PREDICTION OF THERMAL CONDUCTIVITY OF WOVEN FABRIC USING FINITE ELEMENT METHOD

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ABSTRACT: In this work a method is developed for the determination of thermal conductivity of plain woven fabric. A special core spun yarn used as weft yarn in poly-viscose fabric and other two simple plain weave cotton and wool fabric were used. Temperature specified boundary conditions were applied for the determination of effective thermal conductivity of fabric based on the developed geometrical model.

Keywords finite element analysis; thermal conductivity; geometric modelling; core spun yarn

INTRODUCTION

Clothing insulation has a significant impact on the thermal comfort of wearer because its purpose to maintain the uniform body temperature according to the environment and activities of the wearer. Clothing insulation value mainly depends on thermal conductivity of the fibre and entrapped air.

Several studies have been conducted to determine the thermal conductivity and thermal resistance of fabric by considering the proportion of air-fibre and direction of heat flow [1-6].

In this wok we developed the geometrical model of woven fabric on the basis of actual dimensional parameters obtained from Scanning electron microscope (SEM) to simulate the thermal conductivity of fabric by using finite element method (FEM). The results obtained from finite element analysis were compared with the experimental results obtained from a newly developed instrument.

MATERIALS

The materials were used in this work are shown in Table 1. A special core spun yarn was used as weft yarn and simple polyester warp yarn in the ploy-viscose fabric. Anisotropy nature fibre was considered so thermal conductivity along the fibre axis and perpendicular to the fibre axis as shown in Table 2.

Table 1: Fabric Specification

Specifications	Poly-Viscose	100 % Cotton	100% wool
Areal density (g/m^2)	93	132	130
Thickness (mm)	0.341	0.484	0.408
Warp/Weft sett (per inch)	75/85	65/55	70/45
Warp/Weft Yarn linear density (Tex)	7.77/19.68	25.5/25.5	27.8/27.8

SIMULATION AND VALIDATION

At the first stage geometric model of the fabrics were developed by using actual parameter of fabric like warp/weft sett, thickness of fabric and cross-sectional shape of yarn which can be determined by the cross-sectional SEM image (Micrograph) of fabric.

Table 2: Fibre Specifications

Property		polyester [7]	Viscose [7]	Cotton [7]	Wool [7]
Fibre density (Kg/m^3)		1390	1520	1520	1310
Fibre thermal conductivity (W/m.k)	K_{fa}	1.26	1.89	2.88	0.48
	K_{ft}	0.157	0.289	0.243	0.165

K_{fa}: thermal conductivity along fibre axis

K_{ft}: thermal conductivity perpendicular to the fibre axis

Figure 1 shows the geometrical model of 100% cotton fabric generated by TEXGEN [8]. In case of weft core spun yarn in poly-viscose fabric the density (ρ_{feff}) and thermal conductivity of component fibre of core spun yarn can be calculated by following equations:

$$\rho_{feff} = w_{af}\rho_{af} + w_{bf}\rho_{bf} \quad (1)$$

$$K_{feff} = w_{af}K_{af} + w_{bf}K_{bf} \quad (2)$$

where w_{af}, w_{bf}, ρ_{af}, ρ_{bf}, k_{af} and k_{bf} are the weight proportion, density and thermal conductivity of fibre 'a' and 'b' respectively.

In the model air is considered as fluid matrix inside the yarn and entrapped between the two plates. Thermal conductivities of the yarns were calculated on the basis of data obtained from the geometrical model such as fibre volume fraction of yarn (V_{fy}). Yarn axial (K_{ya}) and transverse thermal conductivity (K_{yt}) can be calculated by the following equations:

$$K_{ya} = K_{fa}V_{fy} + K_{air}(1 - V_{fy}) \quad (3)$$

$$K_{yt} = \frac{K_{ft}K_{air}}{V_{fy}K_{air} + (1 - V_{fy})K_{ft}} \quad (4)$$

At the second stage, the calculated thermal conductivities of yarns were used as input material property in Abaqus/CAE and meshed the model by using 4-node linear tetrahedral elements and temperature specified boundary conditions were applied in order to determine the thermal conductivity of the fabric. Figure 2 shows the temperature and heat flux Contour of 100% cotton plain weave fabric.

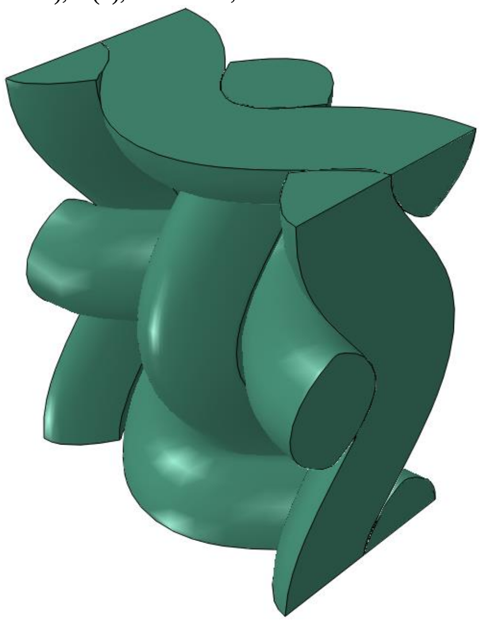


Figure 1: 3D Model of 100% Cotton Fabric

For model validation a test was conducted on the developed instrument which works on the principal of two plates (hot and cold) which provides an initial environment that there is temperature difference between the two surfaces of a fabric to be tested. Fabric is placed between the hot and cold plates, the lower plate is kept at constant temperature by using a controller and the upper plate is cooled by fan heat sink. Heat is flow from lower plate to upper plate because of temperature gradient and the upper plate surface is connected with calibrated heat flux sensor which measures the heat flux. The thermal conductivity of fabric can be determined by measuring the temperature difference across the plate (*ΔT*), heat flow from the heat flux sensor (*Q*) and thickness of the fabric (*t*) as shown in equation 5.

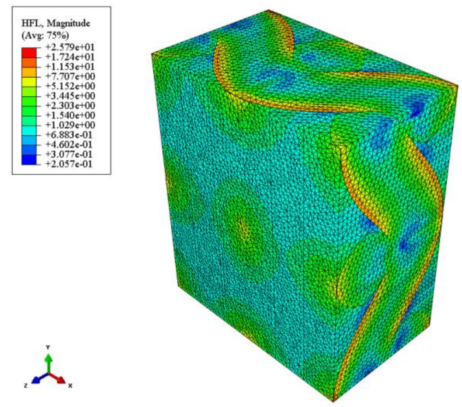
$$K_{eff} = \mathrm{Q}\frac{t}{\Delta T} \quad (5)$$

RESULTS AND DISCUSSION

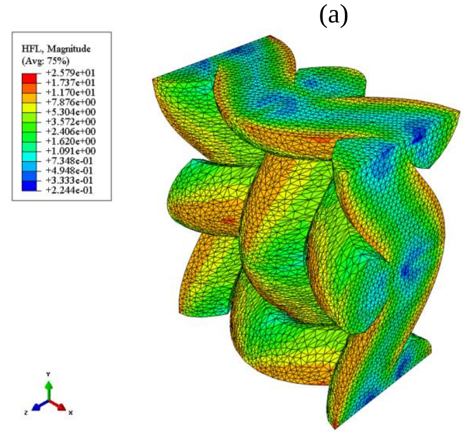
Table 2 shows the comparison of thermal conductivity between the experimental results obtained from the instrument and predicted results which were obtained from the finite element post-processing.

Table 3: Comparison between Experimental and FEM results

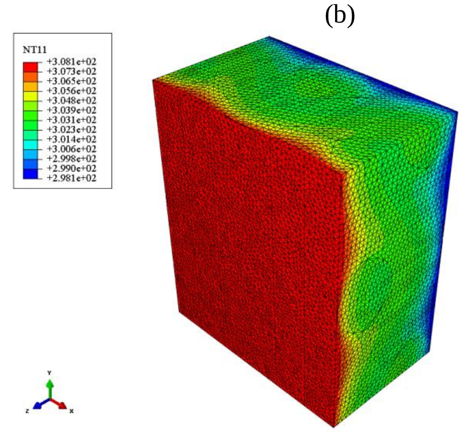
Samples	**Thermal conductivity, K_{eff} (W/m.K)**	
	Experimental	Predicted
Wool	0.0414	0.0445
Poly-Viscose	0.0484	0.0514
Cotton	0.0560	0.0615



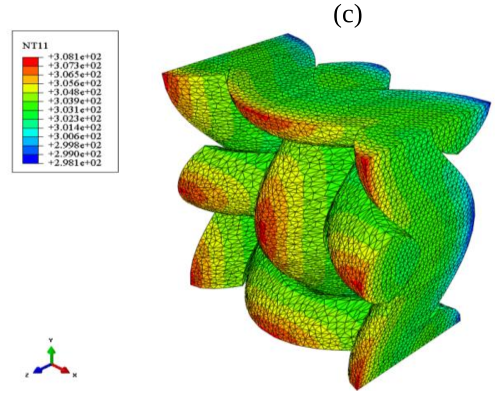
(a)



(b)



(c)



(d)

Figure 2: (a) and (b) Heat Flux contour of 100% cotton fabric with and without air fluid matrix respectively, (c) and (d) Temperature contour of 100% cotton fabric with and without air fluid matrix respectively

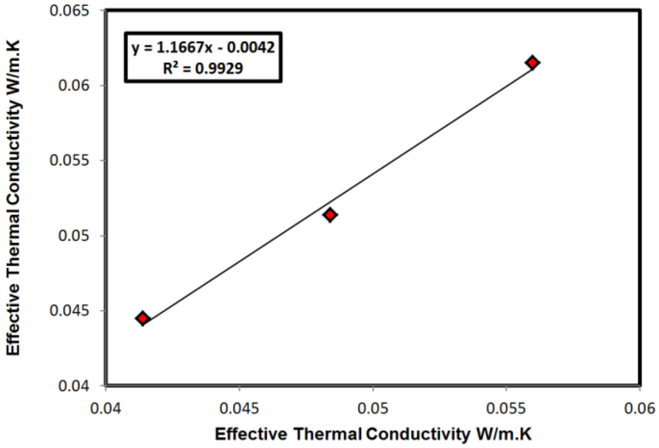


Figure 3: Comparison between Experimental and predicted Effective Thermal Conductivity by FEM

Figure 3 shows the relationship of thermal conductivity between experimental and FE model predicted results. The mean absolute error and correlation coefficient between the experimental and predicted are 7.84% and 0.996 respectively, which shows that the developed model can be used to determine the thermal conductivity of the woven fabric.

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