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Measuring Fabric Sensory Attributes:
Theory and Practice

Ning Pan

Division and Textile and Clothing
Department of Biological and Agricultural Engineering
University of California at Davis, CA 95616, USA

npan@ucdavis.edu

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Abstract

Two major sample configurations are adopted in all the instruments for fabric hand measurement, flat sample as in KES and FAST types machines, and wrinkled sample as in PhabrOmeter. This paper compares the two sample types to examine which one if any offers a better coverage and reflection of the fabric sensory attributes. Fabrics have unique behaviors of drape, wrinkle and tactile sense which are entirely due to the simultaneous occurrence of both in-plane membrane deformation and out-of-plane bending deformation in multiple curvature. Such singular deformation mode cannot be detected by any machines using flat sample, whereas during a PhabrOmeter test, the fabric sample genuinely produces drape, wrinkle in addition to other related deformations. This paper then introduced the theoretical research pertaining to the measurement. Then a split sample experiment is conducted to demonstrate the importance of the internal connections in fabric during drape and wrinkle processes. As such fabric interconnection will be barely disclosed during tests using flat samples, another important advantage of PhabrOmeter is hence clearly shown.

INTRODUCTION

Material speaking, textile fabrics are highly complex media with porous and flexible structure, assembled via friction only and highly nonlinear systems. For instance, in contrast to the common applications of structural mechanics in engineering where buckling signifies failure, usually transited from plastic to permanent deformation, textile fabrics are designed to buckle reversibly in order to meet the requirements, not only of clothing and household textiles, but also in engineering uses such as conveyor belts, coated fabrics for buildings and inflatables etc.

For instance, the differences in mechanical properties are crucial to the suitability of paper and textile fabrics for their particular end-uses. A sheet of paper will easily bend over in one direction under its own weight, but if the slightest curvature is imposed in the perpendicular direction, it will hold up stiffly. If clothes are made out of paper, they are noisy, harsh and unpleasant in appearance because the paper resists double curvature; and, when this is forced, paper can only go into point or line discontinuities, and failure follows in repeated deformations. This makes paper ideal for printed purpose. Textile fabrics, on the other hand, buckle easily and comfortably into rounded folds, drape gracefully and recover reversibly from wrinkling, exhibiting very different deformation patterns [1-3] .

Amirbayat and Hearle [1-3] summarized what referred to as the three principles of the fabric mechanics: the first is that, in contrast to continuous solid sheets or films, there is no direct connection between the in-plane and out-of-plane mechanical properties, with bending stiffness expressed in terms of the Young's modulus, Poisson's ratio and thickness of the sheet. The second principle is the simultaneous occurrence of both in-plane membrane deformation and out-of-plane bending deformation in double curvature. The third is the recognition that the complicated patterns of textile deformation can be regarded as a collection of three-fold 'crow's foot' buckling elements. There is one other special feature of textile buckling: the gravitational forces will be significant on pieces of any size.

PRACTICAL SIGNIFICANCE OF FABRIC MECHANICS

Actually, the unique characteristics of the fabric mechanics render certain exclusive performance, for instance, the sensory traits. The importance of such fabric qualities perceived through sensory organs, like tactile fabric hand, visual fabric drape and wrinkle, is indisputable. However, assessment of these quality attributes until now still largely relies on human subjective sensory judgment, which in many cases is not reliable. Furthermore, while it is common knowledge to textile scientists that these quality traits of the fabric are attributed to the physical properties of the fabric, there is no standard approach by which this aspect can be measured directly. This is mainly due to the fact that such sensory attributes are basically the reflection of the overall fabric quality, related to many individual fabric properties. Rationally any instrumental assessment of fabric sensory attributes has to do two things: testing the relevant fabric properties and then connecting the tested results with the sensory properties.

Looking at the way fabrics are handled by consumers before making a purchase decision, the fabric is deformed at various stress states so as to generate a tactile sensation in the fingers. It was thus recommended by Peirce first in 1930 [4] and much later by Kawabata in 1970’s [5] that the following characteristics of fabric deformation have to be captured for any measurement attempt:

1. low yet complex stresses at large deformation;
2. nonlinearity;
3. friction/hysteresis.

Over time, two classes of measurement approaches have been adopted by existing methods and systems. The first one is to test a fabric sample as a whole and only once, or STSP (single test for single parameter); tests in this category include the cantilever method and circular bend test, both described in ASTM D 1388; the circular bend test in ASTM D 4032; fabric extraction method [6] [7] etc. The simplicity and convenience of this group are obvious, but they have some inherent problems; the major problem with this type is that they provide only a single parameter that cannot completely define a phenomenon as complex as fabric hand. Moreover, it is very difficult to establish the connection between the tested results to human sensory responses; and also, the sensitivity and the repeatability of the test results are highly limited.

The second group of measurement technology can be termed as MTMP (Multiple test for multiple parameters). Peirce first proposed [4] to evaluate fabric hand based on several measured fabric physical properties. Since then, there have been some attempts to use instrument to measure fabric hand. All these efforts climaxed in 1970 when Kawabata and his co-workers in Japan developed a KES-FB system [5] for fabric hand evaluation. When coming to measuring the fabric mechanical properties, the KES system is the widely recognized forerunner with the cutting edge techniques. As in Fig. 1, the KES types of systems share the similar characteristics:

- Individually testing physical properties according to the standard definitions;
- Single direction and simple deformation in each test;
- Multiple measurements to complete.


KES-FB 1 Tensile tester

KES-FB 3 Compression tester

KES-FB 4 Surface friction and geometrical roughness tester

Figure 1. KES fabric measurements.

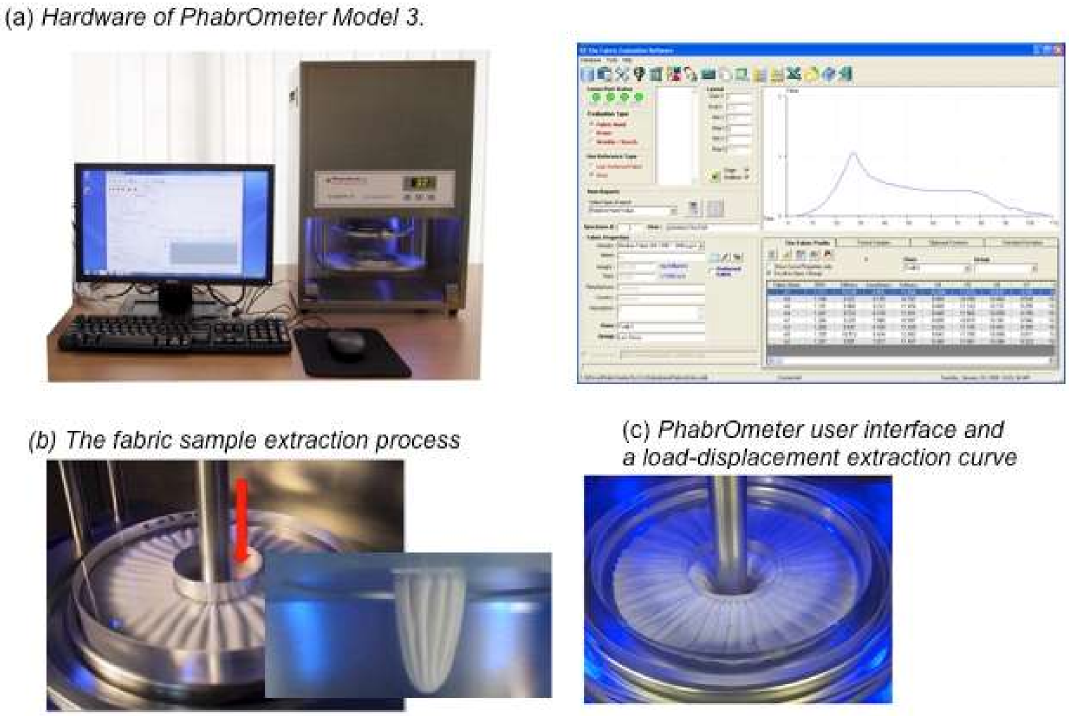
Although capable of measuring various mechanical and structural properties of a fabric sample, this system, and a few similar later ones like FAST [8], etc., failed to associate its measurements with human sensory responses effectively. The excellent measurement scheme to cover wide range of fabric physical properties is a little expensive for most industrial practice in purchasing and operating.

On the other hand and as a result of research by Pan and his coworkers since 1983 [7, 9, 10], a new instrument called PhabrOmeter fabric test system [11] has been developed, as shown in Fig. 2(a). This measurement technique, as illustrated in Fig. 2, appears very similar to the STSP fabric extraction methods [6] [7], where a sample of circular piece is thrusted in Fig. 2b through a nozzle. However very critical (patent protected) improvements have been made in the PhabrOmeter system.

COMPARISON BETWEEN DIFFERENT TEST SCHEMES

In Fig. 1 the KES-FB system [5], six different kinds of properties are covered, including bending, shearing, extension, compression (surface friction) weight and thickness, and at least sixteen parameters (not counting the dual directions of warp and weft) are measured or calculated. It is an excellent approach for fabric mechanical properties measurement, the high precision and wide coverage of fabric properties is unprecedented.

In PhabrOmeter measurement of Fig. 2, no attempt is made to separately measure individual fabric properties deemed to be associated with fabric sensory attributes. Instead, this instrument is based on the previously proposed fabric extraction method [7] with some key patent-protected improvements. During test, a force-displacement curve, Fig. 2(c), is generated through the fabric extraction process, which has been shown to contain implicitly the same fabric properties related to the fabric sensory attributes [7, 9, 10]. Then a computer algorithm was developed based on the pattern recognition technique to derive a series of parameters defining fabric hand, fabric drape and wrinkle recovery. With the key improvements over the original testing extraction action, the instrument possesses very high test repeatability, sensitivity and fast test speed. The instrument has been adopted by various companies in major countries, and some successful applications have been reported [12, 13]. In addition, an AATCC standard test method for the PhabrOmeter, AATCC TM202, has been officially established to guide the users [14]. Also it is clearly shown in Fig. 2(b) and (c) that this test method indeed creates genuine wrinkles on fabric samples tested.


(a) *Hardware of PhabrOmeter Model 3.*

(b) *The fabric sample extraction process*

(c) *PhabrOmeter user interface and a load-displacement extraction curve*

Figure 2. PhabrOmeter and sample extraction process.

It has been analyzed and demonstrated previously that PhabrOmeter actually generates similar amount of information as the KES system [7]. For a properly designed nozzle, if we examine the fabric extraction process carefully, we will find that during the process the sample is deformed under a very complex yet low stress state including tensile, shearing and bending as well as frictional actions, similar to the stress state when we handle a fabric [10]. Consequently, all the information related to fabric hand is reflected by the resulting load– displacement extraction curve. Previously, researchers made use of only one feature of the curve, e.g. the peak or the slope at a point [6], and discarded the rest of the information. If we can identify and derive all this information and classify it in terms of known fabric attributes, the significance is unquestionable.

However there remains a significant difference between the sample deformations during the testing process of different machines; in the KES system in Fig. 1, fabric samples maintain a 2D planar shape in each test, whereas in the PhabrOmeter system in Fig. 2, the sample is thrusted through the nozzle, the fabric is first deformed into a shell shape and then squeezed out. A logical question is whether there are any influences from such different fabric deformation modes, and if yes, how critical?

As stressed before by Amirbayat and Hearle [1-3] there are “three principles” which differentiate fabric mechanics from that of conventional continuum sheets, including the simultaneous occurrence of both in-plane membrane deformation and out-of-plane bending deformation in double curvature; also the complicated patterns of textile deformation as a collection of three-fold 'crow's foot' buckling elements.

- Simultaneous occurrence of both in-plane and out-of-plane deformations in double curvature;
- The complicated deformations as a collection of three-fold 'crow's foot' buckling elements.

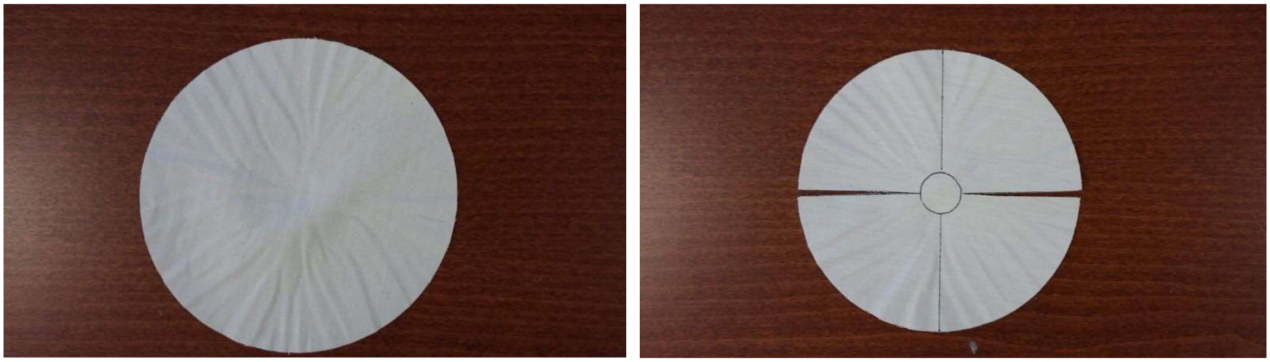
Such characteristics are completely absent in KES system, in Fig. 1, while they are the typical futures in PhabrOmeter system in Fig. 2. To more analytically analyze the sample testing issue, we use an indirect approach to explore it.

THE IMPORTANCE OF FABRIC INTERCONNECTION DURING DEFORMATION

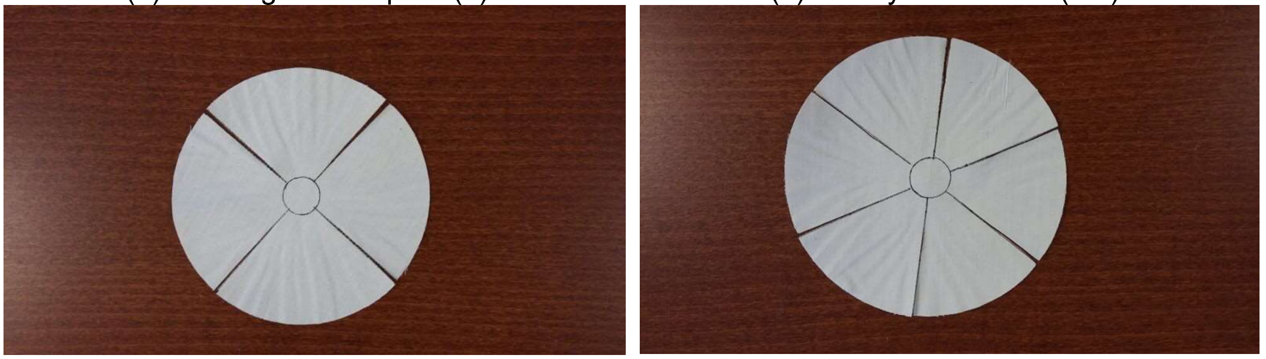
We used the material from Test Fabrics: 439 UXW (weight = 123 g/m^2; Thickness = 9 mm).

Fig. 3a shows the original circular sample termed S(1) for PhabrOmeter test, and Fig. 2c is the general curve. Next, we cut the sample into equal two halves with remaining connection at the center as in Fig. 3b, and conduct the same PhabrOmeter test. We then divide the sample similarly into sections of ¼ s, 1/5 s, 1/6 s, 1/8 s and 1/16 s, as illustrated in Fig. 3c ~ Fig. 3f. We also obtained all the PhabrOmeter curves corresponding to each sample in Fig. 4. In general, as we increase the number of divisions, the sample curves become

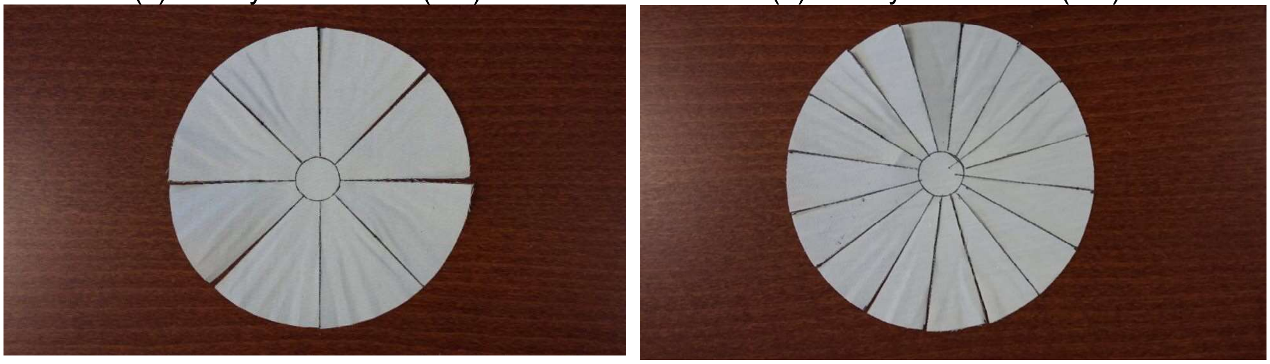
- with more divided pieces in arc-shape;
- more isotropic within each individual arc;
- more diversities with increasing divisions



(a) The original sample S(1) (b) Evenly 2 division S(1/2)



(c) Evenly 4 division S(1/4) (d) Evenly 6 division S(1/6)



(e) Evenly 8 division S(1/8) (f) Evenly 16 division S(1/16)

Figure 3. The fabric sample for shelling test.

If such interconnections indeed exert any influences to the overall mechanics of the whole sample, it should be revealed in the PhabrOmeter curves in Fig. 4. In other words, the differences between the curves of divided samples and that of the original sample in Fig. 3a reveals the impact of the fabric interconnections.

Now by visual inspection of Fig. 4, the curve shape evolution with the number of divisions is not continuous, but changes in steps. All 6 curves can be classified into 3 groups:

- Low degree of divisions including S(1), S(1/2) and S(1/4);
- Medium degree of divisions including only S(1/6);
- High degree of divisions including S(1/8) and S(1/16).

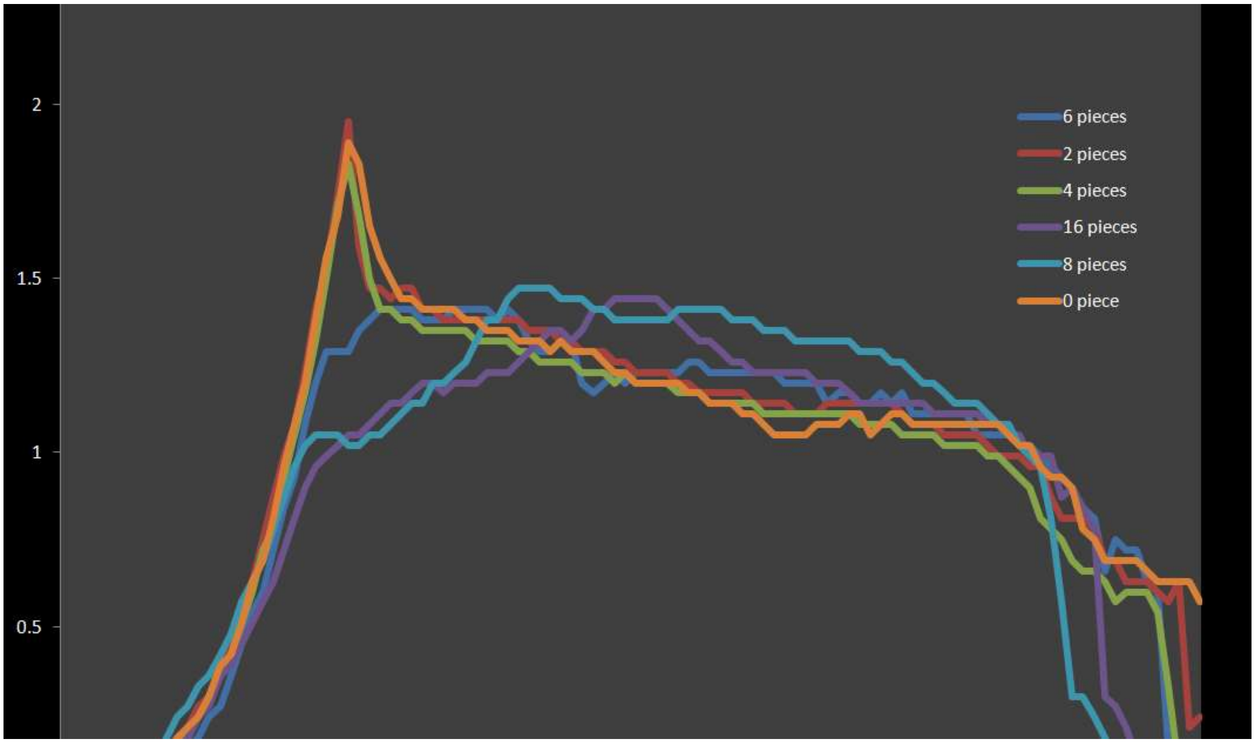


Figure 4. The curves for samples with varying slits.

Therefore, using unidirectional planar piece for test will loss certain information obtainable only when the sample remains in one piece. A circular shape retains the original anisotropy and deforms in multiple curvatures, as fabrics do.

Even though such interconnections in a fabric unlikely embody all the differences between KES and PhabrOmeter tests. PhabrOmeter indeed presents more sophisticated deformations and closer to the practical fabric behaviors.

CONCLUSIONS:

Both theoretical analysis and the split sample test here demonstrated the invalidity of flat fabric samples used in most instruments for fabric hand testing. Whereas PhabrOmeter presents more sophisticated deformations and closer to the practical fabric behaviors. It thus justifies the status of PhabrOmeter as the AATCC standard test for fabric hand.

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Reference Cited

1. Amirbayat, J. and J.W.S. Hearle, *The Complex Buckling of Flexible Sheet Materials .1. Theoretical Approach.* International Journal of Mechanical Sciences, 1986. **28**(6): p. 339-&.
2. Amirbayat, J. and J.W.S. Hearle, *THE COMPLEX BUCKLING OF FLEXIBLE SHEET MATERIALS .2. EXPERIMENTAL-STUDY OF 3-FOLD BUCKLING.* International Journal of Mechanical Sciences, 1986. **28**(6): p. 359-370.
3. Amirbayat, J. and J.W.S. Hearle, *THE ANATOMY OF BUCKLING OF TEXTILE FABRICS - DRAPE AND CONFORMABILITY.* Journal of the Textile Institute, 1989. **80**(1): p. 51-70.
4. Peirce, F.T., *The handle of cloth as a measurable quantity.* , J. Text. Inst. , 1930. **21**: p. T377-416
5. Kawabata, S., *The Standardization and Analysis of Handle Evaluation*. 2nd ed. 1980, Osaka, Japan: The Textile Machinery Society of Japan.
6. Alley, V.L., Jr., *Revised Theory for the Quantitative Analysis of Fabric Hand.* J. Eng. Ind. , 1980. **102**: p. 25-31.
7. Pan, N., *Quantification and evaluation of human tactile sense towards fabrics.* International Journal of Design and Nature 2006. **1**: p. 48–60.
8. Tester, D. and A. De Boos, *Get it right FAST time.* Textile Horizons, 1990. **10(8)**.
9. Pan, N., et al., *A new approach to the objective evaluation of fabric handle from mechanical-properties.* Textile Research Journal, 1988. **58**(8): p. 438-444.
10. Pan, N. and K.C. Yen, *Physical interpretations of curves obtained through the fabric extraction process for handle measurement.* Textile Research Journal, 1992. **62**(5): p. 279-290.
11. Nu Cybertek, I. *PhabrOmeter*. 2014; Available from: http://www.nucybertek.com.
12. Wang, H., et al., *Objective handle evaluation of next-to-skin fabrics knitted from merino wool*. 86th Textile Institute World Conference, Vol 3, Conference Proceedings. 2008.
13. Mahar, T.J. and H. Wang, *Measuring fabric handle to define luxury: an overview of handle specification in next-to-skin knitted fabrics from Merino wool.* Animal Production Science, 2010. **50**: p. 1082-1088.
14. AATCC, *Test Method 202-2012, Relative Hand Value of Textiles: Instrumental Method*. 2012.