53rd CONFERENCE ON EXPERIMENTAL STRESS ANALYSIS
Český Krumlov, Czech Republic, June 1–4, 2015

Determination of Poisson's Ratio of Coated Woven Fabrics

D. Šimić Penava [1,*], Ž. Penava [2], M. Tkalec [2]

[1] *Faculty of Civil Engineering, University of Zagreb, Kačićeva 26, 10000 Zagreb, Croatia*
[2] *Faculty of Textile Technology, University of Zagreb, P.b. Filipovića 28a, 10000 Zagreb, Croatia*
[*] *dianas@grad.hr*

Abstract: Coated fabrics have complex composite structure whose mechanical properties are considerably improved in relation with the initial basic material. They are obtained by applying a certain number of coatings to raw fabrics. In this paper the practical application of uniaxial testing of coated fabrics for determining its breaking properties and Poisson's ratio is presented. Due to the anisotropy of woven and coated fabrics, Poisson's ratio changes over the fabric sample stretching. Experimental testing were carried out on two samples of plain weave cotton fabrics. The fabrics were tested before coating, and after one, two and three coatings. Samples are stretched with tensile force in the weft and warp direction, and based on different measured values of fabric stretching, warp and weft Poisson's ratio is calculated. The values of tensile force and relative extension of coated fabrics were measured, as well as breaking force values, elongation at break, contractions at break.

Keywords: Coated Fabric; Poisson's Ratio; Warp; Weft; Anisotropy.

1 Introduction

Nowadays the use of textile materials in different industrial branches is on the rise, especially in composite materials. In order to significantly improve the initial mechanical properties of textile materials, certain coatings are applied to the basic textile material on one or both sides in one or more layers. This results in a coated textile fabric whose properties are considerably improved in relation to the initial basic material and which can be used for special purposes. The fabric becomes more rigid by the process of coating. The coating has got its specific properties and fills the spaces between the yarns and „cements" warp and weft into one unit. Mechanical properties of the yarns are changed, and the rotation between the yarns is prevented. Coated fabrics can be defined as a composite structure consisting of a series of heterogeneous polymer layers. Structural properties of woven material in coated fabrics are the result of a combination of numerous factors. Uniaxial testing is most commonly performed in coated fabrics using either commercial or custom- designed instruments [1] and analyzing physical and mechanical properties of coated textile products [2]. The Poisson's ratio in fabrics comes out of the interaction between the warp and weft, and can be expressed in terms of structural and mechanical system parameters [3]. Experiments on the extension of the coated fabric sample under static load will be performed. The influence of coating on the values of the Poisson's ratio has been researched too.

2 Theoretical Overview

When a fabric is stretched in one direction, it tends to contract in the direction perpendicular to the direction of stretch. The yarns in the direction of tensile force are flattened out (extended), and in the orthogonal or non-loading direction the yarns have a longer geometrical path to 'curve around'. Because there is no limiting force, waviness (amplitude) of the yarn in the vertical direction of the force increases. The consequence to this is dimension reduction of the fabric width. This phenomenon is called Poisson effect. Poisson's ratio, a measure of the Poisson effect, is the ratio of the relative contraction strain s to the related extension strain ε in the direction of the applied load. To determine the Poisson's ratio of fabrics, devices for measuring tensile strength are used, and the coefficient is determined in the linear part of the diagram of Hooke's law [4]. During testing the fabric to stretch, the initial length of the tested sample l_0 is increased for Δl, and a final sample

Tab. 1: Description of fabrics.

Fabric code	Fabric structure	Yarn count [tex]		Thread density [cm^{-1}]		Aereal density [g/m^2]	Thickness [mm]
		warp	weft	warp	weft		
L0	raw	80	80	20	20	260	0.53
L1	one layer coated					388	0.78
L2	two layers coated					494	0.82

length of fabric is l. The initial width of the fabric sample b_0 is decreased for Δb and the final sample width is b. The physical meaning of Poisson's ratio ν is shown by Eq. (1). Relative contraction and extension strains have an opposite sign.

$$\nu = \left|\frac{s}{\varepsilon}\right| = \left|\frac{l_0}{b_0}\frac{b-b_0}{l-l_0}\right|, s = -\nu\varepsilon \tag{1}$$

The relative longitudinal strain (relative extension strain) ε and transverse strain (relative contraction strain) s is defined in Eq. (2).

$$\varepsilon = \frac{\Delta l}{l_0} \times 100\ \% = \left(\frac{l}{l_0} - 1\right) \times 100\ \% \tag{2}$$

Due to anisotropy of the fabric the Poisson's ratio is being changed in the process of extension of the fabric sample.

3 Experimental Part

The experimental study was carried out by measuring extension of cotton (raw) fabrics and coated fabrics samples under the action of tensile force till rupture [5]. Tensile force acts on the samples that are cut at warp and weft direction. The values of the tensile force in relation with relative extension were measured. For the extensions and tensile forces which act in the warp and weft direction, corresponding contraction strains of cotton fabric and coated fabrics were scanned. The Poisson's ratio of coated fabrics was calculated by using the testing results. Three different samples were available. Raw (cotton) fabric (L0) with plain weave was selected. By applying insulation and one layer of preparation on raw fabric [6], a testing sample (L1) is obtained and with insulation and two layers of preparation, a testing sample with label (L2) is prepared. Their structural properties are shown in Tab. 1.

Yarn count was determined by the gravimetric method according to standard ISO 2060:1994. Number of threads per unit length was tested according to the standard ISO 7211-2:1984. Standard ISO 5084:1996 describes a method for the determination of the thickness of fabric. Standard samples with dimensions 300 $\times$ 50 mm were cut and clamped in clamps of the tensile tester at a distance of l_0 = 200 mm and subjected to uniaxial tensile load till rupture. The pulling speed of clamps is 100 mm/min. The samples were cut in weft direction (φ = 0 °) and warp direction (φ = 90 °). Three tests were done on tensile tester for each mentioned cutting direction of the sample. Tensile properties of all samples were tested in accordance with standard ISO ISO13934-1:2008 using the strip method for measuring fabric strength on a tensile strength tester Textechno Statimat M.

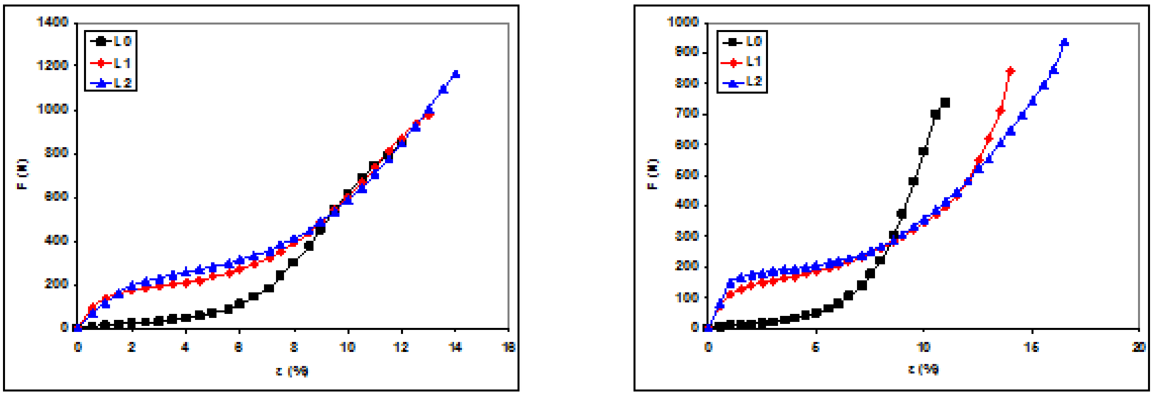
For accurate recording and measurement of spatial deformation of fabric a 1 $\times$ 1 grid pattern was mounted on the tensile tester immediately behind the test specimen; the whole process of drawing the specimen till rupture was recorded by the Panasonic NV-GS500 Digital Video Camera placed on the tripod in front of the device. The horizontal distance between camera and the sample is such that 1 mm on the grid amounted to 10 pixels on the picture. Two sources of white light which mutually close the angle of 90 ° were used for measuring. The number of images N at a certain extension is:

$$N = \frac{\varepsilon l}{100}\frac{60}{v}N_{\mathrm{sl}} \tag{3}$$

The width of each sample was measured in three spots. The transverse strain is obtained after all samples were recorded by camera, and the mentioned grid pattern enables fast and accurate editing of the footage processed by the software package Adobe Premiere.

3.1 Overview of Testing Results

Diagrams (F-ε) of mean values of test results of action of tensile force F and the corresponding longitudinal strain (extension) ε for samples that are cut in weft and warp direction are shown in Fig. 1.



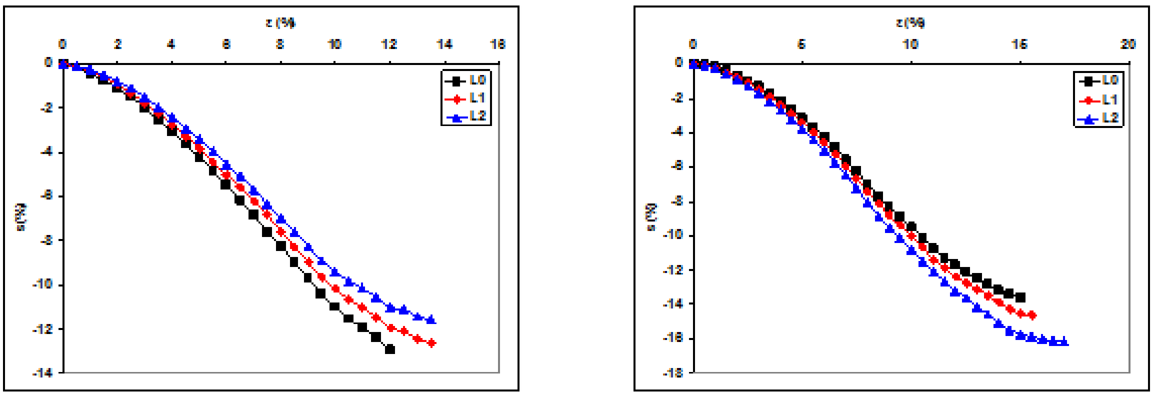
(a) when the force acts in the weft direction (b) when the force acts in the warp direction

Fig. 1: Tensile force-elongation diagram (F-ε) till rupture.

3.2 Determination of Poisson's Ratio

The fabric sample width is b_0 = 500 pixels, which is equivalent to b_0 = 50 mm. Reading the value of the fabric width, after the effect of force, the relative transverse strain is calculated using the Eq. (2). The contraction of fabric in transverse direction, i.e. in the direction which is perpendicular to the direction of stretching occurs. Due to this phenomenon, there is loss of rectangular shape of the sample, i.e. there is contraction of the fabric sample.

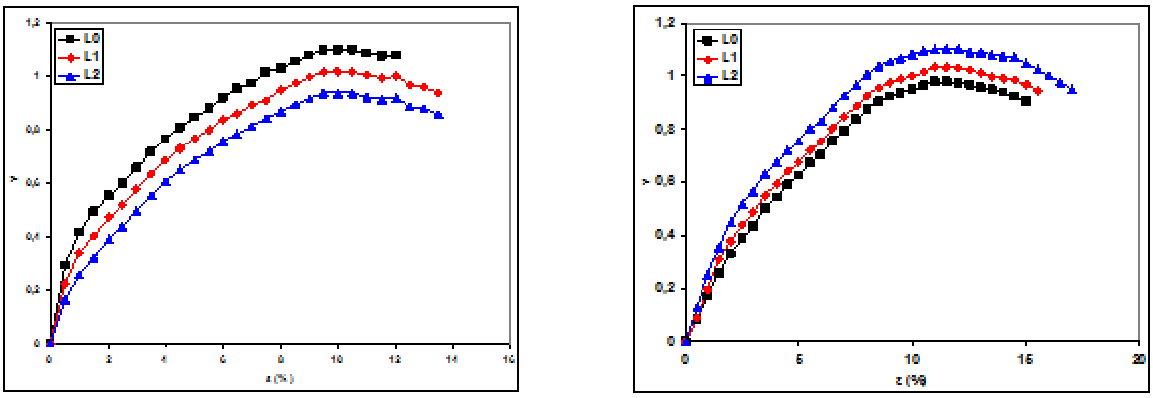
Relation between continuous change of relative contraction s (%) of the sample and its relative extension ε (%) when a force acts on samples that are cut in the weft direction is shown in Fig. 2a by characteristic curve. Fig. 2b shows a characteristic curve of relative contraction of the sample in relation to its relative extension when the force acts on samples that are cut in the warp direction. When a force acts on samples that are cut in the weft and warp direction, at the same of relative extension ε, coated fabric with the highest number of coated layers (L2) has the lowest relative contraction, and raw fabric (L0) has the highest relative contraction s, Fig. 2. From diagrams in Fig. 2 it is evident that fabric contractions are small at the beginning of stretching. After that, with the increase of stretching, the values of fabric contraction also increase.



(a) when the force acts in the weft direction (b) when the force acts in the warp direction

Fig. 2: Diagram of relative contraction of fabric s (%).

According to Eq. (1) and based on the experimental values of relative contraction s and relative extension ε from Fig. 2, the values of Poisson's ratio v are calculated when the force acts on samples that are cut in the weft and warp direction. Fig. 3a shows a curve of the values of the Poisson's ratio v in relation to its relative extension when the force acts on samples that are cut in the weft direction and Fig. 3b shows the values in the warp direction.



(a) when the force acts in the weft direction

(b) when the force acts in the warp direction

Fig. 3: Poisson's ratio v of the fabric.

4 Conclusion

Due to the anisotropy of coated fabrics, Poisson's ratio is not constant, but varies with each fabric extension. Behavior and shape of Poisson's ratio curve of the coated fabric that is subjected to tensile force, mostly depends on its behavior in a direction perpendicular to extension. Poisson's ratio values depend on the number of coatings applied to the raw fabric. The shape of the Poisson's ratio curve for coated fabrics is a result of internal interactions in the coated and raw fabrics. Change in the values of relative contraction of coated fabrics affects on the shape of the Poisson's ratio curve. When the force acts on samples that are cut in the weft direction, Poisson's ratio assumes maximum value at relative extension of coated fabrics between 9 and 10 %. When the force acts on samples that are cut in the warp direction, Poisson's ratio assumes maximum value at relative extension of coated fabrics around 15 %. In weft direction, the values of Poisson's ratio of coated fabrics decrease with increasing the number of coated layers at the same relative extension. In warp direction, the values of Poisson's ratio of coated fabrics increase with increasing the number of coated layers at the same relative extension.

References

[1] R. J. Bassett et al., Experiment Methods for Measuring Fabric Mechanical Properties: a Review and Analysis, Textile Research Journal, 69 (1999) 11, 866–875.

[2] J. Zheng, Measuring Technology of the Anisotropic Tensile Properties of Woven Fabrics, Textile Research Journal, 78 (2008) 12, 1116–1123.

[3] D. W. Lloyd, et al., An Examination of a "Wide jaw" Test for the Determination of Fabric Poisson Ratio, Journal of the Textile Institute, 68 (1977) 9, 299–302.

[4] H. Sun, On the Poisson's ratios of a woven fabric, Composite Structures 68 (2005) 4, 505-510.

[5] Ž. Penava, D. Šimić Penava, M. Nakić, Investigation of warp and weft take-up influence on Poisson's ratio of woven fabric, Tekstil 63 (2014) 7-8, 217-227.

[6] W. H. Russell, G. A. Berger, The behaviour of canvas as a structural support for painting in Science and Technology in the Service of Conservation, IIC, London, 1982. 139-145.