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Heat Transfer in Single-side Napped Fabrics During Compression

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Abstract

This paper presents a systematic analysis of the changes in thickness and the differences in the heat flux transfer for the two surfaces of selected single-side napped fabric, to explore the relationship between their heat flux and thickness during compression. The results showed that heat flow in the un-napped surface was greater than that in the napped surface when the fabric initially contacted the upper plate of a Fabric Touch Tester ($p < 0.05$); few differences of the heat flux between the un-napped and the napped surfaces measured separately with each surface facing upwards for each fabric type were observed when the pressure exceeded 0.6 Pa ($p > 0.05$); the heat flux was linearly correlated with thickness for both the un-napped surface and napped surface when the pressure exceeded 0.6 Pa (correlation coefficient $R^2 > 0.9$); the gradients of the regression equation of heat flux-thickness gradually increased from the initial thickness point to the midpoint of the maximum pressure except for the first heat peak point of the un-napped surface. In conclusion, heat flux was significantly affected by the surface characteristics of the fabrics in the initial stages of compression but was then not affected by either the surface features or the fabric structures at higher levels of compression pressure. The conclusion could be useful in product development and in providing a guide for clothing wearing comfort.

Keywords: Thickness; Heat Flux; Napped Surface; Surface Measurement; First Heat Peak; Standard Pressure

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1 Introduction

The heat and moisture transfer behaviors of clothing have been recognized as being critically important for human survival. Li et al. demonstrated that thermal-wet comfort counted for around 40% of overall wearing comfort [1]. In 1970, Fourt and Hollies [2] conducted a comprehensive study regarding clothing comfort and function, with special emphasis on thermal comfort.

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Schneider and Holcombe [3] studied fabric properties influencing coolness sensation. The fabric used was considered to be comprised of three layers: a dense core layer and two outer layers consisting of a predominance of air with a small number of protecting fibers. They explored the correlation between the thermal response (rate of temperature drop) of skin contacting a fabric and the outer layer thickness (thickness differences at just light pressures) of the fabric. The results showed that the thickness of the outer layers had a negative influence on the rate of subjective coolness perception and temperature on the skin surface during the fabric-skin contact. Li and Brown et al. [4] further investigated the relationship between the subjective perception of coolness and fabric properties. A range of 20 fabrics including micro-polyester lightweight fabrics and wool fleece fabrics were tested. It was found that the subjective perception of coolness was negatively related with the fabric porosity, fiber diameter, and fabric hairiness, but positively related with fiber hygroscopicity. Among those parameters, fiber hygroscopicity, fabric porosity, and fabric hairiness were the most important contributors. Fan et al. [5] investigated the effects of knitted fabric structure on coolness sensation. All the aforementioned studies only focused on the exploration of the relationships between coolness sensation and fabric thermal properties. Few publications regarding the heat transfer mechanism have been found. The human body is rarely in a static state. It is usually continually exposed to transients in physical activity and environmental conditions. Such changes may affect the fabric properties, which could eventually influence the heat transfer and human comfort. Fabric is prone to be compressed, bent and stretched during wearing. As a result, the heat and moisture transfer process between a fabric and skin should be greatly influenced by the contact areas of the fabric-skin contact, which is determined mostly by the surface features of the fabric.

In order to quantitatively evaluate the effects of fabric thermal properties, in 1977, Mecheels et al. [6] highlighted thermal resistance as a major factor. Nowadays, the most widely used index in the U.S. is the "*clo*", which was proposed by Gagge and his colleagues at the Pierce Foundation in 1941 [7]. Methods to measure heat transfer under steady-state conditions have also been developed in the past few decades. Well-known instruments includes the Flat-plate warmth Retaining Tester and the Kawabata Evaluation System [8-11]. Both have some limitations in the objective measurement of fabric touch sensation [12] and they can only test fabric thermal properties under static conditions. A new apparatus, named the Fabric Touch Tester (FTT) [13-16] has been developed to measure the mechanical and thermal sensory properties simultaneously and dynamically. It provides a research platform for objective assessments of both heat transfer and coolness sensation. The FTT can measure the changes in heat flux during the compression of fabrics. In order to conduct an objective and dynamic study of the effect of different fabric structures on heat transfer and coolness sensation, this study investigated a selection of single-side napped fabrics. This paper discusses the differences in the heat flux values and thicknesses of the different surfaces, the correlations between the heat flux values and the thicknesses during compression of the fabric, and then identifies a possible mechanism to explain the effects of fabric properties on thermal comfort.

2 Experimental

2.1 Structure of Thermal and Thickness Module in the FTT

The FTT consists of an upper plate and a lower plate. A heater installed in the upper plate was