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Predicting thermal resistance of cotton fabrics by artificial neural network model

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ABSTRACT

This paper presents the prediction of thermal resistance of handloom cotton fabrics by artificial neural network models using four primary fabric construction parameters, i.e. ends per inch (EPI), picks per inch (PPI), warp count and weft count as the inputs. ANN model with seven nodes in the single hidden layer exhibited the overall best performance with coefficient of determination of 0.90 and 0.86 and mean absolute error of only 5.13% and 4.23% during training and testing respectively. The importance of fabric construction parameters on the thermal resistance of fabrics was also analyzed by the developed ANN model. Weft count, EPI and warp count were found to be the first three most important fabric constructional parameters in descending order of importance in predicting thermal resistance of plain woven cotton fabrics.

1. Introduction

Thermal properties are one of the most important properties of apparel textiles. For instance, thermal insulation is a very important factor for estimating clothing comfort. Thermal properties are influenced not only by the physical parameters like thickness and areal density of fabrics but also by structural parameters such as weave [1]. Clothing comfort is closely related to thermal comfort and the latter is characterized by three important properties namely thermal resistance, thermal conductivity and thermal absorptivity [2]. Thermal properties of textile materials, especially thermal resistance have always been the major concern when comfort properties of clothing are characterized [3]. Thermal resistance is a measure of the body's ability to prevent heat from flowing through it. Under a certain condition of climate, if the thermal resistance of clothing is small, the heat energy will gradually reduce with a sense of coolness [4]. The thermal resistance of textile fabrics is a function of the actual thickness of the material and the thermal conductivity.

Many researchers have studied and analyzed the relationship between the fabric properties and thermal conductivity. In general, it has been reported that the thermal conductivity depends on the physical characteristics of fabrics such as thickness, areal density, and porosity. Ucar and Yilmaz [5] compared the thermal properties of 1×1, 2×2 and 3×3 rib structures and found that the heat loss decreased with the reduction in rib number. Ozcelik et al. [6] studied the thermal properties of textured knitted fabrics and found that thermal resistance of textured fabrics are higher than the fabrics produced with non-textured filaments. Morris [7] presented a study of thermal properties of textiles, and concluded that their thermal conductivity increases with density, based on the observation that when two fabrics are of equal thickness, the one with a lower density shows the greater thermal insulation. However, he reported that there is a critical density of about 60.0 kg/m^3 below which the convection effects become dominant and the thermal insulation falls. Thermal properties of fabric insulators have been investigated by Ukponmwan [8]. Abdel-Rehim et al. [9] studied the heat transfer through two different non-woven fabrics, namely 100% polyester and 100% polypropylene and observed that the thermal conductivity increases with increase in fabric density, and thermal insulation increases with increase in fabric thickness. Dias and Delkumburewatte [10] developed a theoretical model to predict the thermal conductivity of knitted structures in terms of porosity, thickness and moisture content. They found that the thermal conductivity of a dry plain knitted fabric decreases with the increase of porosity.

The powerful modeling capability of ANN has been exploited by a few researchers [11–13] for the prediction of thermal resistance or thermal conductivity of textile fabrics. Fayala et al. [11] predicted thermal conductivity of knit materials by developing an optimal ANN system having four input parameters (yarn conduc-

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Nomenclature

EPI	no. of warp ends per inch
PPI	no. of picks (of weft) per inch
R	correlation coefficient
R^2	coefficient of determination
Ne	yarn count in English or Cotton system, 1 Ne = 1 hank (of 840 yards) per pound
Pa	unit of pressure in Pascal, Pa = N/m^2
E	error vector
E_j	error associated with j-th pattern
T_k	target output at output node k
O_k	predicted output at output node k
W_{jk}	weight connecting the neurons j of hidden layer and neuron k of output layer
ΔW_{jk}	correction applied to W_{jk} at a particular iteration
η	learning rate
O_j	output of neuron j
y_0	transformed output from the node
I	weighted sum to the node
$MAPE$	mean absolute percentage error
MSE	mean squared error

tivity, weight per unit area, porosity, and air permeability). Luo et al. [12] developed a fuzzy neural network (FNN) based local to overall thermal sensation model using feed-forward back-propagation (FFBP) network for prediction of thermal insulation in functional textile design system. Bhattacharjee and Kothari [13] studied the predictability of the steady-state and transient thermal properties of fabrics using a back-propagation ANN system. A comparison was made with two different network architectures, one with two sequential networks working in tandem fed with a common set of inputs and another with a single network (with one set of inputs) that gave two outputs. The networks were then subjected to a set of inputs and the output data of thermal properties, namely thermal resistance and Q_{max}. The first architecture gave better results than the second one.

All the research works on thermal properties of textile fabrics, cited above, were carried out on either on powerloom fabrics or on knitted fabrics. No research work has been done on the prediction of thermal resistance of handloom fabrics till date, although the handloom textiles constitute a timeless facet of the rich cultural heritage of many countries including India. To meet the stringent quality requirements of the market, handloom fabrics must have requisite qualities in terms of drape, handle, air permeability, thermal properties, etc. In the present work, an effort has been made to extend the application of ANN in predicting the thermal resistance of handloom fabrics. Besides, in most of the research works, parameters like fabric thickness, areal density, porosity and air permeability have been used as the input parameters [11,13]. However, these parameters are primarily dependent on fabric construction parameters (EPI, PPI, warp count and weft count), and therefore the former variables cannot be controlled independently during fabric manufacturing. Hence, only four fabric construction parameters namely EPI, PPI, warp count and weft count have been used in this work as the set of input parameters for predicting thermal resistance of handloom fabrics.

2. Materials and methods

2.1. Sample preparation

A woven fabric is made up of two mutually perpendicular (orthogonal) sets of yarns. The longitudinal sets of yarns are termed as warp (individually called end) and the transverse yarns are termed as weft (individually called pick). The schematic representation of a plain woven fabric is shown in Fig. 1 in which warp and weft yarns interlace with each other alternately forming a checkerboard pattern. The linear densities (i.e., coarseness or fineness) of yarns are expressed in terms of yarn count. Ne is one of the units of yarn count in English (indirect) system, which indicates the number of hanks (of 840 yards) that can be produced from 1 lb of yarn. Thus, if the count of a cotton yarn is Ne then the following expression can be written:

$$\frac{\pi d^2}{4} \times \mathrm{Ne} \times 840 \times 36 \times \rho = 1 \quad (1)$$

where d is the yarn diameter in in., ρ is the density of the yarn in lb/in.^{3}. For cotton yarn, this value of ρ is 0.0325 lb/in.^{3} (i.e. 1.1 g/cm^3).

$$\text{Therefore, yarn diameter} = d\ (\text{in.}) = \frac{1}{28\sqrt{\mathrm{Ne}}} \quad (2)$$

The higher value of Ne implies lower yarn diameter and vice versa. The relative closeness of the yarns in a fabric is expressed in terms of ends per inch (for warp yarns) and picks per inch (for weft yarns).

Test samples for this study consist of 25 plain woven cotton handloom fabrics, which have been manufactured using semi-automatic handloom by a skilled weaver. During the manufacturing of the samples, fabric constructional parameters namely ends per inch (EPI), picks per inch (PPI), warp count and weft count were varied as much as possible so that the samples cover a wide range of variability in terms of input parameters. The summary statistics of fabric constructional parameters and thermal resistance values of the fabric samples are shown in Table 1.

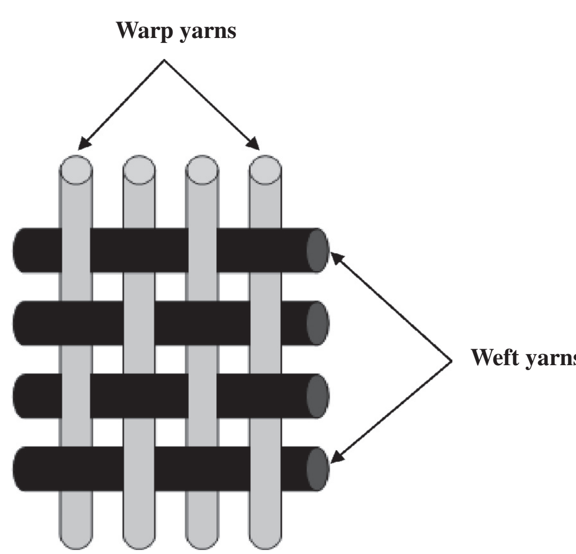

Fig. 1. Plain woven fabric showing warp and weft yarns.