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**Proceedings Paper:**

Mao, N (2014) Towards objective discrimination & evaluation of fabric tactile properties: Quantification of biaxial fabric deformations by using energy methods. In: Proceedings. 14th Autex World Textile Conference, 26-28 May 2014, Bursa, Turkey.

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## **Towards objective discrimination & evaluation of fabric tactile properties: Quantification of biaxial fabric deformations by using energy methods**

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### **Abstract**

In this paper, the actions involved in the subjective fabric hand evaluation process were analysed and the characteristics of the fabric deformations in both subjective and objective fabric evaluation process was identified; the criteria to mimic the required fabric deformations in fabric handle evaluation process and the possibility of quantifying different types of fabric deformations by using energy consumed in the process was discussed.

As an application of the above theoretical analysis and the new concept established, an new fabric handle evaluation system, Leeds University Fabric Handle Evaluation System (LUFHES) based on the quantifications of the controllable fabric biaxial deformations (Mao and Taylor, 2012) was developed for the objective evaluation of the fabric tactile properties, this method mimics the multidirectional fabric buckling deformations in subjective fabric hand evaluation process to address the limitations which previous subjective and objective fabric hand evaluation methods have. More importantly, a new concept of quantifying fabric handle through the quantification of fabric deformations by using the energy consumed in the process of fabric deformations, rather than using human preference, is proposed in the system.

### **1. Introduction**

Tactile properties of a fabric, which influences clothing tactile comfort and is thus one of the main factors affecting consumers' purchasing decisions (Chattopadhyay, 2008), is a sensory perception of a person receives when the fabric is deformed by touching, stretching, rubbing and squeezing by people's hand (Bishop, 1996). Because the fabric tactile properties are subjective sensations of human on the fabrics, it is thus naturally evaluated by using subjective assessment method in which experts are employed to qualify and quantify their hand feeling of fabric tactile properties when the fabric is deformed by hand in various ways respectively and the results are expressed as fabric hand values (Behera and Hari, 2010).

However, the subjective assessment of fabric hand are influenced by various elements and the conclusions for one identical fabric vary from individual to individual, often mixing up with people's personal opinions and subjective preference. Peirce (Peirce, 1930) noted that 'the judgement of fabric hand depends on time and place, on seasons, fashions, personal and racial predilections'. Also, there are debates of finding appropriate judges to decide the subjective preference of fabric tactile properties in clothing design: fashion designers, textile materials experts or non-professional consumers. In addition, the low assessment sensitivity, the adverse effects because of personal subjectivity and preference, and the scaling shift associated with the fatigue and conditioning of human senses all put obstacle in achieving a convincing conclusions from subjective assessment (Pan, 2007).

Since Peirce (1930) pioneered to evaluate fabric handle according to the physical measurement of fabric properties, several systems including Kawabata Evaluation System for Fabrics (KES-F) and Fabric Assurance by Simple Testing (FAST) system were developed to conduct objective measurements. KES-F system was designed in 1970s to study the fabric mechanical properties under low stress or deformation conditions which is similar to what happens when the fabric are handled, worn or shaped (Hu, 2000; Minazio, 1995). KES-F system links the measured 16 mechanical properties of standard wool fabrics directly to the subjective hand preference of Japanese experts by using multivariate statistical regression analysis.

Apparently these traditional objective measurement systems including Kawabata Evaluation System for Fabrics (KES-F) and Fabric Assurance by Simple Testing (FAST) system were developed to evaluate fabric hand properties based on the links between fabric mechanical properties measured and the subjective hand preference of humans. Because of those fundamental difficulties unsolved in fabric hand evaluation, the conclusions of fabric hand from objective fabric hand evaluation methods developed on the basis of the subjective assessment results are debatable. Due to the subjectivity of human perception its conclusions are based, it is argued that this system still carries out subjective rather than objective assessment and that it could not provide an appropriate subjective conclusion of fabric hand assessment in countries other than Japan (Pan et al., 1993, Pan 2007). FAST system is basically a simplified version of the KES-F which was developed by CSIRO in late 1980s to provide the wool fabric industry with a relatively simple and robust system for the objective measurement of the mechanical properties of fabric, and it is frequently used as an alternative to KES-F (Hu, 2000, Tokmak et al., 2010), it has the same problem as KES-F has.

It is clear that, although the fabric properties obtained from the measurements of various instruments in the objective methods such as KES and FAST, the conclusions of the fabric hand obtained from those systems still intrinsically depend on the subjective opinions of a group of experts on standard wool fabrics. Therefore, the conclusions of fabric hand from such objective evaluation systems are not objective and they might be unavoidably biased and debatable.

Another limitation of the existing objective measurement systems is that those systems are not based on a proper analysis and comparison of the fabric deformations formed on both subjective fabric hand evaluation and objective fabric handle evaluation systems. The fabric tactile properties evaluated using existing systems (KES-F, FAST and Fabric touch systems) depends on the measurements of the mechanical properties of fabrics under unidirectional (or one-dimensional) deformations, while the fabrics are always deformed by hand in multiple directions such as fabric buckling in subjective assessments. Pan (Pan, 2007) also argued that the results from these systems are not accurate reflections directly or indirectly of the human tactile response towards fabrics.

In some new developed systems using fabric extraction techniques (Pan (2007), Wool Handle Meter (2013), Pharbrometer (2013)), the fabrics are deformed in multiple directions which is similar to the fabric deformations in human hand during subjective evaluations, these systems are developed based on the measurements of the dynamic mechanical forces of the fabric undertaken when it is forced to go through a narrow opening (a ring, or a nozzle) ; in those methods, the fabrics are randomly deformed in multiple directions which is similar to the fabric deformations in human hand during subjective evaluations and the fabric tactile

properties are quantified based on the dynamic changes of the strain-stress curves obtained. However, the conclusions of the fabric hand obtained are still based on subjective assessments due to it is based on the statistical relationship between the stress-strain curve obtained from the instrument and subjective fabric hand values on several “standard” fabrics. In those systems, the fabric hand is quantified based on eight different features extracted by employing statistical principal component analysis (PCA) from the relationship between the stress-strain curve obtained from the instrument and conclusions of subjective assessment of fabric hand on several “standard fabrics”, so the fabric hand quantification values obtained are still based on subjective assessments. In addition, it is difficult for the fabric deformations in the extraction systems (e.g., nozzle methods) to be controllable and reproducible in repeat tests.

Therefore, it is desirable to develop a 100% objective fabric handle evaluation system for the reliable discrimination and quantification of the fabric tactile properties without involvement of any subjective components, the establishment of such an objective system will be based on a thorough analysis of the fabric deformation and evaluation processes in both subjective fabric hand and objective fabric handle systems.

To address the above limitations of the existing fabric hand evaluation system, a new method, Leeds University Fabric Handle Evaluation System (LUFHES) (Mao and Taylor, 2012), based on the quantifications of the controllable biaxial deformations of fabrics was developed for the objective evaluation of the fabric tactile properties, the fabric deformations in this method mimic the multidirectional fabric buckling deformations in subjective fabric hand evaluation process to address the limitations which previous subjective and objective fabric hand evaluation methods have. Furthermore, a new concept of quantifying fabric handle through the quantification of fabric deformations during the evaluation processes in terms of the energy consumed in the fabric deformation processes, rather than using human preference, is proposed in the system.

In this paper, an analysis of the fabric deformations in both subjective fabric hand evaluation process and objective fabric handle evaluation process was given, the characteristics of the fabric deformation in fabric hand evaluation process was identified, the criteria to mimic the fabric deformations in fabric handle evaluation process and the possibility of quantifying different types of fabric deformations by using energy consumed in the process was discussed.

## **2 Analysis of the fabric deformations in fabric hand evaluation process**

### **2.1 Analysis of fabric hand evaluation process**

In order to fully understand the fabric hand evaluation process, it is worth to examine closely the detailed steps involved in subjective fabric hand evaluation process. The purpose of subjective fabric hand evaluation process is to obtain the sensory perception information of fabric tactile properties through the sensors in human hand and the subjective fabric hand evaluation is usually performed by a group of experts and involves with four functions in sequence:

- (1) Interaction : to carry out certain types of pre-defined interaction activities with fabrics to be assessed;

- (2) Sensation: to sense the stimulations to human hand exerted by the fabrics during the process of performing the interaction activities;
- (3) Perception: to form sensory perceptions of fabric tactile properties in human brain through a series of reasoning process;
- (4) Differentiation and Description: to differentiate the subjective perceptions in different aspects and describe them by using corresponding descriptors.

It is noted that there are two functions performed by human hand in the subjective evaluation process, to interact with fabric and to sense the stimulations exerted by fabrics; while the two functions happens simultaneously in practical subjective fabric hand evaluation process, they are distinctively different and are now separated here.

It is also recognised that the second function above (i.e., sensation) is a biological sensory function performed by human hand and it is difficult to be replicated by using existing technologies; similarly, the third function (i.e., perception) is also a biological process covered by a range of interdisciplinary science sectors including biology, neuroscience, artificial intelligence, psychology and physiology, and it is still in a too early infant stage to realise the replication of this process by using existing technologies. However, it might be possible for both the first function (i.e., Interaction) and the fourth function (i.e., Differentiation and Description) to be replicated in some extent in an objective instrumentation system.

In the first function, i.e., the interaction process, there usually exist two types of interactions between human hand and targeted fabrics in subjective fabric evaluation process:

- (1) the first type: human hand and fingers strikes on a flat piece of fabric which is fixed in a position without apparent deformations; in this process, human hand exerts certain amount of forces onto the fabric and leads to a deformation of the sensory skins in human hand, that is, in the first type of interaction process, the fabric tactile properties are obtained through the sensory skins of human hand on which forces are exerted by fabrics having no apparent fabric deformations. Such action is usually used to obtain the information of the texture and morphology of fabric surfaces, but can obtain limited information of other fabric properties.
- (2) the second type: human hand exerts a certain amount of forces onto a piece of fabric, which is free to move and free to be distorted, to deform the fabrics; in this process, the fabric tactile properties are obtained through the sensory skins of human hand on which forces are exerted by deformed fabrics having various types and amounts of deformations. This type of interaction process is frequently found in most of commercially adopted subjective fabric hand evaluation protocols, and used in most of the existing fabric handle evaluation instrument systems including KES, FAST, Pharbrometer, LUFHES, etc. The fabric deformations in this type of fabric – human hand interaction will be further analysed and discussed below.

## **2.2 Characteristics of the fabric deformations in fabric hand and handle evaluation processes**

The fabric deformations in the second type of fabric – human hand interaction processes can be characterised in their dimensions, directions, types and amount of deformations as shown below:

- (1) Dimensions and directions of deformations: The fabric deformations in subjective fabric hand evaluation process are usually three-dimensional, biaxial (or multiple axial) deformations. The fabric deformations in objective fabric handle evaluation system varies in different instrument systems, they could be unidirectional deformation (e.g., tensile extension in strip test, and shear test) in the fabric plane, unidirectional deformation out of the fabric plane (e.g., cantilever bending, heart-loop bending, forced bending in KES, etc), biaxial deformation in the fabric plane (biaxial extension in flat fabric samples), biaxial deformation in three-dimensional fabrics (biaxial and multiple axial fabric deformation in fabric cylinders, fabric deformation in nozzle extraction test).
- (2) Strain types of deformation: in terms of different types of strain, fabric deformations are classified into shear strain deformation or normal strain deformation. The size of the strains in the fabric deformation is one of the key characteristics of the deformation.
- (3) Recovery types of deformation: The deformation of the fabric macro-/microstructures can be categorised into three types: self-recoverable deformation, recoverable deformation and unrecoverable permanent deformation. The elastic deformation in fabric materials and structures is self-recoverable (i.e., recovered by fabric elastic force) after the external force (e.g. elastic elongation, elastic compression, elastic torsion deformation, etc.) is withdrawn. The recoverable deformation in fabric materials can be recovered when an external force is applied (e.g. relative movement and shape changes of yarns/filaments in fabrics, relative movements and shape changes of fibres in yarns, and changes in elongation, compression and torsion). The unrecoverable fabric deformation usually represents the permanent damage in either fabric materials or structures which is not recoverable by any means (e.g. cracks/elongation in fibres and creases/wrinkles in the fabric surface).
- (4) Amount of deformation: The amount of the fabric deformations described above can be characterised and quantified by using the energy consumed to achieve each of these fabric deformations in the fabric evaluation process, regardless of the fabric deformation happened in the processes of subjective fabric hand evaluation or objective fabric handle evaluation.

It is interestingly to note that the three types of fabric deformations, including self-recoverable, recoverable and unrecoverable deformations, are not only felt and differentiated by using human hand, it is also able to be measured and quantified in specifically designed fabric deformation testing. Therefore, it is possible to design certain testing having distinctive and quantifiable three recovery types of fabric deformation described in (3) linked to the human hand sensory feelings of the three recovery types of fabric deformation. For example, biaxial fabric deformations in various testing in LUFHES system are differentiated and quantified (Mao and Taylor, 2012).

In this system (Mao and Taylor, 2012), the work done by the fabric elastic force to recover this elastic deformation in the objective fabric handle evaluation process corresponds to the fabric elastic forces exerted on human hand in subjective fabric hand evaluation process, thus it reflects the spongy feeling of the fabric on the human hand in subjective fabric hand evaluation processes. The energy consumed both to achieve and to recover this type of fabric deformations in the fabric handling processes is usually used to overcome the friction force encountered, and it represents how easily the fabric is deformed and the deformation is recovered. In other words, it reflects how flexible the fabric feels to the hand in subjective fabric hand evaluation tests. The energy consumed in this type of deformation in fabric handling processes is related to how easily the creases or wrinkles are formed in a fabric, and is similar to crispy feeling in subjective fabric hand evaluation.

Therefore, it is possible to characterise the fabric deformations and then further quantify the fabric deformations by using the amount of energy consumption in each type of fabric deformations in the fabric handle evaluation process; in addition, it is clear that each type of fabric deformations corresponds to the subjective feeling of human hand to the fabrics in subjective fabric hand evaluation process. Thus, the quantification of fabric handle evaluation process can theoretically represent the ranking of the fabric hand feelings in the fabric hand evaluation process.

### **3. Mimicking fabric deformations in objective fabric handle processes to achieve objective fabric handle evaluation**

As mentioned above, the fabric to be evaluated is deformed in various ways in most of subjective fabric hand evaluation methods and existing objective fabric handle evaluation systems. The differences of the fabric deformations in these two fabric evaluation processes are summarised below:

- (1) the fabric are deformed randomly in multiple axial by human hand in subjective assessment process while it is deformed in a designated way by instrument in either unidirectional or biaxial directions in objective evaluation process;
- (2) the deformations of the fabric to be evaluated are sensed by human hand in subjective fabric hand evaluation process while are measured by sensors in objective fabric handle evaluation process.

In practice, it might be difficult to use sensors to obtain identical information of the fabric deformations as human hand feels, but it is possible to mimic the fabric deformations in subjective evaluation process in objective fabric handle evaluation process. That is, the mimicked fabric deformations in an objective instrument system are possible to be similar, if not identical, to that in the subjective evaluation process.

In order to make the fabric deformations in an objective fabric handle system to be able to precisely represent the fabric deformations in a fabric hand evaluation system, the characteristics of the fabric deformations, as described in section 2.2, formed in objective fabric handle system should be ideally identical to that of the fabric deformations formed in the fabric hand evaluation process. However, it is known that the fabric deformations in the fabric hand evaluation process are formed randomly and varies from time to time, and

different from people to people, they are not reproducible. Therefore, the fabric deformations formed in the objective fabric handle evaluation system are required to be similar, if identical, to that in the fabric hand evaluation systems. The similar (or identical) fabric deformations in fabric evaluation systems here means that the two fabric deformations are similar (or identical) to each other in the dimensions, directions, types and sizes of strain, recovery types and their amount. The fabric deformations in objective evaluation system are required additionally to be controllable and reproducible.

Therefore, an objective evaluation process is seen as a true representation of subjective fabric hand evaluation process if the fabric deformations in those two processes are highly similar, if not identical.

**4. The new fabric handle evaluation system (LUFHES) and its fabric handle index descriptors**

LUFHES was designed to measure the fabric handle properties under biaxial deformation. Fabrics to be tested are formed into a fabric cylinder of 80mm in diameter and 50mm in gage lengths and its two ends were clamped in the LUFHES system. A complete measurement in the system consists of quantifications of the fabric deformations in four process: a cyclic twisting of the fabric cylinder in the radial direction, a cyclic compression buckling of the fabric cylinder in the longitudinal direction, an extension of the fabric cylinder in the longitudinal direction and a fabric to fabric surface friction test of the fabric cylinder in longitudinal direction.

A typical force-displacement curve of two cycles of compression and twist buckling deformation of a fabric cylinder in LUFHES is shown in Figure 1. Lines ABC and EFHC represent the compression/twist phases in the first and second cycles of the test respectively. The recovery phases in the first and second cycles are frequently coincided together and are represented by the line CDE. It is noticed that different areas defined in this Figure 1 (i.e., the areas of AGBCKA, AGBCHFA, FHCKF, DCKD, FHCDF, EFDE and EAFE in Figure 1(a) and the areas of AFBKA, EBKE, EBCE, CDAC, CBKC, EDAE and EAFE in Figure 1(b)) represents the energy consumed for the deforming the fabrics during the processes of the fabric handle evaluation.

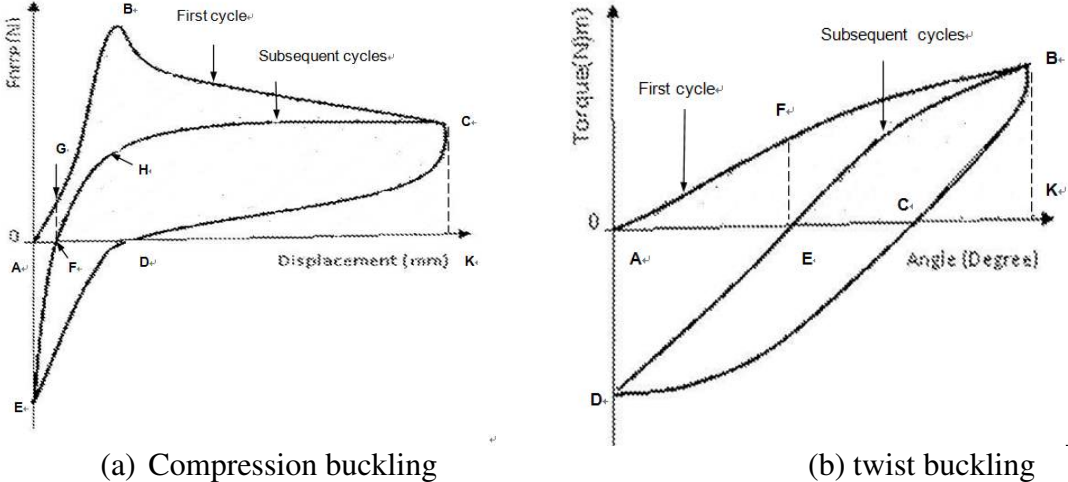


Figure 1 Typical force-displacement curve of fabric compression and twist buckling deformation in LUFHES test

The fabric stiffness, flexibility, sponginess, crispiness and softness are defined based on the above-mentioned energies consumed in various fabric deformations; the fabric smoothness is defined as the fabric friction coefficient and the fabric roughness are defined as the fabric morphology features.

**Key words:** wool keratin, flame retardant

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## Biography of the presenting author

Ningtao Mao is a senior Lecturer in School of Design, University of Leeds (UK), Director of the Performance Textiles and Clothing Research Group. Ningtao obtained his BSc and MSc in Textile Technology (Northwest Institute of Textile Science and Technology, China) in 1985 and 1988 respectively, and obtained his PhD in Textile Technology (University of Leeds, UK) in 2001. He has extensive experience of research and development in textile industries and academic institutions in both China and UK.

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