COMFORT PROPERTIES OF SINGLE LAYER ARAMID WORKWEAR FABRICS

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INTRODUCTION

Comfort is an important consideration determining the acceptability of fabrics used in workwear garments, especially in the hot and humid environments often encountered in the workplace. This research compares Nomex®[1] and other workwear fabrics on the basis of physical properties that influence their thermal and tactile comfort. A sweating skin model is used to compare thermal comfort factors in moderate and hot and humid environments. The Kawabata Evaluation System (KES) is used to characterize mechanical and surface properties that control fabric softness and influence next-to-the-skin contact sensations. Vertical wicking is measured. Comfort predictions are translated to fabric construction parameters. The effects of laundering are examined since it is expected that workwear clothing will be washed often.

METHOD

Table 1 identifies the shirting weight fabrics that were tested. Four are Nomex'' fabrics used in military or industrial shirting applications (NS1–NS4). One material is a lightweight Non-FR polyester/cotton used in ordinary clothing (CS5). Topically treated FR materials include an FR cotton sample (CS6) and an FR polyester/cotton shirting fabric (CS7).

Table 1. Test Fabrics

Fabric	Description	Weight (g/m^2)	Thickness (mm)	Bulk Density (kg/m^3)
NS1	Nomex®	156	0.47	330
NS2	Nomex''	165	0.73	226
NS3	Nomex''	200	0.74	270
NS4	Nomex''	204	0.42	484
CS5	Non-FR Polyester/Cotton	143	0.39	366
CS6	FR Cotton	183	0.55	332
CS7	FR Polyester/Cotton	205	0.53	386

With exception of CS7, all the test fabrics are plain weave constructions (CS7 is a twill).

Simulated Skin Model. We used a specially modified Kawabata Thermolabo thermal analyzing system to measure the heat transfer properties of test fabrics. In this apparatus. simultaneous heat and moisture. transfer is measured using a sweating plate equipped with simulating sweating glands supplying water to the heated surface at a controlled rate. The entire apparatus is located in a special environmental chamber where the temperature and humidity *can* be controlled to simulate various climatic conditions. Details of this apparatus and the experimental procedures that we used *can* be found in Woo and Barker [1].

Fabric Mechanical Properties. The Kawabata Evaluation System (KES) tensile and shear, bending, compression and surface testing instruments were used to characterize the mechanical and surface properties of the test fabrics. These instruments *can* isolate the contribution of individual fabric properties and define the role played by tensile, bending, compression, shear, and surface properties on cutaneous sensations. Detailed information on the KES instruments *can* be found in Kawabata et al. [2].

RESULTS

Thermal Comfort. We have developed procedures for calculating a thermal comfort limit based on heat transfer through test fabrics, as measured using our sweating plate apparatus. This model relies on calculating a comfort limit defined by no heat storage and sweat evaporation over only 20% of the body surface area. The comfort limit is expressed in terms of allowable work load for a given ambient condition. Details of this model are given in Woo and Barker [1]. Figure 2 shows thermal comfort limits calculated using heat transfer measurements through test fabrics in a moderate test environment (21°C. 65% RH). Figure 2 also compares thermal comfort limits predicted for a hot and humid environment (32°C, 90% RH).

Similarity in heat and moisture transfer properties is reflected in the predicted comfort indexes, shown in Figure 2. These predictions indicate that all shirting materials should be perceived thermally comfortable when worn in a standard environment by a person performing work activities, i.e. metabolic heat production rates up to about 400 w/m^2. *On* the other hand, predictions shown in Figure 2 suggest that none of the shirting fabrics should be thermally comfortable when worn in a hot and humid atmosphere, since the maximum comfort limit for these materials is in the 100 to 120 w/m^2 range.

Tactile Comfort. Measurement of KES mechanical properties usually associated with softness show that, before laundering, some Nomex'' shirting fabric (e.g. NS2) are stiffer in extension, shearing and bending than comparable control materials (Figure 3 compares fabric KES bending stiffness). However, Kawabata measurements also show that other Nomex® shirting fabrics have *similar* flexible properties, even when rated before washing (e.g. fabric NS3).

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[1] Nomex *is* a registered trademark for the meta-aramid fiber **from DuPont.**

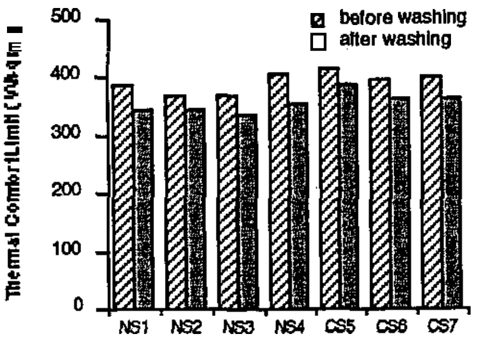

Figure 1. Thermal comfort limit of shirting fabrics

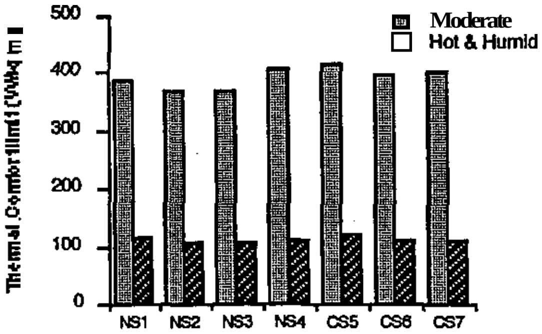

Figure 2. Environment and comfort limits

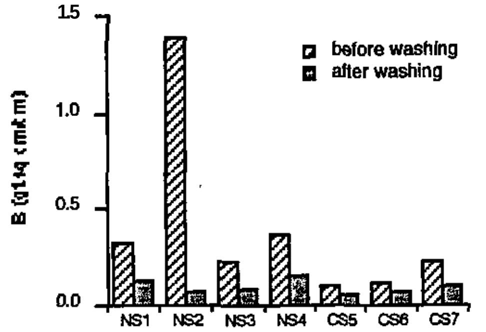

Figure 3. Bending rigidity (B) of shirting fabrics

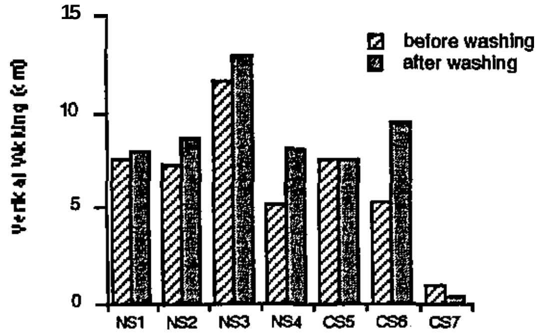

Figure 4. Wicking properties of shirting fabrics

Effects of Laundering. Our experiments show that repeated washing significantly affects fabric structure. These changes translate in most fabrics to small reductions in predicted thermal comfort limits (Figure 1). However, the most profound effects of washing are related to properties that determine fabric softness. In all cases, laundering benefitted the Nomex® test fabrics more than it did the control fabrics in tactile comfort improvement. Dramatic decreases in shear and bending rigidity and increases in extensibility were observed (e.g. KES bending rigidity, Figure 3). These comfort differences in the Nomex® test fabrics seem to be linked to several interrelated changes. The fabric thickens due to an increased proportion of "fluffed up" surface fibers and, at the same time, interyarn friction properties are modified. Loss of finish may also be playing a part.

Wicking Properties. Figure 4 shows that, based on measurements made in a vertical wicking test, Nomex" shirting materials have a capability to wick liquid moisture that is comparable to regular non-FR polyester/cotton shirting fabric (CS5). Nomex® shirtings have far greater vertical wickability than the FR polyester/cotton sample (CS7).

CONCLUSIONS

Wearer reactions to the comfort of single-layer Nomex" fabrics and comparison materials are probably not based on differences in the thermal insulation and moisture vapor permeability properties of these materials. If predictions are made using models that rely solely on the ability of fabrics to transmit heat and moisture vapor, all the test fabrics are predicted to be thermally comfortable in moderate climates, and all the materials would be perceived to be uncomfortable worn in hot and humid environments. Comfort reactions in workwear garments are more likely due to differences in softness related to fabric mechanical and surface properties. Kawabata analysis shows that Nomex® fabrics *can* also be soft and flexible. Our experiments show that laundering has a profound influence on fabric tactile qualities: it affects changes that dramatically increase the softness of some Nomex" workwear materials. Nomex" fabrics show no disadvantages in predicted ability to wick liquid moisture from sweating skin.

ACKNOWLEDGEMENTS

This research was funded by the Nomex®/Kevlar® Aramids Division of DuPont Fibers, E.I. DuPont De Nemours & Company. We also gratefully acknowledge the contributions of Dr. B.J. Baliga and Dr. D.E. Hoffman to this research.

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