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THE TACTILE BEHAVIOR OF TEXTILE MATERIALS: NEW PERSPECTIVES
PART I: FABRIC HANDLE BEHAVIOR

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Abstract

Tactile behavior of fabric may be described by two main categories of parameters: surface parameters and mechanical (or low deformation) parameters. This paper deals primarily with mechanical tactile parameters. It represents a small part of a larger study titled “Developing Design-Oriented Model of Fabric Comfort” directed by Dr. Yehia El Mogahzy. This study was conducted over three year period from 2000 to 2003 and involved top scientists from three major U.S. Universities: Auburn University, Georgia Tech, and North Carolina State University. Some International assistance was also provided. The primary objective of this study was twofold:

1. To establish a clear characterization of fabric and garment comfort using three independent but coordinated approaches: (a) structural modeling of the fabric/skin interaction phenomena, (b) experimental analysis of specially-designed fabrics and garments, and (c) empirical modeling of the fabric comfort phenomenon using a combination of physical, neural-network, and fuzzy logic analysis.
2. To develop a comfort design/manufacturing program to assist spinners, weavers, knitters, and garment manufacturers in producing fabrics of desirable levels of comfort suitable for different modes of applications including: normal/relaxing modes, high physical activity modes, and special task modes.

In this part of the study, the focus was on the analysis of mechanical tactile properties. These include: (1) fabric handle behavior characterized by a set of unique parameters, (2) fabric drape, and (3) fabric stiffness. The driving force of this analysis is the comfort model developed by El Mogahzy et al [1, 2] in which the comfort phenomenon was described by a single index representing the ratio between the true area of fabric/human skin contact and the corresponding apparent area. This ratio was found to be directly related to the tactile comfort characteristics of textile fabrics.

Introduction

Mechanical tactile behavior of fabric has been the subject of hundreds of investigations in which different aspects of tactile behavior were extensively evaluated. As early as 1930, Peirce [3] suggested correlations between fabric handle and fabric mechanical properties and initiated the measurement of the bending stiffness of fabrics. Following Peirce’s work, many other researchers have tried to correlate fabric handle with fabric mechanical properties. These investigations provided a great deal of insight into the fundamental nature of fabric deformational behavior particularly under low stresses.

In practice, fabric tactile behavior has been generally described by the term “fabric handle”. Obviously, the term “handle” can be applied to any situation in which fabric is subjected to any form of deformation, high or low. This makes this term suitable for use whether the fabric is utilized in industrial applications (high loading) or in clothing (relatively low loading). In relation to clothing performance, fabric handle may be defined as a subjective assessment of a textile obtained from sense of touch. It is concerned with the subjective judgment of roughness, smoothness, harshness, pliability, thickness, etc. Judgments of fabric handle are used as the basis for evaluating quality and comfort and thus for determining fabric value within the textile clothing and related industries. The term “comfort” is a more general term that implies many aspects of human-related clothing performance including handle. While comfort implies over time experience with the object of concern prior to passing judgment on its performance, handle implies an initial evaluation of the object prior to passing judgment on its appeal.

The importance of distinguishing between handle and comfort phenomena lies in the fact that each may require a different design focus of textile products. Handle basically reflects a mechanical interaction between human skin and fabric in which both the fabric surface and the material bulk are being spontaneously tested by exerting external body movement. Therefore, handle is a reaction to positive mechanical actions. Comfort on the other hand is a more complex phenomenon because it involves physical interactions between the human body, the fabric, and the external environment. This three-way interaction may occur in a positive media where external environmental effects and/or body physical activities play critical roles. It may also occur in a passive media in which a relaxing body is reacting to a normal to mild external environmental effect [1, 2]. Obviously, factors that can enhance handle characteristics will ultimately lead to better comfort provided that they do not conflict with the thermo-physiological criteria of comfort.

In this study, our approach of handle analysis stems from a structural comfort model that was developed by El Mogahzy et al [1, 2]. This model assumes that tactile comfort is primarily a function of the level of fabric/skin contact, and the degree of fabric/skin intimacy. According to this model, a single parameter that can fully characterize tactile comfort is the so-called Area Ratio, AR, which is the ratio between the true area of fabric/skin (level A), or fabric/fabric (level B) contact and the apparent area of contact, A_t/A_a. The general form of the Area-Ratio model is as follows:

$$\frac{A_t}{A_{app}} = C_M\, K^{-\gamma}\, M_a^{\,1-\gamma}\, P^{\gamma} \qquad (1)$$

where C_M is a constant characterizing the pressure distribution over the true contact area, K is an index of surface hardness under compression, M_a is the number of contacting asperities per unit area of apparent contact, P is the lateral applied pressure, and γ is a highly material-related constant that depends on the shape of pressure-contact area curve [4, 5].

Equation 1 essentially describes the tactile behavior of fabric on the basis of surface-related parameters (surface hardness, K, and number of asperities, M_a) and mechanical-related factors such as the parameters determining the deformational behavior of fabric under lateral pressure (C_M, and γ). We should point out that both surface-related and mechanical factors are interrelated by virtue of the fact that even the sliding effect in the fabric/skin interface involves some form of mechanical deformation imposed by pressure [1, 2].

In light of the above discussion, it was important to evaluate the correlation between mechanical tactile parameters that are commonly measured and the area ratio. These parameters are: (1) fabric handle behavior characterized by a set of unique parameters, (2) fabric drape, and (3) fabric stiffness.

Materials and Methods

Twos sets of fabrics were used in this part of the study. The first set represents single jersey knit fabrics (28 cut, 50CPI/36 WPI) that were produced from three different yarn types: conventional ring-spun yarn, Elite Compact yarn, and Murata MVS air-jet yarn. In addition, each yarn type was made from four different preparatory methods: 100% cotton carded sliver, 100% cotton combed sliver, 80% cotton/20% comber noil sliver, and 90% cotton/10% comber noil sliver. Yarns used in this set were all of 30's English count. Values of fabric thickness and fabric weight of different fabrics are listed in Table 1. In order to restrict the analysis to the effects of yarn type and preparation, it was important that all fabrics be dyed and finished using the same procedure. All fabrics were bleached in a soft flow jet, dyed and finished. The second set consists of four single-jersey knit fabrics (18 cut, 38CPI/28WPI) produced from yarns that were made from cottons subjected to four different gin conditions. These treatments resulted in substantially different levels of short fiber content and corresponding yarn imperfection levels. Yarns used in this set were all of 18's English count and they were all ring-spun.

We should point out that the two sets of fabrics were manufactured by Cotton Incorporated of the U.S.A. and kindly presented to us to perform tactile analysis. Details on the fiber and yarn characteristics of these fabrics can be found in Cotton Incorporated Technical Report [6].

ElMO-HASSAN Area Ratio Test

We measured the true area of contact using a simple and novel technique developed by Elmogahzy and Hassan [7] in which the true area of contact was determined from a high-viscosity ink impression on the fabric sample at different pressure levels. The test method termed "Elmo-Hassan Area Ratio Test" is illustrated in Figure 1. A circular pressure head is used in which a spring-loading is applied uniformly on a circular sample, which is cut in the manner shown in Figure 1. The sample is mounted flat facing the circular pressure head. The rounded base of the pressure head facing the sample is coated uniformly with the high-viscosity ink using a specially designed roller. Six pressure levels were used in this study: 1.769, 5.3, 8.8, 14.11, 26.5 and 35.35 Kg/m^2. The ink-imprint fabric sample is then examined microscopically by taking random images with known apparent areas and determining the sum of ink-imprints on each image. This was achieved using image analysis.

Elmo-Kilinc Handle Test

The handle measurement was performed using a novel testing technique termed "Elmo-Kilinc Handle Test". In contrast with the traditional ring handle test, this technique uses a conically shaped funnel, which is rigidly suspended in a special attachment that is mounted on an Instron-Tester Cross-Head as shown in the top picture of Figure 2. This setup allows pulling a rounded fabric sample through the funnel that is connected at its center to the Instron Load Cell using a special flexible chain. Samples used in this test are cut circular at 9 cm diameter (slightly smaller than the diameter of the funnel wide base).

Figure 2.a illustrates the handle testing sequence. This sequence may be described as follows:

1. As the Instron Cross-Head moves downward, the fabric sample is moved upward against its own weight in a freely folding mode until it hits the internal surface of the funnel wide base at random points of the sample, determined only by the nature of free folding. This eliminates the initial constrained folding typically used in the traditional ring handle test.
2. Upon touching the funnel internal surface, the sample begins to reconfigure and fold in a more organized manner as it is constrained by the conical shape of the funnel base.
3. When the sample center enters the funnel cylindrical nozzle, tension builds up as a result of the friction between the folded fabric sample and the entrance of the nozzle cylinder and the continuing constrained folding. This tension reaches a peak as the fabric surface attempts to enter to and realign with the internal surface of the cylindrical nozzle. The tension peak typically occurs when approximately 2/3 of the fabric length is inside the cylindrical nozzle. During this process, more constrained folding and surface reconfiguration is applied on the sample to accommodate its alignment with the cylindrical nozzle.
4. As the sample becomes completely aligned with the nozzle cylinder, momentary drop in tension occur leading to a profile trough. The extent of tension drop defined by the tension at the trough, or the difference between the peak tension and the trough tension, is expected to be largely a function of sample ease of reconfiguration, or fabric stiffness.
5. Inside the cylindrical nozzle, a case of largely pure friction occurs between the points of the fabric that managed to remain on the surface during folding and the internal surface of the cylindrical nozzle. This friction is largely determined by the internal lateral pressure inside the completely folded sample. A stiff sample will result in high lateral pressure, and a flexible sample will result in low lateral pressure.
6. Depending on the extent of stiffness, or internal pressure, and the points of fabric surface in contact with the internal surface of the nozzle, another tension build up may occur leading to another tension peak that is smaller the initial tension peak. This peak reflects largely the extent of internal pressure in the sample.
7. As the fabric sample exit the cylindrical nozzle, a pressure release progressively occurs leading to a continuous reduction in tension

The handle mechanism described above largely simulates the handle action during human evaluation of fabrics or clothing; it is a complex combination of feeling of the folding nature of the fabric, the ease of reconfiguration, and its surface smoothness [1, 2]. During the movement duration of the fabric through the funnel, a load-time profile is generated, which is termed “the handle profile”. In most cases, this profile takes the common shape of Figure 2.b. From this profile, different handle parameters can be obtained as shown in Figure 2. Note that three categories of handle parameters are obtained:

1. Handle modulus parameters represented by the slopes at the portions of the profile specified in Figure 2.b (i.e. α_1, α_2, and α_3)
2. Handle work parameters represented by the areas under the profile curves specified in Figure 2.b (i.e. A_1, A_2, A_3, and A_4)
3. Handle resistance parameters represented by the forces specified in Figure 2 (i.e. first handle Peak, first handle drop, and second handle peak)

Other Tactile Testing Methods

In addition to the “Elmo-Kilinc Handle Test “, we carried out other tactile-related tests such as fabric stiffness and fabric drape. Figures 3 and 4 show the principles of these tests. In addition, all important physical properties of the fabric samples were tested. These include: air permeability, thermal conductivity (using Alambeta Instrument developed by Lubos Hes), and fabric bursting strength.

Results and Discussions

Correlations Between Different Tactile Parameters

As an initial analytical step, it was important to examine the correlations between different tactile parameters. Using the data of samples 1 through 12 (Table 1), correlation analysis was performed. We should keep in mind however that for this set of samples, the main differences lie in yarn type and spinning preparation. These are not the traditional parameters that are likely to directly influence tactile behavior. Typically, tactile behavior is influenced by parameters such as fabric thickness, fabric weight, fabric style, thread count in the fabric, yarn count, and material type. For this set of samples all these factors were kept approximately constant. In other words, the maximum capability of each method of tactile testing was not fully explored in this set of samples.

Table 1 shows the values of correlation coefficients between the handle parameters described in Figure 2 and other tactile parameters using all the data associated with samples 1 through 12. Points revealed by these correlation coefficients are summarized below:

1. Fabric stiffness area and stiffness maximum peak determined from the D 4032 – 94 Standard test method consistently exhibit positive correlations with most handle parameters, particularly A_3, A_4, and (A_3+ A_4), third handle slope

and handle first drop. Recall that the two areas A_3 and A_4 reflect the work done during the sliding of the fabric sample in the cylindrical nozzle (at which case internal lateral pressure compressing the sample takes place) and as the sample exit the nozzle (at which case, sample unfolding occurs). As indicated earlier, the extent of tension drop defined by the tension at the trough is largely a function of sample ease of reconfiguration, or fabric stiffness.

2. The friction parameter ‘a’, which is largely similar in nature to the classic coefficient of friction [4, 5] exhibits a consistent positive correlation with most handle parameters. On the other hand, the friction parameter ‘n’, which is largely dependent on the nature of lateral deformation during sliding [4, 5] is negatively correlated to most handle parameters.

In light of the above discussion, it follows that the handle parameters derived from the “Elmo-Kilinc Handle Test “exhibit consistent correlations with stiffness and friction parameters. These correlations are expected to be even higher when samples of wide range of tactile properties are used.

Effects of Yarn Type and Spinning Preparation on Tactile Properties

As indicated earlier, samples 1 through 12 (Table 1) represent a unique set in which the two main differences are yarn type and spinning preparation. Figures 5 and 6 compare the tactile parameters resulting from these differences. The results revealed from this comparison are as follows:

1. For carded yarns, MVS exhibited the lowest stiffness and drape coefficient (Figure 5). In other words, MVS was the most flexible fabric made from carded yarns, followed by Elite Compact. Carded MVS fabrics also had the lowest values of handle parameters (A_1+ A_2), (A_3+ A_4), and handle modulus α_1 and α_3. Fabrics made from carded ring-spun yarns produced the highest values of tactile parameters, meaning they were the stiffest and most difficult to handle.
2. For combed yarns, the MVS maintained the lowest drape coefficient, but it was consistently higher than the other two yarn types in all other tactile parameters. Fabrics made from conventional ring-spun yarns and Elite compact combed yarns were similar in their tactile parameters.
3. Both MVS and Elite yarn fabrics lost a great deal of their tactile advantages upon the addition of noils to cotton.

Effects of Gin Treatments on Tactile Properties

For samples 13 through 16, the key effect resulting from different ginning treatments was short fiber content. This point is shown in Figure 7. Also shown in this Figure are the impacts of this treatment on yarn hairiness and total imperfections. As shown in Figure 7, while the total yarn imperfection, IPI, was substantially increased with the increase in short fiber content in the cotton, a minor change in yarn hairiness was observed. This may be attributed to the removal of a great deal of the short fibers as waste during the opening and cleaning process to such an extent that reduced their direct impact on yarn hairiness.

Figure 8 shows the effects of gin treatments on some fabric tactile parameters. These results indicate that the addition of short fibers imposed by the gin treatments resulted in stiffer fabrics. This is evident from the high handle areas and the higher handle peaks as short fiber content increases.

The Relationship between Tactile Parameters and Area-Ratio

As indicated earlier, the purpose of this part of the study is to examine the effects of some fiber-related and yarn-related design parameters on fabric tactile behavior. Since this study is carried out in the context of the comfort model developed by El Mogahzy et al [1,2], it was important to evaluate the correlations between tactile parameters and the area ratio derived from the comfort model. Figure 9 shows a radar diagram reflecting these correlations.

References

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7. El Mogahzy, Y. E., Kilinc, F. S, Hassan, M., “Design-Oriented Fabric Comfort Model”, Poster Representation, National Textile Center Research Forum, Hilton Head, SC, February 2003

Table 1. Different Single-Jersey Knit Fabrics (all bleached in a soft flow jet, dyed and finished).

No.	Type of Spinning	Content	Fabric Thickness (mm)	Fabric Weight (oz/yd^2)	% Short Fiber Content	Yarn Hairiness
1	MVS	100% Cotton, Combed	0.581	4.4	9.9	---
2	MVS	100% Cotton/ Carded	0.570	4.3	6.2	---
3	MVS	80/20 Cotton/Comber Noil	0.615	4.3	12	---
4	MVS	90/10 Cotton/Comber Noil	0.616	4.5	17	---
5	Compact	100% Cotton/ Carded	0.608	4.3	9.9	4.5
6	Compact	100% Cotton, Combed	0.553	4.2	6.2	3.8
7	Compact	90/10 Cotton/Comber Noil	0.578	4.2	12	4.8
8	Compact	80/20 Cotton/Comber Noil	0.584	4.2	17	5.0
9	Ring	100% Cotton/ Carded	0.583	4.1	9.9	6.2
10	Ring	80/20 Cotton/Comber Noil	0.595	4.2	6.2	5.6
11	Ring	90/10 Cotton/Comber Noil	0.587	4.1	12.9	6.2
12	Ring	100% Cotton, Combed	0.563	4.1	17	6.3
13	Ring	100% Cotton/ Carded	0.716	5.3	13.8	7.16
14	Ring	100% Cotton/ Carded	0.711	5.3	14.1	7.17
15	Ring	100% Cotton/ Carded	0.719	5.2	16.6	7.35
16	Ring	100% Cotton/ Carded	0.733	5.3	21.1	7.85

Table 2. Correlation Coefficients between Tactile Parameters.

Handle Parameter	Stiffness Area-Avg	Stiffness Max Peak	Friction (n)	Friction (a)
Handle-A(Total)	0.638	0.842	-0.526	0.774
Handle(A1+A2)	NS	0.580	-0.478	0.393
Handle(A3+A4)	0.530	0.583	-0.486	0.269
Handle(A1)	NS	0.484	-0.676	0.306
Handle(A2)	NS	NS	-0.288	0.640
Handle (A3)	0.525	0.545	-0.537	NS
Handle (A4)	0.650	0.459	-0.590	0.754
Handle Slope1	NS	0.650	-0.794	NS
Handle Slope 2	0.585	NS	NS	NS
Handle Slope 3	0.445	0.658	-0.466	0.281
Handle First Peak	NS	0.654	-0.457	0.654
Handle Second Peak	0.615	0.485	-0.430	0.544
Handle First Drop	0.476	0.570	-0.445	0.581

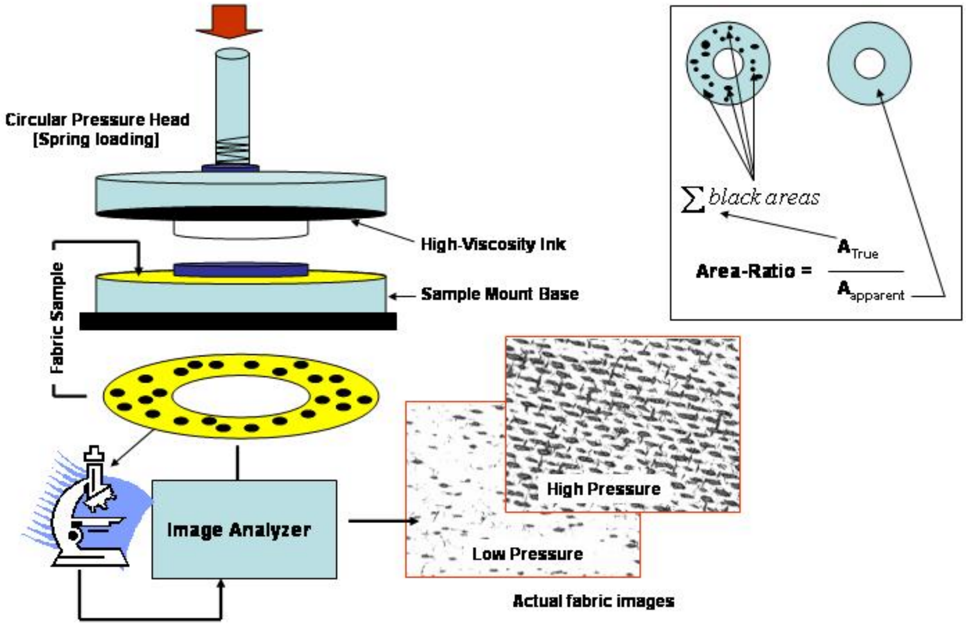

Figure 1. EIMO-HASSAN Area Ratio Measuring Setup Using High-Viscosity Ink Imprint.

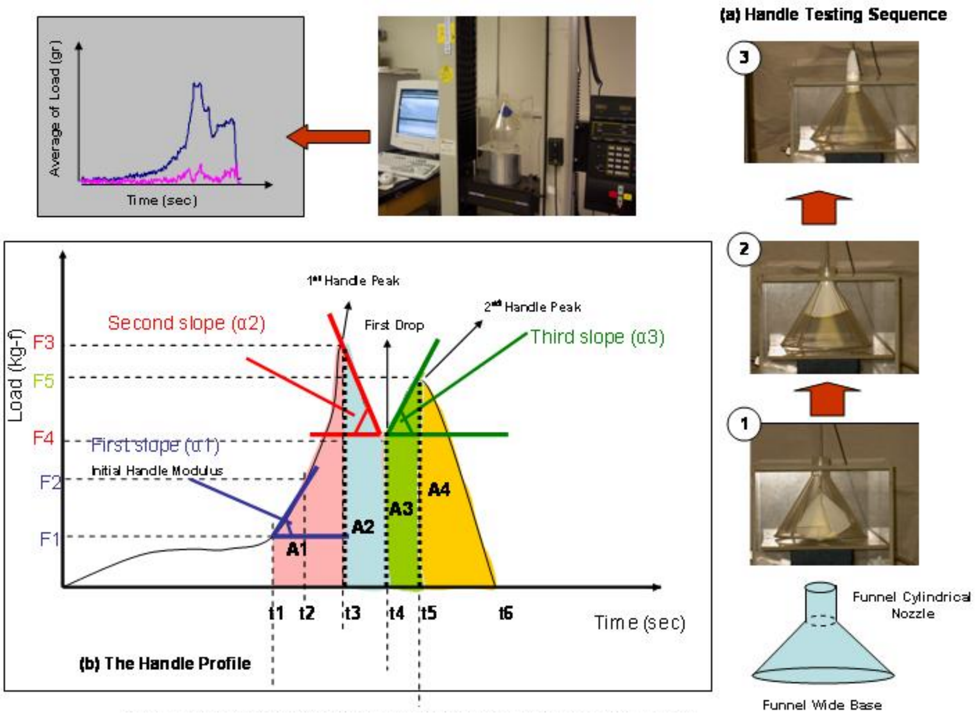

Figure 2. Elmo-Kilinc Handle Test and associated parameters.

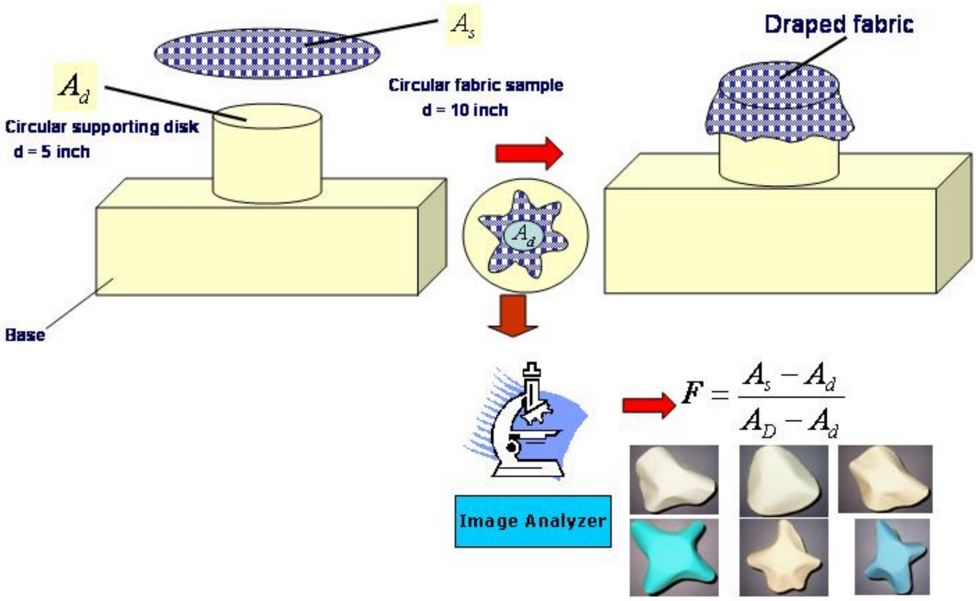

Figure 3. Principle of Drape Test.

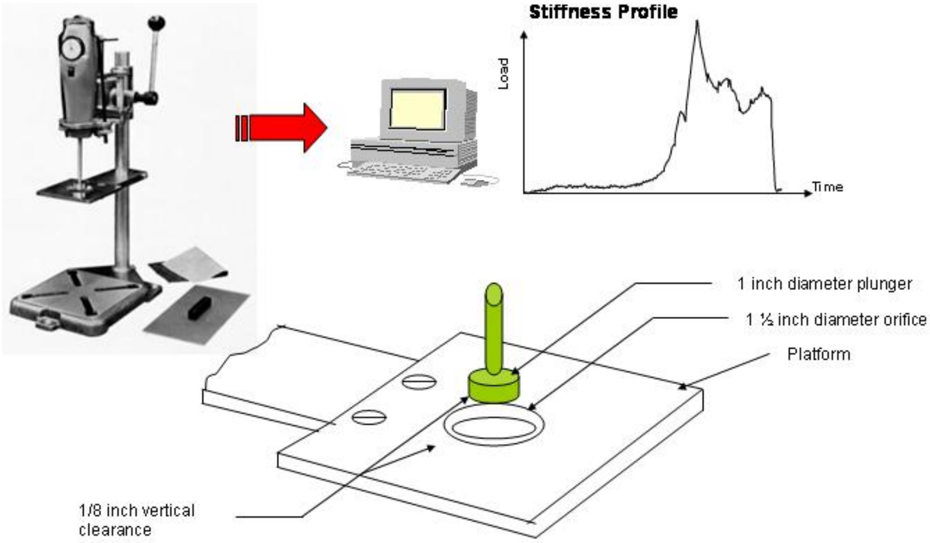

Figure 4. Designation: D 4032 – 94 Standard Test Method for Stiffness of Fabric by the Circular Bend Procedure.

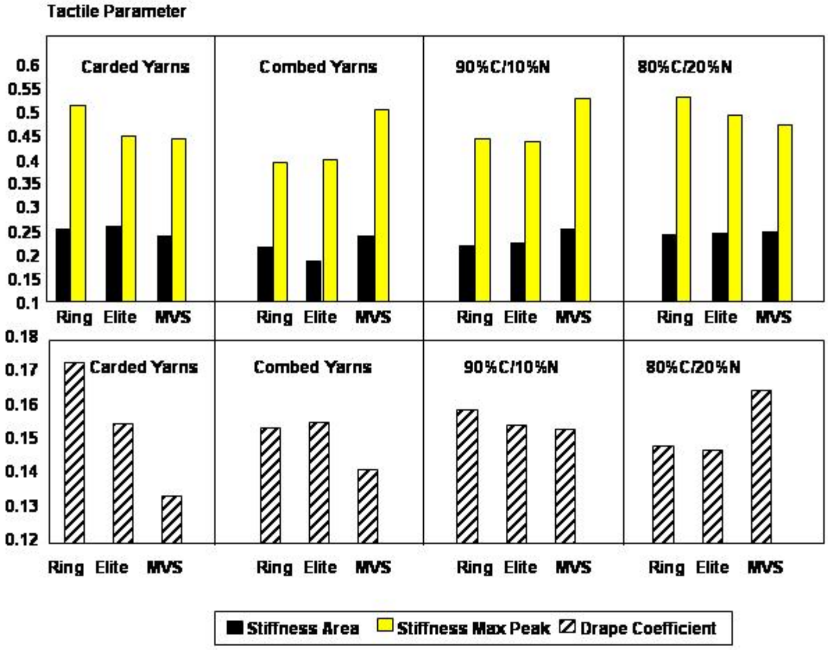

Figure 5. Fabric Stiffness and Fabric Drape at Different Yam Type / Spinning Preparation Combinations.

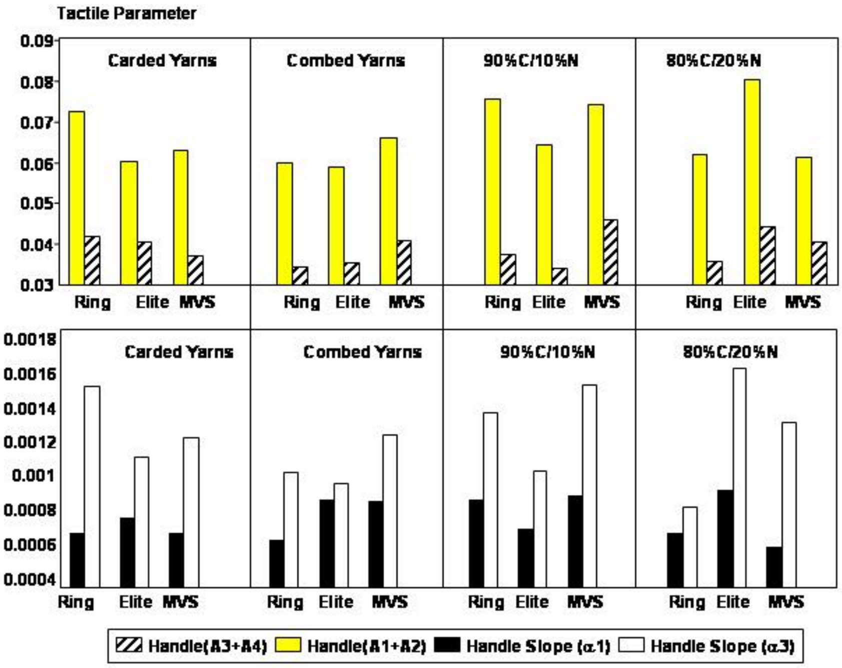

Figure 6. Fabric Handle Parameters at Different Yarn Type/Spinning Preparation Combinations.

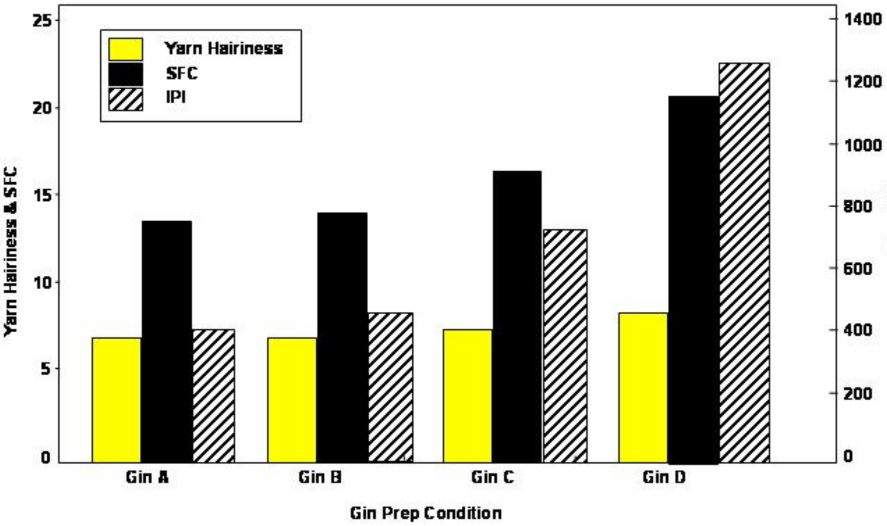

Figure 7. Some Fiber and Yarn Properties at Different Gin Treatments.

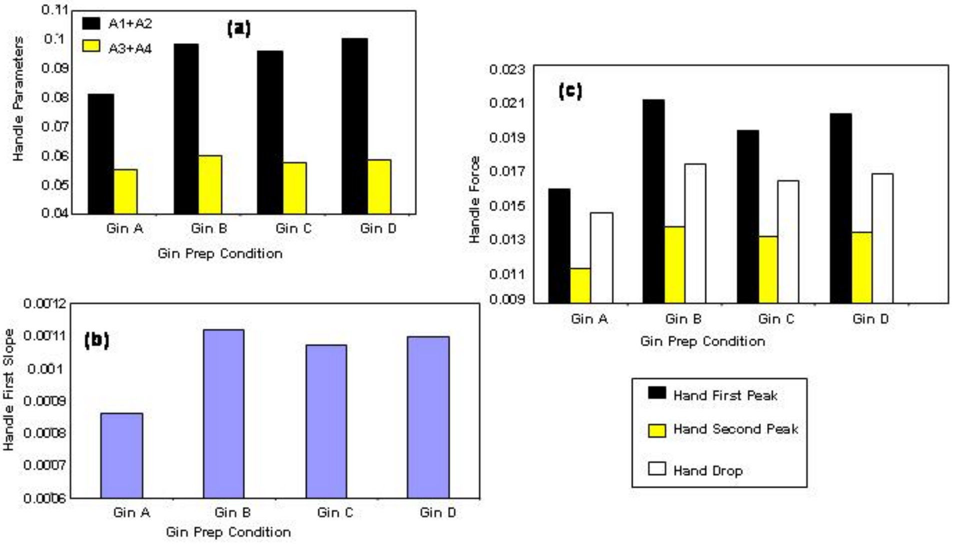

Figure 8. Fabric Tactile Parameters at Different Gin Treatments.

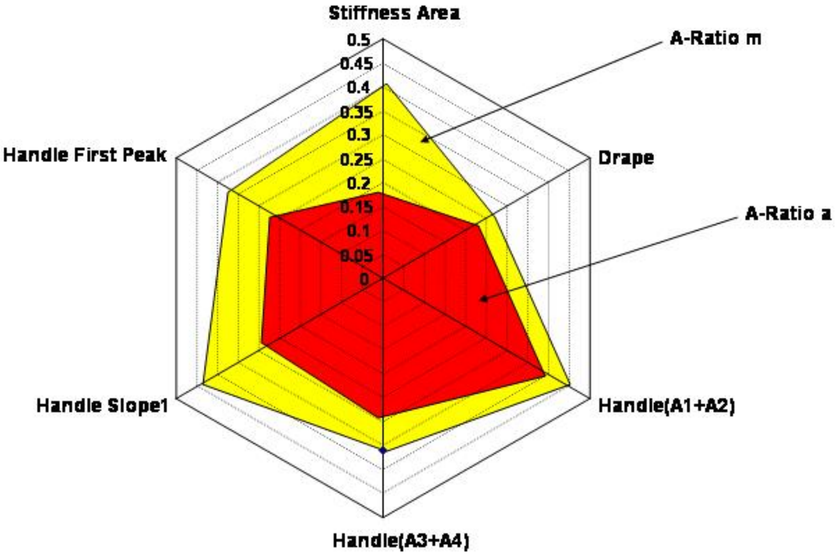

Figure 9. Correlations between Area-Ratio Parameters and Some Yarn and Fabric Characteristics.