensional property data.
- Measurement and control of the comfort, performance and stability of fabrics and clothing during use.

In the future, these applications may extend beyond these applications to reach much extended aims, which are summarized also by Postle [8],

- to maintain and upgrade the quality of all existing textile products,
- to optimize the use of different quantities and varieties of natural and manmade fibers,

- to produce a scientific base for the control of fabric quality and performance as a result of new process and product developments,
- to specify quantitatively and control the performance characteristics of fabrics and clothing, and
- to establish an objective basis for communication between researchers, industry sectors and traders in fibers and products.

Subjective assessment of fabric handle have been used for a long time in textile and clothing industry, but subjective assessment is becoming inadequate for modern textile and clothing applications as the presence of the following changes and developments;

- The increasing variety of fabrics and clothing.
- The retirements of experienced experts and non-replacement of them.
- The quick increase of automation in textile and clothing industries.
- The crucial need for quick response in the textile and clothing industries.
- Increasing difficulties in precise language and communication in terms of subjective assessment of fabric quality attributes.

2.2 The Development of Objective Evaluation System

2.2.1 Fabric Handle and Subjective Evaluation System

The performance of fabric quality related to the mechanical comfort has been evaluated by a subjective method, called handle judgement. This assessment was made by experienced fabric experts with touching the fabric. Fabric hand has been defined as a perceived overall fabric aesthetic quality [9]. Hand influences consumers' priorities and their sense of the usefulness of the product, and also retailer's marketability of the fabric. Subjective evaluation of handle had always been used as the fundamental aspect of communication for the development, production, quality control, specification and marketing of textile materials and garments, before the development of fabric objective measurement technology.

From the analyses of handle, Kawabata and Niwa have believed that, fabric handle have two different types. One handle expresses the fabric characteristics such as stiffness, smoothness, etc. The other one expresses fabric quality such as higher quality or poor quality [10].

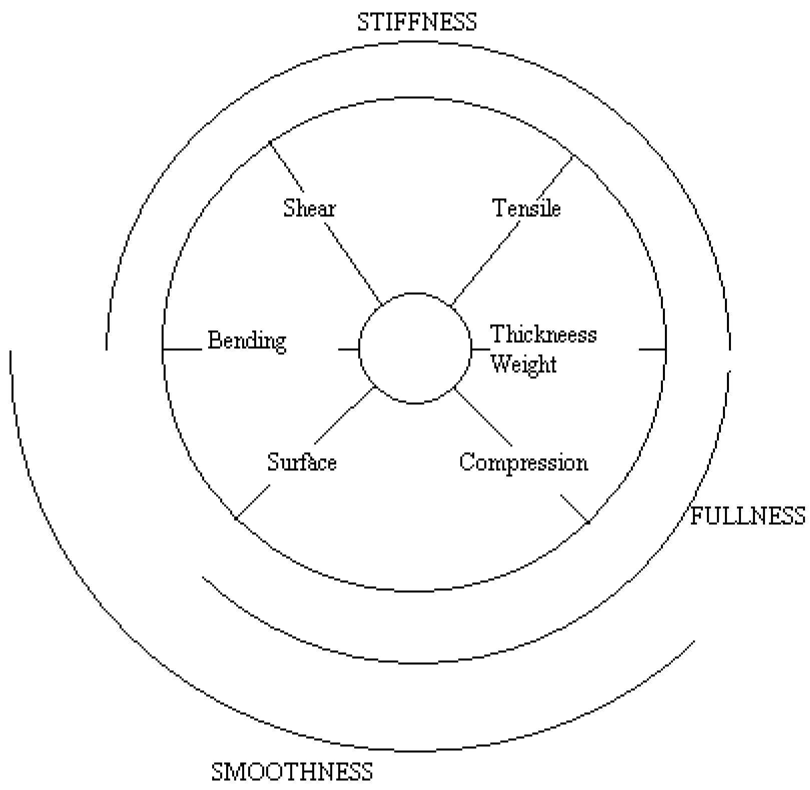


Figure 2.1: The Relationship between Hand Values and Physical Properties [11]

The complex concept of fabric handle may be analyzed as the interaction between a number of much simpler fabric quality attributes such as firmness, fullness, crispness and hardness, smoothness or sleekness [6]. It is also mentioned that, fabric handle is related with many characteristics, including flexibility, stiffness, compressibility, resilience, extensibility, surface contour, weight per unit area, surface friction and thermal characteristics [12]; and the quality, tailorability and performance characteristics of the fabric is related with mechanical, surface and dimensional properties at the low-stress region of this fabrics. These properties are tensile, shear, bending, compression surface friction, hygral expansion and relaxation.

The key elements in subjective hand evaluation may be defined as [5];

- The judges; particularly their expertise
- The criteria of judgement; the choice of descriptors for fabric attributes

- The assessment conditions; seen or unseen, controlled temperature and relative humidity
- The assessment technique; free or specified fabric, manipulation technique for assessment of given attributes
- The method of ranking or scaling the assessment; rank order, graded standards, magnitude estimation
- Analyses of results; relative importance of individual descriptors for end-use, correlation between descriptors, redundancy, fabric-specification profiles, vector maps, and sensory space.

In fabric objective measurement backgrounds, the identification of appropriate, objectively measurable fabric properties, related to the fabric characteristics and assessment techniques used in subjective evaluation, also became a fundamental aim.

2.2.2 Standardization of Fabric Handle

By the establishment of HESC in 1969 by the leading of Kawata, a survay on fabric handle was begun by with experts in textile mills. In the first stage of this committee's activity, twelve experts, mainly from finishing mills dealing with worsted fabrics, became members of HESC.

At first, these experts didn't know what they mean about fabric handle. They just evaluate the fabric handle and express a value judgement. Many discussions started in this committee on the basis of Kawata's survey of fabric handle judgement. In the first stage, the meaning of fabric handle is discussed, and, the understanding of the fabric handle became clear among the HESC members. According to the Committee members [1];

1. the fabric handle that was used in textile mill, or, more precisely, in wool-textile finishing mills in Japan, was professional terminology for expressing the character and quality of a fabric as manifested by its performance with respect to fitting to the human body, the feel of the surface, and comfort in wearing.
2. visual appearance, such as the surface character and the silhouette of a garment when the fabric is tailored, was also an important factor in hand evaluation.
3. there were some important separate features of fabric character involved in the assessment of fabric handle, and it was certain that a common understanding of these features of handle existed among the experts in this area.

There were still differences in understanding of handle among experts, so that the fabric hand had to be standardized. After the discussion with experts, the sequence of judgement of fabric handle was identified as shown in Figure 2.2. The expert touches the fabric firstly and then detects the fabric mechanical properties such as stiffness etc. the expert then expresses his feeling by some summarized subjective descriptors such as Koshi (stiffness). Each of these summarized subjective descriptors is not one simple mechanical property, but is the combination of various properties. These descriptors have been used widely and commonly in the textile industry in Japan, especially in wool sector. Each of these expressions are correlated with the fitting of the fabric to the human body and the mechanical comfort and aesthetic silhouette of the garments made from it. These fabric descriptors are shown in Table 2.1 with English translations and the meanings. Each of these fabric hand expressions is called 'primary hand' by Kawabata.

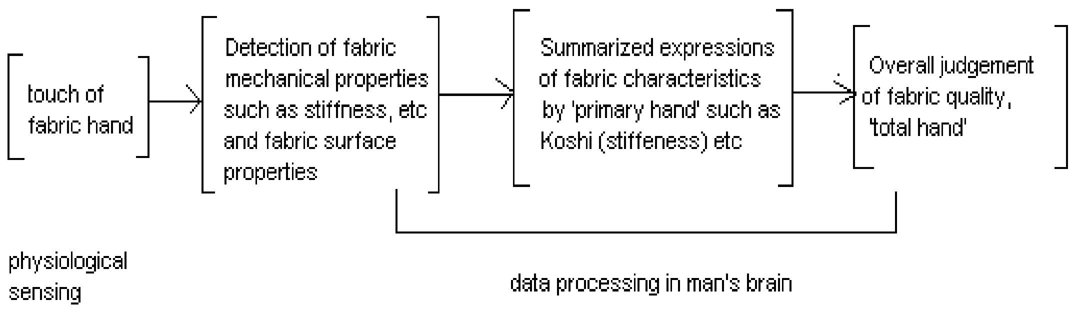


Figure 2.2: The Sequence of Judgement of Fabric Handle by Experts [13].

After the judgements of primary hand values, the experts evaluated the final hand, which defines the fabric quality as good or poor. This overall fabric handle is called 'total hand'.

Table 2.1: The Definitions of Primary Hand Expressions [5]

Primary-hand Expression (Fabric Descriptor)		
Japanese	English Equivalent	Definition
KOSHI	Stiffness	A feeling related to stiffness. A springy property promotes this feeling. A fabric having a compact weave density and made from springy and elastic yarn gives a high value
	Firmness	
	Resilience	
	Springiness	
	Solidity	
NUMERI	Smoothness	A mixed feeling coming from a combination of smooth, supple, and soft feelings. A fabric woven from cashmere fibre gives a high value.
	Sleekness	
	Silkiness	
	Softness	
FUKURAMI	Fullness and Softness	A feeling coming from a combination of bulky, rich, and well-formed impressions. A springy property in compression and thickness, accompanied by a warm feeling, is closely related with this property. (The Japanese word literally means swelling.)
	Fullness	
	Loftiness	
SHARI	Crispness	A feeling coming from a crisp and rigid fabric surface. This is found in a tightly woven fabric made from a hard and strongly twisted yarn. This gives a cool feeling. (The Japanese word means crisp, dry and a sharp sound caused by rubbing the fabric surface on itself.)
HARI	Anti-drape stiffness	The opposite of limp conformability, whether the fabric is springy or not. (The Japanese word means spread)
	Hardness	
	Boardiness	
SOFUTOSA	Softness	Not a primary-hand expression, but a feeling coming from higher NUMERI and FUKURAMI and weaker KOSHI.
KISHIMI	Scroop	The feeling and sound associated with some lightweight silk fabrics.
SHINAYAKASA	Flexibility	A feeling of softness and flexibility characteristics of many silk fabrics.
	Soft-feeling	
	Limpness	
TEKASA	Crepe-like	A feeling characteristics of silk crepe fabrics.

The experts didn’t notice that they evaluate the handle in two steps. They thought that they made their judgements in one step. At the beginning they did not agree the separation of the process. Kawabata and his co-worker asked them some questions, like why a particular fabric has a good or poor handle, with respect to the handle judgement. They answered without exception that the fabric has a poor KOSHI (stiffness), and high NUMERI (smoothness), and etc. These are the factors that describe the fabric character regardless of its quality, and primary hands are the important expressions that are used to have a final decision. After the discussions, the experts agreed that they did the judgements in two-steps. Another point was that the primary hand definitions were not the same for each expert. Therefore, each of the primary hands were selected and formulated with respect to the exact definitions, with the agreement of experts.

The standardization of the primary hands was carried out by HESC members. 500 samples of men’s winter suiting are judged by the means of handle as primary hands, by each expert. Then, the expert divided all the samples in three groups due to its strongest, weakness, and moderateness, in order to strengthen the particular fabric primary hands. He again divided these three groups, in three sub-groups in the same way as in the first grading. After this separating procedure, the fabrics had been in nine groups. Finally, the fabrics that had extremely strong feeling and extremely weak feeling were separated from the strongest and the weakest groups. Thus, a total of eleven grades were given to the fabrics primary hands, and this rating was defined as ‘hand value’. Table 2.2 show the rating system of hand values of the primary hands.

Table 2.2: Hand Value of the Primary Hand [1]

Hand Value	Feeling Grade
10	The strongest
.	
.	
5	Medium
.	
.	
1	The weakest
0	No feeling

The total hand was also graded in the same way as for the rating of primary hand, but the grading was limited from 5 to 0 as shown in the Table 2.3. This rating was defined as 'total hand value'. 214 samples of winter suiting and 156 samples of summer suiting was selected for this judgement. At this time, the objective evaluation of fabric handle had been almost completed.

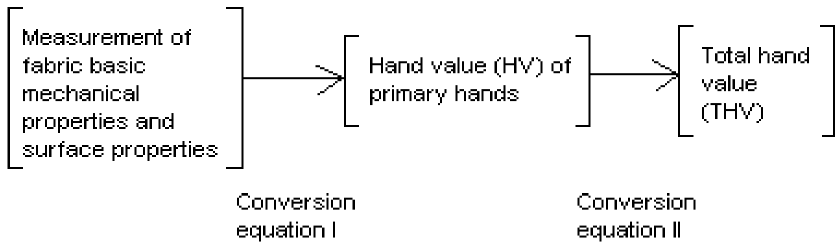


Figure 2.3: The Objective System of Evaluation of Fabric Handle [13].

The experts' subjective system shown in Figure 2.2 was replaced by objective expert system in Figure 2.3.

Table 2.3: Total Hand Value (THV) [1]

Grade	THV
Excellent	5
Good	4
Average	3
Fair	2
Poor	1
Not useful	0

Kawabata and Niwa [10] have defined another value for the appearance of fabrics. In order to derive the fabric property concerning to the making-up property of suit, the fabric mechanical properties were correlated with the appearance of the tailored suit by tailoring factıry experts. This new value is called 'total appearance value' and abbreviated as TAV. TAV of a fabric is a measure of the overall appearance of a suit [14]. TAV is graded in the same way as THV. The components related to appearance are defined as [10];

Formability components: The fabric property relating to formability of smooth three dimensional curve of suit.

Elastic component: It is related to the elastic property of fabric, it makes a beautiful and smooth curve of suit with high shape retention ability.

Drape component: It is related to beautiful suit silhouette.

The derivation of TAV is also carried out in the same way as THV.

Kawabata and Niwa [1] has mentioned about the applicability of primary and total hand. Each of the primary hands refers characteristic feature of fabric handle, due to the assessment of experts. In theory, the ranking of the primary hand values should be the same whoever the expert is and wherever he comes from. In practice, the difference should be small and could be reduced as the improvement of the formulation and the analyses during the research. Thus, primary hand values aim at universal validity as a way of characterizing fabric handle.

Total hand refers the overall quality of the fabric, which is a measure of its selling to the consumer. Its ranking will be effected by the cultural differences and will differ from country to another due to its climate and traditions, will be different due to which market is being aimed, and will change as fashion changes. From another point of view, there could be some fabric properties that is not changeable for consumers as the property related to high quality without considering the traditions, culture, country, or fashion changes, etc., because the quality may come from a fabric property that is the fitting of the body. Thus, total hand value includes both the universality and mobility.

2.3 The Measurement Techniques For Fabrics

2.3.1 General Methods

To have a general knowledge about handle and quality of fabrics, some physical tests were applied to fabrics. The people who was working in this area, specially preferred to measure the properties which defines the finishing processes for desired end-uses and handle.

Besides, before Kawabata has designed the KES-F instruments, to determine the necessary measurement parameters for fabric quality, various kinds of test methods, due to national and international standards for physical parameters such as BS, ASTM, ISO, AATCC and other standards were used.

The test methods for objectively measurable parameters related to fabric hand which are considered to be fundamental by many authors, are shown in Table 2.4.

2.3.2 Fabric Objective Evaluation Techniques

When the traditionally used textile materials are determined, an important criteria is the comfort of the aesthetics and psychological sense of the apparel fabric. The comfort sense of a fabric has various kinds of properties and it can not be determined according to one simple physical parameter. Fabric handle is commonly used to determine the comfort of textile materials.

Objective evaluation is defined as the evaluation of fabric handle, quality and related fabric properties that can be defined as objective properties of the fabrics. The basic aim of this measurement is, to determine the quantity of the desired end-use properties of the apparel and fabrics.

In last decades, the important properties for fabrics which are used as garments, wanted to define as objective measurement. The commonly used fabric assessment was fabric handle judgement which is a subjective evaluation system. But since 1930s lots of researches was made about fabric mechanical properties and these researches were followed in textile industry.

Objective evaluation method is relied on the measurement of mechanical properties of the fabrics. These mechanical properties are the properties which deviated to numerical values from primary hand expressions. Then these hand values (HV) are deviated to total hand values. These are the quality values of the fabric suiting. In Table 2.5, objectively measurable physical properties associated with attribute descriptors commonly used in subjective fabric evaluations is shown.

After the standardization of fabric primary hands and total hand, objective evaluation system for fabric handle was completed.

Table 2.4: Summary of Test Methods for Objectively Measurable Parameters Associated with Fabric Hand [5]

Fabric deformation/Property	Test method/Apparatus	Parameters Measured
Bending (stiffness)	Flexometer, Planoflex, Clark Stiffness Tester, Gurley Stiffness Tester, Olsen Stiffness Tester	Bending length, flexural rigidity, bending modulus, force-deflection curve
Drape	MIT Drape-o-meter, FRL Drapemeter, Cusick Drape Tester	Drape coefficient, drape length, number of nodes, shape factor of nodes,
Tensile	Universal/tensile testers, (Instron, Hounsfield, etc.)	Load-elongation curve, extensibility, recovery, hysteresis, initial Young's modulus
Shear	Universal/tensile testers (Bias-cut samples shear attachment), Mörner and Eeg-Olofsson Tester, Behre's Tester	Load-extension in bias direction, shear-force-shear-angle curve, shear modulus, shear hysteresis
Compression and Thickness (softness in compression)	Thickness gauge, micrometer, Schiefer Compressometer, universal testers (compression cells)	Standard thickness, hardness, thickness-pressure curve, compressibility, compressional resilience and hysteresis
Friction	Firction meter, universal testers (sledge meter)	Coefficients of static and dynamic friction, frictional-force-displacement curve
Roughness (smoothness)	Roughness tester, Bekk/Sheffield paper smoothness testers, comparison with smoothness standards	Roughness index, Bekk seconds, Sheffield number
Warmth	Guarded hot-plate, density method, cover-factor method	Thermal conductivity, thermal diffusivity compactness, cover factor

In the fabric objective measurement context, measurement of physical properties that includes any deformation of the fabrics should be made by using applied stress in the same magnitude as it is imposed by handling the fabric. The methodology is mentioned as the measurement of 'low stress fabric mechanical and surface properties', since the stresses applied in other sorts of textile performance testing are compared with those in fabric handling and making-up properties. The mechanical properties of apparel fabrics are important from the point of view of stresses to fabrics in the making up, as well as physical changes in the fabrics as a result of application of forces in a garment during its use [15].

Table 2.5: Objectively Measurable Physical Properties Associated with Attribute Descriptors Commonly Used in Subjective Fabric Evaluations [5]

Common Subjective Descriptor	**Associated Objectively Measurable Phisical Properties**
Thickness	Thickness, areal density, compressibility/compression
Fullness	Thickness, compression/compressibility, compressive resilience, bending stiffness/hysteresis
Weight	Areal density, thickness
Firmness	Compression/compressibility, shear and bending stiffness/hysteresis, tensile extension/recovery
Crispness	Bending, compression and tensile stiffness and resilience, roughness, friction and sound emitted
Softness	Bending, compression and tensile properties, shear stiffness and hysteresis, areal density, friction
Hardness	Compression/compressibility, shear tensile and and bending stiffness and hysteresis
Stiffness	Bending stiffness, thickness, areal density, shear stiffness/hysteresis, compressibility
Flexibility	Bending stiffness, thickness, areal density, shear stiffness/hysteresis, compressibility
Stretchiness	Tensile extensibility/recovery
Fineness	Thickness, roughness, areal density
Coarseness	Thickness, roughness, areal density
Roughness	Roughness, friction, prickle, shear and bending stiffness, thickness, areal density
Harshness	Bending and shear stiffness/hysteresis, roughness, friction
Smoothness	Roughness, friction, hairiness, specular reflectance
Surface appearance(lustre, hairiness)	Roughness, hairiness, specular reflectance
Scroop	Friction, roughness, shear stiffness/hysteresis, bending hysteresis, bending, loudness and frequency of sound emitted
Rustle	Loudness and frequency of sound emitted, friction, roughness, shear and bending stiffness
Warmth	Thermal conductivity/resistance, thickness, compressibility, hairiness, shear and bending stiffness

It was too difficult to design a fabric because of its non-linear structure. Because of the non-linear structure of fabrics, the mechanical properties and the handle of fabrics are tried to determine with objective measurements, to have numerical values to design the fabrics before manufacturing, and this area became more important.

Fabric mechanical properties are very important to determine fabric quality, appearance and performance of the fabrics and garments.

After the widespreadly acceptance of the objective evaluation system, garment and manufacturing engineers paid more attention to mechanical parameters which deviated from primary hand values as objective measurements and they applied these parameters to their tailorability process controls.

The three criteria of the fabric quality is defined as written below [10];

1.Fabric Handle: Fabric handle is the traditional subjective evaluation of fabric quality. The objective evaluation of handle is totally developed. This depends on originally to feel when touched. The smoothness of the fabric is primarily important.

2.Suit Appearance: This property depends on fabric mechanical properties which is related with predictable making-up properties of suits. Traditionally, this property could be estimated from handle. However, this property was not clear because it is related with the deformation of the mechanical property under the low-load region and it is very difficult to understand this mechanical property by touching. The objective system which is related with this estimation is developed in last times.

3.Wearing Comfort: This property is basically about the tensile and shear deformation of the fabric.

According to Postle [8] the main concept of the objective measurement technology is, to measure the fabrics for garment's quality, tailorability and performance properties with sufficient and necessary sets of instruments. The reason of the possibility of this approach are;

- The possibility of measurement of mechanical and physical properties of the fabrics at low-load region with adequate instruments.
- The successfully development of the analytical methods to explain the data.
- The widespread use of computers and because of this a wide data can be collected and retrieved when needed.

At this period of time at modern industry, objective measurement of the raw materials and products is preferred to subjective measurement. The main reason is the need of 'quick response' and the reduced faults by using the automation in textile and clothing industry. The use of objective evaluation system of fabrics make the textile and clothing industry to adapt these developments.

The primary aim of objective measurement is to make a correlation between sensory reactions and instrumental data by testing and prediction of fabric handle.

The mechanical properties of the fabrics have an important place to determine the quality, performance, appearance and the performance of the fabrics and garments. These properties are influenced not only by fabric finishing but also by the types of wool used for spinning as well as yarn and fabric construction, fabric laundering or dry cleaning, and finally by either physical or chemical degradative processes [6].

2.3.2.1 Kawabata Evaluation System For Fabrics (KES-F)

KES-F system is designed according to the research of Kawabata with HESC and it is the first objective evaluation system. KES-F objective evaluation system is based on the measurement of fabrics in low-load region mechanical properties. In this system scientific principles are applied to instrumental measurements and fabric low stress mechanical and surface parameters such as fabric extension, shear, bending, compression, surface friction and roughness are interpreted. Fabric handle is calculated from the measurements of these mechanical properties.

The following two research and development areas were covered by Kawabata and his co-workers [15];

(1).Determination of the hand values which characterize the linear and non-linear mechanical properties of fabrics,

(2).Development of a quick and accurate measuring system for the fabric mechanical properties.

This work caused to the development of four different types of instruments of Kawabata Evaluation System for Fabrics. The first KES-F instruments were produced in 1973. These instruments are:

1. KES-FB1: Tensile and Shear Tester
2. KES-FB2: Bending Tester
3. KES-FB3: Compression Tester
4. KES-FB4: Surface-friction and Geometrical-roughness Tester

One 20X20 specimen is used to measure with four instruments. It is the facility of using KES-F instruments. With one sample the mechanical properties can be measured for both warp and weft directions and with another one for the bias directions.

The Kawabata Tensile Tester takes a rectangular strip of fabric (5 cm long by 20 cm wide) and applies a strain along the warp direction up to 500 gf/cm. The rate of extension and the rate of recovery is constant, during which the forces are recorded.

A fabric of the same size is used in the Kawabata Shear Tester and held under 10gf/cm tension. The shearing force is applied at right angles to this tension so that the resultant deformation has shear super imposed on tensile strain. The forces are recorded as the shearing movements are applied and reduced.

The bending tester enables samples to be bent accurately and continuously in an arc of constant curvature. The torque exerted during bending and straightening are continuously monitored.

Compressional characteristics are determined as the sample is deformed by two circular plates of 2 cm^2. The rate of loading and recovery is specified.

The Kawabata Surface Tester measures surface roughness and smoothness. Samples are measured in Warp and weft directions, on the face and on the back. A delicate probe is used to traverse the surface of the fabrics during which the vertical movements are recorded to give a measure of roughness. Another probe is slid over the surface and the resistance to movement enables the frictional characteristics of the fabric to be determined.

The friction measurement gives a mean value (and a mean deviation) between the static and dynamic coefficients of friction of metal (steel) to fabric, rather than the more usual static and dynamic coefficients of friction of fabric to fabric.

Weight tests are specified by BS 2471.

Parameters Measured by KES-F System:

A total of 16 parameters can be obtained from this system. These are [7];

Tensile Parameters

- EMT: Percentage tensile elongation which is the ratio of actual extension to the original sample length, expressed as a percentage. EM is typically between %3 and %10.

- WT: Tensile energy or work done in tensile deformation represented by area under the stress-strain curve.

- RT: Tensile resilience which is the ratio of work recovered to work done in tensile deformation, expressed as a percentage. Typical RT values are between %55 and %70. For shirting fabrics RT can be as low as %30.

- LT: Tensile linearity which is a measure that defines the extent of non-linearity of the stress-strain curves. LT values below 1.0 indicates that the stress-strain curve rises below a 45˚ straight line while LT values greater then 1.0 indicate that the stress-strain curve falls above a 45˚straight line. Typical LT values are between 0,55 and 0,7.

Shear Parameters

- G: Shear modulus which is the slope of the shear curve that falls between angles 0.5˚ and 5˚. Typical G values are between 0,6 and 0,9 gf.cm/degree for suiting fabrics. Lower values are expected for shirting fabrics.

- 2HG and 2HG5: Hysteresis width at shear angle 0.5˚ and 5˚, respectively. Typical 2HG5 values are between 1 and 3 gf/cm for suiting fabrics. PE/W blend fabrics tend to have higher G and 2HG5 than %100 wool fabrics.

Bending Parameters

- B: Bending stiffness which is the slope of the bending curve that lies between the radius of curvature of 0.5 cm^{-1} and 1.5 cm^{-1}. Typical values of B are between 0,04 and 0,1 $gf.cm^2/cm$.

- 2HB: Hysteresis width at a bending curvature of 0.1 cm^{-1}. Typical 2HB values are between 0,015 and 0,05 gf.cm/cm.

Compressional Parameters

- T_0: Fabric thickness (mm) at a very low compressive stress of 0.5 gr/cm^2

- T_m: Fabric thickness (mm) at a maximum compressive stress of 50 gf/cm^2

- WC: Compressional energy or work done in compression represented by the area under the compressive curve. For suiting fabrics typical WC values are between 0,1 and 0,5 $gf.cm/cm^2$.

- RC: Compressive resilience which is the work recovered to the work done in compression deformation, expressed as a percentage. Typical RC values are between %35 and %60.

- LC: Compression linearity which is a measure of the deviation of the deformation curve from a straight line. Higher values of LC imply a higher initial resistance to compression. In general, all fabrics have low values for linearity compared with tensile testing. Typical LC is between 0,3 and 0,5. Lower LC makes a fabric feel softer.

Surface Parameters

- MIU: Coefficient of surface friction as measured over 3 cm length of fabric. Typical values are between 0,15 and 0,3.
- MMD: Mean deviation of coefficient of friction. Typical MMD range is from 0,01 to 0,05.
- SMD: Surface roughness (mean deviation of surface peaks representing thick and thin places). Typical SMD range is from 2 to 15 μm.

Originally, KES-F instruments were supplied with chart recorders, and the measured parameters had to be read from the plots and transferred manually to a database for computation. For some years, the instruments have been available with full computerized data collection and processing. The cost of the complete system is around GB£ 100.000. Because of this high price the KES-F system couldn't take place so quickly in textile industry outside of Japan.

Recently (1991), an automated version of tensile and shear tester, KES-F1 Auto, was introduced to industry for rapid uses. And an ultra-sensitive compression tester, KGS-G5 has also been introduced as an improvement on the conventional KES-FB3 compression tester.

In Table 2.6 the 16 parameters that are obtained from KES-F system is represented.

2.3.2.2 The FAST System

Fabric assurance by simple testing (FAST) is a system that consists of three instruments and a test method to measure the properties of wool and wool-blend fabrics, related to fabric making-up properties, tailoring performance and the appearance of tailored garments in wear. The FAST system can be used as an alternative system to KES-F system in fabric development, optimization of finishing, evaluation of new technologies (spinning system, finishing machinery), and buying control for garment makers.

FAST was developed to provide the industry a simple, robust, relatively inexpensive system for fabric objective measurement of mechanical properties of fabrics which are important in garment manufacture. It is mainly used by manufacturers, finishers and garment makers.

Table 2.6: The Parameters Measured on the KES-F System [7]

Property	Symbol	Parameter Measured	Unit
Tensile	EMT	Extensibility, the strain at 500 gf/cm	[%]
	LT	Linearity of tensile load-extension curve	[-]
	WT	Tensile energy per unit area	[gf.cm/cm^2]
	RT	Tensile resilience, the ability of recovering from tensile deformation	[%]
Bending	B	Bending rigidity, the average slope of the linear regiond of the bending hysteresis curve to ±1.5 cm^{-1}	[gf.cm^2/cm]
	2HB	Bneding hysteresis, the average width of the bending hysteresis loop at ±0.5 cm^{-1} curvature	[gf.cm/cm]
Shear	G	Shear rigidity, the average slope of the linear region of the shear hysteresis curve to ±2.5 cm^{-1}shear angle	[gf/cm.degree]
	2HG	Shearing hysteresis, the average widths of the shear loop at ±0,5 shear angle	[gf/cm]
	2HG5	Shearing hysteresis, the average widths of the shear hysteresis loop at ±5 shear angle	[gf/cm]
Surface	MIU	Coefficient of fabric surface friction	[-]
	MMD	Mean deviation of MIU	[-]
	SMD	Geometrical roughness	[mm]
Compression	LC	Linearity of compression-thickness curve	[-]
	WC	Compressional energy per unit area	[gf.cm/cm^2]
	RC	Compressional resilience, the ability of recovering from compressional deformation	[%]
	T	Fabric thickness at 50 N/m^2	[mm]
Weight	W	Fabric weight per unit area	[mg/cm^2]

Critical Fabric Properties for Garment Making [16]

When assessing the tailorability of fabric by hand, the stretchability, looseness, stiffness and stability properties are determined. In engineering these terms are explained as extensibility, shear rigidity and bending rigidity which are called mechanical properties. These properties and the dimensional stability of fabrics can be measured objectively with simple instruments. The importance of these properties to the tailoring operations are;

a)Fabric extensibility: Extensibility affects the laying-up operations. In highly extensible fabric may be stretched while being laid, and when it is cut in the extended shape then it will have a different size. It also affects the sewing operations. Inextensible fabrics may cause seam pucker while highly extensible fabric needs more sewing care to ensure pattern matching [16].

b)Fabric looseness: Looseness affects both the cutting and sewing operations. Very loose fabrics (low shear rigidity) is prone to pattern distortion during cutting and sewing which can result in the buckling of a sewn panel. Very rigit fabric (high shear rigidity) may be difficult to form into a three dimensional shape without unwanted buckling, as well as making it difficult to match patterns [16].

c)Fabric stiffness: Stiffness affects the handle of a fabric as well as the sewing operation. Less stiff fabric (low bending rigidity) has a soft handle but is prone to seam pucker, especially if the fabric is light-weight [16].

d)Fabric dimensional stability: It consists of;

i. Relaxation Shrinkage (how the fabric shrinks during steaming or wetting) [16]

ii. Hygral Expansion (how the fabric dimension changes with changing relative humidity) [16]

iii. Stability of the surface layer of the fabric (which affects the subjective feeling of smoothness) [16]

To measure with FAST system, half meters of fabric at full width is enough. For all 4 test methods, it has to be prepared different samples.

The instruments of FAST system are;

FAST-1: Compression meter

FAST-2: Bending meter

FAST-3: Extensibility meter

FAST-4: It is a test method to measure relaxation shrinkage and hygral expansion of wool fabrics.

FAST-1 Compression Meter: This instrument is developed to measure fabric thickness and surface thickness. Thickness is measured over a circular area of 10 cm^2 at 2 gf/cm^2 and 100 gf/cm^2. Surface thickness is defined as the difference between these two values.

To determine the surface stability, the fabric is measured at 2 gf/cm^2 and 100 gf/cm^2 after steaming and vacuuming 30 seconds. The increase in surface thickness after this process is similar to the increase that occurs during garment manufacture.

The surface layer is measured before and after fabric has been released with steam.

The principle is to position the fabric samples on the reference surface of the compression meter and lowering appropriate weights onto the fabric. The fabric thickness is displayed and printed. From this data the fabric surface thickness and the released fabric surface thickness can be calculated.

FAST-2 Bending Meter: This instrument measures the bending length of the fabric related to the ability of a material to drape. Fabric bending rigidity is calculated from the bending length and fabric mass per unit area.

Very flexible fabric (low bending rigidity) may exhibit seam pucker, while a fabric of higher bending rigidity may be more manageable during sewing, resulting in a flat seam [17].

FAST-3 Extension Meter: This instrument provides a direct measure of fabric extension under selected loads.

The specimens are gripped between two parallel sets of jaws and extended by a selected of 5, 20 or 100 gf/cm. The instrument measures the increase of a 100 mm gauge length of the sample in millimeters and the fabric extension is displayed directly as a percentage.

FAST-4 Dimensional Stability Test: Dimensional stability is a very important property in garments. The lack of dimensional stability can cause poor appearance in garments. The changes in dimensions can occur during using. Changing in humidity causes the change in dimension of fabric, especially from steaming or wetting.

There are three component of dimensional stability in wool fabrics;

1. Relaxation Shrinkage: It occurs during wetting and pressing of fabrics. Once relaxation occurs, it cannot be recovered.

2. Hygral Expansion: It occurs as the moisture in fabric changes in response to changing humidity including steam pressing. This process is reversible.
3. Felting Shrinkage: It occurs when garments are washed. It is also an irreversible process.

In FAST-4 dimensional stability test first the specimen is dried to measure its dry dimension(L_1). Then the specimen is soaked in water to measure its wet relaxed dimensions(L_2). And at least the specimen is re-dried to measure its final dry dimension(L_3).

Information Obtained From the FAST system

Using the FAST system, 14 parameters can be measured and calculated. These parameters are shown in the Table 2.7.

Dimensional Stability (FAST-4)

$$R.S. = \frac{L1 - L3}{L1} \qquad \textbf{(2.1)}$$

$$H.E. = \frac{L2 - L3}{L3} \qquad \textbf{(2.2)}$$

L_1: length of dry, relaxed fabric

L_2: length of wet fabric after relaxation in water

L_3: length of dry, unrelaxed fabric

Extensibility (FAST-3): Using the FAST system, extensibility is measured as a percentage increase in length at sample loading of 5gf/cm, 20 gf/cm and 100 gf/cm width. The quoted value for fabric extensibility is that measured at 100 gf/cm. The extensibilities in the warp and weft directions measured at 5 gf/cm and 20 gf/cm are used to calculate fabric formability. Bias extensibility is measured only at 5 gf/cm width.

Bending Rigidity (FAST-2): Bending rigidity is calculated by;

$$B.R. = W * (B.L.)^3 * 9{,}807 * 10^{-6} \qquad \textbf{(2.3)}$$

with bending rigidity in μN.m, bending lenght in mm and fabric weight in g/m^2.

Shear Rigidity (FAST-3): In the FAST system, shear rigidity is calculated from bias extensibility of the fabric under 5 gf/cm loads, and is given by;

$$S.R = \frac{123}{B.E.} \qquad \textbf{(2.4)}$$

with shear rigidity in µN.m and bias extensibility in %.

Thickness/ surface thickness (FAST-1):The thickness is measured at 2 gf/cm and 100 gf/cm, and the surface thickness, defined as the difference between the thickness at these two loads;

$$S.T = \frac{T(2)}{T(100)} \qquad \textbf{(2.5)}$$

Relaxed thickness/ surface thickness (FAST-1): The relaxed thickness of the fabric is measured after the fabric has been relaxed in steam (open press for 30 seconds)

Formability: The FAST system uses the derived parameter, formability, in the analysis of fabrics. Formability is a measure of the extent to which a fabric can be compressed in its own plane before it will buckle. This parameter, as the product of the bending rigidity and the extensibility of the fabric at low loads, is defined in the FAST system as;

$$F = B.R.*\left[\frac{E(20)-E(5)}{14,7}\right] \qquad \textbf{(2.6)}$$

with formability in mm^2, bending rigidity in µN.m and extension in %.

2.3.2.3 The Comparison of KES-F System and FAST System

Both KES-F system and FAST system were designed to measure the fabrics low stress mechanical properties, but they differ in several ways.

Firstly the specimens used are different. In KES-F system 20X20 cm specimen s used to measure with all four instruments. It makes the measurements faster. In FAST system for all instruments there has to be different samples to measure and the specimens are standard fabric strips 5 cm long.

Secondly, the two measurement systems use different principles. The most obvious difference from KES-F is that FAST has no facility for measuring hysteresis effects, so no information can be gained on fabric recovery characteristics [12].

Although, the two systems uses different measurement principles, in previous works it is found that these two systems have a high correlation coefficient.

Table 2.7: The Parameters Measured on the FAST System [7]

Instrument	Property	Symbol	Parameter Measured	Unit
FAST-1	Compression	T_2	Thickness at 2 gf/cm^2	mm
		T_{100}	Thickness at 100 gf/cm^2	mm
		ST	Surface thickness	mm
		STR	Released surface thickness	mm
FAST-2	Bending	C	Bending lenght	mm
		B	Bending rigidity	μN.m
FAST-3	Tensile	E_5	Extension at 5 N/m	%
		E_{20}	Extension at 20 N/m	%
		E_{100}	Extension at 100 N/m	%
		EB_5	Bias extension	%
	Shear	G	Shear Rigidity	N/m
FAST-4	Dimensional Stability	RS	Relaxation Shrinkage	%
		RC	Hygral Expansion	%
	Derived parameter	F	Formability	%.mm^2

3. PREVIOUS STUDIES

The main research about the relationship between fabric mechanical properties and fabric handle is first mentioned by Pierce [18], in 1930. His article “The Handle of Cloth as a Measurable Quality” which had been published in “The Journal of Textile Institute” in 1930 was the first research about the relation of fabric mechanics and fabric handle. ‘Handle’ of a material is investigated and it is then converted in to numerical values in this article. This paper mainly describes the tests that will help to determine stiffness and hardness, the sensation while fabric is first touched. The ‘Handle’ of a fabric hadn’t been discussed in terms of physical parameters before Pierce. The bending length, the flexural rigidity, the thickness, the hardness or resistance to compression, the bending modulus, the compression modulus, the density and the extensibility are the quantities that may be used as measures of the stiffness of a fabric according to this article. After Pierce first mentioned about the importance of the relationship between fabric handle and mechanics, lots of researchers were attracted to study and develop new studies in this field. Fabric mechanics had been the most important key element of fabric quality in a short time.

In mid 1900’s, researchers revealed their own measurement principles and used different methods. Mörner and Eeg-Olofsson [19] have designed and built an apparatus which measures the shearing properties of a fabric deformed in its own plane. This device also could record the deformation on a graph and provide a complete hysteresis curve for the shear resistance of the fabric.

Livesey and Owen [20] have described a manual instrument, in which a fabric specimen could be taken through a bending cycle. Readings of two angles were taken at steps throughout the cycle, and, after rather laborious arithmetical calculations, the curve of couple against curvature could be plotted.

Owen [21] have described an automatic instrument in which the hysteresis curve is drawn automatically by a pen recorder. This instrument is found to be ideal for research purposes, since the detailed bending behavior may be studied very expeditiously with its aid.

Thorndike and Varley [22] have described an instrument for recording the coefficient of static friction between samples of cloth by reciprocating one sample and recording the resultant motion of the other when restrained by springs. Some test results are given for cloths with different structure, and those made from normal and high-draft worsted system spinning yarns. Each cloth was tested against itself, the pairs of samples used being selected from the same piece of each cloth. In conclusion, the tester seems to be capable of giving results which can have some value in assessing certain properties of cloth. The new instrument has been found to be versatile, easy to use, and quite accurate. The structure has a greater effect and the nature of the fiber appears to be still more important. The coefficient of static friction was higher for plain weave than for any other structure, using comparable yarns. This may indicate that, in a fabric with a float surface, some of the yarn rolls under the influence of frictional forces, an effect which consequently reduces the coefficient of static friction.

Lindberg *et al.* [23] have discussed the characteristic attributes of the loading and the recovery part of shearing and buckling curves, the relation between recovery curves and crease recovery properties of fabrics. They have concluded that there is a close relation between simple deformations such as shearing and plane buckling and complex deformations as buckling of wrinkled fabric shells. A theoretical analyses was given in this study and it is shown that formability can be expressed as the product of an anisotropy ratio and the square of the fabric thickness. Another conclusion was the dependence of shell buckling on both the plane buckling load and shear angle, the shell buckling load decreased as the shear angle load increased. It is further shown that combination of high formability and low shell buckling load generally was attained by combining relatively high thickness with low bending modulus. It is mentioned that there was a certain relation between crease recovery angle and formability, and a good relation between this angle and the non-periodical energy loss in shell buckling.

Treolar [24] have investigated the different shapes of specimens that are used to determine the shear characteristics of fabrics. This study was made of the stress-strain relationships for woven fabrics of viscose and cotton in shear. He concluded that the shear characteristics were sensitive to the shape of the specimen, specifically at low values of the normal tension. This sensitivity was closely related to the reduction in the amount of wrinkling with the rectangular specimen. The inhomogeneity of strain related to the square specimen is substantially reduced by the use of a specimen with a large width/length ratio, with consequent reduction in the wrinkling arising from this inhomogeneity.

In 1970's, Kawabata and Niwa [13, 1, 10, 25, 26] has started to study about fabric mechanics and handle. They studied to make a correlation between fabric mechanics and fabric handle. In 1972, under the sponsorship of the Textile and Machinery Society of Japan, a research committee, The Hand Evaluation and Standardization Committee (HESC), was established by leading of Kawabata. The researches about objective evaluation of fabric handle were accelerated by the foundation of this committee.

The work with HESC on objective evaluation of fabric quality and handle, and his researches on mechanical properties of fabrics made Kawabata to design 'Kawabata Evaluation System for Fabrics' (KES-F) in 1972 [5]. He defined this work as a need for quick and reproducible instrumentation for evaluating the fabric handle. In 1973 the first KES-F instruments were introduced to the industry.

Kawabata and Niwa [1] have investigated the derivation of the mechanical test values into hand values (HV). 214 winter suiting and 156 summer suiting of similar fabrics were chosen. Ten judges were selected for this evaluation and the hand values of these fabrics were evaluated subjectively by these judges. The mechanical parameters were grouped based on six parameters: tensile, bending, shearing, compression, surface and constructional. Statistical and regression analyses were done and equations were derived. THV values were obtained with both subjectively and objectively. The calculated (objective) THV was derived from mechanical parameters. The experimental (subjective) THV which are the values of the judgements, were correlated with the objective values. It is concluded that the objective value follows closely the mean value of the experts. The influences of primary hand values on total hand values were also discussed in this study, and it is mentioned that different countries show a good agreement for winter suiting, but for the summer suiting, a difference in the quality judgement was shown.

Kawabata *et al.* [26] have investigated the relationship between fiber crimp and fabric quality. Various fabrics in different qualities were used for this research. It was found that the fibers taken from high quality fabrics have higher crimp level. The importance of fiber crimp on extensibility was also concluded. The effect of fiber on the improvement of fabric quality was mentioned. The relationship between fiber crimp and primary hand was also investigated. It was found that there is a strong correlation between these properties.

Postle *et al.* [27] have reported the results of an extensive study, involving the variability of measuring low-stress fabric mechanical and surface properties. Seven sets of KES-F instruments were used in different countries for interlaboratory tests, and for each country thirty wool and wool blended fabrics were used for this study. The elastic and inelastic components of fabric deformation in shear, tension, bending and compression; and fabric surface behaviors, surface topography and friction values were given for repeatability and reproducibility. They have presented a series of recommendations for using KES-F series of instruments, for the experimental testing of fabric mechanical and surface properties as a conclusion. They mentioned that each laboratory should decide on the acceptable level of within-laboratory variance required, based on the repeatability. They recommended at least three tests on each instrument for each fabric. For each sample, both in weft and warp directions should be measured. One measurement is sufficient in each thread direction for tensile and bending tests and two measurements in each thread direction for fabric surface tests.

Ly and Denby [28] have presented the precision data in terms of the repeatability and reproducibility of sixteen parameters measured by KES-F system. It is concluded that the repeatability is acceptable for in-house product development and process evaluation. But for commercial specifications, poor reproducibility restricts the use of KES-F system.

Postle [29] has reported the results of a survey about fabric handle assessments and quality attributes involving numerous textile and clothing experts from eight territories. This fabric handle survey carried out on a large number of men's worsted suiting fabrics with participation of Japan, Australia, New Zealand, India, the US, Hong Kong, Taiwan and China. The aim of this survey was to identify the agreement between experts from different countries, if they have the same judgement about handle or if they give the same importance to the same fabric attributes. Not only experienced experts participated but consumers and people without background in textiles also participated to this survey. It was shown that the expert judges show a very good agreement among individuals within each country, and the consumers without background in textile judges show reasonable agreement between themselves. The agreement between each national group judges shows a good agreement in winter fabrics but the cultural and/or climate differences affect the summer fabric ratings.

Harlock [30] has discussed the principles of fabric mechanical property measurements. KES-F system is presented in this study as an objective evaluation system, but it is mentioned that these parameters can be measured by other systems such as Instron type tensile testing machines, Shirley Bending length tester and so on. As a result, the knowledge of these mechanical property data can be correlated with subjective assessment to provide a quality knowledge which is very important for the textile and clothing industry.

Postle *et al.* [31] have studied about the fabric mechanical and physical properties related to the clothing manufacture. Actual measurements; fabric overfeed, formability, shear and hygral expansion, during tailoring was reported. They found out that, the hygral expansion of fabrics in wool-rich fabrics, as they absorb and desorb moisture, can effect the garment appearance. The relationship between tailoring and garment performance and the mechanical properties –fabric longitudinal extension and compression, shear and bending- have been also investigated. It is shown that the maximum degree of overfeeding is directly related to the fabric formability which is defined as fabric bending rigidity and fabric longitudinal compressibility.

Barndt *et al.* [32] have investigated the use of KES-F and FAST instruments in predicting processability of fabrics in sewing. They used wool and polyester-wool blended fabrics, ranging from 150 g/m^2 to 250 g/m^2 in their study. They were followed the procedures described by Ito, in establishing a fabric profile of acceptable mechanical properties for tailoring. They have concluded that FAST system is a better predictor of tailoring difficulties than KES-F system. The presence of the dimensional test makes FAST system to be more sensitive indicator for tailoring problems.

Yokura and Niwa [33, 14, 34] have evaluated the fatigue of jackets tailored from a series of kersey weave fabrics under wear and simulation conditions, by using KES-FB objective evaluation instruments. Both handle durability and shape retention during wear of jackets tailored from kersey weave fabrics with different level of extensibility was evaluated in this study[33]. It is concluded that fabric fatigue is quantified by the increase in shear hysteresis (2HG) and the primary hand value, numeri (smoothness) decreased with both wear and the simulation tests. In another study, Yokura and Niwa [14] evaluated the fabric handle durability and shape retention during wear of men's summer suits and these parameters were evaluated under wear and simulation conditions by the use of KES-FB instruments. In this study TAV (Total Appearance Value) was used to compare the parameters. TAV of a fabric is defined as a measure of the overall appearance of a suit. It is shown that the decrease in the TAV of fabrics with a high TAV, was less than the decrease in the TAV of fabrics with lower TAV after the simulation test. It can be concluded that TAV of the fabrics can be used to characterize the appearance of a suit after wear according to the results. It is found out that the hysteresis properties of fabrics such as bending and shear increased with wear and it is concluded that the fatigue phenomena can be quantified by the increase in mechanical hysteresis properties. Yokura and Niwa [34] have discussed about the increased mechanical hysteresis properties with wear of fabrics and provided some qualitative explanations. The increase of mechanical hysteresis properties of fabrics with wear is considered to be dependent on the structural modification of fiber assemblies, the increase in interfiber friction, and the change in mechanical properties and crimp of fibers.

Ly *et al.* [17] have presented FAST instruments in their study. They compared FAST instruments with similar KES-F instruments to support their new instrumentation system. In all comparisons with KES-F instrument values, they obtained good correlation results. As a conclusion, the authors proposed FAST instruments to fabric finishers and tailors because of its advantages and easiness for use.

Kawabata and Niwa [13] have studied the application of fabric objective measurement of fabric mechanical property and quality for textile and clothing manufacturing. In this study, Kawabata and Niwa have mentioned about three important performance categories. These categories defined as; utility performance (strength, etc), comfort performance (fitting to the human body) and fabric performance for the engineering of clothing manufacture. Fabric mechanical properties were measured in low load level in this research. This condition is similar to the actual fabric deformation as in use. The mechanical properties were measured by KES instruments. These data were directly applied to the objective measurement of fabric handle, for the development of new fabrics and for the engineering of apparel manufacture. The fabric handle was assessed objectively, first primary hands and then the total hand. The accumulation of these data in the database was thought to be very helpful for both engineering and the sale of fabrics and garments. They also presented the control charts in their study. This chart shows the quality zones of the fabrics assessed. The zone of a high quality fabric can be a guide for the development of new fabrics.

Wemyss and De Boss [35] have investigated the interaction between fabric cover factor and finishing on fabric properties. The dimensional property of hygral expansion was determined according to Show’s method and the mechanical properties were evaluated by KES-F system. In conclusion, the properties relevant to tailorability was found to be depend primarily on the finishing methods. According to the article, it can be mentioned that the bending rigidity primarily depends on cover factor and fabric weight, and HE (hygral expansion) is depended on compactness at the basic finishing level. HE can be related mainly to weave crimp and yarn interaction for a wide range of weave structures and cover factors.

A tailoring process control was developed by Ito with the assistance of Kawabata and Niwa [25]. This research had begun in 1975 with the accumulation of a database for the relation between fabric processability and the making-up properties of men's suits. Ito started some trials about tailoring process control according to objective evaluation system and set this system in practice in his company on a suit-production line. This research mainly describes some of the necessary points of the control of tailoring process by Ito. Some properties which affect tailoring such as mechanical properties, steam-press shrinkage, sponging, etc. was described in this study. In the control system each of these properties were compared with tailoring process. Then a tailoring control system was defined which was developed by Ito. In this control system, the determined values were limited according to the tailoring processes. So that when the values were determined they could know if the fabric is ready to tailoring or not. For the details of the indications for control, they prepared a table [25], and in this table the criteria of the parameters, basis of the indication and some examples of the indications were shown. They also presented different control systems developed by other companies after the development of Ito's tailoring process control system and they presented the control charts which was demonstrated in 1983 by Ito and Kawabata. This chart was called 'tailoring control chart'. They have presented the modified version of this chart in their study.

Le *et al.* [36] have investigated the effect of decatizing temperature, rotary pressing and fabric regain on the mechanical properties of fabrics in various constructions and dying stages. The changes in mechanical properties of decatized fabrics were measured by FAST system. Pure wool fabrics with different weave types, and dying stages, were used in this research. In conclusion, it is found out that undyed plain fabrics were the most sensitive ones to decatizing treatment. Bending rigidity was decreased and extensibility and bias extensibility was increased at higher decatizing temperature. Rotary pressing has also effected the mechanical properties, these can be summarized as increasing in bending rigidity and decreasing in tensile properties.

Shishoo [15] studied the fabric mechanical and physical properties in the clothing manufacturing process with a computerized system. In this research, two different projects, were carried on. The first one was about the fabric mechanical properties and tailorability. In this project, a computerized methods analysis (CMA) was used. This computerized system contains the production data collection and standard time determination. The basic mechanical properties that are used in this study were measured by KES-F system. A jacket with pockets and flaps was used as the test garment. It was mentioned that, for a given garment type and a given set of basic patterns, the tailorability of a fabric can be quantified by standard time determinations by using CMA. The correlation between CMA-times that were obtained for various test fabrics and tailorability that was calculated from various mechanical properties was determined and a satisfactorily correlation was obtained, 0,89. The second project was based on fabric mechanical properties and fabric design. In this study, a CAD simulation system was used. The aim of this research was to quantify the relation between fabric mechanical properties and fabric drape/shape. In the second study 0,92 was obtained as the correlation coefficient. This correlation coefficient was obtained from the relationship between drape coefficients of 20 fabrics and mechanical parameter for TAV prediction.

Kit-Lun Yick *et al.* [37] have compared the two commercially available objective evaluation systems (FAST and KES-F) for shirting materials. They compared low-stress mechanical properties, namely bending, shear and tensile properties of shirting materials. They found out that these two systems have a high correlation despite they use different measurement principles. The comparison between FAST and KES-F shear properties, the correlation coefficient was 0,90. The correlation coefficient between bending rigidities of these two systems was 0,97 and this correlation was extremely strong. The correlation of extensibility property was also strong and the coefficient of correlation was 0,96. Between the derived parameters (formability) there was a quite strong correlation, too. The correlation coefficient was found 0,92. As a result, it can be mentioned that, however, the two systems use different measurement principles, there is a good correlation between FAST and KES-F objective measurement systems.

De Boss and Roczniok [38] have studied the importance of formability of the fabrics in finishing stage. They discussed the inadequate formability and the effects on finishing on this property. The importance of formability in garment appearance was described. In the fabrics with low formability, seam pucker may occur more than those of fabrics with high formability. Secondly, the effect of formability on sleeve insertion was defined and it can be said that 'easy to sew' fabrics generally have high warp and weft formability. Thirdly, the formability of fabrics can also be related to the total garment appearance. The important point of seam pucker appears to be related to overall garment appearance. Formability mainly depends on fabric bending rigidity and fabric extension. To increase the formability, in most cases, the extensibility should be increased, and on the other hand dimensions of the fabric should be reduced. Another important point in this study is 'relaxed' and 'unrelaxed' dimensions. In conclusion the finishers must engineer both the final dimensions and the relaxed dimensions as well.

Chen and Collier [39] have introduced a statistical analysis for fabric end-use by fabric physical properties that were determined by KES-FB system. This analysis was used to demonstrate the classification criteria to characterize fabrics for clothing. To characterize fabric end-use properties a multivariate statistical method of discriminant analysis was introduced. The aim of this research was to set up a statistical model to predict fabric end-use directly and to examine the feasibility of the discriminant analysis technique for apparel industry. In this study, ninety apparel fabrics were used which have the end-uses of blouses, shirts and suiting. A statistical analysis was set up for discriminant analysis according to the obtained data from KES-F system, and established the classification criteria for characterizing apparel fabrics used for blouses, shirts and suiting and these end-use properties expressed by three quadratic discriminant functions. The scores which were computed by this functions can be used to grow up new fabrics. This study was an initial study for characterizing fabric end-use properties. But with the reference of this work new mathematical models for apparel industry can be developed.

Fan and Hunter [40, 41] have studied on development of an expert system which can be useful for engineering of design process of worsted fabrics. They presented this work in two articles. They explained the structure, components and functions of the new developed expert system, and discussed the process of fabric engineering in their first study [40]. The second part of the study [41] describes the establishment and evaluation of a neural network model for predicting fabric end-use properties which depends on fiber, yarn and fabric construction properties. In the first study [40], the process of engineering was discussed firstly. Based on the course of engineering, an expert system can be supported by some of these engineering processes; fabric design, predicting of fabric properties and performance, interpretation of testing results, and modification of fabric design and processing parameters. Expert system was developed related to these factors. The system provides a guideline during the fabric is designed, namely it's a guideline for determining the composition, weave, yarn count and sett, yarn type, etc. After the designing of a fabric, the prediction of the properties is made by a neural network model [41]. After the prediction of the fabric, based on these properties, fabric was evaluated by fabric performance interpreter and FAST interpreter. This system provides advice about the engineering processes but leaves the final decision to the user. The application of neural network model consists of input and output units. Input units are parameters which are important for fabric fabric properties and performance. The outputs are fabric properties and performance. The evaluation of the model was made to see whether the effects of fiber, yarn and fabric variables are in agreement with the common knowledge and previous studies, and to see if the values obtained from the model are close to actual values for fabrics. As a result, the model successfully was in agreement with common knowledge and previous studies but large predictive errors exist in results in practice, because of the non-quantifying of the dying and finishing values. In conclusion the model was found out to be a great potential of modeling complex and nonlinear processes in textile industry. It can not be used to predict fabric directly because there are still some parameters can not be quantified, but it can be used to predict fabric properties indirectly based on the properties of a similar fabric manufactured in the same way and environment.

Zhou and Ghosh [42, 43] have developed a generalized fabric bending model based on the bending moment-curvature relation of fabrics. They proposed four loop shapes and analyzed them in the first study [42]. In the continuing study they made a theoretical and experimental analysis and they have investigated the effects of fabric nonlinear bending behavior on the test methods and measured bending rigidity values [43]. They have concluded that the cantilever method (as used in FAST bending meter) is more suitable to adopt for developing an on-line measurement system. It can be concluded that there is a good agreement between simulated results and experimental work as in the literature for cantilever method and heart loop tests. Another conclusion is about the investigation of all the test methods which can characterize fabrics with significantly different bending rigidity. The cantilever test provided the highest bending values; the bending rigidity values, that were determined by heart loop method, were closely to each other for most of the fabrics; and KES-F test had the lowest bending rigidity values.

Kim and Slaten [9] have investigated the relationship between fabric handle and related physical and surface properties by the extraction method. Cotton and cotton/polyester woven fabrics with varying weave constructions and matching pairs of flame retardant treated and untreated fabrics were used. Determined fabric hand by extraction method was effected by physical and surface properties. The important properties that are related to extraction method are drapeability, flexural rigidity, and friction resistance and these properties are related to fabric handle. It is found that physical properties were more effective than surface properties on handle. Drapeability property was the most relevant parameter to represent fabric handle as measured by extraction because of the deformation mechanisms a fabric undergoes during the extraction. This study also demonstrates the determination of a fabric by extraction method provides overall fabric hand for any change in weave structures, the presence of finishing treatments, or wetness and this method was very effective to evaluate fabric handle. Hand measured with this method represents hand as a combination of various physical properties, not as one individual property.

Postle *et al.* [44] have investigated the effect of dyeing and finishing on hygral expansion, relaxation shrinkage and crimp of the yarns in a fabric as measured by KES-F instruments. Pure wool fabrics were used for this research. Dyeing and finishing has effected many mechanical and physical properties of the fabric by changing the crimp of yarns, based on the relaxation of interyarn forces in the unfinished fabrics during processing. The relation of reactive dye and fiber, has changed the fabric crimp as a result of dyeing. In the other hand, the change in crimp has effected the resulting crimp-dependent fabric properties such as hygral expansion and low stress tensile properties. In this study, the most significant result is the effect of the relation of reactive dye and fiber. The interaction between reactive dye and fiber makes a significant change in all fabric properties during dyeing.

Onder, Kalaoglu and Ozipek [45] have studied about the mechanical properties and air permeability of lightweight wool blend apparel fabrics. They studied the mechanical responses in uniaxial tensile and tear tests of gray-state fabrics, and low deformation characteristics in FAST tests of finished fabrics. They also measured drape coefficients and node numbers by using Cusick's method and fabric air permeability. The Sirospun yarns were compared with other conventional two-folded ring spun yarns. It was resulted that fabrics woven from Sirospun yarns have a sufficient tear and tensile resistance, less rigidity, have good drape properties, but more air permeable. The yarn structure is an important factor in determining fabric mechanical responses individually. This Sirospun yarns can be an alternative in wool blend fabrics to two-folded ring spun yarns in appropriate end-use parameters when it is sufficient enough for the product. Another conclusion was about the using of novel polyester yarns. Novel polyester provides good quality fabrics with less bending and shear rigidities and thus soft handle and better drape characteristics. The result of air permeability also supports that with novel polyester blended fabrics, a better comfort conditions can be obtained.

Betcheva *et al.* [46] have investigated the effect of cellulase finishing of dyed cotton fabrics. The effect of enzymatic treatments depending on the pre-existing dyes on the cotton fabrics were evaluated by using KES-F system. The aim of this study was to evaluate the sensitivity of the KES-F system to the enzymatic treatment of dyed cotton fabrics, and the possibility of predicting the influence of reactive dye structures on this process. It is concluded that, geometric roughness parameter of

KES-F system, which characterizes the surface of cotton fabrics, can be used for a quantitative assessment of cellulase finishing. It was found that this parameter was sensitive enough to be applied for evaluating the influence of pre-existing reactive dyes on the cellulase performance during the enzyme finishing. Unlike some other mechanical properties such as bending and shear, the high sensitivity of the surface roughness parameter to the enzymatic treatment was an indication that the cellulase effect was restricted on the surface of the fabrics improving its uniformity and reducing the roughness.

Lahey and Heppler [47] have presented a fabric bending model in their research. This model includes contributions from nonlinear elasticity, and viscous and Coulomb friction with hysteretic effect. This model provides the ability to simulate a continuous sequence of property curves and to generalize to loading conditions not covered in the KES-F regimen. The results obtained from the model were compared with experimental results. It is concluded that hysteretic behavior was observed due to friction between the yarns, and that nonlinear elastic behavior arises from jamming of the yarns and their subsequent compression.

Matsudaira and Sugimura [48] have investigated the aesthetic appearance of swinging flared skirts by developing an objective evaluation equation. The paired comparison method for subjective assessment and KES-F instruments to measure the basic mechanical properties were used. The subjective values were regressed with basic mechanical parameters of the fabrics. It is concluded that, useful and significant objective evaluation equations to estimate various movements of the flared skirts were developed.

Sun and Sylios [49] have investigated the degree of changes in low-stress mechanical properties, and the handle of untreated and O_2 plasma treated fabrics. Wool and cotton fabrics were used for this research. KES-F system was used to measure fabric low-stress mechanical and surface properties. HV and THV values were obtained from mechanical property values by using Kawabata equation. It is found that, plasma treatment changes surface properties and surface roughness leading to an increase in low-stress mechanical properties such as bending and shear rigidities. There was no significant change in fabric total hand value, however between the variously treated wool and cotton fabrics and their untreated counterparts. In conclusion, plasma treated wool and cotton fabrics can be scoured and dyed for shorter periods of time without affecting the total hand value.

Zhang *et al.* [50] have examined the feasibility of fabric softness which was objectively evaluated. Fabric softness was measured by the forces of pulling a fabric sample through a series of parallel pins. The results obtained with pulling forces compared with those values obtained from both FAST results and subjective softness assessments. Their correlation and regression analyses were also carried out. Wool and wool blended woven fabrics with varying weave structures and plain knitted fabrics were used in this study. ın conclusion, the pulling force testing results had a good correlation with the fabric softness subjectively assessed, and there was a good relationship between specific pulling force indexes and selected physical properties obtained from FAST testing. Another conclusion was about the relationship between subjective assessment and objective evaluations, and it is concluded that there is a good correlation between the results of these two assessments.

Alamdar-Yazdi and Shahbazi [51] have investigated the effect of warp and weft densities on the bending properties of polyester viscose woven fabrics. These fabrics were evaluated with KES-F, extraction, and newly-suggested methods. The obtained values from these three methods were compared the concentrated loading method was better able to show the effect of warp and weft density increase as the correlation between the quantitative parameters of the three methods indicated. It is observed that as the density increased, the buckling zone of the fabric under concentrated tensile loading moved up. It shows that the post-buckling slope increases due to warp or weft density, and the ending slope decreases as the fabric density increases.

Matsudaira *et al.* [52, 53] have investigated the measurement of the surface prickle of fabrics. this study carried out in two parts. In the first part of the research [54], a selection of fabrics with a widely differing number and stiffness of protruding fibers was assessed for prickle subjectively and by three objective techniques: low pressure compression-testing, laser-counting of protruding fibers, and a modified audio-pick-up method, in order to find a method of measuring prickle. As a conclusion, the modified audio-pick-up technique showed the greatest potential for measuring fabric prickle or at least for measuring a fabric property that is related to prickle. It was shown that this technique could be used to assess fabric prickle objectively and that a good correlation with the results of a subjective assessment of relative prickliness could be achieved by this objective technique. In the second part of the study [55], the changes in fabric surface prickle during the sequential stages of fabric finishing routines were determined for three fabrics, both subjectively by a panel of judges and objectively by using an audio-pick-up apparatus with a modified stylus. This study records the application of the modified audio-pick-up technique to the measurement of fabric prickle before and after the various stages of fabric finishing. The application of an objective prickle measuring technique was considered to have some potential for explaining the effect of finishing processes on fabric prickle. In conclusion, for most of the merino-wool fabric surface, both subjective and objective methods found prickle, to be very low from loomstate to finished fabric. For two fabric surfaces containing wool fibers, the decreases or increases, in prickle due to sequential finishing processes were appreciable. It is concluded from the first and second parts of the study that the modified audio apparatus provides useful information relating to fabric surface prickle and could form the basis of an objective test for prickle.

Ramgulam *et al.* [54] have investigated a method of using a laser sensor for the measurement of surface roughness and compared the results with those obtained by conventional contact methods. Ten plain woven fabrics were used for the study. ın addition to the non-contact scanner, two other available roughness testers were used for the present studies, KES-F surface tester and the rotary roughness-measuring part of the multipurpose tester. In conclusion, it was shown that the laser sensor can be successfully used for the measurement of geometrical roughness, since tactile examination of surface roughness involves a level of applied pressure, one may argue that contact methods give values closer to the perceived roughness experienced with fingertips and are therefore more suitable for the estimation of fabric handle and comfort.

Gong and Mukhopadhyay [55] have discussed the fabric characteristics of eight fabric groups as measured by KES-F system. These fabrics are grouped by fiber content, fabric construction and special finishing treatment. Silk, polyester, cotton fibers are used as raw materials; satin, twill and plain constructions are used as fabric constructions. Silk fabric is used as the reference fabric. Ten KES-F parameters and two fabric hand descriptions are used to compare the characteristics of fabric groups. In conclusion, the characteristics of silk fabric was defined, firstly. Silk fabric has low shear stiffness, shear hysteresis and bending hysteresis. Caustic-reduced polyester fabrics have very silk-like fabric handle, but they differ from the silk fabric in surface properties. Liquid ammonia-treated cotton fabrics also have a silky hand. Micro-fiber fabrics are soft and smooth, but they do not have the same handle as silk fabric has. Fabric construction has some effect on fabric stiffness, but not on hysteresis. Polyester-lining fabrics have high bending stiffness and polyester/cotton fabrics have very high shear stiffness and hysterersis. These two fabric groups are the least silk-like. Shear properties and bending hysteresis appears to be the most important factors affecting the hand of the fabrics studied.

Hu, Chen, and Newton [56] have compared Webber-Fencher’s law, Kawabata-Niwa’s law and Stevens’s law, for primary hand prediction by using a multiple regression approach. The results showed that the deviations from Stevens's law were much smaller than those from the other three models. Stevens's law had been selected for the prediction of primary hand values. Equations for stiffness, smoothness, and softness and fullness prediction were derived by using the data from 39 worsted fabrics. a psychophysical explanation for the process of fabric hand evaluation, that is a basis of the selection of Stevens's law, was made, additionally.

Matsudaira, Tan, and Kondo [57] have investigated the effect of fiber cross-sectional shape on fabric mechanical properties and handle. To clarify this effect, the basic mechanical properties such as tensile, bending, shear, compressional and surface properties of polyester 'Shingosen' fabric with different cross-sectional shapes were measured by sing KES-F system, and fabric handle was obtained by the objective evaluation method developed by Kawabata and Niwa. It was concluded that, polyester fabric becomes softer and deformable with an increase in the space ratio in the fiber cross-section, however, it becomes inelastic and unrecoverable. FUKURAMI (fullness and softness) and SHINAYAKASA (flexibility with a soft feel) of polyester fabric is greater with higher space ratios, but , KOSHI (stiffness) and HARI (anti-drape stiffness), becomes lower. Fabric bending rigidity is in proportion to fiber bending rigidity if all other conditions such as yarn density, count and finishing conditions remain the same. However, in general, the fabric mechanical properties and handle are controlled by the fiber assembly structure rather than fiber cross-sectional shape.

Postle [58] have studied the measurement of tensile, shear, bending, buckling, longitudinal and lateral compression properties, surface friction, smoothness and dimensions, accurately and reproducibly, of wool and wool blend fabrics; and the correlation of these instrumental measurements with the quality, tailorability and performance of wool fabrics and garments. It is concluded that, wool and wool-rich fabrics are more easily tailored into garments of good appearance than polyester-rich fabrics because of their generally higher levels of extensibility and formability. Relatively lightweight fabrics are usually more difficult to tailor into garments of good appearance because they exhibit very limited longitudinal compressibility before the fabric buckles or puckers.

4. EXPERIMENTAL

4.1 Physical Tests

Physical parameters are tested according to Turkish Standards (TS). The physical tests are applied at Istanbul Technical University, Physical Testing Laboratory. The parameters that are determined are yarn number as N_m, in both warp and weft directions, according to TS 255; twist level as tour/m, according to TS 247; weave design, weight as g/m^2, according to ISO 1833-1977: Method E; yarn densities as (picks/ends)/cm, according to TS 250 EN 1049-2; yarn crimps in both warp and weft directions; tearing resistance in both warp and weft directions, according to EN ISO 13937-3 (TS 1998); and strength resistance in both warp and weft directions, according to EN ISO 13934-1. In Table 4.1, the materials, yarn numbers, fineness, weave designs, and weight of used fabrics are shown. In Table 4.2, yarn densities, yarn crimps, tearing and strength resistance are shown.

4.2 Raw Materials

Twenty one 100% wool and wool blended woven suiting fabrics, with a fineness which differs from 19,5 to 21,5 micron, were used in this study. Ring spun and siro spun yarns are used as the spinning types. Polyamide, polyester, elastane, linen, mohair, and viscon with wool fabrics are used as blended fabrics.

4.3 Calculated Parameters

Weave tightness, cover factor, and weave factor parameters are calculated parameters. Weave tightness of the fabrics are calculated according to Russell, Galuszynski, and Seyam and El-Shiekh. Before defining the tightness, the related parameters of tightness and related weavability theories are defined.

Table 4.1: The Materials, Yarn Numbers, Fineness, Twist Levels, Weave Designs, and Weight of the Fabrics Used

Fabric no	Material	Nm / Twist Level(tour/m) / Fineness(micron)		Weave Design	Weight (g/cm2)
		Warp	Weft		
1	%100 wool	77/2 / 811 / 19,5	78/2 / 812 / 19,5	2/1 twill	163,55
2	%100 wool	72/2 / 678 / 20,5	38/1 / 706 / 21,5	2/1 twill	165,31
3	%100 wool	78/2 / 815 / 19,5	78/2 / 833 / 19,5	plain	144,37
4	%100 wool	80/2 / 813 / 19,5	80/2 / 821 / 19,5	plain	142,37
5	%100 wool	70/2 / 710 / 20,5	37/1 / 760 / 21,5	plain	158,89
6	%80 wool %8 polyamid %8 polyester %4 elastan	72/2 / 718 / 20,5	72/2 / 741 / 20,5	plain	168,89
7	%88 wool %8 polyamid %4 elastan	72/2 / 795 / 20,5	72/2 / 782 / 20,5	plain	182,18
8	%88 wool %8 polyamid %4 elastan	72/2 / 742 / 20,5 66/4 / 520 / 20,5	72/2 / 753 / 20,5 66/4 / 474 / 20,5	2/2 basket and 2/2 filling rib	259,68
9	%54 polyester %44 wool %2 elastan	80/2 / 854 / 20,5	80/2 / 837 / 20,5	2/1 twill	210,02
10	%54 polyester %44 wool %2 elastan	100/2 / 934 / 19,5	100/2 / 917 / 19,5	2/1 twill	159,84
11	%55 polyester %45 wool	82/2 / 900 / 20,5	80/2 / 891 / 20,5	2/1 twill	164,01
12	%55 polyester %45 wool	80/2 / 814 / 20,5	82/2 / 851 / 20,5	3/1(+2 -1)twill	163,51
13	%50 polyester %50 wool	56/2 / 690 / 21,5	56/2 / 670 / 21,5	2-2/2-5(+3)twill	316,54
14	%40 wool %45 polyester %15 linen	70/2 / 750 / 20,5 56/2 / 600 / 20,5	70/2 / 736 / 20,5 56/2 / 698 / 20,5	plain	152,89
15	%40 wool %45 polyester %15 linen	80/2 / 880 / 20,5 54/2 / 680 / 20,5	80/2 / 891 / 20,5 57/2 / 663 / 20,5	4/4 basket	197,07
16	%80 wool %20 polyester	16/1 / 541 / 20,5	16/1 / 534 / 20,5	2/1 twill	251,68
17	%75 wool %25 mohair	76/2 / 837 / 19,5	38/1 / 765 / 20,5	plain	140,93
18	%55 polyester %45 wool	80/2 / 912 / 20,5	80/2 / 850 / 20,5	2/1 twill	167,9
19	%54 polyester %44 wool %2 elastan	80/2 /867 / 20,5	80/2 / 806 / 20,5	2/1 twill	185,19
20	%50 polyester %50 wool	46/2 / 602	46/2 / 612	2/2 twill	294,04
21	%50 polyester %50 wool	67/2 / 866	65/2 / 875	2/1 twill	206,71

Table 4.2: Yarn Densities, Yarn Crimps, Tearing, and Strength of the Fabrics Used

Fabric no	Density [ends(picks)/cm]		Crimp		Tearing (kg.f)		Strenght (kg.f)	
	Warp	**Weft**	**Warp**	**Weft**	**Warp**	**Weft**	**Warp**	**Weft**
1	34	26	12,1	8,5	3	1,3	31,95	25,7
2	32	28	6,1	12,1	1,75	1,8	33,4	23,54
3	28	24	6,8	15,3	3,2	1,1	28,44	23,16
4	28	24	7,8	15,3	1	1,1	25,16	20,87
5	27	24	6,9	25,7	1,2	1,15	29,07	21,68
6	28,5	24,5	17,2	32,6	4,6	1	34,75	20,11
7	28	25	21,5	31	0,9	0,9	28,63	22,64
8	35	25	26,5 25	29,7 30	1,85	1,4	41,71	28,44
9	36	26	28,4	38,6	3,1	2,7	54,15	35,1
10	37	28,5	11,4	27,6	3,35	2	60,89	32,69
11	34	26	6,6	9,4	6	4,3	57,16	47,92
12	36	25	9,3	10,3	3,25	2,2	49,85	43,14
13	59	22	13,4	4,8	6,45	6	73,99	61,41
14	23	23	11,8 11,7	7,5 7,5	3,1	2,75	36,23	33,56
15	31	30	10,4 9,1	6,6 5,2	6,1	6,6	41,6	35,58
16	17	15,5	18,22	17,33	2,4	2,6	26,57	31,7
17	29	24	5,2	17,6	2,02	1,2	27,55	18,2
18	32	26	13,5	8,8	2,5	2,9	51,71	48,13
19	36	25	10,5	33,02	2,3	2,1	60,48	38,43
20	33	28	15,09	10,9	5,53	4,67	102,67	86,5
21	35	26	14,6	7,3	5,62	5,15	94,67	68,5

4.3.1 Weave Factor and Yarn Diameter

4.3.1.1 Yarn Diameter

Two important geometrical parameters that are needed for the maximum-weavability and tightness relationships are the weave factor and yarn diameter.

Yarn diameter can be expressed in terms of yarn linear density in the Tex system as;

$$d = \frac{1}{280{,}2}\sqrt{\frac{N_t}{\varphi * \rho_f}} \qquad \textbf{(4.1)}$$

where;

d : Yarn diameter

N_t : Yarn linear density (tex, g/km)

φ : Yarn packing factor = ρ_y / ρ_f, and

ρ_f : Fiber density (g/cm^3)

The packing factor depends on finer variables (such as fiber crimp, length, size, cross section shape, etc.), yarn parameters (such as twist, spinning method, etc.), and fabric parameters (such as warp and pick densities, weave, etc.). Table 4.3, shows the density of some commonly used fibers.

Table 4.3: Fiber Density [59]

Fiber Type	**Fiber Density (g/cm^3)**
Acetate	1,32
Cotton	1,52
Glass fiber	2,47
Kevlar	1,44
Lycra	1,20
Lyocell	1,56
Nomex	1,38
Nylon 6	1,14
Nylon 6.6	1,13-1,14
Polyester fiber	1,38
Polypropylene fiber	0,91
Rayon	1,52
Wool	1,32

Table 4.4 shows packing factor data for a few types of yarn.

Table 4.4: Packing Factors for Different Yarn Types [59]

Yarn Type	**Packing Factor**
Ring-spun	0,60
Open-end-spun	0,55
Worsted	0,60
Woolen	0,55
Continuous-filament	0,65

For fiber blended yarns, an average fiber density should be used for the equation (4.1). the calculation of average fiber density can be shown as;

$$\frac{1}{\overline{\rho_f}} = \sum \frac{\rho_i}{\rho_{fi}} \qquad \textbf{(4.2)}$$

where;

$\overline{\rho_f}$: Average fiber density,

ρ_i : Weight fraction of the *i*th component,

ρ_{fi} : Fiber density of the *i*th component, and

n= number of components in the blend

4.3.1.2 Weave Factor

The weave factor is a numerical value which expresses the number of interlacing of warp and weft yarns. This factor can be used as a tightness factor to compare fabrics if all other construction parameters are the same. It is defined as the ratio of the tread amount to the interlacing amount. When the warp and weft weave-interlacing patterns are different, two weave factors need to be defined [59];

$$M_1 = \frac{N_1}{i_1} \qquad \textbf{(4.3)}$$

$$M_2 = \frac{N_2}{i_2} \qquad \textbf{(4.4)}$$

where;

M_1 : Warp weave factor,

N_1 : Number of warp ends per weave repeat,

i_1 : Number of filling intersections per weave repeat,

M_2 : Filling weave factor,

N_2 : Number of filling treads per weave repeat, and

i_2 : Number of warp intersections per weave repeat

Table 4.5 shows the values of the warp and weft weave factors of basic weaves.

Table 4.5: Weave Factors of Basic Weaves [59]

Weave	N_1	i_1	N_2	i_2	M_1	M_2
Plain	2	2	2	2	1	1
2x1 Twill	3	2	3	2	1,5	1,5
2x2 Basket	4	2	4	2	2	2
2x2 Twill	4	2	4	2	2	2
Five-harness Sateen	5	2	5	2	2,5	2,5
2x2 Warp Rib	2	2	4	2	1	2
2x2 Filling Rib	4	2	2	2	2	1

4.3.2 Maximum Construction Theories

4.3.2.1 Ashenhurst's Theory of End Plus Intersections

Maximum numbers of warp and weft treads are defined as;

$$t_{1\max} = \frac{M_1}{M_1 * d_1 + d_2} \quad \textbf{(4.5)}$$

$$t_{2\max} = \frac{M_2}{M_2 * d_2 + d_1} \quad \textbf{(4.6)}$$

where;

$t_{1\max}$: The maximum number of warp ends per unit fabric width,

$t_{2\max}$: The maximum number of picks per unit fabric length,

M_1 : The warp weave factor,

M_2 : The filling weave factor,

d_1 : The warp tread diameter, and

d_2 : The filling tread diameter.

For square fabrics, equations (4.5) and (4.6) reduced to one equation, that is;

$$t_{max} = \frac{M}{(M+1)*d} \quad \textbf{(4.7)}$$

4.3.2.2 Ashenhurst's Curvature Theory

The equation for square fabrics, according to Ashenhurst's curvature theory can be defined as;

$$t_{max} = \frac{M}{(M+0{,}732)*d} \quad \textbf{(4.8)}$$

4.3.2.3 Brierley's Theory of Empirical Maximum Weavability

Brierley proved experimentally that the weave factor affected fabric thickness. The higher the weave factor, the thicker was the fabric. Brierley derived an empirical relationship for the maximum sett of square worsted fabrics made from 100% wool, according to his experimental study. this equation, that can be applied to any type of yarn and fiber, is defined as;

$$t_{max} = M^m/1{,}84d \quad \textbf{(4.9)}$$

where;

M: the weave factor,

m: a constant dependent on the weave type, and

d: the yarn diameter

In Table 4.6, the values of m for twill, satin, and basket weaves are shown.

Table 4.6: Values of *m* for Different Weave Types

Weave	***m***
Twill weaves	0,39
Satin weaves	0,42
Basket weaves	0,45

4.3.3 Tightness

Researchers have described a reference fabric that can be used to define a cloth, to help woven fabric designing. The ratio of the cloth construction parameters to the corresponding parameters of the reference fabric was defined as 'fabric tightness' [59]. The objective of developing fabric tightness was to check whether fabric properties could be related to fabric tightness so that the designers could develop fabrics with a certain performance. Additionally, knowledge of fabric tightness could be useful in constructing similar fabrics that may differ in one or more of the construction parameters.

4.3.3.1 Russell's Tightness

Russell suggested a tightness calculation based on the maximum sett of Ashenhurst's theory of end plus intersections. For given yarns and a given weave, maximum sett of this type would have only one set of values. In other words, the reference fabric was is unique. The fabric, warp, and filling construction factors are defined as;

$$C_f = \frac{t_1 + t_2}{t_{1\max} + t_{2\max}} \qquad \textbf{(4.10)}$$

$$C_1 = \frac{t_1}{t_{1\max}} \qquad \textbf{(4.11)}$$

$$C_2 = \frac{t_2}{t_{2\max}} \qquad \textbf{(4.12)}$$

where;

t_1 : end density,

t_2 : pick density,

$t_{1\max}$: maximum end density,

$t_{2\max}$: maximum pick density

the maximum end and pick densities can be estimated from (4.5) and (4.6).

4.3.3.2 Galuszynski's Tightness

Galuszynski [60] argued that the fabric tightness which was defined by Russell does not fit for the different weave types (twill, satin, basket). He suggested the use of Brierley's empirical formula instead of the equations of ends plus intersections.

$$T_f = \frac{t_1 + t_2}{t_{1\max} + t_{2\max}} \quad \textbf{(4.10)}$$

$$T_1 = \frac{t_1}{t_{1\max}} \quad \textbf{(4.11)}$$

$$T_2 = \frac{t_2}{t_{2\max}} \quad \textbf{(4.12)}$$

The maximum end and pick densities can be estimated from (4.9).

4.3.3.3 Seyam and El-Shiekh's Tightness

Seyam and El-Shiekh [61] compared Russell's tightness, which is based on Ashenhurst's theory of end plus intersections, and Galuszynski's tightness, which is based on Brierley's theory of empirical maximum weavability. The comparison showed that Russell's tightness is close to Galuszynski's for plain weaves, twill weaves up to eight harness, satin weaves up to seven harness, and basket weaves up to six and (3x3 basket). Seyam and El-Shiekh have proposed a geometry that is a combination of the theory of ends plus intersections and the racetrack shape for the treads under a float. From the new geometry, they derived the general equations of end and pick densities of the reference fabric as;

$$t_{1\max} = \frac{4 * M_1}{\pi(M_1 - 1) * d_1 + d_1 + d_2} \quad \textbf{(4.13)}$$

$$t_{2\max} = \frac{4 * M_2}{\pi(M_2 - 1) * d_2 + d_2 + d_1} \quad \textbf{(4.14)}$$

The tightness can be calculated according to (4.10), (4.11) and (4.12) formulas where the t_{1max} and t_{2max} are calculated according to (4.13) and (4.14).

Seyam and El-Shiekh compared their tightness to Galuszynski's and found that the proposed new tightness could be used for plain weaves, twill weaves up to thirteen harness, satin weaves up to ten harness, and basket weaves up to eight end (4x4 basket). In practice, these weaves represent more than 90% of the weaves used to construct fabrics.

4.3.4 Cover Factor

Cover factor is defined as;

$$c_1 = \frac{d_1}{p_1} \tag{4.15}$$

$$c_2 = \frac{d_2}{p_2} \tag{4.16}$$

$$p_1 = \frac{1}{S_1} \tag{4.17}$$

$$p_2 = \frac{1}{S_2} \tag{4.18}$$

$$c = c_2 + c_1 - c_1 * c_2 \tag{4.19}$$

where;

c_1: warp cover factor,

c_2: weft cover factor,

c: fabric cover factor,

S_1: warp density,

S_2: weft density,

d_1: warp tread diameter, and

d_2: weft tread diameter.

In Table 4.7 the calculated parameters are shown. These are; warp, weft and total tightness according to Russell, Galuszynski, and Seyam and El-Shiekh; warp, weft and total cover factors, and warp and weft weave factors.

Table 4.7: The Calculated Parameters of the Study

Fabric no	Tightness									Cover Factor			Weave Factor	
	Russell			Galuszynski			Seyam and El-Shiekh							
	Warp	Weft	Total	Warp	Weft	Total	Warp	Weft	Total	Warp	Weft	Total	Warp	Weft
1	0,824	0,63	0,727	0,777	0,594	0,686	0,789	0,603	0,696	0,496	0,378	0,687	1,5	1,5
2	0,917	0,855	0,887	0,751	0,905	0,816	0,883	0,814	0,849	0,478	0,576	0,779	1,5	1,5
3	0,815	0,698	0,756	0,749	0,642	0,696	0,815	0,698	0,756	0,407	0,349	0,614	1	1
4	0,794	0,68	0,737	0,731	0,626	0,678	0,794	0,68	0,737	0,397	0,34	0,602	1	1
5	0,972	0,864	0,918	0,753	0,921	0,824	0,972	0,864	0,918	0,409	0,5	0,705	1	1
6	0,835	0,718	0,777	0,748	0,678	0,714	0,835	0,718	0,777	0,407	0,368	0,625	1	1
7	0,844	0,754	0,799	0,776	0,693	0,735	0,844	0,754	0,799	0,422	0,377	0,64	1	1
8	0,798	0,684	0,746	0,717	0,633	0,679	0,741	0,668	0,709	0,532	0,38	0,71	2	1,25
9	0,842	0,608	0,745	0,793	0,573	0,683	0,805	0,582	0,694	0,505	0,365	0,686	1,5	1,5
10	0,774	0,596	0,685	0,729	0,562	0,645	0,74	0,57	0,655	0,464	0,358	0,656	1,5	1,5
11	0,794	0,607	0,7	0,748	0,572	0,66	0,76	0,581	0,67	0,476	0,364	0,667	1,5	1,5
12	0,795	0,579	0,69	0,752	0,543	0,65	0,75	0,555	0,655	0,504	0,345	0,675	1,714	1,5
13	1,349	0,57	0,948	1,227	0,536	0,909	1,214	0,534	0,902	0,989	0,369	0,993	2,75	1,83
14	0,727	0,727	0,727	0,669	0,669	0,669	0,727	0,727	0,727	0,363	0,363	0,594	1	1
15	0,593	0,574	0,584	0,533	0,516	0,524	0,517	0,5	0,509	0,475	0,459	0,716	4	4
16	0,894	0,815	0,855	0,843	0,768	0,806	0,856	0,781	0,818	0,537	0,489	0,736	1,5	1,5
17	1,018	0,843	0,931	0,776	0,908	0,831	1,018	0,843	0,931	0,422	0,494	0,708	1	1
18	0,747	0,607	0,677	0,704	0,572	0,638	0,715	0,581	0,648	0,448	0,364	0,649	1,5	1,5
19	0,842	0,584	0,713	0,793	0,551	0,672	0,805	0,559	0,682	0,505	0,351	0,679	1,5	1,5
20	0,915	0,777	0,846	0,857	0,727	0,792	0,85	0,721	0,786	0,61	0,518	0,812	2	2
21	0,901	0,669	0,785	0,849	0,631	0,74	0,862	0,64	0,751	0,54	0,401	0,725	1,5	1,5

4.4 Fabric Mechanical Properties

4.4.1 Kawabata Evaluation System For Fabrics (KES-F)

KES-F devices were used to evaluate mechanical properties of fabrics. As explained in the part of 2.3.2.1 tensile, shear, bending and compression properties of fabrics are evaluated. In Figures 4.1, 4.2, 4.3, and 4.4 KES-F devices are shown.

Figure 4.1: KES-FB1 Tensile and Shearing Tester

Figure 4.2: KES-FB2 Pure Bending Tester

Figure 4.3: KES-FB3 Compression Tester

Figure 4.4: KES-FB4 Surface Analyzing Tester

In Table 4.8 the results of KES-FB evaluations are shown.

4.4.2 The FAST System

FAST system instruments were used to evaluate fabric mechanical properties. As explained in the part of 1.3.2.2 Compression Meter, Bending Meter, Extensibility Meter, and a test method to measure the hygral expansion and relaxation shrinkage were used to evaluate extensibility, shearing, bending, compression parameters likely with KES-F instruments, and, additionally, hygral expansion and relaxation shrinkage were evaluated with FAST instruments. In Figures 4.5, and 4.6, the FAST instruments are shown.

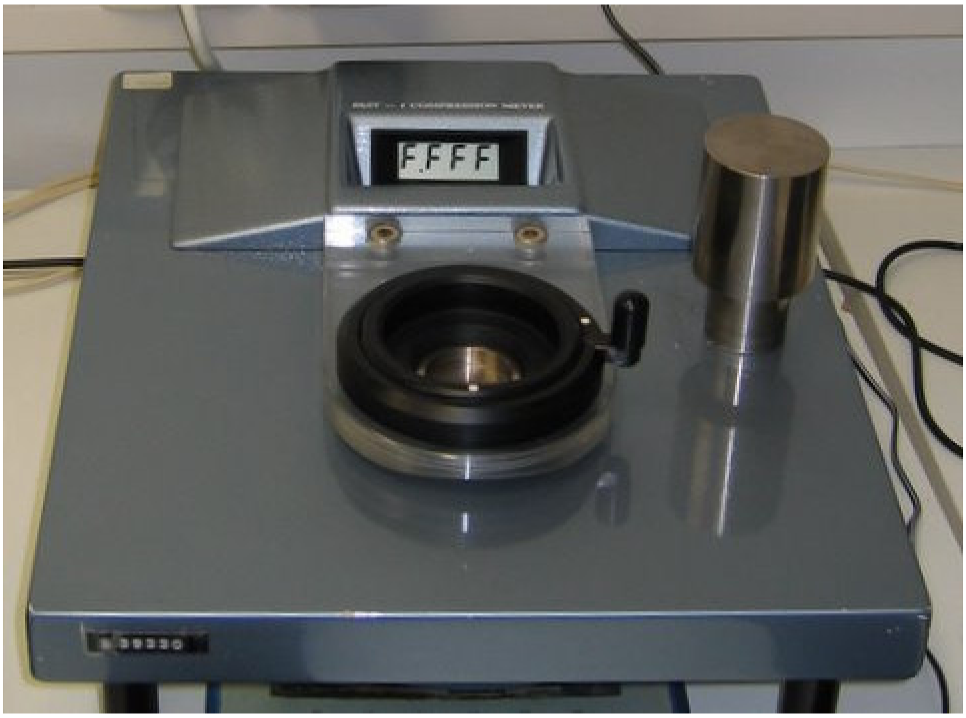


Figure 4.5: FAST-1 Compression Meter

Figure 4.6: FAST-2 Bending Meter

In Table 4.9 the results of FAST evaluation system are given.

Table 4.8: The Results of KES-FB System

	Tensile			**Bending**			**Compression**	**Shear**		
Fabric	EM [%]			B [g.cm²/cm]			WC [g.cm /cm²]	Shear	G [g/cm.deg]	
No	WARP	WEFT	MEAN	WARP	WEFT	MEAN	WARP	WARP	WEFT	MEAN
1	2,64	2,83	2,74	0,065	0,053	0,059	0,09	1	0,88	0,94
2	1,9	3,88	2,89	0,072	0,064	0,068	0,098	0,95	0,86	0,91
3	1,63	4,32	2,98	0,054	0,038	0,046	0,033	1,19	1,01	1,1
4	2,49	4,51	3,5	0,051	0,042	0,046	0,044	1,23	1,1	1,16
5	3	9	6	0,065	0,049	0,057	0,06	0,95	0,68	0,81
6	5,86	11,1	8,48	0,042	0,045	0,044	0,054	0,76	0,73	0,74
7	7,98	10,2	9,09	0,052	0,048	0,05	0,042	1,1	1,11	1,11
8	7,76	10,7	9,23	0,095	0,078	0,086	0,056	1,81	1,67	1,74
9	10,9	14,7	12,8	0,064	0,049	0,057	0,118	1,06	0,89	0,98
10	3,56	10,6	7,08	0,049	0,023	0,036	0,109	1,09	0,74	0,91
11	1,39	2,59	1,99	0,06	0,042	0,051	0,073	0,94	0,88	0,91
12	1,83	2,44	2,13	0,056	0,04	0,048	0,059	1,05	0,97	1,01
13	1,73	1,34	1,54	0,354	0,133	0,244	0,126	1,7	1,6	1,65
14	2,64	1,81	2,22	0,042	0,065	0,064	0,114	1,05	1,04	1,04
15	2,42	1,32	1,87	0,084	0,092	0,088	0,176	0,49	0,51	0,5
16	4,17	4,37	4,27	0,163	0,16	0,162	0,231	1,54	1,48	1,51
17	1,32	5,15	3,24	0,053	0,051	0,052	0,043	1,06	0,88	0,97
18	3,25	2,68	2,97	0,048	0,042	0,045	0,078	0,7	0,64	0,67
19	2,93	13,4	8,16	0,074	0,038	0,056	0,185	1,24	0,73	0,98
20	2,51	2,07	2,29	0,249	0,243	0,246	0,279	3,2	3,07	3,14
21	2,22	1,93	2,08	0,107	0,088	0,097	0,113	1,79	1,67	1,73

Table 4.9: The Results of FAST System

Fabric No	Extension				Shear	Bending			Compression
	E100 [%]			EB5	G [N/m]	B [µN.m]			ST [mm]
	WARP	WEFT	MEAN	Bias		WARP	WEFT	MEAN	
1	2,4	2,8	2,6	2,7	46	6,5	4,4	5,45	0,09
2	1,6	3,5	2,55	2,8	44	7,8	5,1	6,45	0,108
3	1,6	4,5	3,05	2,2	55	4,4	3,5	3,95	0,042
4	2,3	4,7	3,5	2,2	57	4,7	3,4	4,05	0,04
5	3,1	9,3	6,2	3,3	37	5	4,6	4,8	0,056
6	5,9	11,5	8,7	4	30	4,4	4,2	4,3	0,07
7	8,1	10,5	9,3	2,9	43	4,2	3,7	3,95	0,047
8	7,2	9,8	8,5	2	60	6,9	6,5	6,7	0,066
9	10,4	17,3	13,85	3,4	36	6,3	5,1	5,7	0,09
10	3	12,1	7,55	2,8	44	4,4	3,8	4,1	0,092
11	1,3	2,8	2,05	3,2	39	4,3	3,4	3,85	0,068
12	1,5	2,7	2,1	2,9	43	5,3	3,8	4,55	0,064
13	1,1	0,9	1	1,5	79	22,4	9	15,7	0,095
14	2,9	2	2,45	2,5	50	5,1	7,8	6,45	0,104
15	2,3	1,5	1,9	6,4	19	6,4	8,7	7,55	0,152
16	3,4	3,8	3,6	1,9	66	11,1	11,2	11,15	0,203
17	1,3	5,4	3,35	2,7	46	4,6	3,9	4,25	0,045
18	3,8	3,1	3,45	4,2	29	3,8	3,8	3,8	0,057
19	2,9	14	8,45	3,5	35	6,4	4,2	5,3	0,162
20	2	1,5	1,75	0,2	738	37,4	34,7	36,05	0,218
21	2,1	1,6	1,85	1,5	82	10,7	8,7	9,7	0,11

4.5 Fabric Drape

Fabric drape is one of the most important cloth properties in apparel in some cases. The drape of a fabric may be defined as a description of the deformation of the fabric produced by gravity when only part of it is directly supported [62]. Fabric drape is one of the fabric properties which determine the aesthetic appearance of clothing and interior textiles [63]. The ability to fold in two directions at the same time, differentiates fabrics from other sheet materials. This property enables one to mold a fabric to a needed shape or to let it fall on its own and produce a smooth flowing form. This property also requires different characterization methods for evaluating mechanical properties and predicting drape [64].

In this study Cusick Drape Meter is used to evaluate fabric's drape coefficients. Cusick's drape meter consists of a supporting disk on which a larger circular specimen of fabric is placed centrally in such a way that the exterior ring of fabric hangs over the edge of the supporting disk. The form of the overhanging portion of the sample is projected on a sheet of paper using a light source and a concave spherical mirror [62]. The operating principle of Cusick's drape meter is shown in Figure 4.8.

As a measure of drapability the drape coefficient, D, is calculated. The drape coefficient is defined as the ratio of the area of the projection of the draped ring of fabric to the area of the non-draped ring of fabric, multiplied by 100 [62].

The formulation of drape coefficient can be written as [66];

D = (mass of shaded area / total mass of paper ring)*100% **(4.20)**

In Figure 4.7, Cusick's drape meter is shown.

Figure 4.7: Cusick's Drape Meter

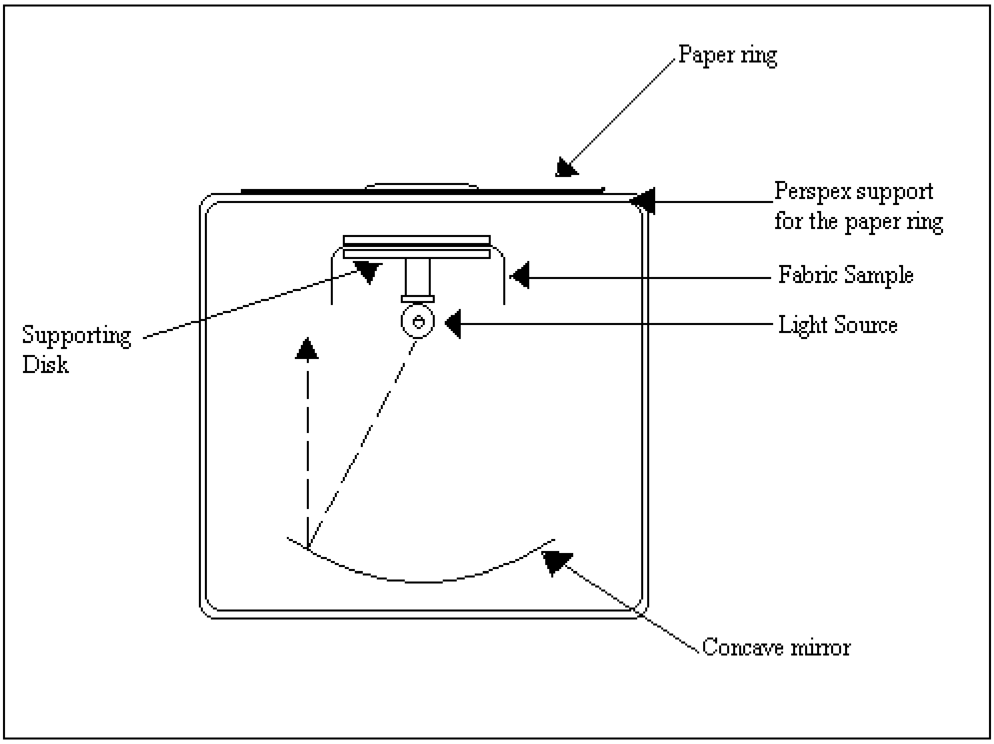


Figure 4.8: The Operating Principle of Cusick's Drape Meter [62]

In Table 4.10, the drape coefficients, node numbers and average amplitudes are shown.

Table 4.10: The Results of Cusick's Drape Meter

Fabric no	Drape ratio	node number	average amplitude
1	0,394	7,8	11,68
2	0,391	6,8	11,64
3	0,385	7,2	11,62
4	0,339	6	11,3
5	0,365	6,2	11,48
6	0,339	8	11,34
7	0,341	7	11,33
8	0,4	7	11,72
9	0,404	7	11,75
10	0,409	7,2	11,78
11	0,383	8	11,62
12	0,36	8	11,47
13	0,529	6,2	12,48
14	0,511	7,8	12,41
15	0,478	7,2	12,2
16	0,509	8	12,4
17	0,427	7	11,88
18	0,342	7,8	11,36
19	0,449	8	12,03
20	0,748	6,8	13,73
21	0,497	7	12,32

4.6 T-Test

Tests of Differences between Means, Independent Groups, Standard Deviation Estimated [67]

This section explains how to test the difference between group means for significance. The formulas are slightly simpler when the sample sizes are equal. These formulas are given first.

Equal Sample Sizes

1. The first step is to specify the null hypothesis and an alternative hypothesis. For experiments testing differences between means, the null hypothesis is that the difference between means is some specified value. Usually the null hypothesis is that the difference is zero.

For this example, the null and alternative hypotheses are:

H_o: $\mu_1 - \mu_2 = 0$

H_1: $\mu_1 - \mu_2 \neq 0$

Tests of Differences between Means, Independent Groups, Standard Deviation Estimated [67]

2. The second step is to choose a significance level. The significance level was chosen 0,05 by SPSS program in our study.
3. The third step is to compute the difference between sample means (M_d).
4. The fourth step is to compute p, the probability (or probability value) of obtaining a difference between and the value specified by the null hypothesis (0) as large as or larger than the difference obtained in the experiment. Applying the general formula,

$$t = \frac{M_d - (\mu_1 - \mu_2)}{S_{M_d}} \qquad \textbf{(4.21)}$$

where;

M_d is the difference between sample means, μ_1 - μ_2 is the difference between population means specified by the null hypothesis (usually zero), and s_{M_d} is the estimated standard error of the difference between means.

Tests of Differences between Means, Independent Groups, Standard Deviation Estimated [67]

The estimated standard error, s_{M_d}, is computed assuming that the variances in the two populations are equal. If the two sample sizes are equal ($n_1 = n_2$) then the population variance σ^2 (it is the same in both populations) is estimated by using the following formula:

$$MSE = \frac{s_1^2 + s_2^2}{2} \tag{4.22}$$

where;

MSE (which stands for mean square error) is an estimate of σ^2. Once MSE is calculated, s_{M_d} can be computed as follows:

$$s_{M_d} = \sqrt{\frac{2MSE}{n}} \tag{4.23}$$

where;

$n = n_1 = n_2$. This formula is derived from the formula for the standard error of the difference between means when the variance is known.

Tests of Differences between Means, Independent Groups, Standard Deviation Estimated [67]

The probability value for t can be determined using a t table. The degrees of freedom for t is equal to the degrees of freedom for MSE which is equal to $df = n_1 - 1 + n_2 - 1$

5. In step 5, the probability computed in Step 4 is compared to the significance level stated in Step 2. Since the probability value is less than the significance level (0.05) the effect is significant.

6. Since the effect is significant, the null hypothesis is rejected. It is concluded that the mean memory score for experts is higher than the mean memory score for novices.
7. A report of this experimental result might be as follows:

Tests of Differences between Means, Independent Groups, Standard Deviation Estimated [67]

Unequal Sample Sizes

The calculations in Step 4 are slightly more complex when $n_1 \neq n_2$. The first difference is that MSE is computed differently. If the two values of s^2 were simply averaged as they are for equal sample sizes, then the estimate based on the smaller sample size would count as much as the estimate based on the larger sample size. Instead the formula for MSE is:

$$MSE = SSE/df \qquad \textbf{(4.24)}$$

Where; df is the degrees of freedom ($n_1 - 1 + n_2 - 1$) and SSE is:

$$SSE = SSE_1 + SSE_2 \qquad \textbf{(4.25)}$$

$SSE_1 = \Sigma(X - M_1)^2$ where the X's are from the first group (sample) and M_1 is the mean of the first group. Similarly, $SSE_2 = \Sigma(X - M_2)^2$ where the X's are from the second group and M_2 is the mean of the second group.

The formula:

$$MSE = \frac{s_1^2 + s_2^2}{2} \qquad \textbf{(4.26)}$$

cannot be used without modification since there is not one value of n but two: (n_1 and n_2). The solution is to use the harmonic mean of the two sample sizes. The harmonic mean (n_h) of n_1 and n_2 is:

$$n_h = \frac{2}{\frac{1}{n_1} + \frac{1}{n_2}} \qquad \textbf{(4.27)}$$

The formula for the estimated standard error of the difference between means becomes:

$$s_{M_d} = \sqrt{\frac{2MSE}{n_h}} \quad \textbf{(4.28)}$$

<u>**Summary of Computations**</u> **[67]**

1. Specify the null hypothesis and an alternative hypothesis.
2. Compute $M_d = M_1 - M_2$
3. Compute $SSE_1 = \Sigma(X - M_1)^2$ for Group 1 and $SSE_2 = \Sigma(X - M_2)^2$ for Group 2
4. Compute $SSE = SSE_1 + SSE_2$
5. Compute $df = N - 2$ where $N = n_1 + n_2$
6. Compute $MSE = SSE/df$
7. Compute:

$$n_h = \frac{2}{\frac{1}{n_1} + \frac{1}{n_2}}$$

8. (If the sample sizes are equal then $n_h = n_1 = n_2$).
9. Compute:

$$s_{M_d} = \sqrt{\frac{2MSE}{n_h}}$$

10. Compute:

$$t = \frac{M_d - (\mu_1 - \mu_2)}{s_{M_d}}$$

where $\mu_1 - \mu_2$ is the difference between population means specified by the null hypothesis (and is usually 0).

11. Use a <u>t table</u> to compute p from t (step 9) and df (step 5).

5. RESULTS AND DISCUSSION

5.1 Results of T-Test

To estimate the similarity of selected fabric pairs for drape ratio, FAST bending rigidity, FAST shear rigidity and FAST extension values, t-test is carried out to these fabrics. The similarities are analyzed according to weave type, yarn count and materials of fabrics. The effects of these properties are discussed and explained below.

5.1.1 T-Test for Drape Ratio

5.1.1.1 Effect of Weave on Fabric Drape

In this part, the fabrics 1-2 and 3-5 which have the same material and same yarn numbers are compared by t-test. The comparison is made according to weave type. Fabrics 1-2 are 2/1 twill fabrics and fabrics 3-5 are plain fabrics. The significance level (α) is chosen 0,05, which is used to make statistical analyses. Statistical analyses are done for drape ratio, FAST bending rigidity, FAST shear rigidity and FAST extension values. Firstly the null hypothesis and the alternative hypothesis are chosen. The hypothesis for drape ratio is shown below as an example;

$$D_T = D_P \Rightarrow H_0$$

$$D_T \neq D_P \Rightarrow H_1$$

The *t* value is estimated 2,014 and p value is estimated 0,075. Since p value is greater than α, it can be said that drape ratio is not significant for %100 wool fabrics between twill and plain fabrics. So, we accept the null hypothesis in other words.

Fabrics 11-12 are also compared for the weave design of the fabric. These two fabrics also have the same materials (wool-polyester) and the same yarn count. 11^{th} fabric has a 2/1 twill design and 12^{th} fabric has a fancy twill design. According to t-test for drape results, p value is estimated 0,089, which means drape is not significant between these two different kinds of weave designs.

Fabrics 12 and 18 are also compared according to their weave designs. These two fabrics have the same materials (wool-polyester) and the same yarn counts. This comparison is also resulted as not significant like the examples above.

We can conclude according to t-test results that weave is not effective on drape distinctively.

5.1.1.2 The Effect of Yarn Count on Fabric Drape

To assess the effect of yarn count on fabric drape, fabrics 9-10, 10-19, and 9-19 are chosen. These fabrics have the same materials (wool-polyester-elastane), 9th and 19th fabrics have the same yarn counts, 10th fabric's yarns are finer than those of 9th and 19th fabrics. For fabrics 9-10 the yarn count is found "not significant" for drape results, and, for fabrics 10-19 and 9-19, the yarn count for drape results is found significant. It can be seen from yarn crimp levels (Table 4.2) that the 19th fabric has elastane fibers only in the warp direction of the fabric and 9th fabric has elastane both in warp and weft directions. The 9th fabric's drapeability is increased because of the use of elastane in both warp and weft directions although it is a heavy fabric. It can be concluded that yarn count is significant on drapeability of fabrics while between the fabrics 9-10 this effect is not seen. The usage of elastane fiber in both warp and weft directions, effects drapeability of fabrics more than the used amount of this material.

5.1.1.3 The Effect of Material on Fabric Drape

Fabrics 6-7, 9-18, 9-11 and 9-21 are compared for the estimation of fabric drapeability. There is no significance between fabrics 6-7 for drape results. The difference of these fabrics is, 6th fabric has polyester unlike 7th fabric. And it is shown that polyester doesn't affect the drapeability for these fabrics. The result for fabrics 9-18 is significant. This result is obtained because of the different weights of these two fabrics. These fabrics have the same yarn counts but 9th fabric has elastane in both warp and weft direction, but a heavy fabrics. 18th fabric is lighter than 9th. Statistically there is a difference between these fabrics. 9-11 fabric pair has a difference, too. The statistical result is "significant", but this value is nearly the limit value. This difference can be explained by the weights of these fabrics, and it is dependent to yarn densities. There is a distinctive weight difference between these fabrics, but the statistical difference is still on the limit. We can say that the usage of elastane fiber makes the fabric more drapeability. The absence of elastane in 21st fabric makes a big difference between fabrics 9-21, although the weights are nearly the same. The yarn counts are also different but elastane fiber makes the 9th fabric more drapeable. When fabrics 11 and 18 are compared with 19th fabric the effect of elastane can be seen, but here, the effect of weight is more apparent.

5.1.2 T-Test for Bending Rigidity

5.1.2.1 The Effect of Weave on Bending

The comparisons of the same fabrics as used to compare the drape results are also used to compare bending, shear and extension results. The results of bending, shear and extension are the values that are calculated by FAST system. For fabrics 1-2 and 3-5 there is significance for bending rigidity. The packing of the yarns in the weave could affect the bending property of the fabric. The yarn densities of fabrics 1-2 are less than those of 3-5 fabrics that may effect the bending of the fabrics. There is also significance between fabrics 11-12, and it is the effect of the weave type. There is no significance between fabrics 12-18. When we consider the results of these fabrics, there is an apparent significance between these fabrics, but in statistical analyses, the significance does not appear. The high variance between these fabrics can be the reason for this, not to see the difference that we can say that weave design effects bending.

5.1.2.2 The Effect of Yarn Count on Bending

It can be said that yarn count effects bending. The results for fabric pairs for both 9-10 and 10-19 are found significant. Although, 10th fabric is a lighter fabric (the yarns are finer), both 9th and 19th fabric weights effects bending. The difference can be concluded as the difference of yarn counts. There is no significance between fabric pairs 9-19. The usage of elastane in one or two directions of the fabric did not affect the bending property

5.1.2.3 The Effect of Material on Bending

Fabrics 6-7 has the similar results as drape results. There is no significance between these fabrics for bending property. Fabric pair 9-18 is found significant. Although 9th fabric contains elastane fiber, 18th fabric has a lower weight. Fabrics 9-11 also have a difference. The result is significant. Fabrics 9-21 are also significant. These two fabrics have nearly the same weights but elastane fiber in 9th fabric makes the bending rigidity to be lower. There is no significance between fabrics 11-19 but when we consider the FAST bending results we can easily see the difference. Fabric pair 18-19 is found to be significant. Both 11th and 18th fabrics have a lower bending value than 19th fabric. This difference can be because of the difference in weight.

5.1.3 T-Test for Shear Rigidity

5.1.3.1 The Effect of Weave on Shear

For 1-2 and 3-5 plain and twill fabrics, there is no significance. For fabrics 11-12 there is also no significance. There is a difference between fabrics 12-18.

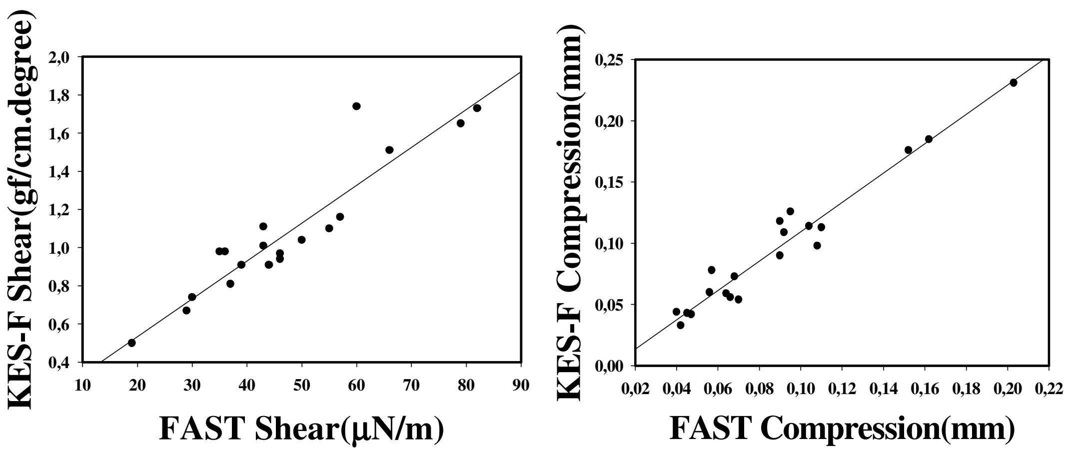
5.1.3.2 The Effect of Yarn Count on Shear

For 9-10, 10-19 fabric pairs, there is significance for shear properties. These fabric pairs have similar physical properties. The difference is the yarn counts of these fabrics. This difference makes the shear property to change between fabrics. It can be said that yarn count effects shear property of the fabrics.

5.1.3.3 The Effect of Material on Shear

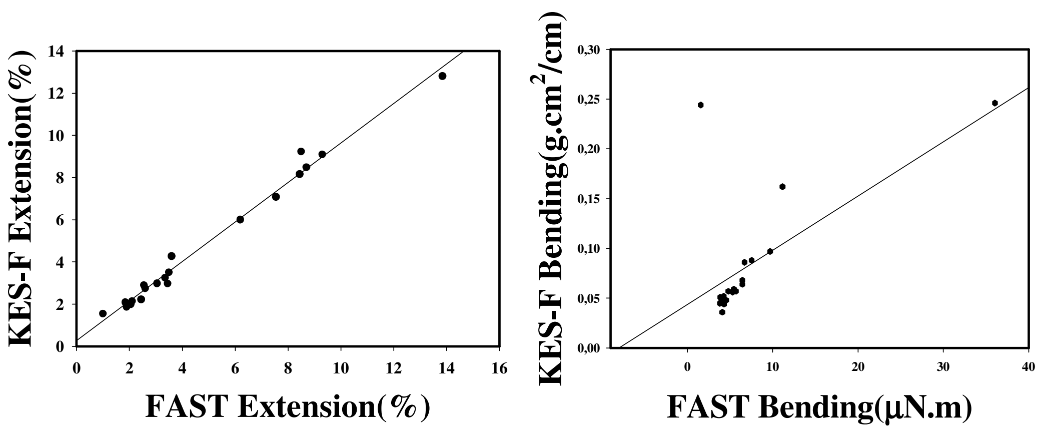
9-18, 9-11, 9-21, 11-19, 18-19 and 6-7 fabric pairs are used to estimate the effect of material on shear property. fabric pair 9-18 is found to be different for shear properties. The statistical result is significant. 9th fabric includes elastane both in warp and weft directions, and the fabric is a heavy fabric. Weight effects shear parameter of the fabric. Usage of elastane decreases the shear parameter of the fabric. The shear result of 9th fabric is lower than it is supposed to be because of elastane. It can be seen from the difference between fabrics 9-21. These two fabrics have nearly the same weights but the shear value of 21st fabric is nearly two times of 9th fabric. Yarn count is also effective for these two fabrics. 21st fabric is a thicker fabric and the yarn count of the fabric is also thicker than this of 9th fabric. There is no significance between 9-11 fabric pair although 9th fabric contains elastane fiber and has a higher weight value. There is no significance also between fabric pair 11-19. There is significance between fabric pair 18-19. 18th fabric doesn't contain elastane fiber and 19th fiber contains elastane fiber and has a higher weight value. But, there is no difference for shear values between these fibers. Fabric pair 6-7 shows a difference for shear values. 6th fabric has polyester fiber as a material, which is different from 7th fabric. Polyester fiber may affect the shear value. It can be said that material of fabrics effect shear values.

5.2 The Comparison between FAST and KES-F Parameters



r =0,9268 r =0,9775

Figure 5.1. The Comparison of *FAST* and *KES-F* Shear and Compression Values



r =0,994 r =0,6272

Figure 5.2. The Comparison of *FAST* and *KES-F* Extension and Bending Values

As shown in Figure 5.1 and 5.2 the correlation between FAST and KES-F values are very high. According to this program, correlation coefficients are found to be; 0,9268 for shear parameters, 0,9775 for compression parameters, 0,994 for extension parameters and 0,6272 for bending parameters. These values show that FAST and KES-F instruments measure similar values, although they use different measurement principles. As shown in literature [25, 15] the values show a similarity among previous studies, and the present study. Both FAST and KES-F instruments can be used to measure mechanical properties of fabrics.

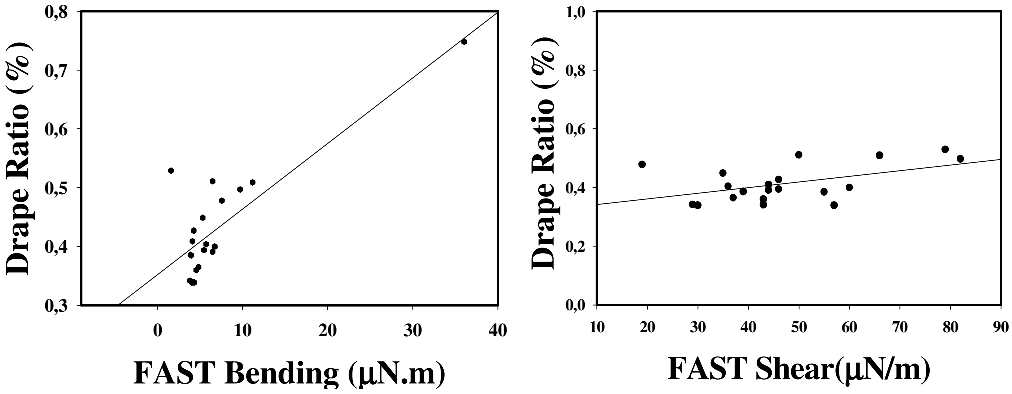
5.3 The Comparison of Drape Coefficient with FAST and KES-F Bending and Shear Properties

Drape is the term used to describe the way a fabric hangs under its own weight. It has an important role on how good a garment looks in use. The draping qualities required from a fabric will differ completely depending on its end-use. Drape is a very complex attribute of a fabric. It can be dependent on most of the physical and mechanical properties of a fabric. But very important two mechanical properties are known as primary dependent for fabric drape. These are bending and shear properties of a fabric. According to these mechanical properties we decided to correlate drape coefficient with FAST bending and shear properties and KES-F bending and shear properties to see the correlation of these values.

The bending length is dependent on the weight of the fabric and is therefore an important component of the drape of a fabric when it is hanging under its own weight. However, when a fabric is handled by fingers the property relating to stiffness that is sensed, in this situation, is flexural rigidity which is a measure of stiffness independent of the fabric weight.

The behavior of a fabric when it is subjected to shearing forces is one of the factors that determine how it will perform when subjected to a wide variety of complex deformations during use. It is the property that enables that enables it to undergo more complex deformations than two-dimensional bending and so conform to the contours of the body in clothing applications. Because of these complex deformations fabric drape is related to shear property.

5.3.1 The Correlation between Drape Ratio and, FAST Bending and Shear

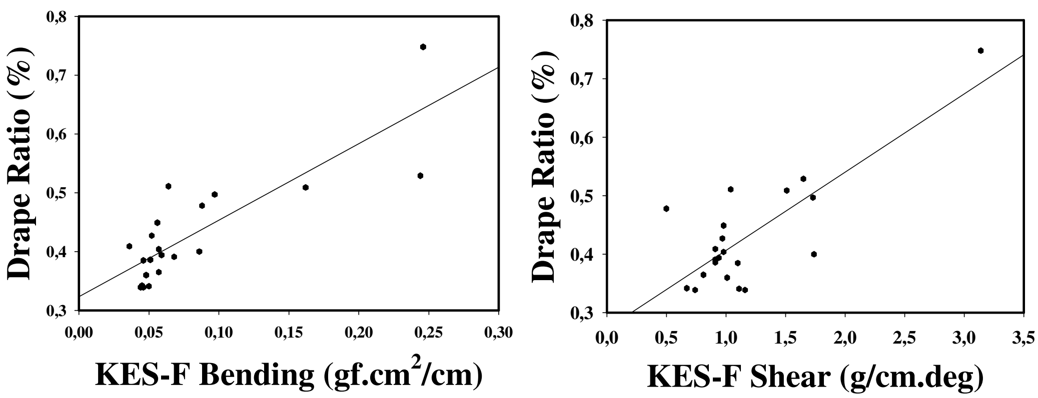


r =0,8231 r =0,7972

Figure 5.3. The Comparison between Drape Ratio and, *FAST* Bending and Shear Values

The correlation between drape coefficient and *FAST* bending and shear properties are high as it can be seen from the Figure 5.3. According to the Figure 5.3 the correlation coefficients are; 0,8231 for drape ratio and FAST bending parameter, and 0,7972 for drape ratio and FAST shear parameter. The correlation of *FAST* bending and drape ratio has a better correlation coefficient. It can be said that, bending property is more related with drape property than the shear property.

5.3.2 The Correlation between Drape Ratio and, KES-F Bending and Shear



r =0,8329 r =0,7895

Figure 5.4. The Comparison between Drape Ratio and. KES-F Bending and Shear Values

The correlation between drape ratio and KES-F bending and shear properties are high as shown in Figure 5.4. According to Figure 5.4 correlation coefficients are found; 0,8329 for drape ratio and KES-F bending parameter, and 0,7895 for drape ratio and KES-F shear parameter. It is known that fabric drape property is mostly related with fabric shear and bending properties.

As shown in Figures 5.3. and 5.4. the correlations are high. The correlation coefficients are very similar for both comparisons of drape with FAST and KES-F bending and shear parameters. It can be said that drape is dependent mostly on bending and shear parameters of fabrics. As it is known that drape is a very complex attribute, it is not only dependent on bending and shear parameters, but also the other properties of fabrics. But their effects are not as much as bending and shear. That's the reason of correlation coefficients are not nearly %100. In literature [65] drape coefficient is correlated with mechanical properties and correlation is found in the range from 60 percent to 95 percent for ten fabric samples. In present study, the correlations are found in the same range as in literature.

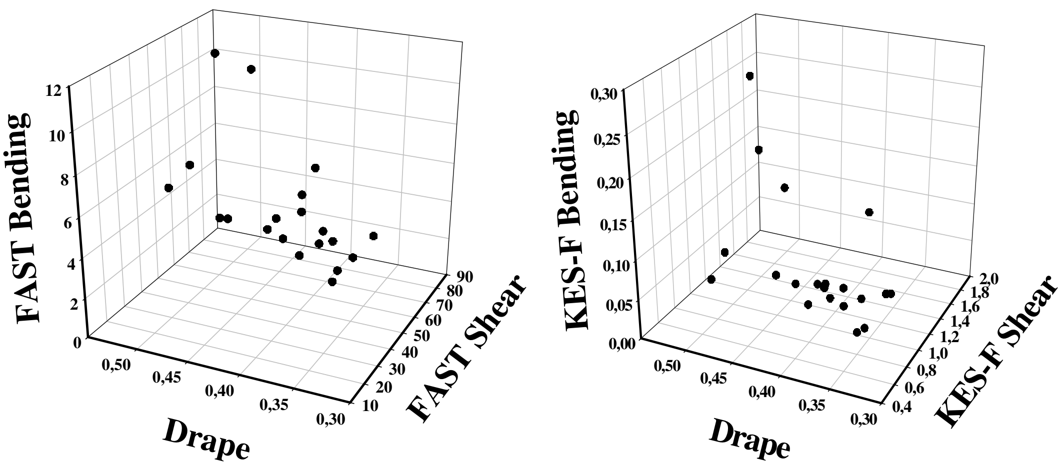


Figure 5.5. The Relationship between Bending and Shear Properties Measured with FAST and KES-F, and Drape Ratio

In this study we also tried to formulate drape ratio by the names of bending and shear properties with both FAST and KES-F results and with tightness factor of Seyam and Galuszynski. Derived formulas are shown below;

$Drape=K_b*0,866+K_s*0,0602+0,288$ (r = 0,862) **(5.9)**

$Drape=K_b*1,059+K_s*0,0604+0,452-T_g*0,251$ (r = 0,883) **(5.10)**

$Drape=K_b*0,940+K_s*0,625+0,407-T_s*0,170$ (r = 0,879) **(5.11)**

$$Drape=F_b*0,00948+F_s*0,812*10^{-4}+0,357 \quad (r = 0,824) \qquad \textbf{(5.12)}$$

$$Drape=F_b*0,001145-F_s*0,324*10^{-4}+0,223+T_g*0,181 \quad (r = 0,838) \qquad \textbf{(5.13)}$$

$$Drape=F_b*0,001039+F_s*0,3449*10^{-4}+0,306+T_s*0,0066 \quad (r = 0,827) \qquad \textbf{(5.14)}$$

Where;

K_b: KES-F Bending Value

K_s: KES-F Shear Value

F_b: FAST Bending Value

F_s: FAST Shear Value

T_g: Tightness of Galuszynski

T_s: Tightness of Seyam

The formulations are done according to regression tables below, that are obtained by SPSS programme.

5.4 Formulation of Total Hand Value

Total hand value can be explained as the derivation of hand value. Total hand value is graded from 0 to 5. "0" means the fabric is not useful, and "5" means that the fabric is excellent. THV results are obtained from KES-F results, according to mechanical values of fabrics. In present study, THV value that is obtained from KES-F system is tried to be formulated in names of FAST mechanical values; bending, shear, extension and compression. THV values are determined for both men and women suit wear. This formulation is made according to these two different values of THV. These formulations are shown below;

$$THV_{men}=F_b*0,167-F_s*0,394*10^{-2}+F_e*0,134-F_c*4,751+0,472 \quad (r = 0,522) \qquad \textbf{(5.15)}$$

$$THV_{women}=F_b*0,127-F_s*0,45*10^{-2}+F_e*0,106-F_c*0,462+1,072 \quad (r = 0,527) \qquad \textbf{(5.16)}$$

Where;

F_b: FAST Bending Value

F_s: FAST Shear Value

F_e: FAST Extension Value

F_c: FAST Compression Value

THV_{men}: Total Hand Value for Men Suit Wear

THV_{women}: Total Hand Value for Women Suit Wear

6. CONCLUSIONS

In this research wool and wool blended fabric's mechanical properties are obtained by using objective evaluation systems. T-test, correlation, multi regression and ANOVA analyses are applied to the findings to measure the relationship between physical and mechanical properties. The relationship between KES-F and FAST system, the relationship between drape ratio and, bending and shear properties measured by FAST and KES-F system, and the effects of weave, yarn count and material of the fabrics on drape, bending, shear and extension properties are investigated. The following conclusions are drawn from the findings of these investigations:

- It is found that KES-F system and FAST system have a good correlation between each parameter, although they use different measurement principles.
- A high correlation can be obtained between drape and, mechanical and physical properties
- It is found that drape of a fabric is primarily dependent on fabric's bending and shear properties more effectively than other physical properties.
- It is found that, the effect of weave for drape is not significant, but it depends on other physical parameters of fabrics for bending, shear and extension properties.
- The effect of yarn count also depends on other physical properties of fabrics.
- The effect of elastanee is significant for drape, shear and extension parameters, but bending does not affected by the usage of elastane fiber.
- THV value that is obtained from KES-F system is formulized in means of FAST bending, shear, compression and extension values, but a moderate relationship is obtained.
- FAST system can easily be used for industrial usages, because of its easiness, cheaper price than KES-F system and its robust structure. However, KES-F system is mostly being used for laboratory studies.

- Since the textile industry is still searching for a reliable method in order to end the quality discussions between fabric manufactures and consumers, but objective evaluation systems like KES-F and FAST seems that they will be used and will have an important role in the future as today.

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APPENDIX

a) Regression (Drape-KES-F Bending and Shear)

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	KESFSHEA, KESFBEND	,	Enter

a All requested variables entered.

b Dependent Variable: DRAPERAT

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,862	,742	,714	5,0889E-02

a Predictors: (Constant), KESFSHEA, KESFBEND

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,134	2	6,719E-02	25,947	,000
	Residual	4,661E-02	18	2,590E-03		
	Total	,181	20			

a Predictors: (Constant), KESFSHEA, KESFBEND

b Dependent Variable: DRAPERAT

Coefficients

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
Model		B	Std. Error	Beta		
1	(Constant)	,288	,027		10,794	,000
	KESFBEND	,866	,300	,555	2,887	,010
	KESFSHEA	6,017E-02	,033	,355	1,846	,081

a Dependent Variable: DRAPERAT

b) Regression (Drape-KES-Galuszynski)

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	GALUSZYN, KESFSHEA, KESFBEND	,	Enter

a All requested variables entered.

b Dependent Variable: DRAPERAT

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,883	,780	,741	4,8437E-02

a Predictors: (Constant), GALUSZYN, KESFSHEA, KESFBEND

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,141	3	4,704E-02	20,050	,000
	Residual	3,988E-02	17	2,346E-03		
	Total	,181	20			

a Predictors: (Constant), GALUSZYN, KESFSHEA, KESFBEND

b Dependent Variable: DRAPERAT

Coefficients

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
Model		B	Std. Error	Beta		
	(Constant)	,452	,100		4,522	,000
	KESFBEND	1,059	,307	,678	3,444	,003
	KESFSHEA	6,041E-02	,031	,356	1,947	,068
	GALUSZYN	-,251	,148	-,230	-1,694	,109

a Dependent Variable: DRAPERAT

c) Regression (Drape-KES-Seyam)

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	SEYAM, KESFSHEA, KESFBEND	,	Enter

a All requested variables entered.

b Dependent Variable: DRAPERAT

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,879	,772	,732	4,9226E-02

a Predictors: (Constant), SEYAM, KESFSHEA, KESFBEND

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,140	3	4,660E-02	19,232	,000
	Residual	4,119E-02	17	2,423E-03		
	Total	,181	20			

a Predictors: (Constant), SEYAM, KESFSHEA, KESFBEND

b Dependent Variable: DRAPERAT

Coefficients

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
Model		B	Std. Error	Beta		
1	(Constant)	,407	,083		4,887	,000
	KESFBEND	,940	,294	,602	3,193	,005
	KESFSHEA	6,249E-02	,032	,369	1,979	,064
	SEYAM	-,170	,114	-,183	-1,496	,153

a Dependent Variable: DRAPERAT

d) Regression (Drape-FAST Shear and Bending)

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	FASTSHEA, FASTBEND	,	Enter

a All requested variables entered.

b Dependent Variable: DRAPERAT

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,824	,679	,643	5,6817E-02

a Predictors: (Constant), FASTSHEA, FASTBEND

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,123	2	6,145E-02	19,035	,000
	Residual	5,811E-02	18	3,228E-03		
	Total	,181	20			

a Predictors: (Constant), FASTSHEA, FASTBEND

b Dependent Variable: DRAPERAT

Coefficients

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
Model		B	Std. Error	Beta		
1	(Constant)	,357	,025		14,573	,000
	FASTBEND	9,475E-03	,006	,700	1,561	,136
	FASTSHEA	8,118E-05	,000	,129	,289	,776

a Dependent Variable: DRAPERAT

e) Regression (Drape-FAST-Galuszynski)

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	GALUSZYN, FASTBEND, FASTSHEA	,	Enter

a All requested variables entered.

b Dependent Variable: DRAPERAT

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,838	,703	,650	5,6250E-02

a Predictors: (Constant), GALUSZYN, FASTBEND, FASTSHEA

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,127	3	4,240E-02	13,402	,000
	Residual	5,379E-02	17	3,164E-03		
	Total	,181	20			

a Predictors: (Constant), GALUSZYN, FASTBEND, FASTSHEA

b Dependent Variable: DRAPERAT

Coefficients

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
Model		B	Std. Error	Beta		
1	(Constant)	,223	,117		1,902	,074
	FASTBEND	1,145E-02	,006	,845	1,834	,084
	FASTSHEA	-3,243E-05	,000	-,052	-,110	,914
	GALUSZYN	,181	,155	,166	1,168	,259

a Dependent Variable: DRAPERAT

f) Regression (Drape-FAST-Seyam)

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	SEYAM, FASTBEND, FASTSHEA	,	Enter

a All requested variables entered.

b Dependent Variable: DRAPERAT

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,827	,683	,628	5,8050E-02

a Predictors: (Constant), SEYAM, FASTBEND, FASTSHEA

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,124	3	4,124E-02	12,237	,000
	Residual	5,729E-02	17	3,370E-03		
	Total	,181	20			

a Predictors: (Constant), SEYAM, FASTBEND, FASTSHEA

b Dependent Variable: DRAPERAT

Coefficients

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
Model		B	Std. Error	Beta		
1	(Constant)	,306	,108		2,827	,012
	FASTBEND	1,039E-02	,006	,768	1,605	,127
	FASTSHEA	3,449E-05	,000	,055	,114	,911
	SEYAM	6,602E-02	,134	,071	,493	,628

a Dependent Variable: DRAPERAT

g) Regression (THV for Men Suits-FAST)

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	FASTCOMP, FASTEXT, FASTBEND, FASTSHEA	,	Enter

a All requested variables entered.

b Dependent Variable: THVMEN

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,522	,273	,091	1,16972

a Predictors: (Constant), FASTCOMP, FASTEXT, FASTBEND, FASTSHEA

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
	Regression	8,206	4	2,052	1,499	,249
	Residual	21,892	16	1,368		
	Total	30,098	20			

a Predictors: (Constant), FASTCOMP, FASTEXT, FASTBEND, FASTSHEA

b Dependent Variable: THVMEN

Coefficients

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
Model		B	Std. Error	Beta		
1	(Constant)	,472	,800		,590	,564
	FASTSHEA	-3,936E-03	,007	-,486	-,603	,555
	FASTBEND	,167	,125	,957	1,336	,200
	FASTEXT	,134	,079	,374	1,689	,111
	FASTCOMP	-4,751	8,105	-,241	-,586	,566

a Dependent Variable: THVMEN

h) Regression (THV for Women Suit Wear-FAST)

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	FASTCOMP, FASTEXT, FASTBEND, FASTSHEA	,	Enter

a All requested variables entered.

b Dependent Variable: THVWOMEN

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,527	,278	,098	,82144

a Predictors: (Constant), FASTCOMP, FASTEXT, FASTBEND, FASTSHEA

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4,159	4	1,040	1,541	,238
	Residual	10,796	16	,675		
	Total	14,955	20			

a Predictors: (Constant), FASTCOMP, FASTEXT, FASTBEND, FASTSHEA

b Dependent Variable: THVWOMEN

Coefficients

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
Model		B	Std. Error	Beta		
1	(Constant)	1,072	,562		1,909	,074
	FASTSHEA	-4,496E-03	,005	-,788	-,980	,342
	FASTBEND	,127	,088	1,029	1,442	,169
	FASTEXT	,106	,056	,420	1,904	,075
	FASTCOMP	-,462	5,692	-,033	-,081	,936

a Dependent Variable: THVWOMEN

T-Test (Effect of Material on Shear Property)

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	FASTSH9 - FASTSH18	7,18833	2,69601	1,10064	4,35904	10,01763	6,531	5	,001
Pair 2	FASTSH9 - FASTSH11	-2,58833	4,15849	1,69770	-6,95240	1,77574	-1,525	5	,188
Pair 3	FASTSH9 - FASTSH21	-47,85833	14,20562	5,79942	-62,76621	-32,95045	-8,252	5	,000
Pair 4	FASTSH11 - FASTSH19	3,74167	4,22511	1,72490	-,69232	8,17565	2,169	5	,082
Pair 5	FASTSH18 - FASTSH19	-6,03500	2,38201	,97245	-8,53476	-3,53524	-6,206	5	,002
Pair 6	FASTSH6 - FASTSH7	-12,49667	2,45019	1,00029	-15,06798	-9,92535	-12,493	5	,000

T-Test (Effect of Weave on Shear Property)

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	FABR1_2 - FABR3_5	-,8892	11,1738	3,2256	-7,9887	6,2103	-,276	11	,788
Pair 2	FASTSH11 - FASTSH12	-4,00000	4,41853	1,80386	-8,63697	,63697	-2,217	5	,077
Pair 3	FASTSH12 - FASTSH18	13,77667	5,73932	2,34307	7,75362	19,79971	5,880	5	,002

T-Test (Effect of Yarn Count on Shear Property)

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	FASTSH9 - FASTSH10	-7,91000	2,56684	1,04791	-10,60374	-5,21626	-7,548	5	,001
Pair 2	FASTSH10 - FASTSH19	9,06333	3,50168	1,42955	5,38855	12,73812	6,340	5	,001

T-Test (Effect of Material on Drape)

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	DRAPE9 - DRAPE18	6,2000E-02	1,6613E-02	7,4297E-03	4,1372E-02	8,2628E-02	8,345	4	,001
Pair 2	DRAPE9 - DRAPE11	2,0200E-02	1,6162E-02	7,2277E-03	1,3262E-04	4,0267E-02	2,795	4	,049
Pair 3	DRAPE9 - DRAPE21	-9,36000E-02	1,5372E-02	6,8746E-03	-,11269	-7,45131E-02	-13,615	4	,000
Pair 4	DRAPE11 - DRAPE19	-6,52000E-02	9,4710E-03	4,2356E-03	-7,69598E-02	-5,34402E-02	-15,393	4	,000
Pair 5	DRAPE18 - DRAPE19	-,10700	7,4498E-03	3,3317E-03	-,11625	-9,77498E-02	-32,116	4	,000
Pair 6	DRAPE6 - DRAPE7	-2,00000E-03	2,2583E-02	1,0100E-02	-3,00407E-02	2,6041E-02	-,198	4	,853

T-Test (Effect of Weave on Drape)

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	FABR1_2 - FABR3_5	1,740E-02	2,732E-02	8,640E-03	-2,1449E-03	3,694E-02	2,014	9	,075
Pair 2	DRAPE11 - DRAPE12	2,3800E-02	2,3816E-02	1,0651E-02	-5,77142E-03	5,3371E-02	2,235	4	,089
Pair 3	DRAPE12 - DRAPE18	1,8000E-02	1,5508E-02	6,9354E-03	-1,25580E-03	3,7256E-02	2,595	4	,060

T-Test (Effect of Yarn Count on Drape)

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	DRAPE9 - DRAPE10	-5,60000E-03	2,1007E-02	9,3947E-03	-3,16838E-02	2,0484E-02	-,596	4	,583
Pair 2	DRAPE10 - DRAPE19	-3,94000E-02	1,5821E-02	7,0753E-03	-5,90442E-02	-1,97558E-02	-5,569	4	,005

T-Test (Effecy of Material on Bending)

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	FASTBD9 - FASTBD18	2,02000	1,46569	,42311	1,08874	2,95126	4,774	11	,001
Pair 2	FASTBD9 - FASTBD11	1,97750	1,81931	,52519	,82157	3,13343	3,765	11	,003
Pair 3	FASTBD9 - FASTBD21	-3,80917	3,28303	,94773	-5,89511	-1,72323	-4,019	11	,002
Pair 4	FASTBD11 - FASTBD19	-1,48667	1,13825	,32858	-2,20987	-,76346	-4,524	11	,001
Pair 5	FASTBD18 - FASTBD19	-1,52917	1,52828	,44118	-2,50019	-,55815	-3,466	11	,005
Pair 6	FASTBD6 - FASTBD7	,35417	1,36297	,39346	-,51183	1,22016	,900	11	,387

T-Test (Effect of Weave on Bending)

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	FABR1_2 - FABR3_5	1,6671	2,0865	,4259	,7860	2,5482	3,914	23	,001
Pair 2	FASTBD11 - FASTBD12	-,74333	1,09050	,31480	-1,43620	-5,04634E-02	-2,361	11	,038
Pair 3	FASTBD12 - FASTBD18	,78583	1,57958	,45599	-,21779	1,78945	1,723	11	,113

T-Test (Effect of Yarn Count on Bending)

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	FASTBD9 - FASTBD10	1,63500	1,19557	,34513	,87537	2,39463	4,737	11	,001
Pair 2	FASTBD10 - FASTBD19	-1,14417	1,42117	,41026	-2,04714	-,24120	-2,789	11	,018

CURRICULUM VITAE

Özge TOKMAK was born in Hatay in 1983. She graduated from “Mehmet Akif Ersoy İlkokulu” in 1995, from “Yüksel Acun Anadolu Lisesi” in 2001, and from Çukurova University Textile Engineering department in 2005. After her graduation she attended İstanbul Technical University for her M.Sc. degree. She attended Erasmus Programme in Slovenia in 2007 spring term, and studied on her thesis in Maribor University Laboratory.