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Application of fuzzy logic for the determination of fabric drape

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Abstract
Investigation has been carried out to predict the drape parameters and describe clearly the drape phenomenon using fuzzy logic method. Forecasting features allow manufacturers to save time and improve their productivity. The bending rigidity, (in warp, weft, and skew direction), shear rigidity, and weight of fabric samples were used as the key input variables for the model, whereas drape coefficient, drape distance ratio, folds depth index, and node number were used as output/response variables. The results show that changing the values of fabric parameters significantly affected the fabric drape and a representative correlation values were found between the experimental values and those calculated by the fuzzy system.

***Key words**: Fuzzy-C-mean (FCM), fuzzy logic, fabric drape, drape coefficient, node number, drape distance ratio, folds depth index.*

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I. Introduction

Textile fabrics are often the final product of the textile process. Their properties must directly meet the user requirements; obviously, the prediction of their properties and their final behavior is very important. The fabrics are complex structures. The structural complexity in conjunction with the materials complexity do not usually permit the development of computer-aided engineering tools for the support of the design phase, as it usually is the case in other engineering fields, such as mechanical, structural, naval, electrical, and so on. Therefore, a lot of effort has been given toward the development of computational tools for the prediction of the behavior of the fabrics [1].Fabric engineering activities are increasingly based on computational models that aim at the prediction of the properties and the performance of the fabrics under consideration [2].Various computational tools have been used to represent the fabrics in a computational environment and to predict their final properties [3–7]. Among others, finite element method (FEM)analysis has supported mainly the prediction of the behavior of the complex textile structures under mechanical loads. In the case of classification problems, artificial neural networks(ANNs) have proved to be a very efficient tool for the fast and precise solution. ANNs have found an increasing application in the textile field in the classification and in the prediction of properties and optimization problems [8].The drape is proved to be an important criterion in the selection and development of textiles for clothing. It is based on the physical and mechanical properties of fabrics. In this context, it is necessary to highlight the influence of mechanical properties, such as bending rigidity and shear rigidity. Therefore, the drape depends somehow on the construction parameters and fabric materials [9, 10].Drape has been widely studied in the literature review. The fabric drape has been measured by the F.R.L. Drapemeter according to Chu et al. [11]. They defined a dimensionless value called the drape coefficient (DC). Their work was revised by Cusick [12] who modified the experimental method and used a parallel light source reflecting a circular specimen drape shadow from a hanging disc onto a paper ring. The DC calculation is based at this stage in terms of paper tracing and weighing method. It is defined as the ratio between the draped shadow paper weight and the full specimen paper weight. The DC varies from 0 to1. It is high on stiff fabrics and low on floppy fabrics. But the hanging area of the samples modifies significantly the value of the DC.Mooreka and Niwa [13] use the DC to characterize the drape ability of fabrics and investigate the relation between this coefficient and some measured mechanical properties. Residual regression and multiple regression methods have been used to find correlations between DC and bending rigidities and weight per unit area of fabric. Ayada and Niwa [14] found that the mechanical properties of fabric are strongly linked to the fabric drape; they proved that bending, shear, and fabric mass are the most important factors affecting the appearance of the garment. The concept of deformable models is also used by researchers of the field in the modeling and simulation of the textile fabrics.

Therefore, the works of Bruniaux et al. [15, 16] reflect an interest in simulating the dynamic behavior of textile fabrics. Essentially, they study the influence of weaves, the surface density, and the nature of the yarn on the drape. Keeping with the same focus, we shall quote the paper of Ghith et al. [17]through which the author predicts the DC using the artificial neural network method. He also presents the effect of some fabric properties on DC. We have used the PCA method [18], which has eliminated the thickness parameters as this variable is not correlated withthe drape parameters. On the contrary, this method is mainly descriptive. Again, the links cannot be measured and the variables cannot be classified in terms of importance .In this paper, the authors present the Fuzzy logic method to predict the drape behavior (DC, node number, DDR, and folds depth index [FDI]) that has not been used in the previous researches from a very limited input data that are obtained easily using basic equipments (Bskew, Bweft, Bwarp, G, and W). This method is able to deliver all the outputs by a single calculating system. The desired drape parameter values obtained from the Fuzzy logic method are compared to the experimental data obtained from image analysis

II. Technical details

A number of fabrics woven and plain and twill have been used. The fabrics are 80% cotton and20% cotton/polyester. The fabric weight is measured using French Standard NFG07-104 [19]. Maximum, minimum, and average standard deviation of fabric properties and drape parameters have been determined. The following procedures have been involved.

a) Measurement of the bending rigidity
b) Measurement of the shear rigidity
c) The measurement of DC, NN, FDI, and the DDR

Modifications in the system of Cusick drapemeter, as shown in Figure 2, are made by the addition of an achievable MATLAB application to calculate the DC (%) [20]

Figure 1 Experimental device for determination of drape parameters

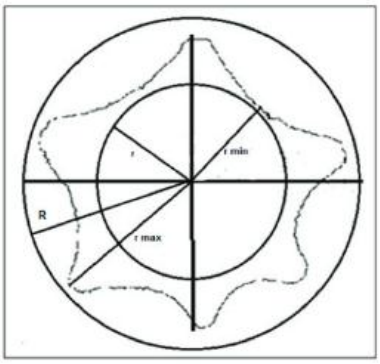

Figure 2 The various dimensions used in the calculation of drape distance ratio (DDR%) and the folds depth index (FDI%)

Image analysis method is used to calculate the real surface of the drape to determine numerical DC. This method is based on the shift from the original color image to the grey level image and finally to the binary one. The method of image processing for the fabric drape measurement is characterized by precision, speed, and the ability to reach various measurements

The DC can be calculated using the following formula:

$$DC = \frac{\text{drape surface}(\text{pixel}) - \pi \times \left(\text{supported disc ray}(\text{cm}) \times c\right)^2}{\pi \times \left(\text{total ray}(\text{cm}) \times c\right)^2 - \pi \times \left(\text{supported disc ray}(\text{cm}) \times c\right)^2}$$

where DC is the drape coefficient and c the correlation between the centimeter and the pixel.
The node number is an important parameter linked to the virtual appearance of clothing. The distribution of the different distances of all the points of the outer contour shows the presence of the minimums and the maximums as shown in Figure 3. The number of nodes is the number of maximums found in the curve representing the ray as a function of the angle of rotation. The DDR and the FDI are calculated using the equation formula submitted by [21]

$$DDR = \frac{R - r_{ad}}{R - r}$$

where r_{ad} is the rays mean value of fabric drape.

$$FDI = \frac{r_{max} - r_{min}}{R - r} \qquad (5)$$

where r_{max} is the maximum ray of draped sample and r_{min} is the minimum ray of draped sample.

Fuzzy logic method has been applied. The concept of Fuzzy logic comes from the observation that the Boolean variable taking only two values: true or false. Thus, several areas own reasoning is applying the Fuzzy logic of modeling, decision support, and the representation of human knowledge. Fuzzy logic allows the modeling of data imperfections and is to some extent similar to the flexibility of human reasoning By introducing the notion of degree of belonging into the verification of a condition, we allow one condition to be in another state than true or false. Fuzzy logic thus confers considerable flexibility on the reasoning that uses it, which makes it possible to take into account inaccuracies and uncertainties. One of the interests of Fuzzy logic in formalizing human reasoning is that rules are stated in natural language. By its numerical aspects, it is opposed to modal logics. It is based on the mathematical theory of fuzzy sets by Zadeh [22],which presents an extension of the theory of classical sets to sets defined imprecisely.

o evaluate the performance of the obtained Fuzzy logic models, three statistical performance criteria, including correlation coefficient (R), mean absolute relative error(MARE), and root mean square error (RMSE), were used in this study. These parameters were calculated for testing (T)and training (tr) phases

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{K=1}^{N}\left(y_{p-y_k}^{k}\right)^2}{N}}$$

$$R = \sqrt{\left(1 - \frac{\sum_{k=1}^{N}(y_k - y_p^{k2}}{\sum_{K=1}^{N}(y_k - \bar{y}_k{}^2}\right)};\ \overline{y_k} = \frac{1}{N}\sum_{K=1}^{N} y_k$$

$$\mathrm{MARE} = \frac{1}{N}\sum_{k=1}^{N}\left|\frac{y_{k-y_p^k}}{y_k}\right| \times 100$$

3.1. Selection of inputs/outputs for the Fuzzy inference system

The Fuzzy logic system has a class of inputs and an output class. In Table 2 the minimum average and maximum values of some properties of fabrics are presented to be taken as inputs in the system. The input parameters are divided into two classes: the mechanical parameters that are bending rigidity in the skew, warp, and weft directions and the shear rigidity. Also,there is the construction parameter that is the basis weight. Statistical summary of output variables such as DC, node number, DDR, and the FDI are presented in Table 3.
n Table 4, the selected classes are three in number (low,medium, and high). The choice is made according to the following classification of results found by the Fuzzy-C-mean(FCM) method [23]

3.2. Choice of membership functions

This study section is devoted to the choice of the membership function for the different properties. It is conducted according to the results found in the Fuzzy classification made by Hamdiet al. [23]. The choice of interval data and the upper and lower limits of each class in every parameter are performed according to the results presented in Table 1.

3.2.1. Membership function for input variables

The membership functions for input variables have been determined. They are the bending rigidities, shear stiffness, and surface density. It is remarkable that the selected classes are three in number and that the shape used is trapezoidal. The coordinates of each main item belonging to a form with a specific class have been determined. We note that the presentation of the membership function of each class has its own specificity. In fact, the first class is characterized by three points: the first is the minimum experimental value and the level of the highest membership, the second point is the minimum experimental value of the second class, and the third point corresponds to the maximum experimental value in this class with a zero-affiliation degree. The second class is characterized by four points. The first is the minimum experimental value in this class. The second is the maximum experimental value in the first class. The third point is the minimum experimental value in the third class and the fourth point is the maximum experimental value in the second class and having a zero-affiliation degree. Finally, the third class is characterized by three points. The first is the minimum experimental value in this class and has a degree equal to zero. The second point is the maximum experimental value in the second class and the third point represents the maximum value in the third class.

3.2.2. Membership function for output variables.

The membership function for output variables is presented through the DC, NN, DDR, and FDI. The same procedure is followed for the submission of membership functions as cited in the foregoing and according to the data obtained. List of rules used, a list of rules linking the input and output variables have been determined. Intuitively, it seems that the input variables as such are approximately appreciated by the brain, thus corresponding to the degree of verification of condition of Fuzzy logic. A comprehensive system of rules based on the Fuzzy logic helping to make decisions is called Fuzzy inference system. This list is based on the expertise of some industrialists, professionals, and researchers who are experts in the field of textile and clothing and the experimental tests performed in this work. In this table, the following codes are used:“L”: This code stands for the term “Low.”“M”: This code stands for the term “Medium.”

“H””: This code stands for the term ““High.”

3.4. General structure of the Fuzzy system

The executed Fuzzy calculation system is characterized by thefollowing parameters:The type of Fuzzy system = ‘Mamdani’.Number of inputs = 5.Number of outputs = 4.Rules number = 23.The method used in the procedure is “And” = ‘min’.The method used in the procedure is “Or” = ‘max’.The method used in the phase is fuzzification = ‘centroid’.
Figure 3 shows the general structure of the fuzzy system

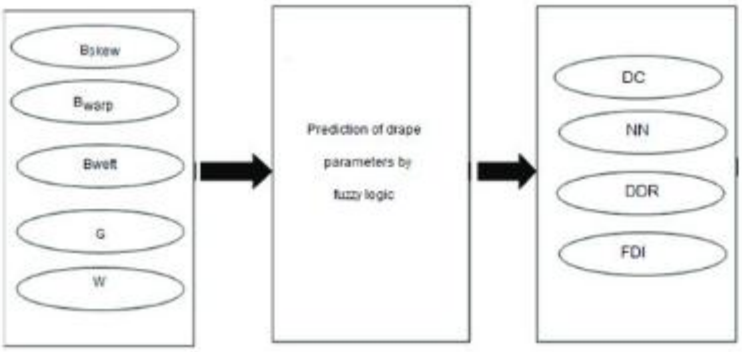

Figure 3. The general structure of fuzzy system

3.5. Fuzzy response surfacesFuzzy logic is a method based on the principle of membershipdegrees. In this context and depending on the rules that linkinputs and outputs to the membership of each property offunctions with upper and lower limits of each class and eachvariable, one can draw the evolution of each output dependingon the selected inputs. Figure 8 presents the Fuzzy responsesurfaces of variations of drape parameters according to thebending rigidities in the warp and skew directions.According to Figure 7, we can conclude that DC increaseswith Bskew and Bwarp. The number of node increases when Bskewand Bwarp decreases. The DDR increases when Bskew and Bwarpdecreases. The FDI increases with Bskew and Bwarp

3.6. Evaluating the results of calculating drape parameters

To validate the results found by the realized computing system,conducting a test step is necessary. Figure 9 shows thecorrelation between the experimental values and the valuescalculated by the Fuzzy system. This analysis is performed toevaluate the effectiveness and reliability of the method basedon Fuzzy logic of calculating drape parameters (DC, NN, DDR,and FDI).Throughout this figure, a high correlation values appears.Indeed, the correlation coefficient values of DC, NN, DDR, andFDI are as follows: RDC = 0.943, RNN = 0.936, RDDR = 0.969,and RFDI = 0.946. From these results, it is possible to concludethat the computing system is considered as efficient to a greatextent and that it has reached a success rate. At the same timeand according to Table 6, the values of the average of the rootmean square error (RMSE) obtained are acceptable becausethey are less compared to the standard deviation, which provesthe acceptance limit of this error for all the characteristics ofdrape studied. In the footsteps of what has just been mentioned,the mean absolute relative errors (MARE) are very low. From these results, we can conclude that our computing system isconsidered representative and significant.

III. CONCLUSIONS

The fuzzy logic method described for the prediction of drapeparameters has been found efficient for proving all drape properties at the same time, which indicates a high correlationbetween theoretical and experimental values (RCD = 0.943, RNN= 0.936, RDDR = 0.969, and RFDI = 0.946). It further implies thatthe Fuzzy logic model is feasible for the prediction of fabricdrape from the values of fabric bending rigidity in 3threedirections (warp, weft, and skew direction), shear rigidity, andfabric surface mass

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