STUDIES ON DIELECTRIC PROPERTIES OF WOVEN FABRICS

by

KAUSIK BAL
Department of Textile Technology

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Woven fabrics; Dielectric properties - Woven fabrics.

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Dedicated to my Parents, my Didun (Grandmother), my family, relatives and to all my teachers

CERTIFICATE

This is to certify that the thesis titled 'Studies on Dielectric Properties of Woven Fabrics', being submitted by Mr. Kausik Bal 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 him. He has worked under my 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.

Dr. V. K. Kothari
Professor
Department of Textile Technology
Indian Institute of Technology Delhi
Hauz Khas
New Delhi 110016

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Kausik Bal

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ABSTRACT

The dielectric properties are some of the fundamental properties of electrically insulating materials including most of the fibre polymers. The dielectric properties of fibrous materials have been studied by a number of researchers in the past. Knowledge of dielectric properties of a fibre material gives useful insight to its structure and physico-chemical nature. Capacitance measurement has gained useful application in textile industry for evenness testing. In some of the more recent applications of textiles, especially in the form of woven fabrics, the electrical and dielectric properties of these materials play a very important role. Such applications include the fabric reinforced composites for electrical applications such as printed circuit boards, electrostatic discharge, fabric based electromagnetic shielding devices, etc. Capacitance measurement may offer the scope of developing nondestructive testing of various fabric properties and be of much use in the textile and allied industries.

It is difficult to study the dielectric properties of porous medium such as fibrous materials. The major difficulty lies in the interpretation of the measured values. The form of the material and the geometry of the structure may affect the results and it is not easy to establish an exact relationship between the form and structure of the assembly and the measured properties. The review of literature gives a wide range of studies on many type of fibres including natural and man-made fibres arranged in many forms from single fibres to fabrics. The measurement of dielectric properties of such materials has been done at different frequencies starting from low frequencies to microwave frequencies. Measurement methods varied also. While such diverse studies have helped in understanding a lot of phenomena related to dielectric properties, it also poses a big problem in comparing the results given in various literatures. Thus the permittivity of cotton fibres, for example, has been reported to be from 2.3 to 18 by various authors under different conditions. Textile fibres themselves have a lot of variability which make consistent predictions of properties less accurate. The influence

of moisture and temperature makes the situation even more complicated. Moisture in particular plays a very important role in the dielectric measurements and since most of the commodity textile fibres are hygroscopic, hence in capacitance measurement of textile materials the condition of the samples and their moisture content influence the results significantly. While the dielectric properties of fibrous materials such as fibre bundles, slivers and yarns are studied extensively, very less is discussed in the literature on the dielectric behaviour of fabrics. In this research endeavour the dielectric properties of woven fabrics were studied. In particular, the methods to interpret the measured capacitance values in terms of the permittivity of the fibre materials were investigated.

The measurement of dielectric properties was carried out following ASTM D150 standard which is widely used for measuring permittivity and loss factor of electrically insulating solid materials. This choice of testing method enables comparing the data with those of other porous or non-porous insulating materials. Studies with standard specimens of plastic sheets showed that nondestructive measurement was possible using this method. All measurements were done under room temperature which was controlled at standard value. Hence the influence of temperature variation was not present. Woven fabrics were studied as majority of the fabrics used today are woven materials. Woven fabrics of high density polyethylene, nylon, polyester and viscose were studied. High density polyethylene fabric enabled studying the dielectric properties without the influence of moisture. Both this fabric and the nylon fabric were made from monofilament yarns. This simplified the material configuration as the yarns could be considered as solid flexible cylinders. Woven fabrics made from yarns of uniform blend of polyester and viscose staple fibres were used in this study to investigate the role of blend proportion on the measured values.

Four analytical models were discussed and equations establishing the relationship between the permittivity of the fibre material and the measured effective permittivity were derived for each of these models. The first model considered a very simplified geometry assuming the fabric as a solid polymer sheet occupying the entire area of the measuring electrode plates but occupying only a fraction of the gap between the parallel plates. The second assumed a similar sheet, but occupying only a fraction of the area of the plates. The third model incorporated basic non-crimped fabric configuration with warps and wefts and the fourth model assumed a plain woven fabric with interlacements. None of these models considered yarn structures and all of these assumed only two phase systems of air and fibre polymer. Comparison with results obtained from measurement of capacitance of four different plain woven fabrics made from high density polyethylene monofilaments showed that the fourth model gave the best results.

A number of mixing laws are reported in literature for describing the relationship between the measured effective permittivity of mixtures and the permittivity of the component materials using the volume fraction of the components as a structural parameter. These laws have been applied to a number of porous materials and literature indicates that different mixing rules apply to different mixture systems. More important representative equations of these mixing laws were used in the present study and applied to a two phase system of heterogeneous mixture of air and fibre polymer and it was found that all of these equations give almost similar relationship within the measured range of values. This was ascribed to the very low volume fraction which is typical of most woven fabrics and also to the low contrast of permittivity of air and fibre materials.

It was found that a second order polynomial equation fits the experimental results well in case of woven fabrics. Predicted permittivity value using extrapolation of this curve was very close to the values predicted by different mixing equations. This was observed consistently for all the fabrics under study. It was suggested accordingly that the extrapolation method gave a more convenient way of interpretation of the measured values.

Studies with nylon fabric at different humidity conditions showed that the permittivity increases with moisture content. The permittivity of the fibre with moisture was obtained by extrapolation and when these extrapolated values were plotted against the volume fraction of moisture in the fabric, the regressed line was close to the upper limit given by Hashin and shtrikman.

Both moisture content and dielectric properties of the polyester-viscose blended fabrics were studied. A new faster pre-conditioning and conditioning method of samples was developed for moisture content measurement and it was observed that a short conditioning time such as 10 minutes gives low value of moisture content but gives almost same linear dependence of moisture content on the proportion of viscose in the blend. This observation paved a way of determining the blend proportion in polyester-viscose blended fabrics using a fast and physical method. The dielectric measurements on these fabrics at different frequencies showed that the permittivity of the fabrics increased with the proportion of viscose in them and for frequencies such as 100 KHz the permittivity changed almost linearly with the proportion of viscose. This indicated that dielectric measurement can also be used to determine the blend proportion in polyester-viscose blended woven fabrics. The suitability of these two possible physical methods of determination of blend proportion was discussed by comparing different features of the two methods and it was concluded that the dielectric measurement can give useful advantage by providing a physical nondestructive fast method for determination of blend proportion of woven fabric. It is expected that in industrial situations these advantages may outweigh the limitations of the accuracy.

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