ANALYSIS OF THE DEFORMATION CHARACTERISTICS OF WOVEN TEXTILE MATERIALS IN PLAIN WEAVE

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(ORIGINAL SCIENTIFIC PAPER)
UDC: 677:677.017
DOI: DOI: 10.5937/savteh2401050S

Deformations of woven materials occur in the process of forming fabrics into more complex textile structures, as well as during the exploitation of finished products. Several factors influence the deformation properties of textile materials. The key factors are the properties of the yarn used, the construction of the fabric and the density of the warp and weft threads. The anisotropic properties of woven materials impose the need to analyze the deformation in the direction of the warp and in the direction of the weft of fabric. In addition, the research includes the analysis of the deformation of woven materials at an angle of 45 ° in relation to the direction of the warp. The results of the research showed that increasing the density of the weft threads leads to an improvement in the characteristics at the limit of yielding and breaking in the direction of the weft and at an angle of 45 °. Based on the obtained results, dependencies were proposed that can be used to predict the deformation of woven textile materials in a plain weave using tensile force in the direction of the warp, in the direction of the weft and at an angle of 45 °.

Keywords: fabric, plain weave, breaking characteristics, yielding of material

Introduction

Mechanical characteristics represent a complex of properties that determine the ability of woven materials to resist the action of various external forces that can cause various types of deformation (shearing, compression, tension, twisting, bending, etc.). As a result of the action of these deformations, there are changes in the shape and dimensions of the fabric. The size of the resulting deformation depends on the type, direction, intensity and time of force action, as well as the relaxation period. In addition to the change in shape and size, there is also a disruption of the structure of woven materials [1, 2]. The destruction of the fabric structure occurs at the moment when the applied tensile force exceeds the breaking force value in terms of intensity. The different behavior of woven material when stretched in different directions is the result of their anisotropy [3, 4].

In order to explain the dimensional changes of woven material during exploitation, new devices and methods were developed for measuring the mechanical characteristics of woven materials [5-7]. Also, methods have been developed for predicting the breaking forces of woven materials and changes in the dimensions of the samples until breaking [8, 9]. However, a review of the literature reveals a lack of literature data on methods for determining limit loads that can cause significant deformations of fabrics. That is why the paper presents a method that can be applied to determine the limit values of the load. Also, in the industry, a conclusion is very often made about the quality of a fabric (if the mechanical properties are observed) only on the basis of its breaking characteristics, which is often not enough to get a realistic image of the material. By knowing the values of the forces and elongation at the yield point of woven materials, a realistic image of the values of the forces that the fabric can be subjected to during exploitation is obtained. In this way, the properties of the fabrics will be preserved and thus the good quality of the finished products will be ensured in accordance with the designed characteristics.

Material and methods

The properties of 20 different woven fabrics were analyzed. The fabrics were formed in industrial conditions on modern weaving machines from yarns with a raw material composition of PES/Co 50/50%. All fabrics are formed on the same warp 25x2 tex (breaking force – 1157 cN; breaking elongation – 8.5%), with thread density 27 cm^{-1}. Weft yarns are with a linear

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The manuscript received: 29. 1. 2024.
Paper accepted: 26. 2. 2024.

density of 25x2 tex (breaking force - 1157 cN; breaking elongation - 8.5%), 50 tex (breaking force - 1033 cN; breaking elongation - 9.3%), 41.67 tex (breaking force – 807 cN; breaking elongation – 8.8%) and 29.41 tex (breaking force – 609 cN; breaking elongation – 6.9%), with thread densities for each applied weft; 14 cm^{-1}, 16 cm^{-1}, 18 cm^{-1}, 20 cm^{-1} and 22 cm^{-1}.

The breaking characteristics were measured on the dynamometer MesdanLab Strength Tester, Standard ISO 13934/1 [10]. In addition, data were recorded on the basis of which the force-elongation dependences were defined for all analyzed fabrics in the direction of the warp, in the direction of the weft and at an angle of 45 ° (in the direction of the diagonal). Figure 1 shows an example of force-elongation dependence in all three analyzed directions for one fabric sample (Ttwa = 25x2 tex, Ttwe = 29.41 tex, dwa = 27 cm^{-1}, dwe = 18 cm^{-1}).

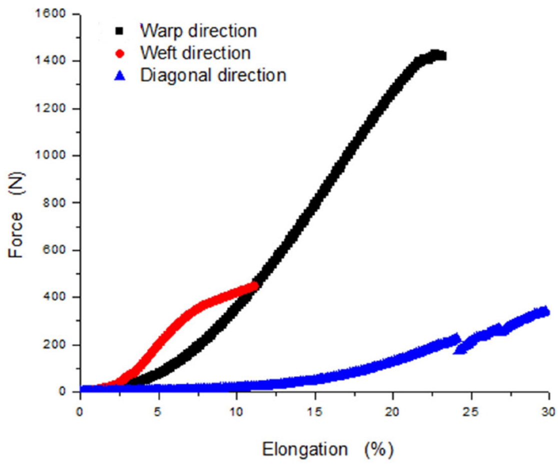
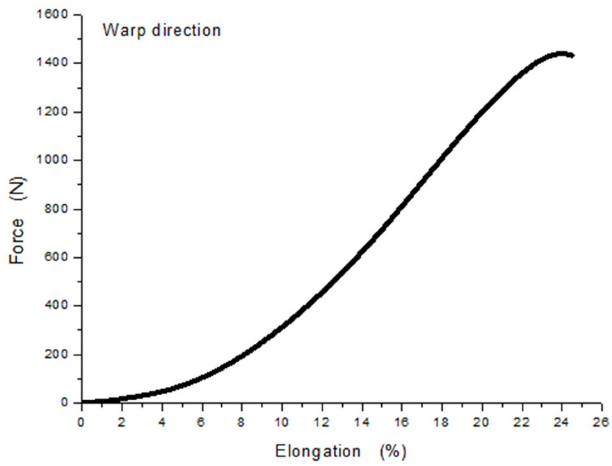


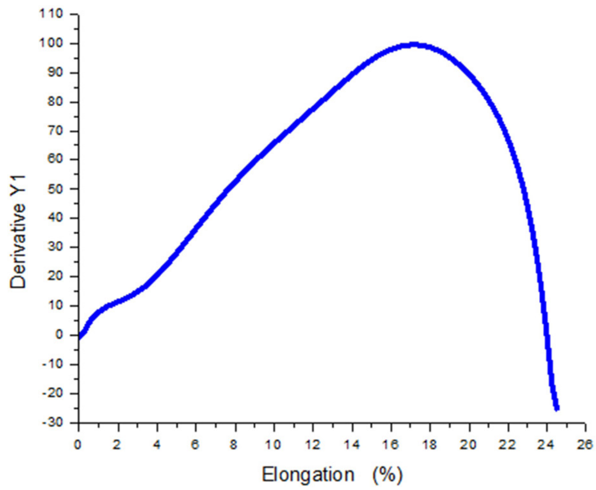
Figure 1. Force-elongation of fabrics in different directions

The force-elongation dependences are presented in the form of a ninth-degree polynomial function, where the coefficients of determination have values approximately equal to 1 (Figure 2a).

By analyzing the flow of the force-elongation function, the yield limit was determined for each analyzed fabric sample in the direction of the warp, in the direction of the weft and in the direction of the diagonal. By defining the maximum of the first derivative of the function (Figure 2b), where the second derivative of the function is equal to zero, the yield limit is determined, as well as the force parameters - elongation at the yield limit.



(a)



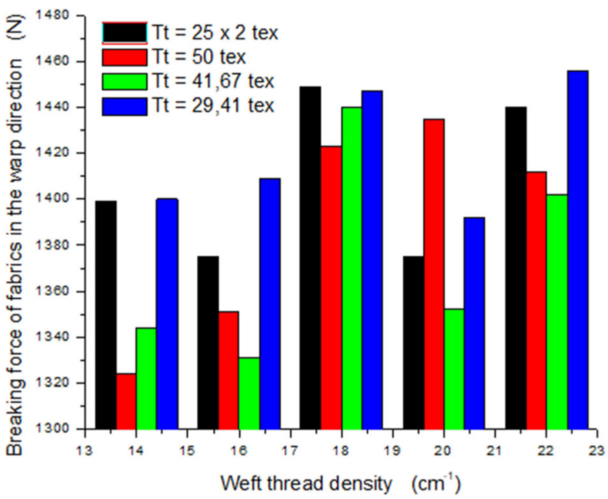
(b)

Figure 2. The force-elongation function (a) and the first derivative of the force-elongation function (b)

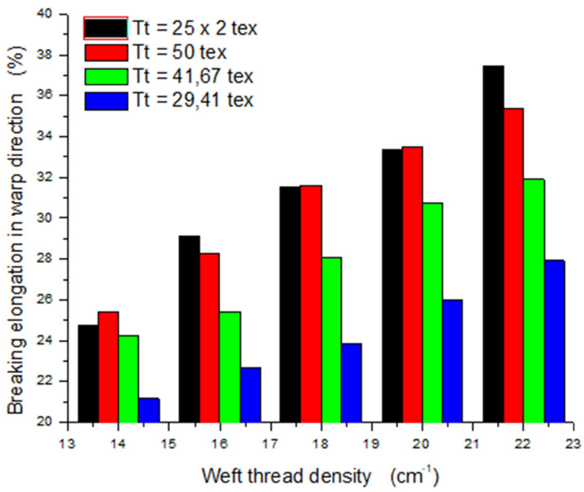
Results and discussion

When tensioning the fabric, geometrical changes in the structure of the woven material occur, which are determined by the intensity and direction of the force. Geometrical changes at low loads occur as a result of overcoming and redistributing of warp and weft crimp. By further increasing the tensile force, resistance to stretching is provided by the fibers in the yarn, which elongate in the direction of the force until the moment when the frictional forces between the fibers are overcome, i.e. when sliding between the fibers occurs and the material loosens. By further increasing the tension force, resistance is provided by the yarns that stretch and at the same time suffer the compression of the other yarn system, until breaking. The transition from phase to phase does not mean that the deformations from the previous phase stop. The straightening of the threads in the direction of the force as well as the sliding between the fibers continues until the break. In the diagonal direction (Figure 1), the threads slip when stretching the samples, which is especially pronounced in fabrics with a lower density of weft threads (sudden drop in force during stretching - break in the graphic).

Figure 3 shows the influence of the weft density on the breaking force and breaking elongation of the analyzed fabrics in the direction of the warp.



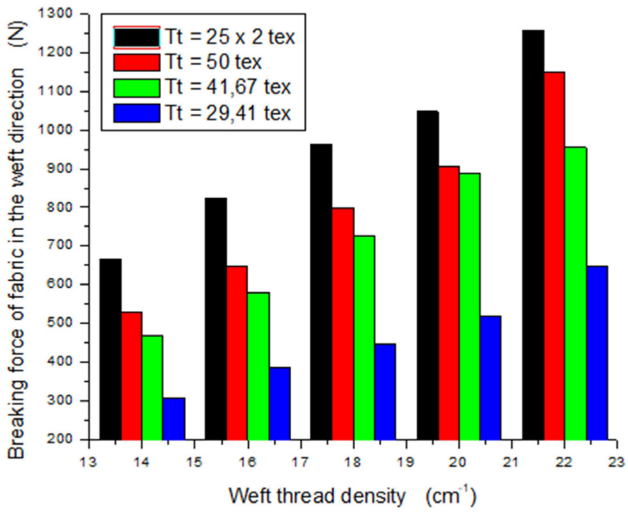
(a)



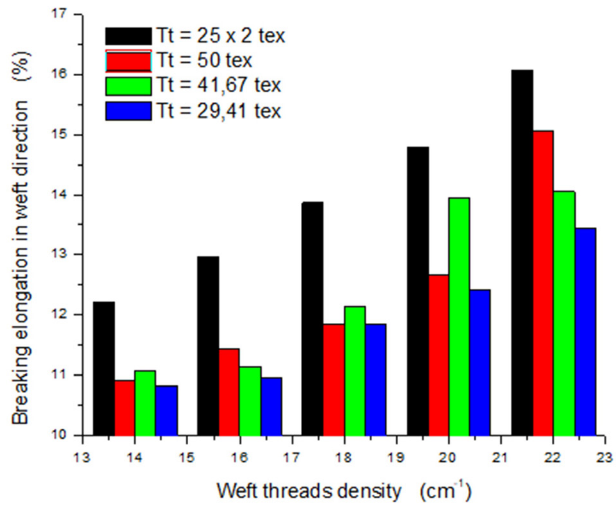
(b)

Figure 3. Influence of weft density on breaking force (a) and breaking elongation (b) of the fabric in the warp direction

Based on the obtained results, it is not possible to see a clear influence of the change in the density of the weft threads on the breaking force of the fabric in the direction of the warp (Figure 3a). In contrast to this, increasing the density of the weft threads leads to an increase in the breaking elongation of the fabrics in the warp direction (Figure 3b). Also, it is observed that the elongation at break is less in fabrics with applied wefts of smaller linear density. Crimp of the warp depends, among other things, on the density of the weft threads and their linear density, namely a higher weft density and a thicker weft lead to higher values of the warp crimp [11], which may be the reason for the obtained results of breaking elongation of the analyzed fabrics.



(a)

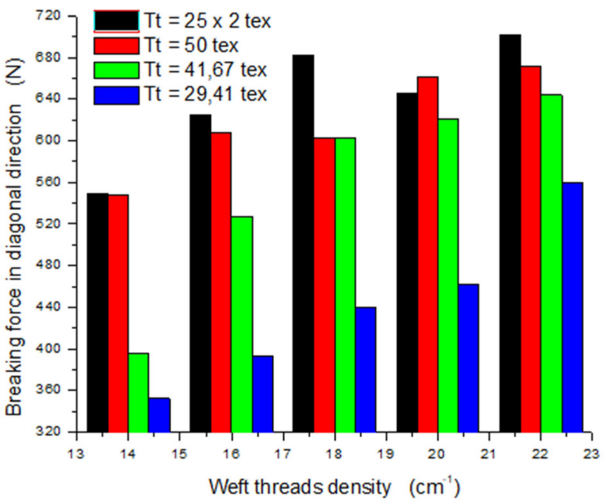


(b)

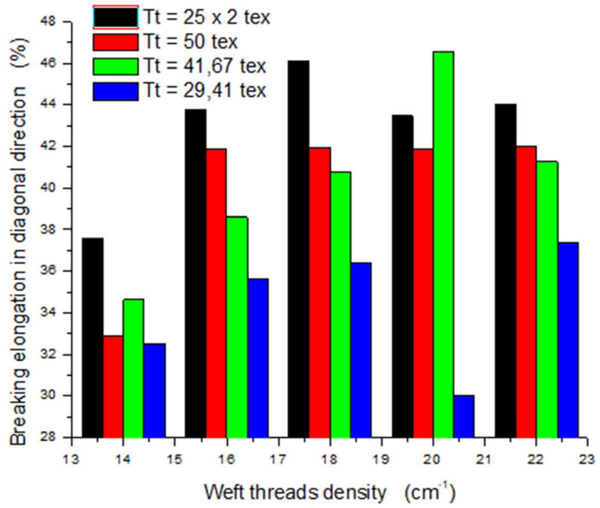
Figure 4. Influence of weft density on breaking force (a) and breaking elongation (b) of the fabric in the weft direction

Figure 4 shows the influence of the density of the weft on the breaking characteristics of the analyzed fabrics in the weft direction. It can be seen that the density of the weft threads and the breaking force of the fabric in the weft direction have a significant relationship (Figure 4a), which is the expected result. Also, an increase in the breaking elongation of the fabric in the direction of the weft is observed due to the increase in the density of the weft threads (Figure 4b).

The breaking force of the applied weft yarn has a clear effect on the breaking force of the fabric in the weft direction. In addition, the application of the twisted yarn for the weft (25 x 2 tex) gave the highest values of breaking force and breaking elongation in the direction of the weft for all analyzed fabrics.



(a)



(b)

Figure 5. Influence of weft density on breaking force (a) and breaking elongation (b) of the fabric in the diagonal direction

Figure 5 shows the influence of weft thread density on the breaking characteristics of the analyzed fabrics in the diagonal direction. Figure 5a shows the influence of the density of the weft on the breaking force of the fabric in the diagonal direction. The higher density of the weft contributes to the improvement of the strength of the fabric in the diagonal direction. Based on the obtained results, no clear influence of weft density on breaking elongation in the diagonal direction can be observed (Figure 5b).

The use of twisted yarn for the weft generally gave the best results in terms of the breaking characteristics of the fabrics when tensioning in the diagonal direction. Single yarn (50 tex), whose linear density corresponds to the twisted yarn (25 x 2 tex) has a higher breaking elongation compared to the twisted yarn, but even in this case, the breaking elongation of the fabric in the weft direction with twisted yarn applied is generally the highest, other things being equal parameters, which is the result of the good characteristics of twisted yarns [12].

Woven materials have different applications and, accordingly, it is very important to have information about the value of the load that the materials can bear without being deformed. Textile materials are characterized by elastic, viscoelastic and plastic deformation. Their clear demarcation is not possible due to the nature of the structure and construction of woven materials, but it is possible to define areas dominated by certain deformations.

By analyzing the force-elongation graph, it is possible to define the limit after which the yielding of woven materials occurs (the maximum of the first derivative of the force-elongation function). When loading the fabric below the yield point, most of the deformation is reversible, while loading the fabric above the yield point causes a large part of the irreversible deformation.

Figure 6 shows the values of the force participation at the yield point in relation to the breaking force of the fabric. The change in the density of the weft has a negligible effect on the increase in the percentage of the force component at the yield point in the breaking force in the direction of the warp. The mean value of the percentage of yielding at break for the warp direction of the analyzed fabric is 67.3%. The increase in the density of the weft yarns in the fabric contributes to the increase in the percentage of the force at the yield point in the breaking force in the direction of the weft, and this growth is particularly pronounced when the values in the diagonal direction are analyzed. An increase in the density of the weft threads contributes to an increase in friction between the warp and weft yarns, due to a greater number of connecting points of the warp and weft per unit area, so the material provides greater resistance to thread slippage when the fabric is stretched in the observed direction.

Figures 7-9 show graphs showing the relationship between elongation at break and elongation at yield point in the warp direction, the weft direction and the diagonal direction. The speed of stretching the fabric sample until breaking is 100 mm/min.

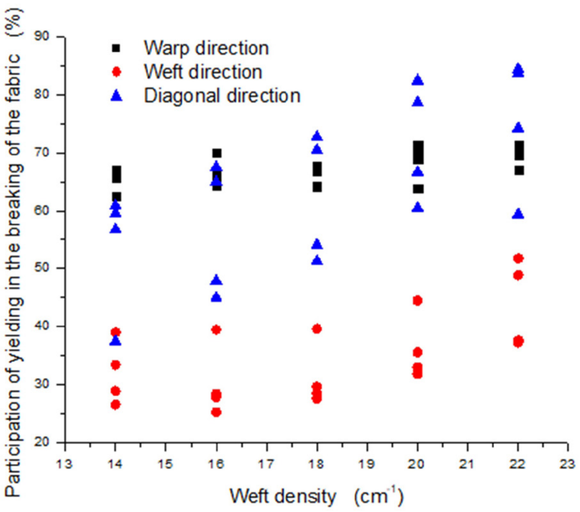


Figure 6. The percentage of the force at the yield point in the breaking force of the fabric

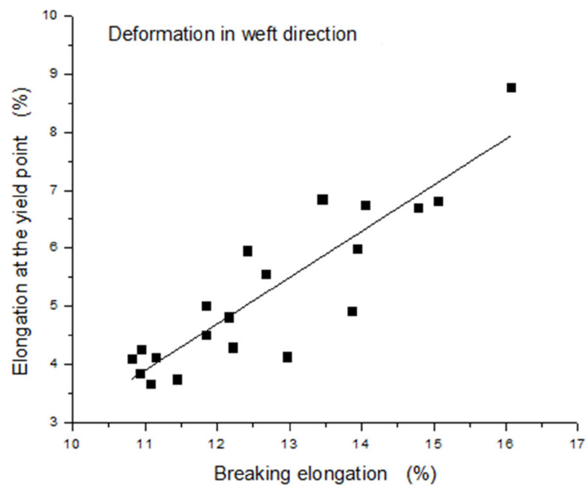


Figure 8. Relationship between elongation at the yield point and breaking in the weft direction

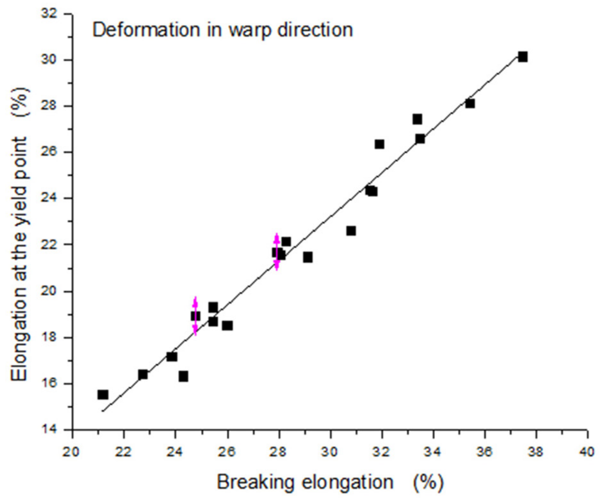


Figure 7. Relationship between elongation at the yield point and breaking in the warp direction

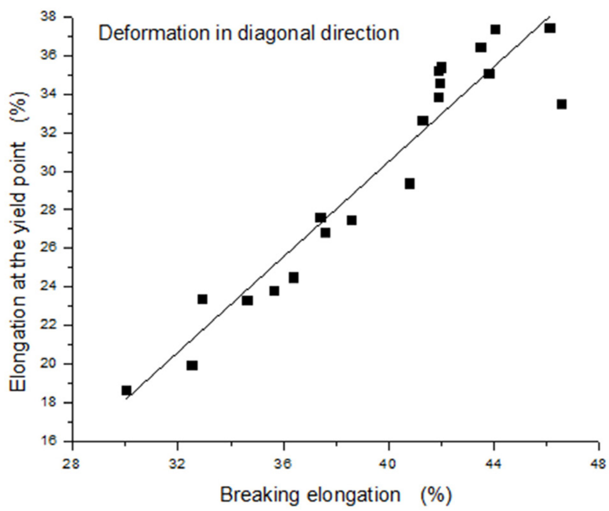


Figure 9. Relationship between elongation at the yield point and breaking in the diagonal direction

The relationship between elongation at break and elongation at the yield point is represented by an equation of the form y=a+bx, and Table 1 shows the parameters of the correlation dependence.

Table 1. Correlation dependence parameters

Function	$y = a + b\,x$				
Parameters	*a*	*St.error*	*b*	*St.error*	r^2
Warp direction	-5,3516	1,1382	0,9526	*0,0393*	0,9686
Weft direction	-4,8538	1,2294	0,7961	0,0963	0,7801
Diagonal direction	-18,8264	3,6680	1,2331	0,0923	0,9032

The obtained dependences can be applied to determine the elongation at the yield point for the corresponding fabrics with the applied plain weave of the raw material composition PES/Co 50/50%. Since the force-elongation dependence is defined for each sample, the force values for the defined elongation at the yield point can be calculated. The given values represent the limit values of loading and stretching, after which significant deformations of woven textile materials occur.

Conclusion

Based on the obtained results, it can be concluded that with the increase in the density of the weft threads in the fabric, the following changes occur:

- the breaking force of the fabric increases in the direction of the weft,
- break elongation increases in the direction of the warp and in the direction of the weft,
- the breaking force in the diagonal direction has an increasing trend,
- growth trend has values of force and elongation at the limit of yielding in all three analyzed directions.

In addition, the linear density of the weft affects the value of the warp crimp, and therefore the elongation of the fabric in the direction of the warp.

Deformations of fabric materials in the process of exploitation depend on their structural and constructional solutions. Determining the parameters of woven materials at the yield point and relating them to breaking characteristics can be used to predict the behavior of fabrics during exploitation. Also, conditions are created for the proper selection of the structural solution of the woven material in accordance with its future purpose. This can improve the technical preparation of weaving production, without test series of samples, which contributes to saving time, energy and raw materials.

Acknowledgment

Republic of Serbia - Ministry of Education, Science and Technological Development, Program for financing scientific research work, number 451-03-65/2024-03/200133.

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Izvod

ANALIZA DEFORMACIONIH KARAKTERISTIKA TKANIH TEKSTILNIH MATERIJALA U PLATNENOM PREPLETAJU

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UDK: 677:677.017
DOI: DOI: 10.5937/savteh2401050S

Deformacije tkanih materijala nastaju u procesu oblikovanja tkanina u složenije tekstilne srtukture, kao i prilikom eksploatacije gotovih proizvoda. Više faktora utiče na deformaciona svojstva tekstilnih materijala. Ključni faktori su svojstva primenjene pređe, konstrukcija tkanine i gustine osnovinih i potkinih žica. Anizotropna svojstva tkanih materijala nameću potrebu za analizu deformacije u pravcu osnove i u pravcu potke. Pored toga, istraživanje obuhvata i analizu deformacije tkanih materijala pod uglom od 45 ° u odnosu na pravac osnove. Rezultati istraživanja su pokazali da povećanje gustine potkinih žica dovodi do poboljšanja karakteristika na granici popuštanja i prekida u pravcu potke i pod uglom od 45 °. Na osnovu dobijenih rezultata predložene su zavisnosti koje mogu poslužiti za predviđanje deformacije tkanih tekstilnih materijala u platnenom prepletaju pri zatezanju u pravcu osnove, u pravcu potke i pod uglom od 45 °.

Ključne reči: tkanina, platneni prepletaj, prekidne karakteristike, popuštanje materijala