FABRIC ENGINEERING FOR ULTRAVIOLET RADIATION PROTECTION

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FABRIC ENGINEERING FOR ULTRAVIOLET RADIATION PROTECTION

by

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Department of Textile Technology

Submitted

in fulfilment of the requirements of the degree of

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Dedicated to my family

CERTIFICATE

This is to certify that the thesis titled **'Fabric Engineering for Ultraviolet Radiation Protection',** being submitted by **Mrs. Piyali Hatua** to the Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy,** is a record of bonafide research work carried out by her. She has worked under our guidance and supervision and fulfilled the requirements for submission of the thesis which has attained the standard required for a Ph.D. degree of this Institute.

The results contained in this thesis have not been submitted, in part or in full, to any other university or institute for the award of any degree or diploma.

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ABSTRACT

Ultraviolet rays (UVR) are human carcinogen. Over-exposure to UVR from solar or artificial origin has a potential risk to human health. Hence adequate level of skin protection from UVR is essential. Use of clothing is the most simple and convenient way of UV protection. UV protective properties of fabrics and clothing are evaluated by their ultraviolet protection factor (UPF).

The UV protection characteristics of almost all known apparel fibres such as cotton, silk, polyester etc. had been explored by various researchers. Recently, regenerated bamboo viscose fibre has emerged as a promising material for the apparel use. From the results reported in literatures, conflicting views regarding the better UV protection property of bamboo viscose with respect to that of natural cotton have emerged. A systematic investigation on the *in vitro* UV protection property of bamboo viscose fibre with respect to that of natural cotton was carried out to clarify this conflict.

Fabric samples were produced from cotton and bamboo viscose yarns and their UPF were tested. The UPF of both cotton and bamboo viscose fabrics was predicted by empirical models using fabric cover % and areal density as input variables. A comparative analysis of UPF was carried out between cotton and bamboo viscose fabrics using curve fitting technique. The analysis showed that the apparently higher UPF of bamboo viscose fabrics can be attributed to their higher areal density and cover resulting from higher shrinkage though the fabrics were woven using same yarn count and thread density. The areal density based UPF predictive model developed for cotton performed equally well for bamboo viscose fabrics bolstering the fact that there is no distinguishable differences in the UV protection property of these two fibres. The fabrics woven from cotton and bamboo viscose yarns and

having similar cover % and areal density showed similar UPF and UV transmittance behaviour.

Yarn parameters such as twist may have significant influence on the UV protection property of fabric. Also hollow yarn structure can provide higher cover % due to its higher degree of flattening, which in turn can offer better UV protection. Among the fabric parameters, fabric cover is the most important parameter which determines the UPF. However, for the same fabric cover, fabric thickness and individual pore size may play a decisive role in influencing the UPF. The effects of yarn twist level and hollow yarn structure on UPF of cotton woven fabrics were investigated in this research. The influences of fabric thickness and individual pore size on UPF were explored keeping the fabric cover same.

Yarn samples were produced varying twist in three levels (3.6, 3.9 and 4.2). Fabric samples were produced keeping all parameters constant except yarn twist. No discernible effect of yarn twist on cotton woven fabric UPF was observed within the experimental range.

To produce hollow yarn structure, first core-spun yarn was manufactured in ringframe using polyvinyl alcohol (PVA) multifilament as the core. Fabric samples were produced from the core-spun yarn. PVA was washed out from the core of yarn during preparatory wet processing treatment of fabric samples, leaving a hollow yarn structure in the fabric. Fabrics with hollow yarn structure resulted higher UPF in comparison with the fabrics made from normal yarn due to enhanced fabric cover arising from higher yarn flattening. The difference was more prominent at higher cover %. Also the enhancement in UPF, due to the use of hollow yarn structure, was amplified after UV absorber treatment of the samples.

Fabric thickness was varied keeping cover % constant by maintaining the ratio of diameter and spacing of both warp and weft yarns constant. This study was carried out using 100% polyester and 100% cotton yarns. UPF of polyester fabrics decreased with the decreasing fabric thickness when fabric cover was kept at same level. After UV absorber treatment, UPF of polyester fabrics first decreased and then increased with the decreasing fabric thickness. On the other hand, no significant change in UPF of cotton fabrics was observed with the decreasing fabric thickness at constant cover %. After UV absorber treatment, cotton fabrics showed similar trend like polyester fabrics at lower cover (88%). However, UPF increased continuously with decreasing thickness at higher levels of cover (93 and 96 %). The individual pore size in the fabric along with fabric thickness and inherent UV protective property of the fibre materials played a crucial role in determining the UPF of fabrics.

Attempt was made to predict the UPF of woven fabrics using different modeling methodologies, namely nonlinear regression, artificial neural network (ANN) and adaptive network based fuzzy inference system (ANFIS). Thirty-six fabrics were produced by varying the proportion of polyester, weft count and pick density at three levels. Nonlinear regression, ANN and ANFIS models were developed using 27 training datasets. Nine testing datasets were used for evaluating the prediction performance of the models. The ANN model demonstrated the best prediction performance, among the three developed models, followed by ANFIS. Analysis of the developed regression, ANN and ANFIS models showed that UPF improves with higher proportion of polyester, coarser yarn count and higher pick density.

ANN model was then used in combination with genetic algorithm (GA) for the fabric engineering. The aim of fabric engineering is to choose the optimum combination of input parameters i.e. fabric construction parameters so that the targeted fabric properties are achieved. In this research, fabric engineering for ultraviolet protection and comfort properties (air permeability and MVTR) was attempted using hybrid ANN-GA system. ANN was used for developing predictive models as it yielded best prediction result for UPF. GA was used as a tool for solving the optimization problem.

Forty-two fabric samples were produced varying six parameters, namely polyester fibre blend in warp and weft, warp and weft count, end and pick density. Separate ANN models were developed for UPF, air permeability and MVTR using the test results pertaining to 36 samples. Four feasible combinations of UPF, air permeability and MVTR were chosen from the Pareto charts of UPF-air permeability and UPF-MVTR. The fitness function of GA was so formed that the targeted UPF, air permeability and MVTR can be achieved. Penalty function method was adopted to convert the constrained optimization problem into unconstrained problem by combining the objective (UPF) and constraints (air permeability and MVTR). The developed ANN-GA hybrid system was run to elicit the optimized set of input parameters for achieving the targeted fabric properties. The hybrid ANN-GA system was accurate in achieving target fabric properties but lacked precision in terms of input parameter combinations. Further, to counter this problem, end and pick densities were searched considering the availability of the yarns (polyester blend and count) in the warehouse. The ANN-GA system demonstrated accuracy as well as precision in this case. To validate the developed ANN-GA based fabric engineering system, four fabric samples were woven using the optimized set of input parameters and their functional properties were measured. The targeted and achieved properties of four validation samples were in reasonably good agreement as the mean error for UPF, air permeability and MVTR were 8.3, 14.9 and 2.1 %, respectively.

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