2005 Beltwide Cotton Conferences, New Orleans, Louisiana - January 4 - 7, 2005

AN INNOVATIVE METHOD FOR MEASURING OBJECTIVE TOTAL FABRIC HAND

Yehia Elmogahzy, Fatma Selcen Kilinc, Monir Hassan and Ramsis Farag
Auburn University
Auburn, AL

Abstract

This paper introduces a new method of measuring fabric hand based on realization of the different low-stress deformational components that may be involved in a subjective hand evaluation. These include: bending, compression, surface touch, free drape and constrained drape. The method aims at overcoming a great deal of the problems associated with statistical reproducibility and characterization parameters found in previous methods. The output of this method is represented by the so-called "hand profile". This is a force-time profile, which encompasses the various modes of low-stress deformation encountered during a hand evaluation. . Each zone of the profile reflects a specific mechanism of fabric hand. This feature is important particularly when an enhancement of a particular hand-related parameter is required in the process of fabric design. The profile also produces a single fabric hand index represented by the total area under the hand profile. This parameter is termed "Objective Total Hand", or OTH. Evaluation of this parameter proved that it is highly correlated to subjective hand assessments of tens of woven and knit fabrics and highly related to the different objective parameters constituting fabric hand.

Introduction

Through the touch and feel of fabric and with little experience, human can gain information that no other testing technique could fully yield. When the power of human touch is compared with other sensory means such as vision, it is always found that the sense of touch has better ability to discriminate and recognize complex stimulus patterns than the visual system does. This is because, human skin has a remarkable ability to detect even the slightest touch and any point on the human body can cause a sensation of touch. The primary human organ used for touch is the human hand; a very powerful organ which performs several sensory mechanisms supported by over 17000 nerve endings that are sensitive to non-noxious mechanical deformation of the skin in the glabrous skin of one hand.

In general, the term "fabric hand" describes the way a fabric feels when it is touched and manipulated by hand. It is an action noun that implies evaluation of fabric reaction to different modes of low-stress deformation imposed by human hand. A more general term that is commonly used in the industry is "fabric handle". This is an action verb that reflects the evaluation of fabric reaction to different modes of deformation at all levels of applied stress (low or high). In this case, fabric handle may imply different handling actions such as touching, folding, cutting, transporting, sewing, and pressing. In this paper, we will use the term "fabric hand" to imply an integrated evaluation of fabric "manipulability", or the extent of ease of response of a fabric sample through applying a multiplicity of unnecessarily organized manipulative actions.

The fascination with fabric hand by researchers and technologists in the field has been a result of two basic facts. First, it represents one of the most important initial attractions that draw people attention to fabrics and garments in the marketplace. Secondly, a great deal of complexity is associated with characterizing it as a result of the multiplicity of interactive factors influencing it. The issue of fabric hand is commonly addressed in view of two types of perceptions: an active perception resulting from an initiative taken by human to actually touch and feel (handle) a piece of fabric by hand, and a passive perception resulting from wearing a garment and unintentionally feeling its interaction with the skin and body movement. The significance of distinguishing these two types of fabric hand is that the first one primarily leads to an initial judgment of how the fabric feel, which may influence the appeal and the purchasing decision of a fabric or garment. In this regard, the person handling the fabric typically attempts to characterize his/her perception of fabric hand. At this point, it is often the case where verbal descriptors do not fully reflect the actual perception. This point often creates a problem to researchers analyzing the correlations between subjective hand scaling results and objective hand parameters. On the other hand, the passive fabric hand reflects a true experience with the fabric or garment after a period of wearing experience. In this regard, the information is essentially imposed on the skin, and the wearer has some justification for his/her decision.

Most investigators rely on active hand in establishing correlations between subjective and objective means of fabric evaluation. This approach is simple and very doable. In addition, it reveals good information particularly when fabrics of extreme hand characteristics are being compared. However, irreproducibility and unreliability can be of major concern, particularly when fabrics of small hand differences are being compared or when an inappropriate control sample is used.

The key question that has been addressed in most hand studies is "what constitutes fabric hand?" Despite the extensive research in the area, a universal answer to this question is yet to be fully established. Indeed, every study on fabric handle, including some of the most recent studies, seems to aim at addressing this question using particular fabrics. As a result, and despite the significant developments in the field, a universal quantitative measure of fabric hand has not yet entered the textile and apparel database.

The main reason that a universal answer to the question of "what constitutes fabric hand?" has not been fully established lies in the fact that the subjective aspect of fabric hand represents the driving force toward characterizing this critical phenomenon. Indeed, it is commonly agreed that it is necessary to examine the subjective assessment of hand before examining its relationship to fabric mechanical and surface properties. Since there is no standard format of subjective evaluation, no standard answer is provided. Until such a format is established, research on the subject will continue and many more attempts to address this question will be made.

Standardizing the subjective hand evaluation requires translating various personal judgment criteria into reliable characterization categories that reflect true global mutual communication about fabric quality. The fact that personal judgment is typically of continuous nature, calls for utilization of advanced analytical techniques such as fuzzy logic to establish realistic membership functions of fabric hand characterization. This approach will provide many advantages over the traditional discrete psychological scaling. However, standard descriptors must be established first. More critically, a universal quantitative measure of fabric hand should be considered as the basis for developing reliable fuzzy membership functions (El Mogahzy, 1993, 1999).

Perhaps, the best and most acceptable answer to the question of what constitutes fabric hand was the one established by Peirce in his classic paper in 1930. In this study, Peirce pointed out three basic determinants of fabric handle: bending stiffness, bulk compressibility, and surface friction. Fabric drape was added as another component of fabric hand by later studies. This is because it reflects the fabric ability to conform to multiple curvatures. Figure 1 shows these components. Other parameters such as shear, crease recovery, and fabric thickness were also considered as determinants of fabric handle.

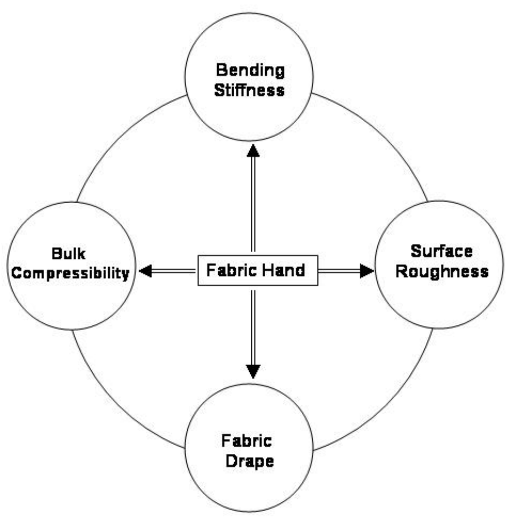

Figure 1. Components of Fabric Hand

Developments in Fabric Hand Objective Evaluation

In general, there are two types of hand evaluation that have been used by researchers over the years: (a) indirect systems of fabric hand (handle) evaluation, and (b) direct methods of fabric hand (handle) evaluation. The difference between these two categories lies in the types of parameters produced by each category and their associated interpretations. Indirect systems do not characterize handle in a direct fashion. Instead, they produce instrumental parameters that are believed to represent basic determinants of fabric handle such as fabric stiffness, fabric roughness, and compressibility. Only through parallel subjective assessment and cross-correlations, some parameters that are believed to simulate fabric handle are estimated. The two common methods of this category are the Kawabata system (KES®) and the FAST (Fabric Assurance by Simple Testing) system. Direct methods of fabric hand (handle) evaluation represent creative techniques that are intended to simulate two or more aspects of hand evaluation and produce quantitative measures that are labeled as hand force or hand modulus. These methods include: the ring method and the slot method. It should be pointed out that the term “direct” does not necessarily mean more representative or more accurate in comparison with the indirect systems.

ELMOGAHZY-KILINC Hand Method

As an integrated part of a larger study on fabric comfort (KILINC , 2004, Hassan, 2004) directed by Dr. El Mogahzy and sponsored by the National Textile Center of the U.S.A, a new method of testing fabric hand was developed. This method was called “ELMOGAHZY-KILINC Hand Method”. The underlying concept of this method was inspired by the theoretical and experimental efforts made by many of the previous outstanding investigations in the field. However, the method aims at overcoming a great deal of the problems associated with statistical reproducibility and characterization parameters found in previous methods.

The ELMOGAHZY-KILINC method shares some common features with previous direct methods including the Alley et al method, 1976, and the Grover et al method, 1993. However, it exhibits distinct features in both the geometrical setup and the critical parameters produced. The uniqueness of this method stems from its simulative and interpretive capabilities. It is perhaps, the first method that introduces a single hand index that reflects most of the constituents of fabric hand.

The main premises of the method are as follows:

- The issue of fabric hand is an issue of simulation and interpretation
- A viable fabric hand evaluation technique should be reproducible and representative of the fabric being studied
- A single fabric hand index that reflects most of the fundamental components of hand as established by Peirce and many other researchers will represent a major step toward incorporating fabric hand in the fabric quality database
- The method should be inexpensive and very efficient (this method takes only one minute to completely evaluate a fabric sample).

Figure 2 shows the basic components of the ELMOGAHZY-KILINC hand method. A flexible light funnel is used to represent the media through which the fabric sample is pulled through. The idea of using a funnel media instead of the ring or the slot arrangement is to provide better simulation of fabric hand. The contoured flexible surface of the light funnel simulates anticipated hand modes such as drapability, stretching, internal sample compression, lateral pressure, and surface friction. These modes are achieved both simultaneously and sequentially. In addition, the funnel media allows both constrained and unconstrained fabric folding or unfolding, which simulates one of the mechanisms of fabric handle. Different funnel types and sizes can be used; however funnel material should exhibit a great deal of flexibility (e.g. Teflon®-plastic funnels). The funnel is rigidly suspended in a special horizontal attachment that is mounted rigidly on the movable head of the AU® mechanical tester. This machine was designed by Dr. ElMogahzy for the purpose of performing low-deformation testing applications including tension, compression, stiffness, shear, and friction testing. The AU® mechanical tester is equipped with digital control and a host of software programs that allow monitoring, analyzing and profiling test results.

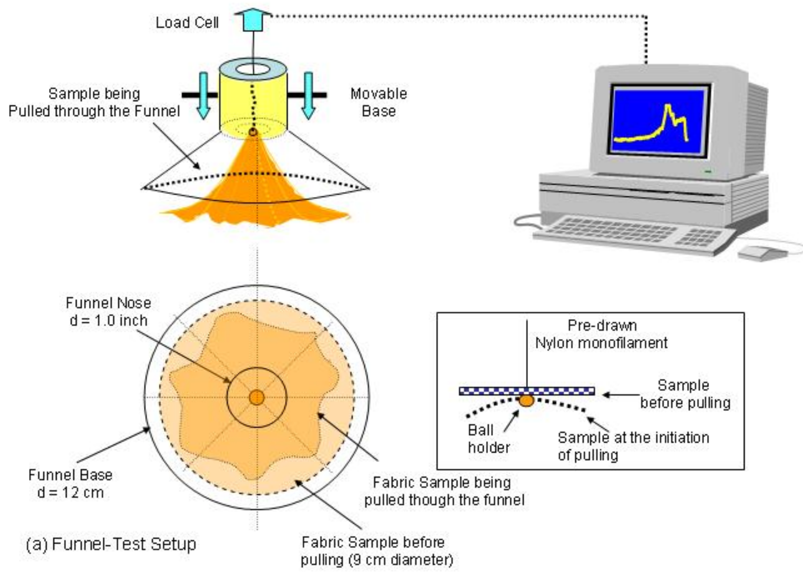

Figure 2. The ELMOGAHZY-KILINC Fabric Hand Method

For the purpose of the hand test, fabric samples are cut circular at 9 cm diameter (smaller than the diameter of the funnel wide base). However, the sample diameter may be changed if funnels of different dimensions are used as long as a ratio of 0.75 is maintained between the sample diameter and the base diameter. At this ratio, statistically reproducible results were obtained.

In general, as the movable head of the AU® mechanical tester moves downward, the funnel moves downward and the fabric sample is pulled through. During this process, the following sequence of sample behavior takes place (see Figure 3):

- Initially, the sample is in a flat horizontal position.
- The initial downward movement of the funnel results in an upward movement of the fabric sample against its own weight and in a freely folding mode. Images taken of the sample at this initial step (shown in Figure 3) indicates an unconstrained folding leading to fabric drape. At this point, a very stiff sample will typically exhibit a simple one-dimensional folding similar to that of a piece of paper and a flexible sample will exhibit multi-curvature drape.
- As the funnel continues to move downward, the sample begins to touch the inside wall of the conical part of the funnel at random points determined largely by the initial drape.
- The contact between the fabric sample and the inside wall of the conical part of the funnel initiates a constrained folding similar to that imposed by human hand compression of fabric during subjective evaluation. In addition, the conical shape of the funnel allows a great deal of reproducibility of this constrained folding. The extent of folding at this stage is largely determined by a combination of fabric stiffness and fabric inter-fold friction.
- As the sample attempts to enter the funnel cylindrical nozzle, tension builds up as a result of a combination of stretching, compression, shear, and initial frictional effects. This tension reaches a peak at some point of the entering process at which the folded sample becomes aligned with the cylindrical nozzle of the funnel. At this point, the tension drops. The tension peak was found to typically occur 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.
- The momentarily tension drop lasts for about one to two seconds after which the tension begins to rise again. 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 folding stiffness.

- Inside the cylindrical nozzle, the fabric sample undergoes internal compression, which depends on its folding status at the entrance point. In addition, sliding 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. As a result, fabrics of different folding stiffness will exhibit different frictional stick-slip patterns. In addition, an internal shear and elongation in the constrained sample is also expected, which increases with the increase in the length of the sample entering the cylindrical nozzle. As a result, another tension build up occurs.
- The friction mechanism in the cylindrical nozzle is largely determined by the internal lateral pressure created by pressing the sample inside the nozzle and the extent of pre-folding. A stiff sample will result in high lateral pressure, and a flexible sample will result in low lateral pressure.
- The second tension build up is typically smaller than the initial tension peak. However, for samples of extremely high folding resistance (stiff and rough samples), it can indeed exceed the first peak.
- As the fabric sample exits the cylindrical nozzle, a pressure release progressively occurs leading to a continuous reduction in tension. This pressure release results in a case of internal stress relaxation, unfolding, and some form of crease recovery.

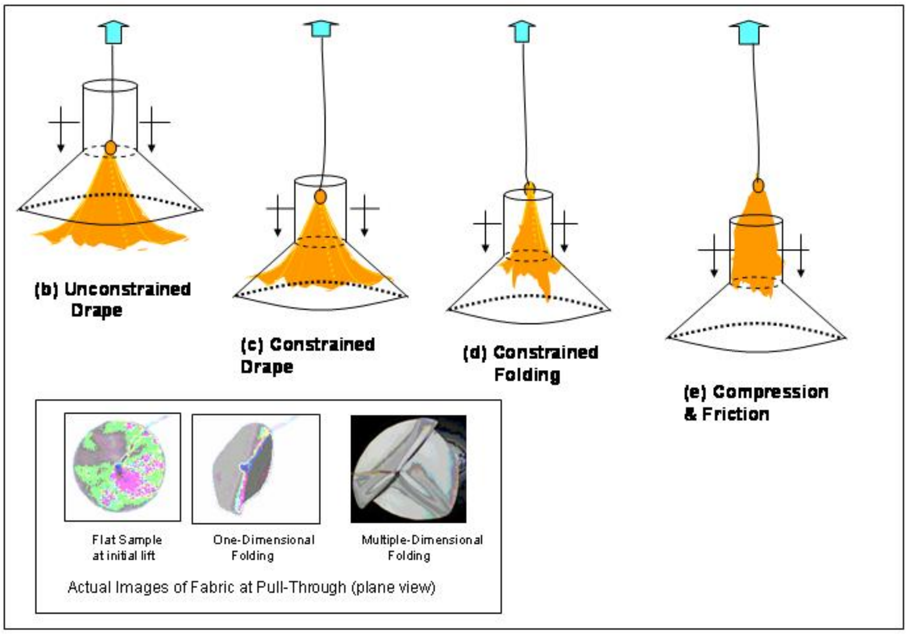

Figure 3. Basic Steps During Pull-Through Test of the ELMOGAHZY-KILINC Fabric Hand Method

The Hand Profile

During the duration of the fabric pull through the funnel, a force-time profile is generated, which is termed "the Hand Profile". For most apparel fabrics, this profile takes the common shape shown in Figure 4. The Hand Profile can be divided into four primary zones identified by the areas under the curve A_1, A_2, A_3, and A_4.The first zone expands from the starting point of the test to the point at which the fabric touches the inside wall of the conical part of the funnel. This zone represents a simple case of lifting a flat rounded sample off the base. The area under the curve of this zone, A_1, primarily reflects the work done to lift the sample (mainly a function of fabric weight and the vertical distance, h, to the touch point). However, the shape of the curve at this zone was found to reflect the extent of uniformity of sample drape behavior. In most cases, a smooth initial rise of this zone curve was witnessed. However, fabrics that exhibited a great deal of unbalance or spirality were associated with clear irregularity in the initial curve.

The second zone of the handle profile begins at the moment the fabric touches the inside wall of the conical part of the funnel and ends at the point of maximum handle resistance (point A). It reflects a combination of stretching, compression, shear, bending stiffness, and fabric inter-fold friction. The maximum resistance (point A) and the slope, θ_o, can be interpreted in similar fashion to that used for the maximum handle peak and the handle modulus parameters considered in previous methods (Alley et al, 1976, and the Grover et al, 1993). In addition to these two parameters, we also considered the area under the curve of this zone, A_2. This area primarily reflects the work done to resist the constrained deflection and reconfiguration of the sample. Accordingly, this area is expected to be largely a function of a combination of stretching, compression, shear, bending stiffness, and fabric inter-fold friction.

The third zone of the handle profile begins at point A and ends at the point of tension trough (point B). The slope associated with the tension drop, θ_I, as well as the tension trough (point B) quantitatively characterizes the ease of reconfiguration, or fabric folding (alignment) flexibility. The area under the curve of this zone, A_3, primarily reflects the work done in reconfiguring and aligning the fabric sample under lateral deflection.

The fourth zone of the hand profile begins at point B and ends at the end of the test duration period. This zone is characterized by two parameters, the peak resistance of this zone, F_{max}, which is termed “friction peak”, and the area under the zone curve, A_4. As indicated earlier, this zone entirely reflects a friction process determined by the internal lateral pressure created by pressing the sample inside the nozzle and the extent of pre-folding. A stiff and rough sample will result in high lateral pressure, and high friction. A flexible and smooth sample will result in low lateral pressure, and a low friction. The progressively increasing tension in this zone is associated with the increase in the sample length entering the cylindrical zone. As was also indicated, this peak is typically smaller than the initial tension peak (point A). However, for samples of extremely high folding resistance (stiff and rough samples), it can indeed exceed the first peak. In this regard, the difference between the two peaks (P_{max} - F_{max}), is a useful parameter to characterize the overall manipulatability of fabric under a combination of constrained folding and rubbing action. In this regard, a positive difference would indicate a stiff but smooth fabric, and a negative difference would indicate a flexible but rough sample.

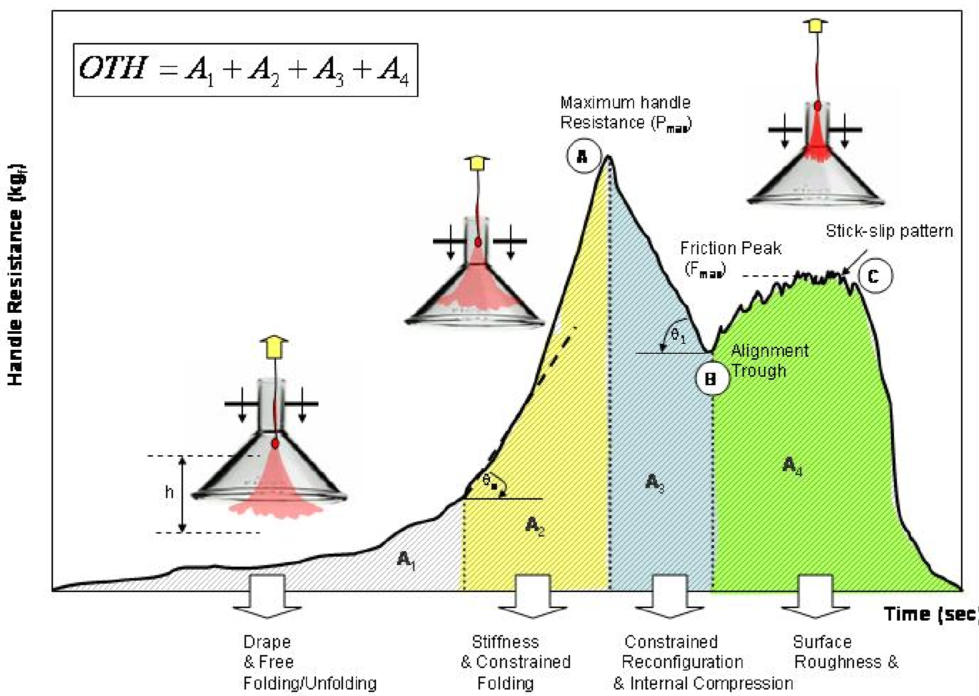

Figure 4. ELMOGAHZY-KILINC Fabric Hand Profile

Single Fabric Hand Index

As indicated above, the hand profile reflects most possible deformational modes involved in a hand trial. In addition, each zone of the profile reflects a specific mechanism of fabric hand. This point is important particularly when an enhancement of a particular hand-related parameter is required in the process of fabric design. If the goal is to establish a single fabric hand index, the Total Area under the ELMOGAHZY-KILINC hand profile will provide an excellent quantitative parameter. This parameter is termed “Objective Total Hand”, or OTH and it is the sum of the four areas discussed above. Detailed studies in which this parameter was evaluated proved that it is highly correlated to subjective hand assessments of tens of woven and knit fabrics considered in these studies and it is highly related to the different objective parameters constituting fabric hand. Some of these results are presented below.

Some Experimental Results of Fabric Hand

Merits of the hand test method discussed above were clearly realized from extensive testing of different fabrics. Some of the fabric types tested are listed in Table 1. These fabrics represent different fabric categories (woven and knit) and different patterns within each category. All fabrics were made from 100% cotton fibers.

Figures 5 and 6 show average values of some of the hand parameters described above for the different fabrics of Table 1. Among the woven fabrics, the twill fabric, which was made for durable heavy denim, exhibited the highest Objective Total Hand (OTH), the highest maximum peak, and the highest hand modulus. The plain weave, which represents light weight dress shirt exhibited the lowest Objective Total Hand (OTH), the lowest maximum peak, and the lowest hand modulus. Figure 7 shows the hand profiles produced for these two fabrics. The hand profile of the plain weave was zoomed out (in a separate figure) to illustrate the details of the profile, which were masked by the high magnitude of the twill fabric. As can be seen in Figure 7, the twill weave fabric required substantially higher hand force and hand work at different zones of the profile than the plain weave fabric. In addition, it exhibited a much higher resistance to hand, as demonstrated by the different slopes of the profile, than the plain weave sample. The hand profile of the plain weave sample also showed a tendency to exhibit an early drop in the hand resistance as illustrated by the dotted circles shown in the graph. This early drop is typically a result of a release in tension caused by some unfolding of the fabric at the transition stage from free folding to constrained folding. Among the knit fabrics, Figures 5 and 6 clearly show that double-knit samples had higher Total Hand than the single-jersey sample. Figure 8 shows the hand profiles produced for the single-jersey and the interlock knit sample. As can be seen in this Figure, the interlock double-knit sample required higher hand force and hand work at different zones of the profile than the single-jersey sample.

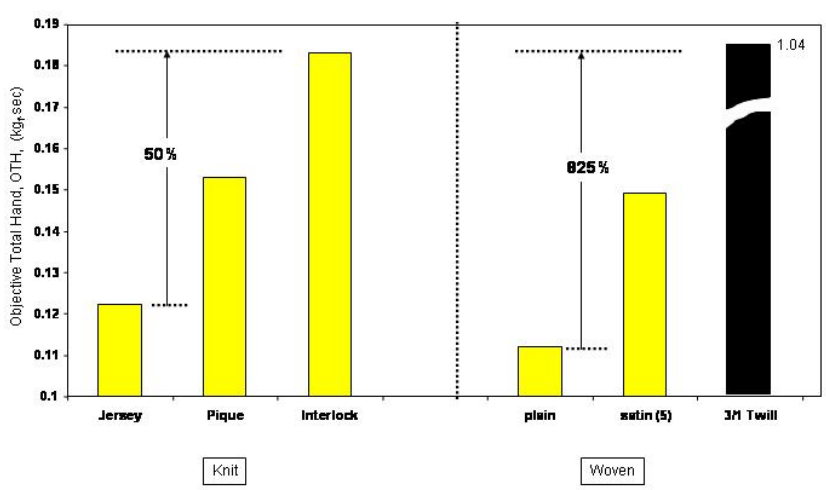

Figure 5. Objective Total Hand (OTH) of Selected 100% Cotton Fabrics

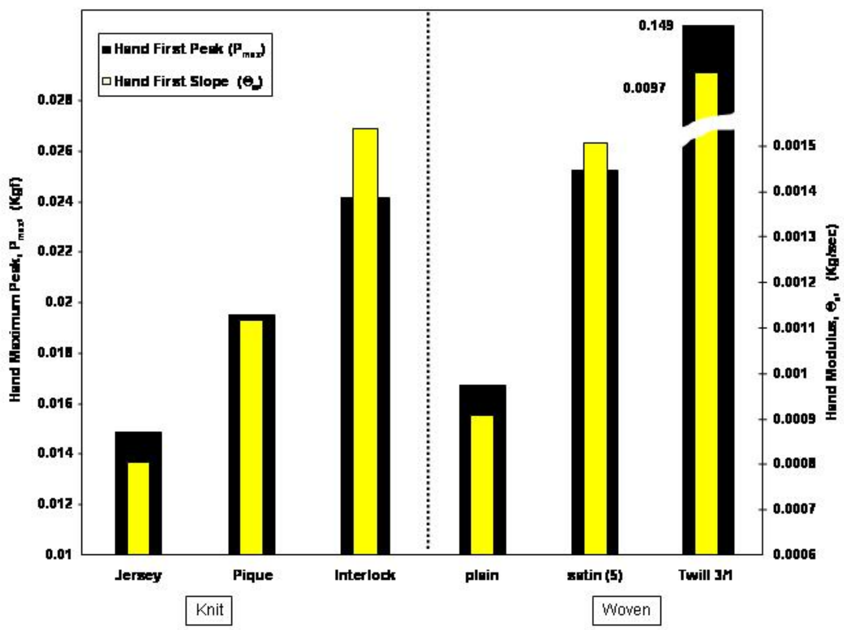

Figure 6. Hand Peak & Modulus of Selected 100% Cotton Fabrics

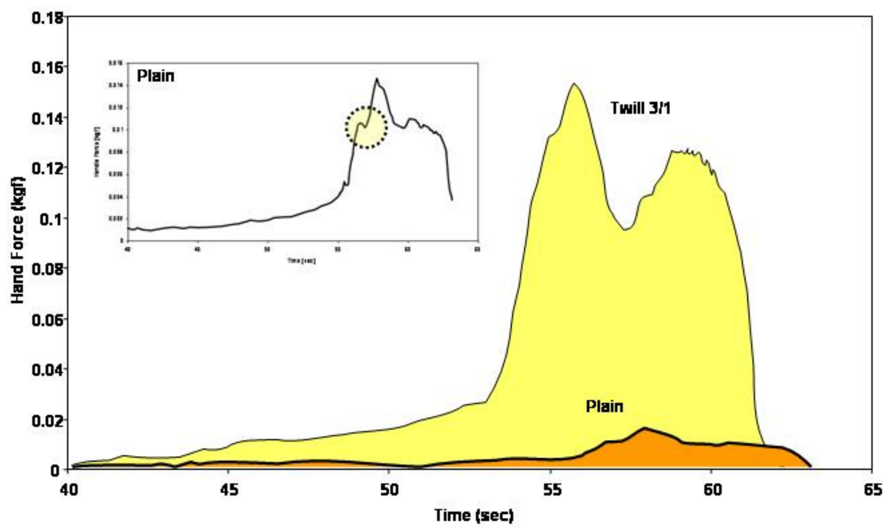

Figure 7. Hand Profiles of Twill and Plain Weaves

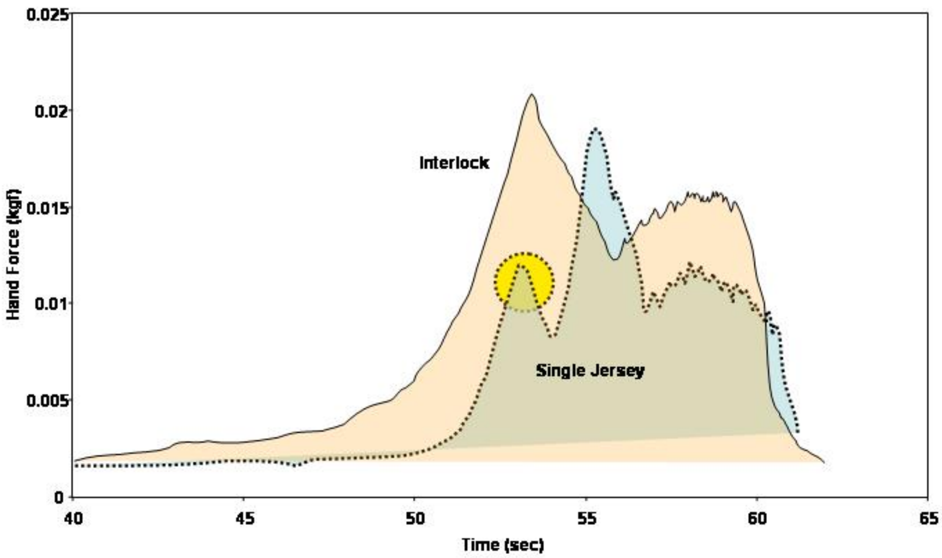

Figure 8. Hand Profiles of Jersey and Interlock Knits

As indicated earlier, the ELMOGAHZY-KILINC hand test method reflects most of the parameters constituting fabric hand. These include: fabric stiffness, fabric drape, and fabric surface roughness. This point can be illustrated by examining the values of these parameters, tested independently, for the selected fabrics described in Table 1.

Table 1. Average values of Mechanical Tactile Parameters

Fabric Type	Ne (Lengthwise)	Ne (Widthwise)	Thread Count (Lengthwise)	Thread Count (Widthwise)	Fabric Thickness (mm)	Fabric Weight (g/m^2)
Plain	35	34	76	66	0.3048	104
Satin (5)	45	44	144	74	0.3302	124
3/1 Twill	7	20	79	65	0.705	290
Jersey	27	27	33	46	0.6215	157
Interlock	44	44	41	40	0.9400	177
Pique	26.5	26.5	26	40	0.793	193

Figure 9 shows the values of fabric stiffness for these fabrics. Fabric stiffness was measured using ASTM D 4032 – 94 Standard Test Method for stiffness of fabric by the circular bend procedure. Additional effort was made to acquire the data during the test duration so that a stiffness profile can be obtained from which two basic measures can be determined: maximum stiffness load (Newton), and the area (N.sec) under the resistance force-time diagram (stiffness profile). These values reflect the ease of deformation under bending, which is a critical tactile comfort characteristic. This was made possible via data acquisition Lab-view program. As can be seen in Figure 9, among the woven fabrics, the twill weave sample exhibited the highest stiffness level and the plain weave sample exhibited the lowest stiffness. Among knit fabrics, the interlock double-knit sample had the highest stiffness and the single-jersey sample had the lowest. These results are in full agreement with the Total Hand results, the hand resistance values, and the hand modulus values of this set of fabrics.

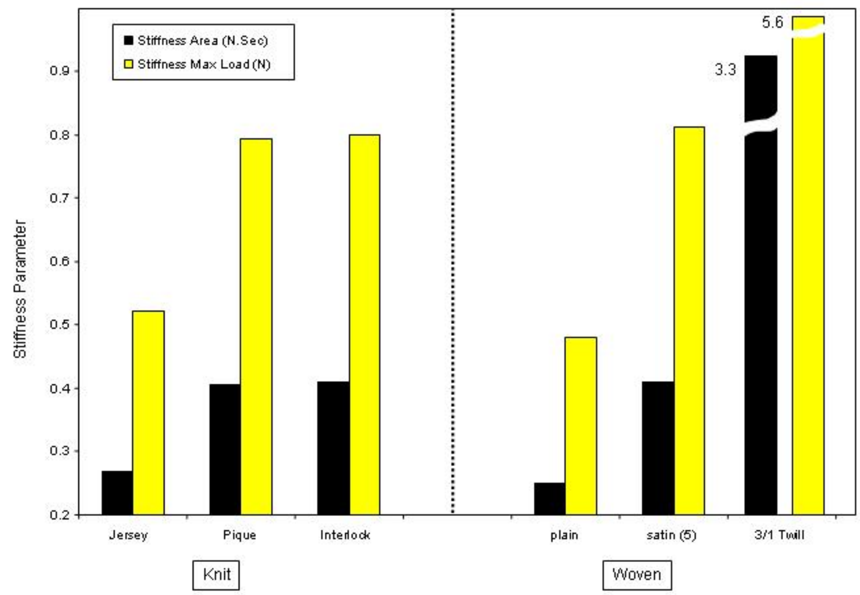

Figure 9. Stiffness Area of Selected 100% Cotton Fabrics

Figure 10 shows the drape coefficient values of the same set of fabrics described in Table 1. As indicated earlier, drape is the term used to describe the way a fabric hangs down under its own weight in folds. It has an important bearing on how good a garment looks in use. In addition, it indicates the conformity of garments to body contours. In this study, we measured drape using the familiar BS5058 standard method in which drape is expressed by the so-called "drape coefficient"; the higher the drape coefficient, the lower the fabric drapeability, or the lower the propensity to drape.

As can be seen in Figure 10, knit fabric samples generally exhibited lower drape coefficients or higher propensity to drape than woven fabric samples. In general, it is well known that knitted fabrics are relatively floppy and garments made from them will tend to follow the body contours. Close examination of the values of drape coefficients of different fabrics will indicate a direct correspondence between these values and the initial area of the hand profiles.

Another important factor that contributes to the overall hand quality of fabric is surface roughness. This parameter was measured using geometrical surface image analysis and classic friction tests. In this chapter, we report the frictional results. Fabric friction was tested using the straightforward setup shown in Figure 11 in which the apparent contact area is well-defined. This method can be used for fabric-to-metal or fabric-to-fabric friction.

The coefficient of friction, μ, was determined from the classical law of friction, $F_A = \mu P$ (where F_A is the frictional force per area, and P is the lateral pressure). This law typically assumes that the coefficient of friction, μ, is constant at all levels of lateral pressure and is independent of the area of contact. This assumption has been questioned in previous studies (e.g. El Mogahzy and Gupta, 1991, 1993), and it was generally found to be inappropriate for materials deforming elastically or viscoelastically under lateral pressure. Fibers typically deform visco-elastically under lateral pressure. When the fibers are formed into fibrous structures or assemblies, the assumption of viscoelastic deformation should continue to hold as a result of the porous structure of fiber assemblies.

Many formulae have been developed to model the friction phenomenon of different materials. Gupta and ElMogahzy performed theoretical and experimental analyses aiming at evaluating different relationships between the frictional force and the normal force for fibrous materials (El Mogahzy and Gupta, 1991, 1993). They concluded that the best expression that can characterize this relationship is:

$$F_A = a\,P^n$$

The above relationship indicates that the frictional coefficient, defined by the ratio F/N, is not constant as suggested by the classic friction law. Instead, it is a function of the normal force, N, applied on the contacting area. This is revealed by the following equation:

$$\mu = \frac{F_A}{P} = aN^{n-1}$$

In this study, the parameters 'a' and 'n' were determined from the relationship between the coefficient of friction, as defined by the classical law ($\mu = F_A/P$), and the lateral pressure P.

Figure 12 illustrates the values of the friction parameters 'a' and the Hand Area, A_4, for the different fabrics listed in Table 1. As can be seen in this Figure, knit fabric samples generally exhibited higher 'a' values (or higher friction) than woven fabric samples. The point of interest, however, is the relationship between the Hand Area A_4, which directly reflects the resistance to friction in the cylindrical nozzle zone and the friction parameter 'a'. This clearly indicates that the ELMOGAHZY-KILINC hand test method is capable of detecting the mechanical hand effects associated with surface roughness.

We should point out that the ELMOGAHZY-KILINC method has been used for evaluating fabrics of the same type under different treatments including dyeing and finishing and washing treatments and the results clearly showed its usefulness in design and performance enhancement applications (KILINC, 2004, Hassan, 2004).

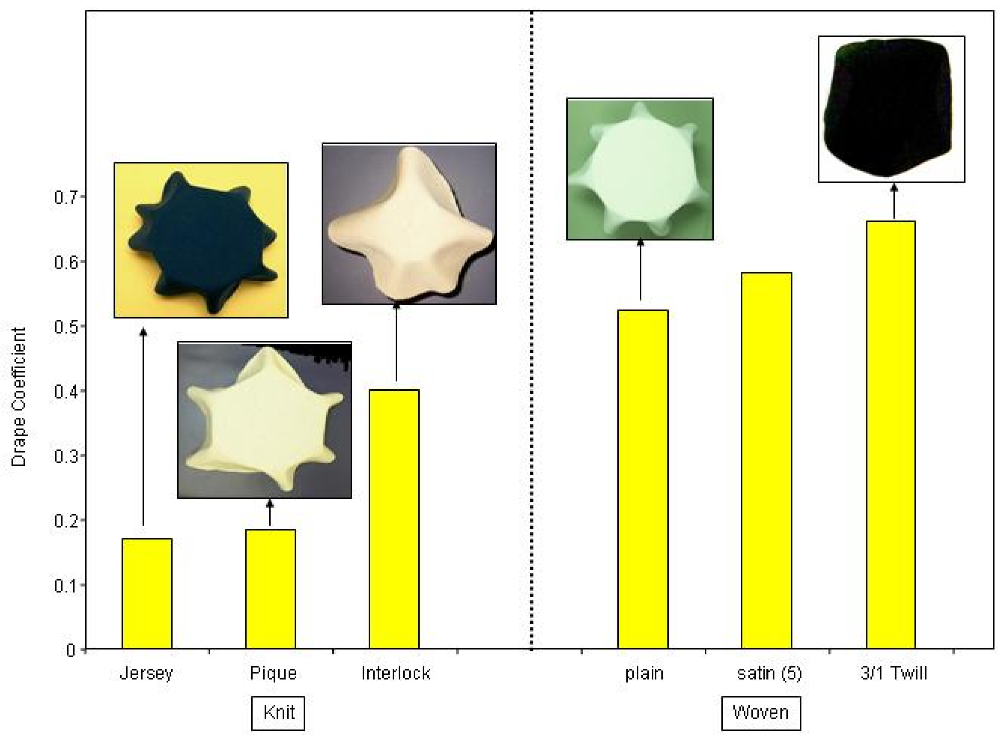

Figure 10. Drape Coefficient of Selected 100% Cotton Fabrics

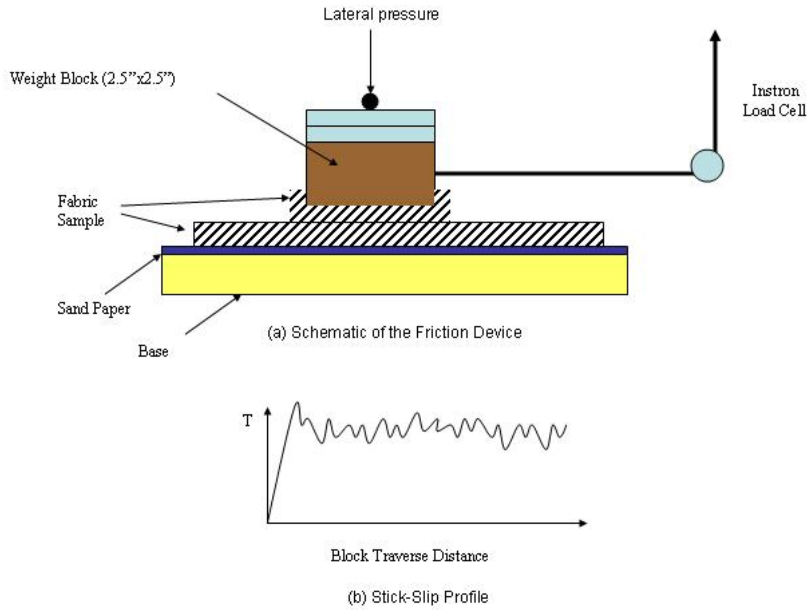

Figure 11. Sled Friction Method

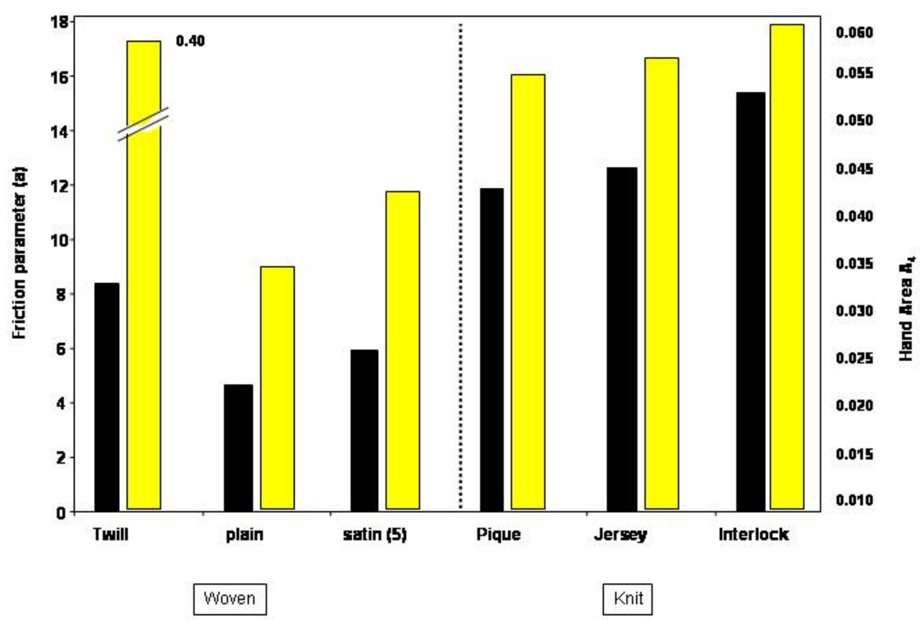

Figure 12. Fabric/Sand paper Friction Parameter 'a' of Selected 100% Cotton Fabrics

Closing Remarks

The phenomenon of fabric hand will continue to interest researchers of different sectors of the textile/apparel pipeline. The subjective nature of this important phenomenon will remain an essential aspect of research and implementation. This is primarily due to the critical importance of human judgment, which is highly variable and often psychologically driven. Unfortunately, subjective evaluation does not yield precise design guidelines except for extreme hand conditions. An objective hand evaluation coupled with subjective assessment seems to be the appropriate approach. In addition, a comprehensive database of hand parameters associated with human judgment scores will be very beneficial. We hope that this paper will stimulate textile and apparel producers to establish database of fabric hand of different products. Such a database will be extremely useful as we approach the era of complete internet shopping in which little or no intimacy with fabrics will be involved in making purchasing decisions.

Literature

El Mogahzy, Y. E., Understanding Fabric Comfort, Textile Science 93 International Conference Proceedings, Vol.1, Technical University of Liberec, Czech Republic, 1993.

El Mogahzy, Y. E., “Survey of Human Comfort with respect to Clothing”, A special report submitted to the United Nation via Thomson & Kirk Social Enterprise Consultant, New York, NY, 1999.

Peirce, F. T., The Handle of Cloth as a Measurable Quantity, J. Text Inst., 21, pp.T377, 1930

KILINC, F. S., A Study of the Nature of Fabric Comfort: Design-Oriented Fabric Comfort Model, Ph.D. Thesis, Auburn University, U.S.A., 2004.

Hassan, M., “Computer-Based System for Evaluation and Recognition of the Structural and Surface Characteristics of Fabrics, Ph.D. Thesis, Al Mansoura University, Egypt, 2004

Grover, G., Sultan, M.A., and Spivak, S.M., A Screen Technique for Fabric Handle, J. Textile Inst., 84(3), pp.1-9, 1993.

Alley, V. L., and Mchatton, A. D., Nozzle extraction process and handlemeter for measuring handle, US4103550 (NASA), 1976

El Mogahzy, Y., and Gupta, B.S., Friction in Fibrous Materials Part II: Experimental Study of the Effects of Structural and Morphological Factors, Text. Res. J. 63(4), pp 219-230, 1993.

Gupta, B.S., and El Mogahzy, Y., Friction in Fibrous Materials Part I: Structural Model, Text. Res. J. 61(9), pp 547-555, 1991.