EFFECT OF STRUCTURE PARAMETERS ON WOVEN COTTON FABRIC TENSILE

ẢNH HƯỞNG CỦA THÔNG SỐ CẤU TRÚC TỚI TÍNH GIÃN CỦA VẢI BÔNG DỆT THOI

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ABSTRACT

Tensile is an important characteristic of the clothes. The relationships between tensile characteristics and fabric parameters are quite complex and multiple variables. The study of factors, which affect on the fabric bending characteristic, contributes to build the basis for the design and selection of fabric. This paper introduces the effects of cotton woven fabric structure parameters on bending characteristics. The fabric structure parameters were determined according to TCVN, ISO standards and Peirce model. Fabric bending were determined using KES-FB1 device of KESF. Fabric's characteristics are Warp linearity of load extension curve LT, Tensile resilience RT, Warp tensile energy WT, elongation EM in warp and weft directions. The relationships between tensile characteristics and fabric parameters are constructed using Bayesian Model Average method. The results showed that existing multi-linear relationships between structure parameters and fabric tensile characteristics (R^2 = 0.999). Tensile characteristics are affected significantly by fabric thick, setting, yarn count and cover factor.

Keywords: *Tensile property, woven cotton fabric, fabric structure parameters, multiple linear regression model.*

TÓM TẮT

Đặc tính kéo giãn rất quan trọng đối với chất lượng vải may mặc. Mối quan hệ giữa các đặc trưng kéo giãn và thông số kỹ thuật của vải khá phức tạp với nhiều biến số. Nghiên cứu các yếu tố ảnh hưởng tới đặc tính kéo giãn của vải góp phần xây dựng cơ sở cho thiết kế và lựa chọn vải phù hợp với yêu cầu của sản phẩm may. Bài báo này giới thiệu kết quả nghiên cứu ảnh hưởng của các thông số cấu trúc tới tính kéo giãn của vải bông dệt thoi. Thông số cấu trúc vải được xác định theo các tiêu chuẩn TCVN, ISO và mô hình Peirce. Các đặc trưng kéo giãn của vải được xác định trên thiết bị KES-FB1 của hệ thống KESF (Kawabata Evaluation System for Fabric) gồm độ tuyến tính giãn LT, biến dạng đàn hồi kéo RT, công kéo WT và độ giãn EM theo hướng sợi dọc và ngang. Mối quan hệ giữa đặc trưng kéo giãn và thông số cấu trúc vải được thiết lập dựa trên kỹ thuật BMA (Bayesian Model Average). Kết quả cho thấy tồn tại mối quan hệ tuyến tính đa biến giữa đặc trưng kéo giãn và thông số cấu trúc vải với hệ số R^2 = 0,999. Độ dsfy, mật độ, chi số sợi và độ chứa đầy vải là những thông số cấu trúc ảnh hưởng đ áng kể tới đặc tính kéo giãn của vải thí nghiệm.

Từ khóa: *Đặc tính kéo giãn, vải bông dệt thoi, cấu trúc vải, mô hình đa tuyến tính.*

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1. INTRODUCTION

Tensile is an important property that should be considered when choosing a fabric. Numerous studies have investigated the factors affecting the tensile property of the fabric. De Jong and Postle applied an energy analysis to the woven fabric structure to investigate deformation [1]. The independence of the fabric construction is advantageous in using energy analysis of fabric behavior. There are some difficulties encountered when applying a general force analysis to fabric structure. Thus, when using force analysis, it is found necessary to divide the unit cell of the structure into segments, at the ends of which forces and/or couples might act. The length of each segment had to be varied because the point of action of the internal forces is not fixed. The tensile properties of plain woven fabrics were tested in both the grey and the finished state, and the computed results are employed to explain the behavior of yarns during fabric extension.

One of the difficulties in analyzing the tensile behavior of woven fabrics lies in the fact that any extension occurring at an angle to the warp or weft direction usually involves a different mechanism of deformation [2]. Therefore, the tensile performance of a fabric is apparently an integration of a multi-directional effect. Hu et al. term this phenomenon the 'anisotropy' of tensile properties of woven fabrics [3]. In this study, twill and satin woven fabrics usually demonstrate lower tensile work (WT) as compared with plain woven fabrics, due to the presence of floats, but no apparent difference can be observed in the WT values of plain, 2/2 twill and 3/3 twill woven fabrics in the warp direction if their warp densities are kept constant. In addition, the value of WT will increase with the rise in weft densities, indicating that more work is needed to extend the fabric with high weft density. Weft density is an important factor governing EMT elongation values. With the increase in weft density for any fabric type, a rise in the magnitude of EMT in all directions will be observed. A direct image of this is an outward spreading along any direction for all woven fabrics. As the width of a fabric is usually fixed, the yarns will jam and come into contact when the weft density has reached its limit.

A woven fabric's tensile property is very difficult to study due to the great bulkiness in fabric structure in addition to the complexity in the structure and strain distribution of its constituent fibers and yarns and of the fabric itself as well as the strain variation during deformation [3]. The tensile stress–strain relationship of a woven fabric can be successfully described by an exponential function [4]. Regarding the various tensile parameters (WT, EMT, LT, RT), a great deal of similarity is found in their polar diagrams: their shapes are all symmetrical to the warp and weft directions; the value of each parameter differs with the angle; and the maximum happens exactly at either the warp (WT of satin, LT) or weft directions or at $\pm 45^0$ angle (WT, EMT) corresponding to the warp and weft directions. The polar diagram of each parameter can be classified into two similar groups depending on the relationship of parameter values between the warp and weft directions [5]. The strain-hardening phenomenon is found in woven fabrics. This phenomenon has a significant effect on the tensile properties of a woven fabric, as reflected by the variation in the Young's modulus value between warp and weft directions [6].

Actually the fabric is designed and manufactured mainly with structural parameters. Therefore, the study of the effect of fabric structure parameters on the tensile property is necessary to predict the tensile behavior of the fabric and to establish the basis for the selection of the fabric in accordance with the requirements of the garments. This paper presents the results of studying the influence of structural parameters on the tensile characters of light and medium weight weave cotton fabrics.

2. METHOD

2.1. Experiments determine the structure and tensile parameters of fabrics

Eight woven cotton fabrics (from 89.11g /m^2 to 142.98 g/m^2) were selected for the experiment in this study.

Table 1. Details of the studied woven fabrics

Fabric sample	W (g/m^2)	Thickness Tm (mm)	Warp Ned (Ne)	Weft Nen (Ne)
1	89.11	0.17	142	126
2	107.10	0.17	155	126
3	113.65	0.21	84	66
4	115.00	0.22	81	74
5	122.20	0.20	114	105
6	137.69	0.24	86	87
7	138.95	0.23	67	63
8	142.98	0.23	69	67

Fabric thickness Tm (mm) is determined according to TCVN 5071: 2007. The yarn settings (yarns/inch) are determined according to ISO 7211 / 2-1984. The weight of fabric W (g/m^2) is determined according to ISO 3801: 1977; The Ne of yarns are determined according to TCVN 5095: 90. The fabrics Peirce cover factors were calculated:

Warp cover factor: $k_1 = \frac{n_1}{\sqrt{Ne_d}}$; Weft cover factor: $k_2 = \frac{n_1}{\sqrt{Ne_n}}$

Fabric cover factor: $k_c = k_2 + k_2 - \frac{k_1 k_2}{28}$

Where suffix 1, 2 are warp and weft directions, respectively; n is fabric setting. Experimental determination of fabric structure parameters was carried out in Mechanical Laboratory, Vietnamese Textile and Garment, under standard conditions.

8 fabric tensile parameters were determined according to the KESF (KES-FB1). Those parameters were measured in two labs (Engineering Garment Faculty, Liberec University of Technology and Kyoto Institute of Technology) under standard conditions.

Fig. 1. KES-FB1 device to determine the tensile properties of the fabric

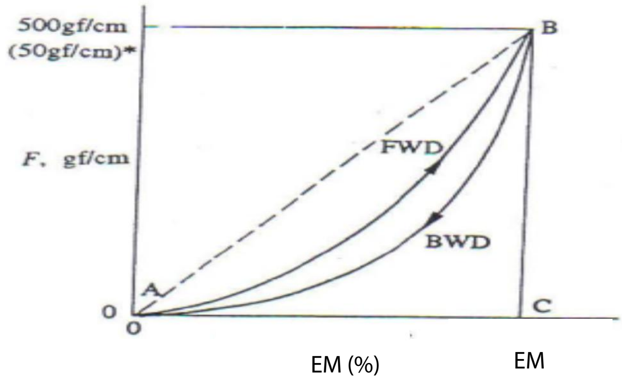


Fig. 2. The tensile graph

The tensile characteristics are determined by Linearity of load extension curve LT, Tensile energy WT (g.cm/cm^2), Tensile resilience RT (%) and elongation EM (%) in the directions warp and weft with 3 samples of 20x20cm on each fabric. Where:

$$LT = \frac{WT}{S_{\Delta ABC}}; \; WT = \int_0^{EM} E dE$$

LT, WT, RT, EM are defined on the tensile diagram (Fig. 2), shown on the control program of the computer.

2.2. Determination of the multivariable relationship between the structural parameters and the tensile properties of the fabric using the BMA technique

In this study, the optimal model demonstrates the multivariable relationship between structural parameters and tensile characteristics were determined using BMA technique on R software. BMA technique has attracted interest in the application of statistical data in recent years. This method brings many models from low to high based on weight and BIC (Bayesian Information Criterion). From these results, choose the most suitable model, has the few variables and explains the most data.

BIC is one of several indicators considered to be the optimal model for expressing linear relationships between independent and dependent variables, which are recommended for use by statisticians. Using the BIC allows for a balance between the complexity (number of variables) and the optimization of the model. The lower BIC is, the better model is.

$BIC = n \log(RSS_p) + p \log n$

Where n is the number of sample sizes; p is the number of input variables in the model; RSSp (Residual Sum Square) is the determined value of the model with input variable p.

3. RESULTS AND DISCUSSION

The obtained experimental results include the structural parameters: the fabric thickness Tm (mm), the weight of fabric W (g/m^e), fabric warp setting Md (yarns/10cm), fabric weft setting Mn (yarns/10cm), the Ne of warp yarns Ned, the Ne of weft yarns Nen, the warp cover factor k_1 (%),the weft cover factor k_2 (%), the fabric cover factor k_c (%) and warp and weft tensile parameters LT1, LT2, RT1, RT2, WT1, WT2 và EM1, EM2 of 8 cotton woven fabrics.

A pairwise correlations of the values of fabric structure values using the R software were obtained the graph (Fig. 3), shows a significant correlation coefficient, in which the correlation coefficient k_1 and k_c (r = 0.99 > 0.95). Thus, it is possible to remove the k_c parameter and use the remaining 8 fabric structure parameters as the independent variables of the correlation models.

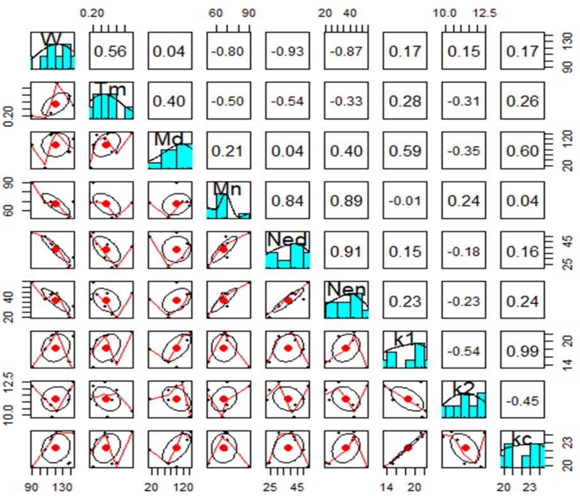


Fig. 3. The pairwise correlation graph of fabric structure parameters

The fabric tensile characteristics LT1, LT2, RT1, RT2, WT1, WT2 and EM1, EM2 are not completely independent of one another (Fig. 4). Correlation coefficient r = 0.96 when considering relationship between EM1 and WT1; EM2 and WT2 (r = 0.99). Therefore, it may not be possible to consider the WT1 and WT2 because EM1 and EM2 can characterize the tensile property similar to WT1, WT2. Thus, the six dependent variables of the correlation models include LT1, LT2, EM1, EM2, RT1, RT2.

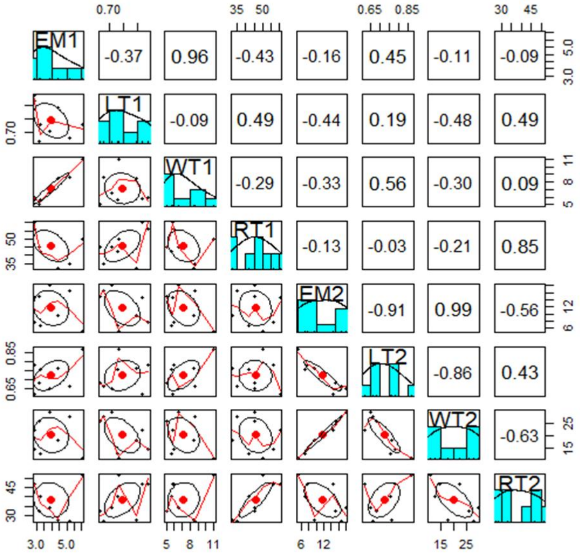


Fig. 4. The pairwise correlation graph of tensile characteristics

Experimental data is processed by BMA technique on R software to find the optimal multi-linear model between the inputs and the output. The results are as follows:

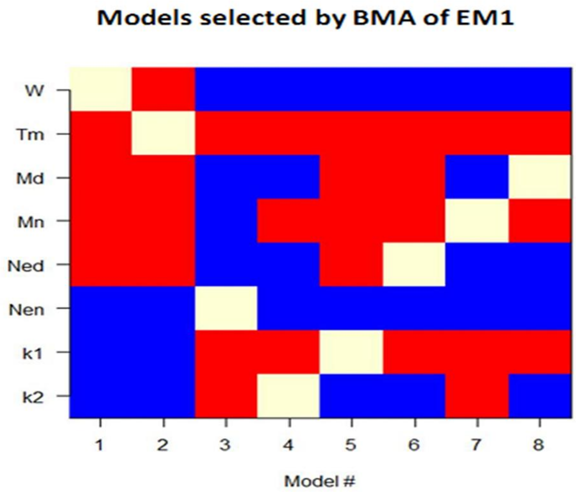
Warp elongation EM1: 8 models were selected. Where, the optimal model is:

EM1 = 87.92 + 24.31*Tm + 0.085*Md + 2.41*Mn +0.55*Ned – 2.86*Nen –0.83*.k_1 – 14.39*k_2; R^2 = 0,999 and BIC = -40,71.

Weft elongation EM2: 18 models were selected. Where, the optimal model is:

EM2 = 127.24 – 6.22*Tm – 0.005*Md + 1.86*Mn – 1.89*Ned – 1.49*k_1 – 12.58*k_2 ; R^2 = 0,999 and BIC = -42,78.

The differences of the fabric structure parameters explain 99.9% of the difference of the tensile parameters EM; 0.1% of difference is due to the effect of other factors. BMA diagrams show that the fabric structure parameters have significant influences on the elongation EM (Fig. 5).



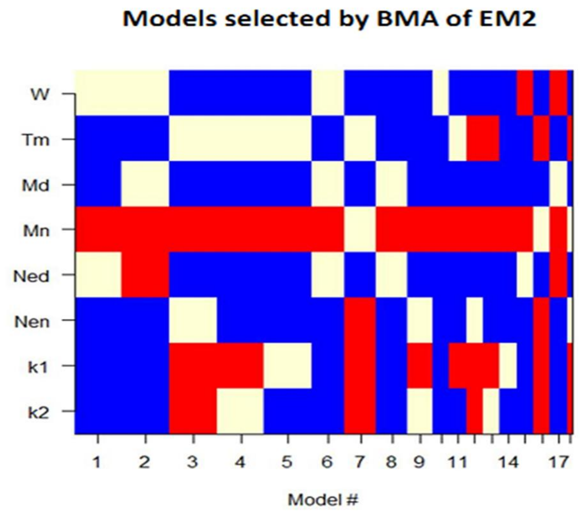


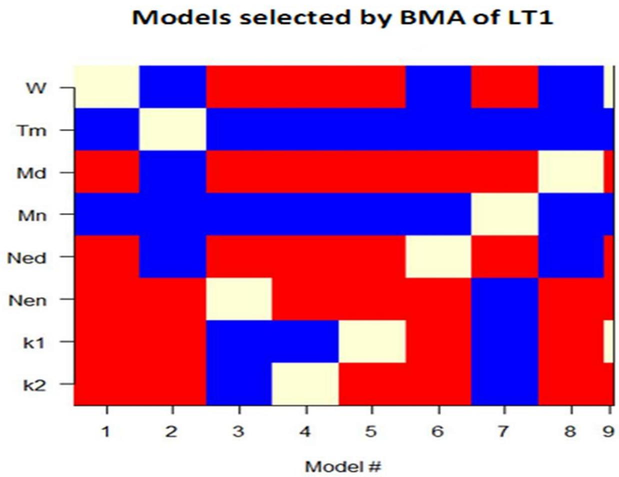
Fig. 5. The BMA diagrams of the models show the EM1 and EM2 elongation

Warp linearity of load extension curve LT1: 9 models were found. Where, the optimal model is:

LT1 = -1.59 – 0.49*Tm + 0.001*Md – 0.074*Mn + 0.005*Ned + 0.044*Nen + 0.004*k_1 + 0.417*k_2 ; R^2 = 0,999 and BIC = -40,71.

Weft linearity of load extension curve LT2: 9 models were found. Where, the optimal model is:

LT2 = 4.67 – 0.054*W + 1.08*Tm + 0,05.Mn – 0.0034*Md – 0.077*Ned + 0.16*k_1 + 0.24*k_2 ; R^2 = 0,999 and BIC = -42,79.



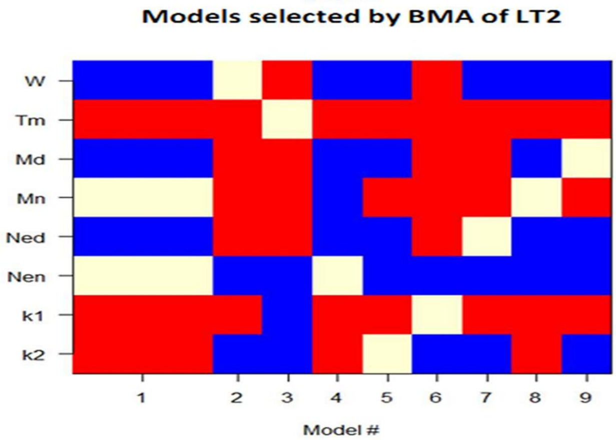


Fig. 6. The BMA diagrams of the models show the LT1 and LT2

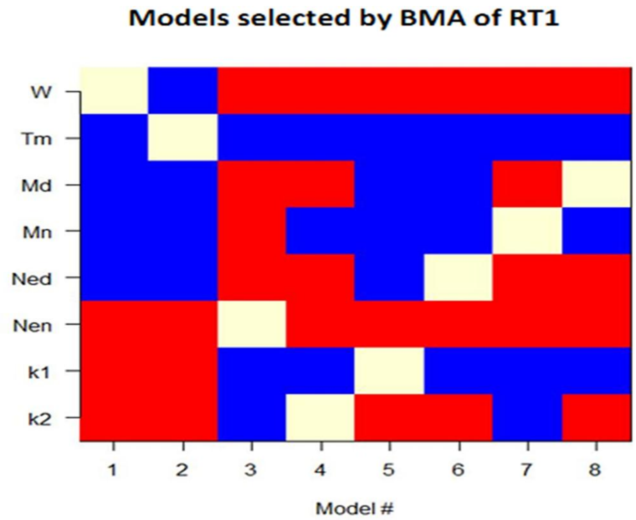
Warp tensile resilience RT1: 8 models were selected. Where, the optimal model is:

RT1 = - 761.2 – 51.02*Tm – 0.75*Md – 21.88*Mn – 4.2*Ned + 25,79*Nen + 6.34*k_1 + 130.07*k_2; R^2 = 0,999 and BIC = - 40,70.

Weft tensile resilience RT2: 13 models were selected. Where, the optimal model is:

RT2 = - 658.25 + 1.79*W - 0.35*Md – 13.31*Mn + 15.9*Nen + 73.29*k_2; R^2 = 0,999 and BIC = - 44,86.

BMA diagrams show that the fabric structure parameters have significant influences on the tensile characteristics (Fig. 5 to 7). Thus, the fabric structure parameters have significant effects on the warp and weft elongation EM1, EM2; Linearity of load extension curve LT1, LT2; Tensile energy WT1, WT2 and tensile resilience RT1, RT2.



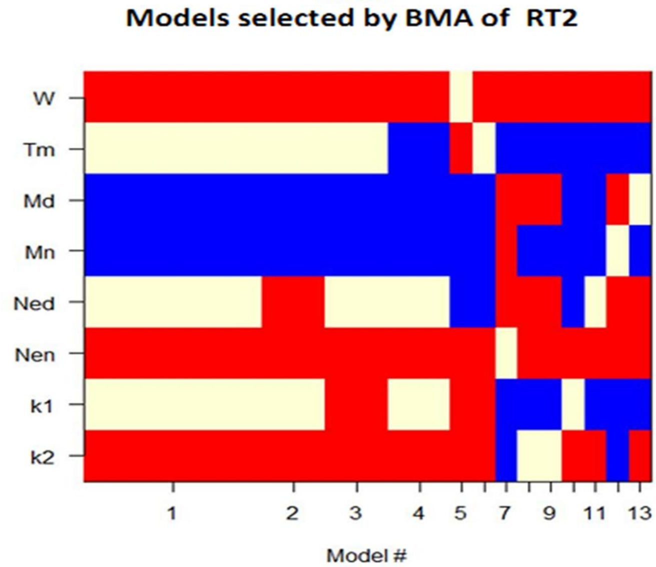


Fig. 7. The BMA diagrams of the models show the RT1 and RT2

4. CONCLUSIONS

Structural parameters have different effects on fabric tensile characteristics. The thickness, yarn settings, weight of fabric, Ne of yarns and cover factors are structural parameters that significantly affect the tensile characteristics of the experimental fabrics. There exists multi-linear relationships between the structural parameters and the tensile characteristics of the fabrics with significant correlation coefficients.

The established multi-linear models show the relationships between warp and weft elongation EM1, EM2; Linearity of load extension curve LT1, LT2; Tensile resilience RT1, RT2 and the structural parameters of the experimental woven cotton fabrics, as the basis for the design and selection of fabric with tensile characteristics in accordance with the requirements of products in industrial garment.

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