Developing A Design-Oriented Fabric Comfort Model

Project No. S01-AE32

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Objectives and Summary:

This project represents what is perhaps would be considered as the most comprehensive study of fabric comfort. Our primary objective has been to develop a “Design-Oriented Fabric Comfort Model”. The purpose of this model is twofold:

- 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 existing specially-designed fabrics and garments that have proven to provide good handle and good comfort effects, and (c) empirical modeling of the fabric comfort phenomenon using a combination of physical, neural-network, and fuzzy logic analysis.
- 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.

Over a three-year period, we have accomplished the following:

- Developed a design-oriented structural model of fabric comfort
- Utilized the model in developing simple three-way characterization index of fabric comfort (tactile, thermal, and moisture)
- Conducted a very extensive testing and evaluation program that covers almost all possible fabric types and styles and many fiber and yarn types
- Developed a systematic testing and evaluation program of fabric comfort
1. Technical Details

Theory

In the first year of this project, we developed a structural model in which different tactile parameters were incorporated. This model is based on the assumption that both tactile and thermal/moisture aspects of comfort are determined directly or indirectly by the ratio between the true area of fabric/skin contact and the apparent area of fabric/skin contact.

The general form of the model is as follows:

$$\frac{A_t}{A_{app}} = C_M K^{\gamma} M_a^{1-\gamma} K_i^\gamma E^\gamma V^{3\gamma} (\phi(t))^{\gamma}$$

where
- $A_t$ = the true fabric/skin area of contact, $A_{app}$ = the apparent fabric/skin area of contact, $\gamma = 1/(1+\alpha)$, $K$ is a surface resilience constant (SI units = N/m$^{2(\alpha+1)}$), and $\alpha$ is a constant, which lies between 0 for purely plastic behavior and 1.0 for purely elastic behavior, $C_M = a$ constant dependent on the load distribution on the area of contact (approaches unity for most distributions), $M_a = the number of asperities of contact per unit area, $\phi(t) = [\frac{1}{t^3} - \frac{1}{t_o^3}]$ is a thickness-related function derived on the basis of modification of the classic Van Wyk equation:

$$P = K_i E V^3 [\frac{1}{t^3} - \frac{1}{t_o^3}]$$

$K_i$ is a constant, $E$ is the Young’s modulus of fibers, $V$ is the volume of fibers, and $t, t_o$ are thickness of the fiber mass at two different levels of pressure.

In the second and third year of this project, the structural model has been modified substantially with the support of numerous experimental results of the different parameters in the model. The details of this modification will be reported in two papers that are expected to be published 2004 in the Textile Research Journal.

The ultimate objective of the structural model is to develop an objective characterization of fabric comfort that can be described by a simple index, yet it can reveal values of all comfort-related design factors from fibers to garments (see general concept in Figure 1).
The structural model developed accounts for all design-related factors that can influence fabric comfort. Examples of these factors are shown below.

- Fiber type
- Dimension characteristics (length, timeliness, crimp, density)
- Tensile properties
- Bending properties
- Elasticity under various deformational modes
- Surface morphology
- Friction

- Yarn type
- Dimension characteristics (count, twist, density)
- Tensile properties
- Bending properties
- Elasticity under various deformational modes
- Hairiness
- Surface irregularities
- Friction
- Abrasion

- Fabric type
- Dimensional characteristics (weight, thickness, fabric count, cover factor, crimp)
- Tensile & bending Properties
- Elasticity under various deformational modes
- Surface roughness
- Friction
- Abrasion
- Creasing & drape
- Multi-dimensional bucking

- Finish type & percent
- Surface roughness
- Friction
- Abrasion

Figure 1. Illustration of Optimizing the Area-Ratio
Experimental
On the experimental side, an extensive testing program was developed to evaluate different aspects of fabric comfort over the last three years. This program consisted of the following main evaluation elements:

1. Analysis of fabric surface characteristics (Stick-slip profiles and Image-Analysis)-Auburn University
2. Handle & Stiffness analysis (Fabric Contour profile, Cantilever stiffness test, multi-node stiffness, and drape analysis)-Auburn University
3. Kawabata System analysis- Georgia Tech
4. Moisture transport analysis-NCSU
5. Thermal Analysis-Auburn University & Georgia Tech

The Area-Ratio being the key characterization parameter of fabric comfort was analyzed using a reference ink-printed method (see Figure 2). The Area ratio was also estimated from the structural model and experimental values were compared with estimated theoretical values using the three-scale technique shown in Figure 1. In addition, image analysis techniques and thermal photography methodology are currently being entertained to obtain accurate area ratio values.

Examples of results obtained from these experiments are shown in Figures 3 through 5. Detailed interpretation of these results and many other results obtained in this study have been reported in many presentations (see project publications) and more will be reported in future publications.
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Figure 3: Plain-Weave Woven Fabric Analysis [Basic Characteristics]

Figure 4: Plain-Weave Woven Fabric Analysis [Tactile Properties]

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Figure 5. Plain-Weave Woven Fabric Analysis
[Tactile Properties-Cont'd]

Figure 6. Plain-Weave Woven Fabric Analysis
[Fabric-Thickness Function]

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Project Statistics:

Industrial and Academic Contacts:
Over the last three years, the team has established the following industrial contacts:
(1) Decathlon Sportwear Corporation (Ian Wilkinson), (2) ElSaiad-Trecot (M. Saiad), (3) Buhler Yarns Corp (David Sasso), (4) Manifattura di-Legnano (Italy/Irene Raggio), (5) TJY (Kim Walker), (6) Cotton Incorporated (Mike Watson & William Rearrick), (7) SENSORA Co. (Czech Republic), (8) USDA, SRRC (Kearney Robert), (9) KATO-TECH Company, (10) Glen Raven Knit Fabrics, Glen Raven, N.C., (11) Swift Spinning (Trey Hodges), (12) Kabo Textile Company (Egypt/Nagui Gebrial). Many of these industrial contacts have offered material (yarn, fabric, and garments) and have closely examined the work results and evaluated their merits.

In addition to the industrial contact, we have established the following academic contacts:
- Dr. Lubos Hes-Comfort Instrumentation Expert (Liberec University, Czech Republic)
- Dr. ElHawary Design Expert (Alexandria University)

Publications & Presentation:
Over the last three years, the team has accomplished the following publications or presentations:

Publications/Presentations:
S01-AE32 (formerly I01-A32): Developing a Design-Oriented Fabric Comfort Model [with Georgia Tech & NCSU]

- Radhakrishnaiah, P., Handle and Comfort Properties of Apparel Fabrics Fused With Nonwoven Lining Materials, Joint INDA-TAPPI Annual Conference (INTEC-2002), September 23-26, 2002, Atlanta, GA.
- Radhakrishnaiah, P., A Review of Recent Developments Relating to Performance Enhancement of Synthetic Apparel Fibers, Joint TQCA–ATIE Annual Conference, October 2-4, 2002, Myrtle Beach, SC.
- Huang Hua, A Comparison of the Performance Properties of Enzyme and Caustic Scoured Knit Fabrics, Annual Meeting of the American Chemical Society, Nov 16-18, 2002, Charlotte, NC.
- Henderson, G., Farais, Lisa, Comfort Modeling for Garment Design, Senior Project Presentation, Auburn University, May 2002

In addition, three PhD theses are expected to be completed by early 2004:

- Hua Huang, “Frictional Behavior of Woven Fabrics and its Role in Determining Tactile Comfort, Supervised by Dr. Radhakrishnaiah, P, Georgia Tech

In addition, two MS theses are expected to be completed early 2004:

- Archana Kumar, Relationship Between Material Properties and Comfort in Commercial Athletic Wear, Supervised by Dr. Lewis Slaten, Auburn University
- Burcak Karaguzel, "Porosity and Wicking Characteristics of Woven and Knitted Fabrics and Effect of Structural Factors”, Supervised by Dr. B.S. Gupta, NCSU