ANNALS OF THE UNIVERSITY OF ORADEA
FASCICLE OF TEXTILES, LEATHERWORK

ANALYSIS OF BREAKING CHARACTERISTICS OF COTTON FABRICS OF THE MOST FREQUENT WEAVES

DJORDJEVIC Suzana[1], KRSTIC Radica[2], KODRIC Marija[3], DJORDJEVIC Dragan[4]

[1] Academy of Vocational Studies Southern Serbia, Department of Technological Art Studies, 16000, Leskovac, Serbia, E-Mail: szn971@yahoo.com

[2, 4] University of Nis, Faculty of Technology in Leskovac, 16000, Leskovac, Serbia; E-Mail: drdrag64@yahoo.com

[3] Innovation center University of Nis, 18000, Nis, Serbia; E-Mail: izida50@gmail.com

Corresponding author: Djordjevic, Dragan, E-mail: drdrag64@yahoo.com

Abstract: *The behavior of three raw cotton fabrics of different basic weaves and approximate yarn settings and yarn counts, when subjected to tensile deformation, is described in this article. The values of the breaking force in the fabric in the linen weave have the highest mean numerical value, while the cotton fabric in the atlas weave has the lowest values. The fabric in the twill weave has the highest values for elongation at break, while the lowest values are present in the fabric in the atlas weave. The fabric in linen weave is the most resistant to external deformations, while the fabric in twill and atlas weaves are the weakest. The standard deviation and coefficient of variation for fabrics in all weaves have values that move within a range that confirms the validity of the results. In some cases, larger variations of these statistical data mean that these results can be taken with a certain amount of caution. It seems that there are a lot of latent stresses in the fabric, which are relaxed during the action of the tearing force, causing greater variations in the measurement results. Deformation curves after nonlinear fitting of the breaking force-elongation at break dependence are described by polynomial equations of the fourth and fifth degree, with the fact that about 99% of the variability of the dependent variable can be explained by means of the analyzed independent variables. Polynomial models are practically usable because they can predict with high reliability the deformation behavior of fabrics with similar weaves in the direction of the warp. There are statistically significant correlations between numerous values for breaking force from the experiment and the polynomial model.*

Key words: *cotton fabric, weave, breaking properties, correlation, polynomial regression.*

1. INTRODUCTION

Fabrics belong to the group of inhomogeneous materials with a very complex structure that originate from their building elements (fibers, yarns). The properties of woven materials are conditioned by the properties of all elements of lower structural rank that participate in their construction. Primarily, the properties of fabrics depend on the properties of the yarn, as its basic structural element [1,2].

Accurate prediction of fabric properties is a very complex issue that can be difficult to solve without simplification. The complexity of the problem arises from the fact that the properties of the fabric depend on the construction and technological parameters. Construction parameters include fineness and properties of warp and weft yarns, warp and weft density, and weave. Technological parameters are the type of loom and weaving conditions, i.e. warp and weft tension, weft feeding speed, beating-up motion force, etc. [3-5].

In this work, the behavior of three cotton fabrics with different basic weaves and approximate densities and threads finenesses, when subjected to stretching deformations, was investigated. These are raw fabrics (100% cotton) that should go through finishing and dyeing and/or printing stages by the end of production.

Breaking characteristics, breaking force and elongation at break, modulus of elasticity and work at rupture were analyzed as very important properties of the fabric considering that they directly determine the quality and utility value of the final product. At the same time, these parameters represent the starting point for defining the level of subsequent chemical treatments.

2. EXPERIMENTAL PART

Raw fabrics in linen, twill and atlas weave, made of 100% cotton yarns with close values for count and setting of warp and weft threads, were used in the research. The basic properties of the examined fabrics are shown in table 1.

Table 1: Nominal values of the basic properties of cotton fabrics

Yarn count (tex)		Yarn setting (cm^{-1})		Mass per unit area (g/m^2)	Weaves
Warp	**Weft**	**Warp**	**Weft**		
30	20	31	23	192	Linen
29	21	30	22	189	Twill
31	19	29	23	178	Atlas

The fabrics are woven under production conditions in the weaving mill, on a Picanol Omni 4P pneumatic loom (manufacturer Picanol, Belgium), loom speed 750 min^{-1}, shed forming cam mechanism, working width 1900 mm, profiled reed, number of harness 8, warp tension 1.5–2.5 kN. After weaving, the relaxation of the fabric is achieved in a relaxed state for 24 hours. After stabilization, the mechanical properties of the fabrics were checked.

Fabric testing methods:

- Breaking force *(F)* and elongation at break *(ε)*, according to the SRPS ISO 5081 standard.
- Work at rupture is obtained after integration of the deformation curve F–ε shown in the diagram of the same name with the help of the OriginPro program package.
- The modulus of elasticity, *E*, represents the ratio between the stress σ (N/mm^2) in the elastic region and the unit elongation ε (%). The modulus of elasticity was determined by the graphical method with the help of the mathematical software OriginPro, by drawing the dependence diagram $\sigma : \varepsilon$.

Each result shown in the paper is the mean value of 10 measurements. Also, statistical data for each measurement were analyzed, polynomial fitting and correlation analysis of deformation properties of fabrics was performed.

3. RESULTS AND DISCUSSION

Tables 2 and 3 show the results for breaking force and elongation at break of the analyzed cotton fabrics.

The measured values of the breaking force parameter in the linen weave in the warp direction have the highest mean numerical value of 201 N. Also, the same weave, in the weft direction, has the highest breaking force value of 158 N. The lowest values of this mechanical indicator have the cotton fabric in the atlas weave, in both directions, for the warp (190 N) and the weft (145 N).

The standard deviation (SD) and coefficient of variation (Cv) for the fabrics in all weaves have values that range within the range confirming the validity of the results.

Somewhat larger variations of these statistical data for the breaking force of fabrics in linen and atlas indicate that these results can be taken but with a certain amount of reserve and caution. It seems that there are a lot of latent stresses in the fabric, which are relaxed during the action of the breaking force, causing greater variations in the measurement results. As the fabrics have very similar yarn count and setting values, these differences in breaking force results come mainly from the weave. It should not forget the influence of the transverse threads, which take over a part of the resistance to the stretching force, that is, by wrapping the longitudinal threads, they increase the friction between the fibers of those threads, thereby strengthening them [6,7].

Table 2: Results of breaking force of cotton fabrics with different weaves

Statistical parameters	Breaking force, N					
	Linen		Twill		Atlas	
	Warp	Weft	Warp	Weft	Warp	Weft
Mean value, N	201	158	195	151	190	145
Standard deviation, SD, N	5.37	4.12	4.14	2.79	4.31	4.82
Coefficient of variation, Cv, %	2.67	2.61	2.11	1.85	2.27	3.32

According to Table 3, the elongation at break of fabrics in all weaves varies from 6.2 (warp direction, atlas weave) to 7.5% (weft direction, twill weave). The pattern in twill weave has the highest values for elongation at break, which is related to the interweaving structure of the warp and weft and the residual stresses in the fibers, i.e. the yarn. Statistical data additionally clarify the obtained measurement values of this examined parameter.

Table 3: Results of elongation at break of fabrics

Statistical parameters	Elongation at break, %					
	Linen		Twill		Atlas	
	Warp	Weft	Warp	Weft	Warp	Weft
Mean value, %	6.9	7.2	7.0	7.5	6.2	7.1
Standard deviation, SD, %	0.42	0.43	0.91	0.72	0.49	0.70
Coefficient of variation, Cv, %	6.11	5.98	13.04	9.66	7.90	9.86

Figures 1 show diagrams of dependence breaking force-elongation at break in the direction of the warp, i.e. weft. It is about the so-called deformation curves that explain the fabric's reaction to stretching.

At the beginning of stretching for both directions of the threads, all fabrics have a small increase in the breaking force with the increase in elongation, and later after 2.5% elongation there is a sudden increase in the breaking force from 20 to 200 N.

Table 4 shows the values of the modulus of elasticity of the used cotton fabrics by warp and weft. In a mathematical sense, the data were obtained from the equation $\sigma = E \times \varepsilon$, in which the modulus of elasticity is the coefficient of the direction of the linear part of the curve (slope), while the coefficient of determination, in all cases, was 1, which confirms the absolute functionality of the variables.

According to the results from the Table 4, it is observed that the fabric in the linen weave has the highest values for the modulus of elasticity in both directions, while the lowest values are registered for the cotton fabric in the twill weave, also in both directions.

This means that the largest applied force (stress) is necessary to deform the fabric in the linen weave compared to the fabrics in the other weaves, which coincides with the results of the other measured parameters.

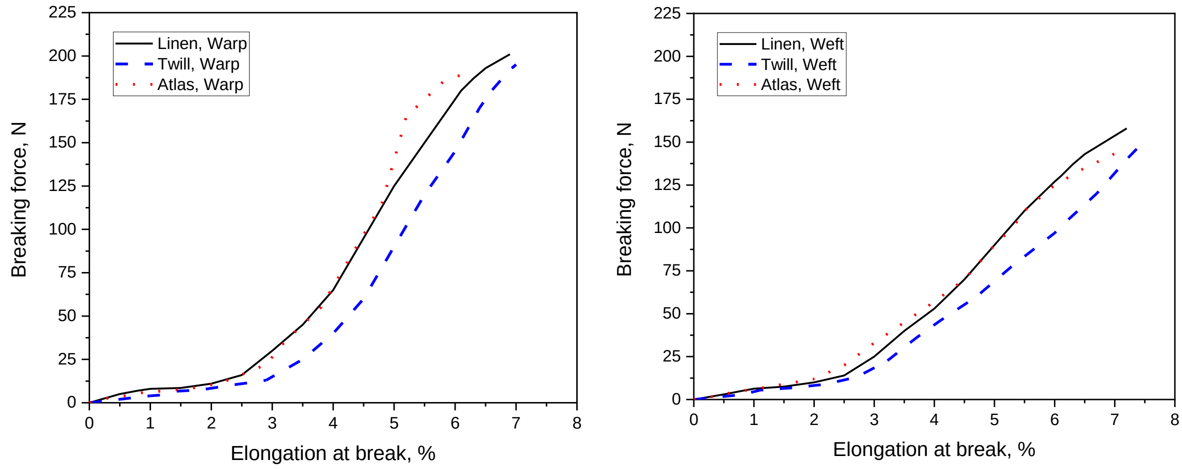

Fig. 1: Deformation curve of the analyzed fabrics in the warp and weft direction

Also, Table 4 shows the results of the work at rupture of cotton fabrics of different weaves, by warp and weft. Less work at rupture means less resistance of fabrics to external deformations, i.e. to stretch to rupture in this case. According to the results, the highest resistance to deformations was shown by the fabric in linen weave, while cotton fabrics in twill and atlas weaves have the lowest values of this parameter.

Table 4: Results of elongation at break of fabrics

Statistical parameters	Linen		Twill		Atlas	
	Warp	Weft	Warp	Weft	Warp	Weft
Modulus of elasticity, kPa	400	250	160	140	300	240
Work at rupture, J	1.48	1.26	1.20	1.12	1.15	1.22

Deformation curves after nonlinear fitting of the breaking force–elongation at break dependence are represented by diagrams in Figure 2. The procedure of fitting the experimental data was done, i.e. formulating the function $F(x)$ that approximates the unknown dependence of $f(x)$, so that the deviations of experimental values from computational estimates are small in a certain sense [6,7].

The diagrams in Figure 2 can also be called scatter diagrams, given that, in an obvious way, they provide a visual representation of whether or not there is dependence and interdependence between variables x and y, as well as its character and intensity.

Table 5 gives data related to the appearance of the equation of the fourth and fifth degree polynomial, which very well describes the breaking force-elongation at break relationship for each of the tested fabrics of different weaves, in the warp and weft direction. Based on these equations, the behavior of the same or similar fabrics in terms of mechanical characteristics can be predicted with sufficient reliability without practical measurement of breaking force and elongation at break.

A good measure of the adequacy of a polynomial model is confirmed by the coefficient of determination, R^2. In the specific case, it is stated that about 99% of the variability of the dependent variable can be explained by means of the analyzed independent variables.

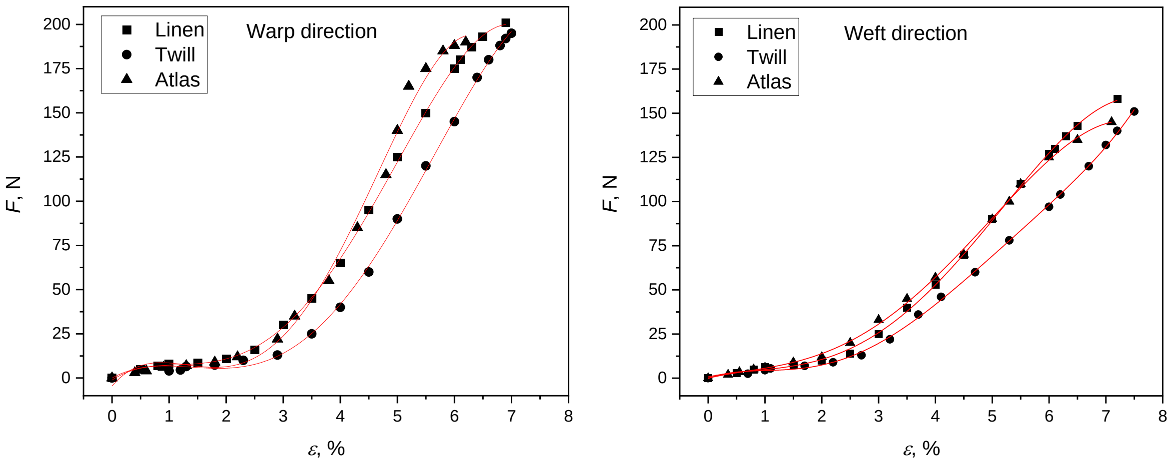

Fig. 2: Deformation curves after non-linear fitting in the warp and weft direction

Tab. 5: Polynomial equations of the second degree according to the fitting of deformation curves

Weaves		A polynomial equations of the fourth and fifth degrees	R^2
Linen	Warp	$F = -0.04 + 18.18\cdot\varepsilon - 16.31\cdot\varepsilon^2 + 5.94\cdot\varepsilon^3 - 0.48\cdot\varepsilon^4$	0,9998
	Weft	$F = 0.70 + 7.20\cdot\varepsilon - 5.39\cdot\varepsilon^2 + 2.57\cdot\varepsilon^3 - 0.21\cdot\varepsilon^4$	0.9996
Twill	Warp	$F = -1.18 + 21.25\cdot\varepsilon - 18.38\cdot\varepsilon^2 + 5.50\cdot\varepsilon^3 - 0.39\cdot\varepsilon^4$	0.9994
	Weft	$F = -0.21 + 12.33\cdot\varepsilon - 12.79\cdot\varepsilon^2 + 5.81\cdot\varepsilon^3 - 0.86\cdot\varepsilon^4 + 0.04\cdot\varepsilon^5$	0.9995
Atlas	Warp	$F = -4.55 + 38.00\cdot\varepsilon - 35.57\cdot\varepsilon^2 + 11.59\cdot\varepsilon^3 - 0.97\cdot\varepsilon^4$	0.9952
	Weft	$F = 0.06 + 7.26\cdot\varepsilon - 3.55\cdot\varepsilon^2 + 2.05\cdot\varepsilon^3 - 0.18\cdot\varepsilon^4$	0.9992

Figure 3 shows a diagram that defines the correlation dependence of the results for the breaking force of the fabric in the fabric weave in the direction of the base determined according to experimental and modeled values. According to the appearance of the correlation curve, a high coverage of the experimental points is noticeable, the value of the correlation parameter according to Pearson (Pearson's r = 0.999) is close to 1, which confirms a strong connection and mutual dependence [7,8].

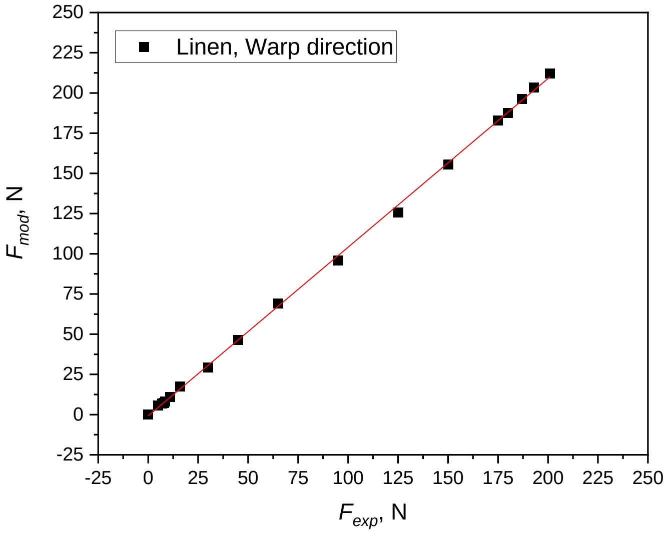

Fig. 3: Correlation of breaking forces of cotton fabric estimated by experimental and modeled values

5. CONCLUSIONS

The quality of the fabric itself is influenced by many factors, primarily the quality of the raw materials, the structure and constructive solution, the type of loom on which the fabric is made, the expertise of the workers, the organization of work, etc.

Based on the analysis of the deformation properties of three cotton fabrics with different weaves and very similar other characteristics, it can be concluded:

- The values of the breaking force of the fabric in the linen weave have the highest numerical value, while the cotton fabric in the atlas weave has the lowest values.
- The fabric in twill weave has the highest values for elongation at break, while the lowest values are present in the fabric in atlas weave.
- According to the results for the modulus of elasticity and the work at rupture, it is stated that the fabric in linen weave is the most resistant to external deformations, while the fabric in twill is the weakest.
- Deformation curves after non-linear fitting of the breaking force-elongation at break dependence are successfully described by polynomial equations of the second degree.
- Correlation analysis of the dependence between numerous values for breaking force from the experiment and the polynomial model showed that there are statistically significant correlations between these parameters.

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