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Analysis of the Mechanical Properties of Woven Fabrics from Glass and Basalt Yarns

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Abstract

Among many other materials for the reinforcement of composites, technical fabrics are increasingly being used for the same purpose, especially from glass and basalt tows, which have good mechanical properties. During tensile stress these fabrics are elongated in the direction of tensile force, and at the same time they contract crosswise in relation to the action of the tensile force. In this paper the tensile properties of woven fabrics made from glass and basalt yarns were investigated. Measurements were focused on the lateral contraction, according to which Poisson's ratio can be calculated. For these purposes, an innovative device as an upgrade of the strength tester and samples of fabrics of non-standard shapes (cross and square) were used. Mechanical properties of the yarns from which the fabrics were made were analysed before and after weaving in order to define the impact of weaving on them.

Key words: glass fabrics, basalt fabrics, physical mechanical properties, Poisson's ratio, lateral preload, lateral contraction.

Introduction

In textile industry application, glass fibres are commonly used due to their nonflammability, strength, abrasion resistance, cost effective processing and reasonable price. With the recent development of inorganic fibres, particularly in the late 80s, a greater amount of filament basalt fibres were manufactured. Fabrics woven from glass and basalt filaments belong to the group of technical fabrics and are flat materials with specific properties that those of yarns spun from natural fibres can not compete with. Qualitative features of these fabrics are based on their good mechanical properties and durability. They are often used in different forms and for different applications, but as a one-layer product such fabrics do not always have satisfactory properties. Therefore their use is mostly as part of a composite. However, due to the surface smoothness of multifilament threads there is a risk of the displacement of interlacing points or yarn slippage. The displacement of warp and weft threads in the fabric is more distinctive in places of thread floats; this is the reason why a plain weave is the most appropriate. This disadvantage can be partly solved by adding warp threads interlacing in a leno weave. In this way interlacing points are reinforced and thus stabilise the fabric. This method of weaving requires two and sometimes even three warp beams from which the warp is simultaneously unwound. Fabric design with predetermined properties requires detailed work and experiments, particularly in the case of fabrics that are in a relaxed state, they are unstable at inter-

lacing points, as fabrics made from glass and basalt filaments are. These fabrics are orthogonally anisotropic, i.e. orthotropic, and their properties are largely dependent on the direction in which they are stressed.

Among the end-use properties of glass and basalt fabrics, one should note generally high strength along with a relatively low density, high thermal resistance and nonflammability, good insulative characteristics, resistance to microorganisms, as well as good chemical resistance to oils, fats and organic solvents, acids and alkalis in the pH-range from 3 to 9. Major disadvantages are sensitivity to strong alkalis, surface corrosion, fragility and relatively hard processability [1 - 7].

Multifilament yarns are used for the production of basalt and glass fabrics, where filaments are glued together (roving yarn) into tape shapes (tows) to ensure compactness and improved properties (strength, evenness). This kind of yarn is inserted in the warp and weft directions in order to obtain a fabric of uniform appearance. Yarns made from glass and basalt fibres have very low elasticity and their deformation in weaving during the shed formation and beat-up action is unavoidable. It is therefore essential to control warp tension in the weaving cycle, i.e. it is desirable that warp tension is kept to a minimum so that shed cleanliness can be maintained. This is the reason why the weaving process of these fabrics is carried out by direct unwinding of warp threads from the bobbins on the creel next to the loom. The weft is also unwound from crosswound

bobbins, while it is necessary to establish a strict control of unwinding and tension maintenance during weft insertion into the shed. With regard to raw materials and yarn appearance (smooth, tape shape, low values of fineness, and low density), weft insertion is usually done using rigid rapiers/ elastic tapes or air jet insertion [8, 9].

This paper deals with the mechanical properties (tensile force, elongation at break, lateral contraction, Poisson's ratio) of glass and basalt fabrics of different constructions in order to prepare guidelines for the fabric constructor when designing a new fabric construction for a composite reinforcement. For these purposes a device for measuring lateral contraction as an upgrade of the strength tester and fabric samples of nonstandard shapes were developed.

The advantage of this innovative device is that it can be easily mounted on any kind of strength tester. During the test, the device is not fixed but hung and balanced in a horizontal position. The innovation of this kind of testing is that the lateral shrinkage of the sample during a tensile test to break in the longitudinal direction can be measured. Thus it is possible to investigate the interdependence of the breaking force and elongation in the longitudinal direction and the force in the lateral direction of the sample. Measurement of lateral displacements is possible throughout the sample by shifting the side clamps, which has not been possible with known devices. The sample can be square-shaped, wherein all

the threads in a square participate in testing, or cross-shaped, where only parts of the sample that are fixed in the clamps participate in testing. Forces occurring in the lateral direction of the textile material when it is subjected to tensile stress is a parameter that has not yet been measured before. With modification of the mechanical model of the woven fabric, it can improve simulation of the behaviour of woven fabric subjected to tensile stress.

Fabric deformation under a load and definition of Poisson's ratio

The macroscopic material characteristic "Poisson's ratio" is only applicable to macroscopically homogeneous solid materials, while a woven fabric is a complex hierarchical structure and not a solid material. In the fabric construction there are individual fibres which have their own Poisson's ratio, there also are longitudinally loaded fibre bundles/yarns which might be homogenised and characterized with their own Poisson's ratio; there are transverse (not loaded directly) fibre bundles/yarns which are compressed in their longitudinal direction (the contraction is determined by their Young's modulus) by secondary forces induced from the longitudinally-stretched bundles/yarns; there is the crimp of warp and weft fibres, and there is certain friction between warp and weft fibres within their interlacing regions. All of the factors above make their contribution to the characteristic which is defined as "Poisson's ratio", which "expresses the ratio of lateral contraction in relation to longitudinal fabric elongation". This is why, in the case of textile materials, the Poisson ratio is not easy to define, just like for solid materials. It is more complex and impossible to be described in all the details mentioned above, thus it has to be considered in that context.

Many researchers have dealt with the elastic constants of woven fabrics. Kilby was the first who noted the relationship of the Poisson ratio with the shear and elastic modulus of woven fabric. He developed a simple geometrical model of woven fabric and used it to study the stress-strain relationship. Hearle noted the nonlinearity of Poisson's ratio, and De Jong tried to calculate it mathematically. The first mechanical model for calculation of the initial Young's modulus and Poisson's ratio of woven fabrics was established by Leaf, while Nhan and Collier developed computer simulations of

fabric drape for which it was necessary to have knowledge of the elastic constants of the material. Sun, Bao and Shahab worked on theoretical calculations of the Poisson ratio of fabric through the structural and qualitative parameters of yarn in the warp and weft [10 - 17].

The balance disorder of forces in the warp and weft at the interlacing point occurs due to the application of forces in one or more directions. **Figure 1** shows the influence of the forces when stretching the

warp to transverse forces and contraction of the weft in the case of a plain weave based on the Kawabata model [18 - 20].

For better resolution, the image is divided into three parts.

According to **Figure 1**, the following relations can be established:

$$F_1 = F_{T1} \cdot \sin \alpha_1 \quad (1)$$

$$F_2 = F_{T2} \cdot \sin \alpha_2 \quad (2)$$

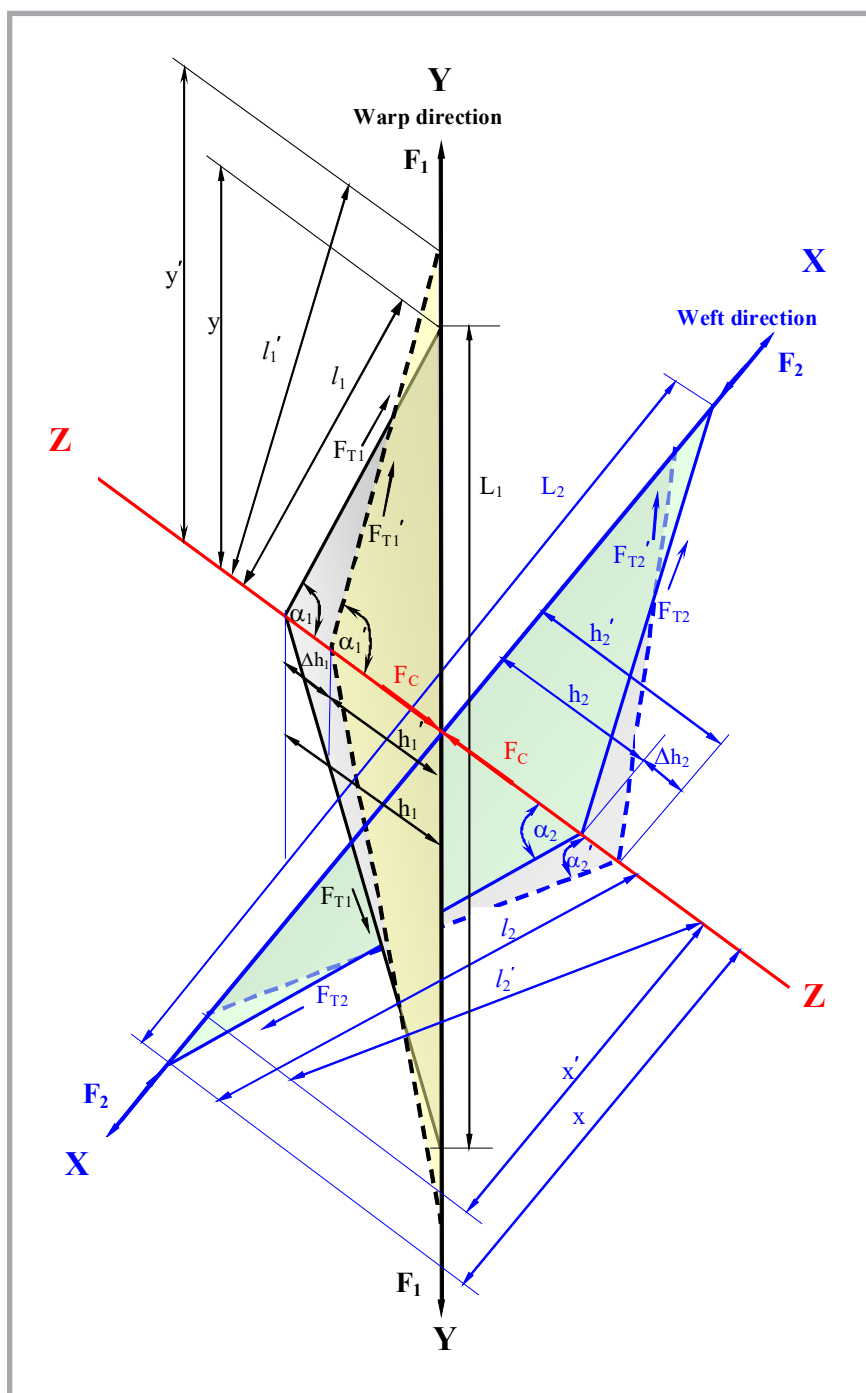


Figure 1. Geometry of the interlacing point of the plain weave in an equilibrium state and state of stress; dashed lines - position of threads under stress.

$$F_c = 2F_{T1} \cdot \cos \alpha_1 = 2F_{T2} \cdot \cos \alpha_2 \quad (3)$$

$$\cos \alpha_1 = \frac{2h_1}{\sqrt{h_1^2 + L_1^2}}; \quad (4)$$

$$\cos \alpha_2 = \frac{2h_2}{\sqrt{h_2^2 + L_2^2}}$$

$$\sin \alpha_1 = \frac{y}{l_1} \Rightarrow l_1 = \frac{y}{\sin \alpha_1} \quad (5)$$

$$\sin \alpha_2 = \frac{x}{l_2} \Rightarrow l_2 = \frac{x}{\sin \alpha_2} \quad (6)$$

$$h_1 = l_1 \cos \alpha_1; \quad h_2 = l_2 \cos \alpha_2 \quad (7)$$

$$\Delta h_1 = h_1 - h_1' \Rightarrow \Delta h_2 = h_2 - h_2' \quad (8)$$

Elongation of woven fabric in the warp/weft direction:

$$\varepsilon_y = \frac{y' - y}{y} \cdot 100 \text{ in \%}; \quad (9)$$

$$\cos \alpha_2 = \frac{2h_2}{\sqrt{h_2^2 + L_2^2}}$$

Elongation of warp and weft yarn:

$$\varepsilon_y' = \frac{l_1 - l_1'}{l_1'} \cdot 100 \text{ in \%}; \quad (10)$$

$$\varepsilon_x' = \frac{l_2 - l_2'}{l_2'} \cdot 100 \text{ in \%};$$

Thickness and longitudinal displacement relation:

$$\frac{\Delta h}{y - y'} = g \frac{\alpha_1 + \alpha_1'}{2} \quad (12)$$

Poisson's ratio:

$$\nu = -\frac{\varepsilon_y}{\varepsilon_x} \quad (13)$$

where, F_1 the force acting in the longitudinal direction, F_2 – the force acting in the transversal direction, F_c – the compressive force acting in the direction of the Z-axis at the contact point between the warp and weft, F_{T1} – the warp thread tension in an equilibrium state, F_{T2} – weft thread tension in an equilibrium state, α_1 – the angle between the warp thread direction and Z-axis, α_2 – the angle between the weft thread direction and Z-axis, l_1 – the half length of the unstretched warp thread at the crossing point, l_2 – the length of the unstretched weft thread at the crossing point with the warp thread to the X-axis, ν – Poisson's ratio, ε_x – displacement of the uncontracted weft thread along the X-axis,

Table 1. Construction parameters of the fabrics tested; l numbers refer to the nominal value of fabric mass, G – glass, B – basalt, P – plain, T – twill.

Sample designation ¹	Raw material	Linear density, tex	Weave	Fabric density, ends/cm = picks/cm	Surface mass, g/m ²
GP 600	Glass filament	1200	plain	2,5	600
GT 600			twill 2/2		
GP 300		600	plain	5,0	300
BP 300	Basalt filament	300	twill 2/2		
BT 300					

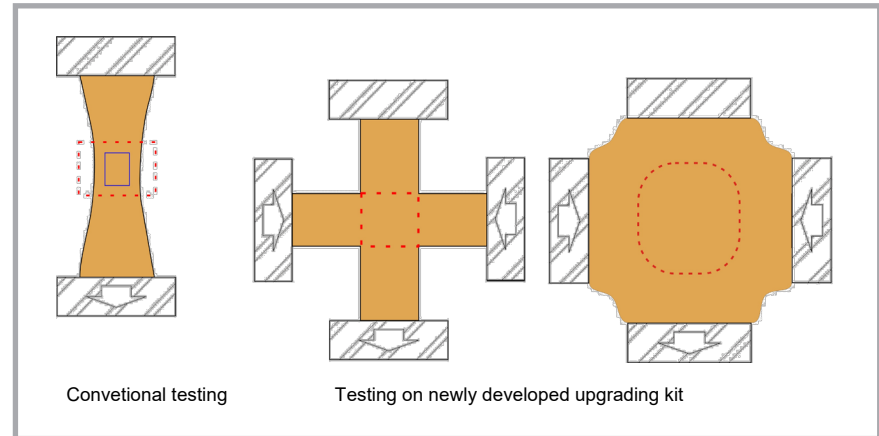


Figure 2. Poisson ratio of woven fabric (macro scale): method comparison.

ε_y – displacement of the unstretched warp thread along the Y-axis, ε_x' – displacement of the contracted weft thread along the X-axis, ε_y' – displacement of the stretched warp thread along the Y-axis, h_1 – distance of the non-deformed warp thread from the X-axis (at the crossing point with the weft thread = maximum distance), h_2 – distance of the non-deformed weft thread from the Y-axis (at the crossing point with the warp thread = maximum distance), h_1' – distance of the deformed warp thread from the X-axis (at the crossing point with the weft thread = maximum distance), h_2' – distance of the deformed weft thread from the Y-axis (at the crossing point with the warp thread = maximum distance), l_1 – half the length of the non-deformed warp thread at the interlacing point, l_2 – half the length of the non-deformed weft thread at the interlacing point, l_1' – half the length of the deformed warp thread at the interlacing point, l_2' – half the length of the deformed weft thread at the interlacing point, x – distance of the end of the non-deformed weft thread from the origin (along X-axis), x' – distance of the end of the deformed weft thread from the origin (along Y-axis), Δh_1 – deviation of the warp thread from the contact point

between the warp and weft along the Z-axis which occurred during deformation, Δh_2 – deviation of the weft thread from the contact point between the warp and weft along the Z-axis which occurred during deformation.

Material and methods

For analysis of the mechanical properties of technical reinforcing fabrics, five fabrics of different construction parameters were selected from the manufacturing program of the producer (Table 1). Constructional parameters of the fabrics

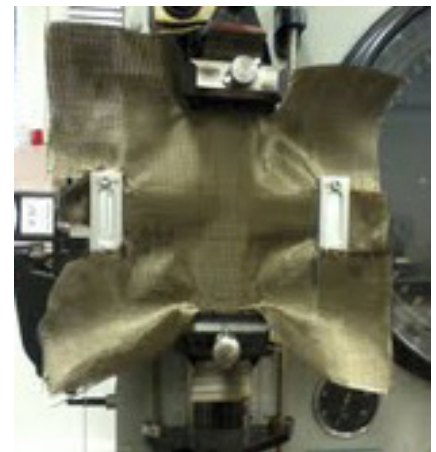


Figure 3. Measurement of tensile force and elongation at break on the tensile strength tester as well as of the lateral contraction of basalt fabric with the new upgrade kit.

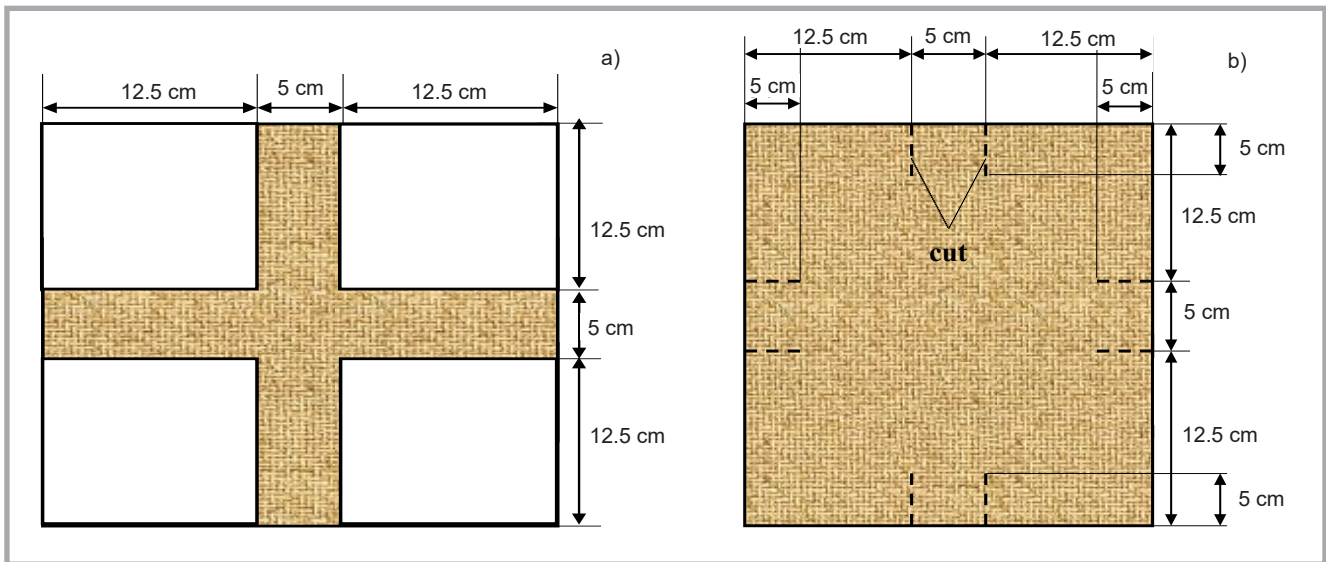


Figure 4. Appearance of test specimens: a) non-standard cross-shaped specimen suitable for testing lateral contraction, b) non-standard square-shaped specimen with the rest of the fabric suitable for testing lateral contraction.

were tested according to the following standards: ISO 2060 (linear density), ISO 7211-2 (fabric density), ISO 3801 (surface mass) and ISO 5084 (fabric thickness).

The tensile force and elongation at break of standard fabric samples were tested according to the standard EN ISO 13934-1 using a tensile strength tester made by Aparecchi Branca S.A (Italy). The measuring conditions were as follows: the preload on the tensile strength tester and upgrade kit 5 N, speed of the clamps 100 mm/min, distance between the clamps of the tensile strength tester 200 mm and temperature 25 ± 2 °C, Rh $65 \pm 5\%$.

In order to test lateral contraction in the case of the fabric tensile load, the tensile strength tester made by Aparecchi Branca SA with new upgrade kit and non-standard shapes of fabric samples (**Figures 2 - 4**, see page 85) were used. Measurement conditions were the same as for the tensile forces of standard fabric samples. The upgrade kit consists of one fixed and one movable clamp, a scale for reading out forces and a thread for preload adjustment. The lateral force is tested in such a way that the left and right side of the non-standard sample (cross-shaped or square-shaped) is fixed in the clamps of the upgrade kit under a certain preload. A cut in a part of a 5 cm wide square-shaped sample is fixed in the clamps of the tensile strength tester. During vertical elongation of the sample on the tensile strength tester, the clamps of the upgrade kit approach each other in order to contract the sample laterally. Upon completion of the tests or after breaking the sample, the maximum lat-

eral contraction to the breaking point is read out. Preliminary tests of various fabric samples showed that so-called cross-shaped and square-shaped samples are the most appropriate for testing lateral contraction. On the square-shaped sample incisions were made so that it could be fixed into the clamps, while cross-shaped samples of 50 mm width were formed with additional thread counting.

Disadvantages of current methods (camera recording):

The sample is marked before setting the preload.

Measurement accuracy is questionable because of the small distance between the mark and „free end“ of the sample.

The sample can be stretched only to a certain percentage because when it comes to sample deformation, analysis of displacements becomes impossible.

Benefits of displacement testing on the upgrade kit:

Clamps of the instrument are sufficiently distant from the marked part of the sample so that they can not have an effect on the results.

Periodic boundary conditions are taken into consideration.

It is possible to set a preload on the sample in the horizontal direction.

Mechanical properties of the yarns (tensile force, elongation at break, tensile strength) were tested on a Statimat M

tensile strength tester (Germany) according to Standard ISO 3341 and under the following conditions: distance between the clamps- 500 mm, testing speed- 500 mm/min, preload: -0.5 cN/tex.

In order to establish the linear relationship between the data of different properties within the different groups of samples described in the discussion above, the Pearson product-moment correlation coefficient, often simply called a correlation coefficient, was calculated.

In order to prove whether a single structural fabric parameter has a statistically significant impact on the individual mechanical properties of fabrics, the analysis of variance using the statistical program IBM SPSS Statistics (Version 21) was used. If the significance is less or equal to the value of 0.05, the differences between groups of data are significant, and in this case the null hypothesis (differences between groups are not significant) is discarded, or the impact of an individual constructional parameter is essential.

Test results

Test results of linear density, fabric density, surface mass and thickness of technical fabrics tested are shown in **Table 2**. **Table 3** shows the results of mechanical properties of test fabric samples of standard, cross and square shape. **Table 4** shows the results of analysis of variance

for the tensile force of standard fabric samples.

In order to gain insight into the interconnectedness of data of the vertical tensile force obtained for various shapes of samples in different directions of threads and for samples of various raw material compositions, the correlation coefficients were calculated for the following groups:

- samples of the same raw material composition but differ in the surface mass and weave,
- samples of different raw material compositions (made from glass and basalt yarns) but equal in other constructional parameters,
- in different directions (in the warp and weft directions) of samples of glass fibres,
- samples from the same groups but of different shapes (cross-shaped and square-shaped).

The results of correlation coefficients between the different raw material compositions and sample shapes are presented in **Table 5**.

Discussion

Tensile force and elongation at break of standard fabric samples

Fabric samples of equal linear density and fabric density in the warp and weft directions were used for analysis of the mechanical properties of technical fabrics. Five fabric samples in two different weaves were made of glass and basalt yarns. At the same time, appropriate pairs of samples to compare are GP 600 - GT 600, BP 300 - BT 300 and, partially, samples GP 300 - BP 300, which have different linear density, fabric density and raw material, but they are similar in the surface mass per unit area and thickness (**Tables 2, 3**). The fabric samples were identified according to the mass per unit area, because this fabric constructional parameter is essential for the use of these fabrics as a composite reinforcement.

Table 2. Results of actual fabric construction parameters; T_t – yarn fineness (tex), D – fabric density (threads/cm), T – fabric thickness (mm), M – fabric mass (g/m²), \bar{X} – mean value, CV – variation coefficient (%).

Sample	T_t , tex	D, threads/cm		T, mm	M, g/m ² actual/nominal
		Warp	Weft		
GP 600	\bar{X}	1240	2.5	2.5	0.54
	CV, %	7.7	8.1	7.8	2.30
GT 600	\bar{X}	1240	2.5	2.5	0.52
	CV, %	6.7	8.1	5.7	4.40
GP 300	\bar{X}	611	2.6	2.6	0.29
	CV, %	9.4	9.8	10.7	3.44
BP 300	\bar{X}	304	5.0	5.0	0.21
	CV, %	6.6	4.7	6.8	2.11
BT 300	\bar{X}	304	5.0	5.0	0.22
	CV, %	6.7	4.2	7.4	2.27

Table 3. Tensile forces and elongation at break of standard fabric samples; \bar{X} – mean value, CV – variation coefficient, F – tensile force, ϵ – elongation at break

Sample designation	In warp direction		In weft direction		
	F (N)	ϵ (%)	F (N)	ϵ (%)	
GP 600	\bar{X}	1680.1	9.5	1819.8	6.0
	CV, %	9.46	6.7	7.6	7.4
GT 600	\bar{X}	1736.5	5.65	1411	5.5
	CV, %	15.1	5.9	16.4	4.6
GP 300	\bar{X}	945	8.75	895	7.0
	CV, %	10.8	6.8	11.2	5.6
BP 300	\bar{X}	885	6.25	920	6.83
	CV, %	5.59	3.9	7.8	5.8
BT 300	\bar{X}	900	6.25	927.5	6.75
	CV, %	5.71	4.3	1.6	3.3

Table 4. Results of variance analysis of the tensile force of standard samples.

Factor	Type of weave	Mass per unit area	Yarn fineness	Fabric density	Direction of testing
Significance	0.024	0.001	0.001	0.041	0.9

Variance analysis showed that the surface mass per unit area, type of weave, linear density and fabric density have a significant influence on the tensile force (**Table 4**), hence the following could be concluded:

Influence of surface mass: Samples with greater mass have a higher tensile force. When designing a new technical fabric, greater surface mass can be achieved: a) using a coarser yarn with the same fabric density because such a yarn withstands higher loads; b) with increasing fabric density, as in this case a higher number of threads participate in the load

and each thread contributes to increasing the value of the tensile force;

Influence of weave: Most of comparable fabric samples (with the exception of sample GP / GT 600 in the weft direction) have a higher tensile force in the twill weave than in the plain weave. This means that several thread passages (or fewer thread floatations) reduce the fabric tensile force, which is contrary to theory. Namely, if the warp threads are loaded, then the weft inhibits warp deformation because of the coefficient of friction between the two threads, which means that a higher force for the deformation and breakage of warp threads is necessary. Obviously in

Table 5. Correlation coefficients between lateral and tensile forces.

Sample	Cross-shaped samples			Square-shaped samples			Cross-shaped and square-shaped samples	
	In warp direction	In weft direction	In both directions	In warp direction	In weft direction	In both directions	In warp direction	In weft direction
Glass fabrics	0.9742	0.9792	0.9678	0.8840	0.8991	0.8860	0.9085	0.9201
Basalt fabrics	-	-	-	-	-	-	0.8364	0.8560
Glass and basalt fabrics	0.8298	0.8753	-	0.7191	0.8860	-	-	-

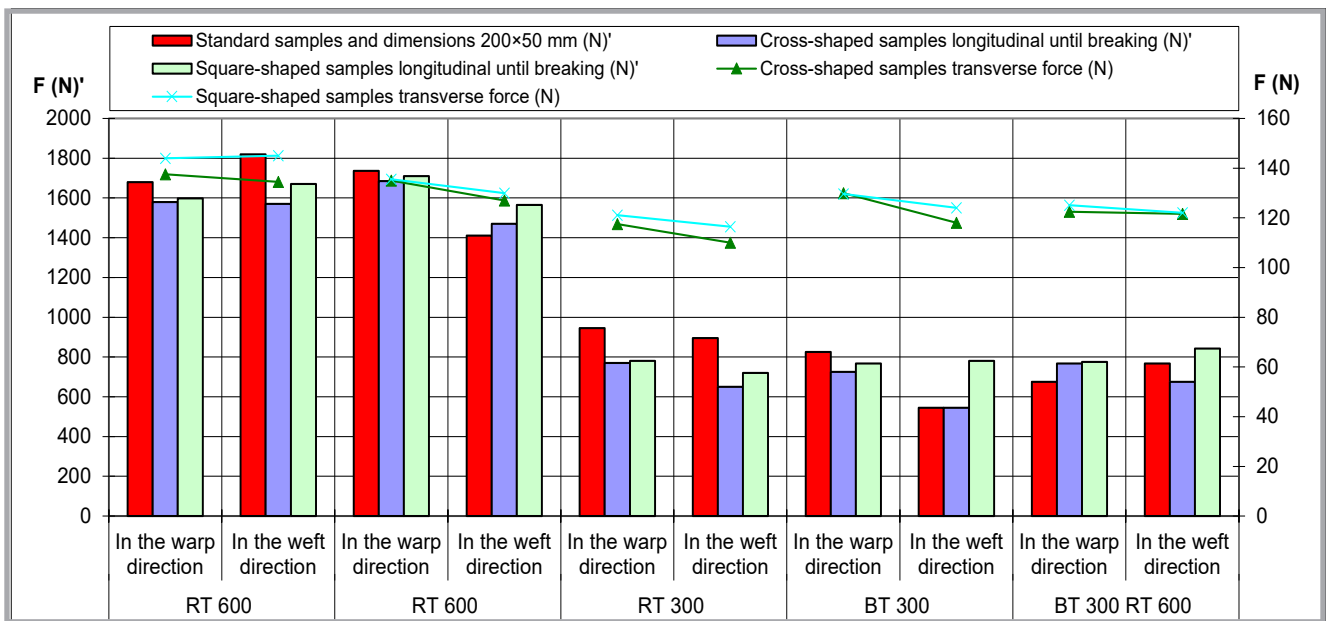


Figure 5. Longitudinal and lateral forces at the moment of breaking of all fabric samples tested; $F(N)'$ – longitudinal force at the moment of breaking, $F(N)$ – lateral force at the moment of breaking.

the case of very stiff threads, yarn weakening occurs at the passage points, and consequently these fabrics have a lower tensile force. The reason for this is perhaps that not only warp threads but also the plain fabrics underwent greater destruction in weaving compared to twill fabrics. In the case of sample GP/GT 600 – weft direction, the plain fabric has a higher tensile force in comparison with twill fabric. The sample mentioned has the highest coefficient of variation (16.39%) in comparison with the other samples, which may be correlated with the results;

Influence of linear density and fabric density:

If glass fabric samples GP 600 are compared with GP 300 of the same fabric density (2.5 threads/cm) and different linear density (1200 or 600 tex), it can be concluded that the fabrics with a higher value of linear density withstand greater loads. Results of the tensile force of sample GP 300 with a higher value of linear density and lower fabric density and BP 300 (having a lower linear density and a higher fabric density) show quite a comparable level of the tensile force (945 N and 885 N, respectively), indicating that higher fabric density significantly contributes to increasing the value of the fabric tensile force. It should be noted that in this case the raw material also exerts its effect, and the basalt filaments have a higher tensile force (4.84 GPa) than glass filaments (3.45 GPa).

Variance analysis also indicated that the direction of the tensile force does not

exert any influence on the fabric tensile force, which is logical because the fabrics had the same linear density and fabric density in both directions. In fact, it turned out that fabric samples sometimes have a higher tensile force in the warp direction and sometimes in the weft direction. Despite a higher tensile force of weft threads after weaving in comparison to the warp threads, some fabric samples had a higher tensile force in the warp direction (samples: GT 600 and 300 GP).

Tensile force of nonstandard fabric samples

As the purpose of this study is the comparison of Poisson's ratio of fabric samples and, in this context, the need for measuring lateral contraction, two shapes of non-standard fabric samples for testing were developed: cross-shaped and square-shaped. In addition, the impact of the shape of the non-standard sample on the value of the tensile force was determined (Figure 5).

In most of the samples (with the exception of samples GT 600 - weft, BP 300 - weft, BT 300 - warp) the tensile forces of the fabric tested for cross-shaped and square-shaped samples were slightly lower than those of the samples tested under standard conditions. It can also be established that the tensile forces of the square-shaped samples are greater than those of the cross-shaped samples. Variance analysis showed that the shape of the fabric sample (standard, cross-shaped,

square-shaped) has no statistically significant effect on the tensile force of the fabric (significance was 0.735). There were also no statistically significant effects among cross-shaped or square-shaped fabric samples (significance = 0.765). It can be concluded that non-standard forms of fabrics are suitable for measurements of fabric tensile properties.

Lateral contraction of nonstandard fabric samples

It can be claimed that the lateral forces of square-shaped samples were slightly higher than those of cross-shaped samples, but the difference was not statistically significant (significance was 0.358).

Observing lateral tensile forces (Figure 5), it can be ascertained that higher longitudinal tensile forces mostly affected higher lateral tensile forces, with the exception of sample GP 600. The lateral tensile forces are, on average, 8.5 times lower than the longitudinal tensile forces. Table 5 shows the correlation coefficients between longitudinal tensile and lateral forces of the fabrics. Correlation coefficients were calculated in order to obtain insight into the correlation between longitudinal tensile and lateral forces for the same sample. The correlation coefficients of only basalt samples cannot be calculated due to a small number of samples. The correlative values obtained are relatively high, ranging from $R = 0.7191$ (in the case of the correlation of lateral tensile forces and longitudinal tensile forces of square-shaped samples in

the warp direction of the glass and basalt fabric) to $R = 0.9792$ (in the case of the correlation of lateral tensile and longitudinal lateral forces of cross-shaped samples in the warp direction of the glass fabric). The correlations are medium high and high. In the case of cross-shaped samples slightly higher correlation coefficients than in the case of square-shaped samples were obtained.

Lateral fabric contraction was higher in the fabric tested in the warp direction, ranging from 0.95% to 1.9%, while it ranged from 0.88% to 1.14% in the weft direction. The results of variance analysis showed that there were no statistically significant differences between the contraction of the square-shaped and cross-shaped fabric samples (significance - 0.189).

Poisson's ratio of non-standard fabric samples

Based on the measurements of elongation at break and lateral contraction, Poisson's ratio, which expresses the ratio of lateral contraction in relation to longitudinal fabric elongation, was (ν , Equation 13). According to the results obtained, a comparison with respect to the shape of the samples (Figure 6) was carried out, and it was found out that there was no significant effect (significance was 0.446). The average value of Poisson's ratio was 0.122 for cross-shaped samples, and 0.113 for square-shaped ones. As viscoelastic materials, these fabrics have a low Poisson's ratio, and hence these materials deform longitudinally ten times more than transversely.

Basalt fabrics have a higher Poisson's ratio in relation to glass fabrics, and the difference between them was statistically significant (correlation coefficient - 0.001). It can also be concluded that fabric samples of greater mass (RT 600 in plain weave and RT 600 in twill weave) had a lower Poisson ratio than other samples in both testing directions and both sample shapes. The impact of surface mass was statistically significant (significance - 0.0). Variance analysis also shows that the type of weave has no statistically significant impact (significance - 0.580).

In the warp and weft directions, the samples in a plain weave have a higher coefficient on square-shaped samples (plain weave: 0.100 and 0.112, twill weave:

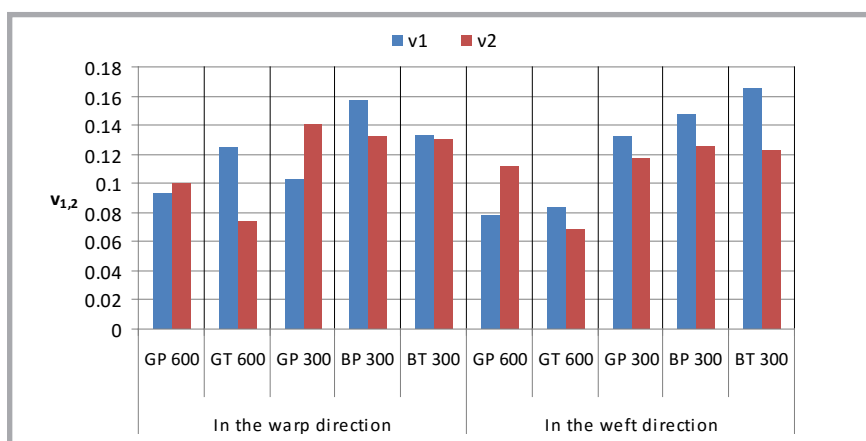


Figure 6. Poisson's ratio of fabric samples tested in the warp and weft directions; ν_1 – Poisson's ratio of the cross-shaped sample, ν_2 – Poisson's ratio of the square-shaped sample.

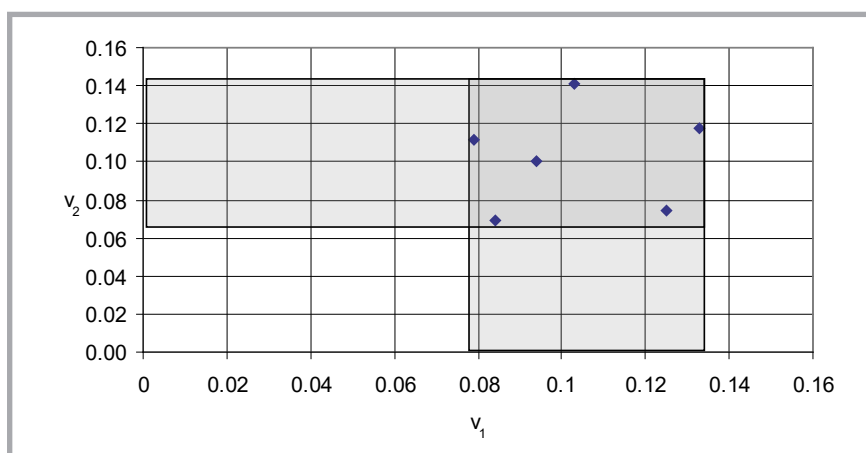


Figure 7. Poisson's ratio for glass fibre fabrics – scatter of values for cross-shaped and square-shaped samples.

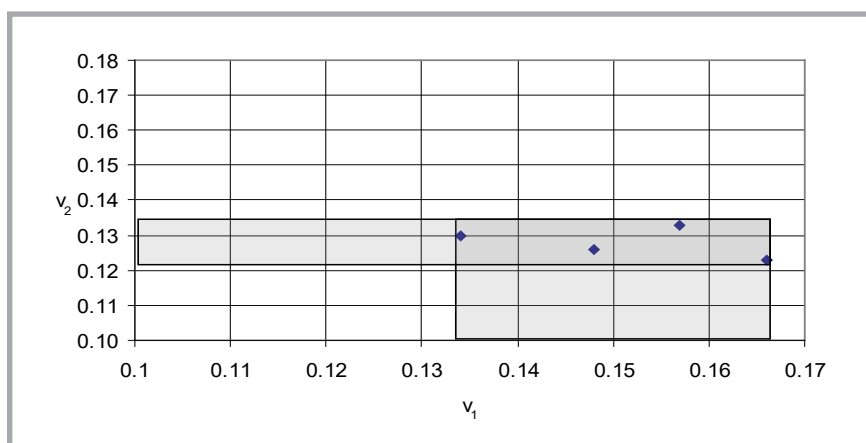


Figure 8. Poisson's ratio for basalt fibre fabrics – scatter of values for cross-shaped and square-shaped samples.

0.074 and 0.069), and a twill weave has a higher coefficient on cross-shaped samples (plain weave: 0.094 and 0.079, twill weave: 0.125 and 0.074).

In order to find out the accuracy of determining the Poisson's ratio using this method, the scatter of values of Poisson's

ratio in two, non-standard sample shapes to be tested was calculated. The scatter of values of the Poisson's ratio of glass fabrics in cross-shaped samples was 0.079 to 0.133 (difference: 0.133 to 0.079 = 0.054), while in square-shaped samples it was 0.069 to 0.141 (difference: 0.141 to 0.069 = 0.072) (Figures 7 and 8). Ac-

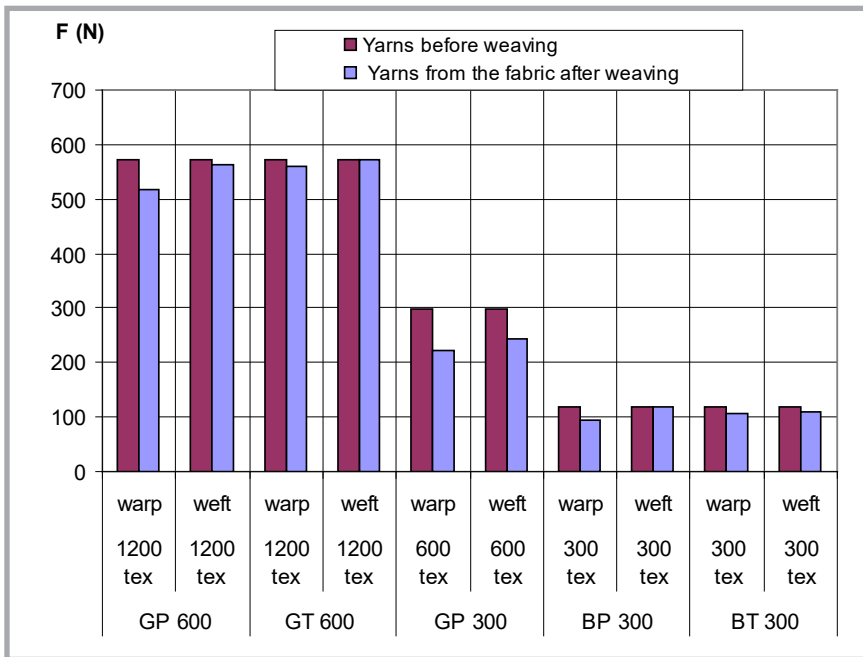


Figure 9. Tensile forces of warp and weft yarn before and after weaving.

According to the results obtained and the differences, it can be ascertained that the square-shaped samples of basalt fabrics have lower scattering values of Poisson's ratio.

Influence of weaving on yarn mechanical properties

A glass multifilament yarn with a fineness of 1200 and 600 tex and a basalt multifilament yarn with a fineness of 300 tex were used for weaving technical fabrics. Measurement results of the tensile force before weaving (Figure 9) show that a coarser thread has higher values of the tensile force, meaning that it can withstand higher loads.

In the weaving process for almost all fabric samples (with the exception of sample BP 300 in the weft direction), yarn tensile forces (Figure 9) decreased, meaning that yarns at the points of passing from one to the other side of the fabric lost their strength, but this was not statistically significant (significance was 0.9). The highest drop in the value of tensile forces of the warp threads (25.1%) and of the weft threads (18.3%) was recorded for the glass fabric (GP 300), with a linear density of 600 tex, and the lowest drop for warp (2.3%) and weft (0.31%) threads in sample GT 600. The plain weave samples of glass and basalt fabrics had the greatest reduction in tensile forces in comparison with the twill fabric samples. The reason for this is that each warp thread interlaces with each weft thread in the case of a plain weave

(meaning that this weave has the greatest number of thread passages from one side of the fabric to the other), while in a twill weave (K2/2) each warp thread interlaces with every other weft thread (the weave has more floats). Sample BP 300 was the only one to have a higher tensile force of yarn after weaving than before. This occurrence can be explained by the greater deviation of the coefficient of variation of yarn tensile forces.

It should be noted that the difference in the reduction of tensile forces in the warp was noticeably higher in all samples compared to the weft, despite the fact that the fabrics had the same linear density and density of warp and weft threads, which indicates that the warp threads were affected by slightly higher tensions in the weaving process.

The results of tensile forces of yarn before and after weaving confirmed the basic characteristics of these materials, i.e. their rigidity causes sensitivity problems in weaving. Observing the elongation at break of glass and basalt yarns, it may be noted that the glass yarns had a higher elongation at break than basalt yarns before and after weaving. Analysing the value of the elongation at break of yarns before and after weaving, it can be noted that these yarns practically had very low crimp. Namely, due to their stiffness they lie almost straight in the fabric, thus the elongation at break after weaving was almost indistinguishable from the elongation before weaving (Ta-

ble 3). Analyses of variance confirmed that there was no statistical significant effect of the weaving on yarn tensile forces (significance - 0.571).

Conclusion

This paper analyses mechanical properties (tensile force, elongation at break, lateral forces, lateral contraction, Poisson's ratio) of glass and basalt fabrics in order to prepare guidelines for a woven fabric constructor when developing new fabric constructions for reinforcing composites using a newly developed device for measuring lateral forces and contraction as an upgrade kit for a fabric strength tester and fabric samples of non-standard shapes. In the phase of a new product development it is essential that fabrics woven from yarns with high values of flexural rigidity for composite reinforcement have high tensile force, low elongation at break and high Poisson's ratio. Based on the analysis of mechanical properties of the basalt and glass fabrics tested, it can be concluded that:

- the newly defined shapes of fabric samples for measurement of tensile and lateral forces are comparable with those of the tensile force of fabric samples of standard shapes;
- a higher value of Poisson's ratio can be achieved using a lower surface mass and basalt yarns instead of glass yarns; the difference between plain and twill weave 2/2 is not statistically significant;
- the difference in the reduction of tensile forces in the warp was noticeably higher in all samples compared to the weft, despite the fact that the fabrics had the same linear density and density of warp and weft threads, which indicates that the warp threads were affected by slightly higher tensions in the weaving process. In this respect, special attention must be paid to the control of yarn tension during weaving;
- the weaving process has a very small impact on the elongation at break of glass and basalt multifilament yarns that have negligible values of crimp because of their stiffness.

The test results of glass and basalt fabric obtained by testing on the strength tester with simultaneous measurement of the lateral contraction to break for standard and non-standard samples provide broader insights into the behaviour of flat materials in the application.

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References

1. Artemenko SE. Polymer composite materials made from carbon, basalt, and glass fibres. Structure and properties. *Fibre Chemistry* 2003; 35(3): 226-229.
2. Artemenko SE, Kadykova Yu A. Polymer composite materials based on carbon, basalt, and glass fibres. *Fibre Chemistry* 2008; 40(1): 37-39.
3. Singha KA. Short Review on Basalt Fibre. *International Journal of Textile Science* 2012; 1(4): 19-28.
4. Cerny M, Glogar P, Golias V, Hruska J, Jakes P, Sucharda Z, Vavrova I. Comparison of mechanical properties and structural changes of continuous basalt and glass fibres at elevated temperatures. *Ceramics – Silikáty* 2007; 51(2): 82-88.
5. Ólafsson H, Þórhallsson E. Basalt fibre bar Reinforcement of concrete structures. http://www.ru.is/media/sel-grein-ar/Basalt-paper-HO_ETh.pdf (accessed 13 October 2013).
6. Kovačević S, Ujević D, Brnada S, Brlobašić Šajatović B. *Structural Multi-layered Composite Textiles Materials: Textile Science and Economy III*. Ed. Pavlović M, Milan, Zrenjanin, University of Novi Sad., Technical faculty, 2011, pp. 50-67.
7. Šomodi Ž, Kovačević S, Dimitrovski K. Fabric Distortion After Weaving - An Approximate Theoretical Model: *5th International Textile, Clothing and Design Conference 2010 - Magic World of Textile*. Ed. Dragčević Z, Hursa Šajatović A, Vujasinović E, Dubrovnik, Faculty of Textile Technology. Croatia, 3-6 October 2010, pp. 729-734.
8. Skoko M. Investigation of the Properties with Multiaxial Strengths and Deformations of Coated Fabrics. *Tekstil* 1998; 47(7): 339-344.
9. Behera BK, Hari PK. Woven textile structure: *Theory and applications*. Ed. Cornwall, UK: Woodhead publishing series in textiles, 2010.
10. Kilby WF. Planar stress-strain relationships in woven fabrics. *Journal of The Textile Institute* 1963; T9: 54.
11. Hearle JWS, Ozsanlav V. Studies of Adhesive-Bonded Non-Woven Fabrics, Part II: The Determination of Various Parameters for Stress Prediction. *Journal of Textile Institute* 1979; 70(10): 439-451.
12. De Jong S, Postle R. An Energy Analysis of Woven-Fabric Mechanics by Means of Optimal- Control Theory, Part I: Tensile Properties. *Journal of Textile Institute* 1977; 68(1): 350-361.
13. Leaf GAV, Kandil KH. The Initial Load-Extension Behavior of Plain Woven Fabrics. *Journal of Textile Institute* 1980; 71(1): 1-7.
14. Collier JR, Sargand SM, O'Toole G. Drape Prediction by Means of Finite-Element Analysis. *Journal of Textile Institute* 1991; 82(1): 96-107.
15. Sun H, Pan N, Postle R. On the Poisson's Ratios of a Woven Fabric. *Composite Structures* 2005; 68(4): 505-510.
16. Bao L, Takatera M, Shinohara A. Error Evaluation on Measuring the Apparent Poisson's Ratios of Textile Fabrics by Uniaxial Tensile Test. *Sen-ito Kogyo* 1997; 53(1): 20-26.
17. Shahabi NE, Saharkhiz S, Varkiyani MH. Effect of Fabric Structure and Weft Density on the Poisson's Ratio of Worsted Fabric. *Journal of Engineered Fibres and Fabrics* 2013; 8(2): 63-71.
18. Kawabata S, Masako N, Kawai H. 3-the Finite-deformation theory of plain-weave fabrics, Part I: The biaxial deformation theory. *Journal Textile International* 1973; 64(1): 21-46.
19. Kawabata S, Masako N, Kawai H. 4-the Finite-deformation theory of plain-weave fabrics, Part II: The uniaxial. Deformation theory. *Journal Textile International* 1973; 64(2): 47-61.
20. Kawabata S, Masako N. 38-A Finite-deformation theory of the 2/2-twill weave under biaxial extension. *Journal of Textile Institute* 1979; 70(10): 417-427.

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The **Laboratory** is active in testing fibres, yarns, textiles and medical products. The usability and physico-mechanical properties of textiles and medical products are tested in accordance with European EN, International ISO and Polish PN standards.

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- linear density of fibres and yarns, ■ mass per unit area using small samples, ■ elasticity of yarns, ■ breaking force and elongation of fibres, yarns and medical products, ■ loop tenacity of fibres and yarns, ■ bending length and specific flexural rigidity of textile and medical products

Other tests:

- **for fibres:** ■ diameter of fibres, ■ staple length and its distribution of fibres, ■ linear shrinkage of fibres, ■ elasticity and initial modulus of drawn fibres, ■ crimp index, ■ tenacity
- **for yarn:** ■ yarn twist, ■ contractility of multifilament yarns, ■ tenacity,
- **for textiles:** ■ mass per unit area using small samples, ■ thickness
- **for films:** ■ thickness-mechanical scanning method, ■ mechanical properties under static tension
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