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Measurement of Tensile Properties of Seersucker Woven Fabrics of Different Structure

Abstract

Seersucker woven fabrics are characterised by the occurrence of puckered and flat strips in the warp direction, creating a 3D woven structure. Such a kind of structure influences the properties of fabrics significantly. In the work presented, seersucker woven fabrics of different structure were investigated. Diversification of the structure was achieved by the application of different weft yarns. The aim of the work was to analyse the relationship between the structure of seersucker fabrics and their tensile properties. Additionally the influence of test sample preparation on the measurement results was the subject of analysis. Measurement of the mechanical properties: breaking force and elongation at break was made using standardised test methods. The investigations performed showed that in the case of seersucker woven fabrics, the repeat of the puckered strips is a very important factor. Both the number of puckered strips as well as their width influence the results of the mechanical properties of fabrics.

Key words: *seersucker woven fabrics, breaking force, elongation at break, test specimen preparation.*

Introduction

Fabrics made from both natural and man-made fibres have been extensively used for different applications: clothing, decoration, industrial, medical and others [1]. Due to this fact, their durability and resistance to repeatable loading are two of the most important properties, especially in the case of textiles for technical applications. The measurement of tensile stress–strain properties is the most common mechanical measurement of fabrics. It is used to determine the behaviour of a sample under an axial stretching load. Many scientific works have been published till now in the area of the tensile stress-strain properties of textile materials. Authors have presented many factors influencing directly or indirectly the final values of the breaking force and elongation at break of fabric in the warp and weft directions [1-7]. Such factors as the raw material, yarn kind [2, 3], yarn mechanical properties (breaking force and elongation at break) [2-4], yarn twist, fabric weave, warp and weft density, way of finishing etc should be mentioned here. [4-6]. Omeroglu & Ulku [2] and Al-metwally & Salem [3] stated that fabrics woven from compact yarns had higher tensile strengths than those woven from ring yarns. Kumpikaite [5] established that as the weft setting increases, the fabric's breaking force slightly decreases, and the elongation at break increases. She also stated that there is no correlation between the fabric weave factor and breaking force, and as the coefficient of the weave increases, i.e. the rigidity of the weave decreases, the elongation at break decreases [5]. In another work, Kumpikaite [6] concluded that the breaking force in the warp direction of weaves with evenly distributed floats is lower than that of horizontally striped weaves. Gabrijelčič et al. [7] investigated the influence of weave and weft characteristics on the tensile properties of fabrics. Among others, they stated that when the yarns used in the warp and weft were of similar characteristics (count, raw materials), the weft had a smaller effect on the shape of the stress-strain curve and on the final values of the breaking force of fabrics in the warp direction. They also found out that the breaking force and elongation at break in the warp direction were higher when doubled yarns were used as the wefts instead of single threads [7].

There have also been numerous other articles published till now in the area of the tensile stress- strain measurement of woven fabrics and on the dependencies between the breaking force and elongation at break of woven fabrics and their structural parameters. It seems that is nothing more to do in this matter. The principles of tensile stress-strain tests are rather simple and they have not changed much over the past 70 years. Considerable advance can be observed only in the area of the testing devices used for tensile measurement and data processing.

However, the majority of works published till now have considered flat fabrics of base (fundamental) or derivative weaves. Some problems can appear in the context of patterned weaves, especially woven fabrics classified as 3D or 2D +. A basic common definition of 3D fabrics is that these types have a third dimension in the thickness layer [8]. According to Chen [9], structures that have a substantial dimension in the thickness direction formed by layers of fabrics or yarns, are generally termed as three-dimensional (3D) fabrics. There are different types of 3D woven fabrics of different structure classified according to several classifications based on the shedding mechanisms, weaving process, geometries and configurations of yarns, their interlacements and fibre axis [9-11]. 3D woven fabrics can be manufactured with both 2D and 3D weaving. Depending on the way of manufacturing. the surface properties of 3D woven fabrics can be different. There are 3D fabrics with a smooth surface. In this group some kinds of spacer fabrics or two-layer woven fabrics can be included [8, 12-14]. There are also 3D woven fabrics with a textured surface created from different elements such as plisse or pleated fabrics, terry fabrics, velvet fabrics, etc. [8, 15]. The three-dimensionality of woven fabrics can also be achieved by an appropri-

Table 1. Basic structural properties of fabrics investigated.

Parameter	Unit	Value					
		Variant V1		Variant V2		Variant V3	
		20 tex x 2	30 tex x 2	20 tex x 2	30 tex x 2	20 tex x 2	30 tex x 2
Weave – warp I	–	plain					
Weave – warp II	–	rep 2/2					
Warp density	cm⁻¹	12.7	12.8	12.6	12.3	11.4	11.6
Weft density	cm⁻¹	11.4	10.4	11.5	10.4	11.4	11.4
Mass per square meter	g m⁻²	212.9	252.9	207.8	245.6	192.8	230.0
Take up – warp I	%	8.3	7.9	6.0	8.2	5.2	11.1
Take up – warp II	%	49.8	60.2	48.8	49.6	49.7	47.2
Take up – weft	%	7.1	8.7	6.4	6.2	9.2	6.7

ate combination of warp yarns of different tensions as well as by the application of weft yarns of different elasticity [16].

Into the last group of 3D woven fabrics, seersucker woven fabrics are included. Seersucker, also known as the crimp effect, is characterised by the presence of a three-dimensional (3D) wavy effect (puckered) and relatively flat sections, particularly in stripes [17]. Typical seersucker woven fabrics are characterised by the occurrence of puckered and flat strips in the warp direction. They are manufactured from two warp sets on a loom with two loom beams [14]. One beam carries warp yarns for the flat strips and the other – warp yarns for the puckered strips. The seersucker effect is created due to the different tension of both sets of warp. There are also other methods of seersucker woven fabric manufacturing, for instance the application of yarns of different elasticity [18] or by appropriate fabric finishing when the alkali-printed stripes of a cotton cloth shrink and force the nonprinted stripes to take a characteristic wavy form [17].

Seersucker woven fabrics create a unconventional 3D woven structure, which should be taken into consideration while preparing test samples for measurement of the structural, mechanical and utility properties of seersucker woven fabrics of a unique patterned structure. Till now, measurement of the basic structural, mechanical and other properties of seersucker woven fabrics has been performed using the standardised testing methods developed and commonly applied to measure typical flat 2D – (two-dimensional) woven fabrics. The principle of the tensile strength test is simple: a test piece is held in two places and extended until it breaks. Taking into consideration that generally fabrics are heterogeneous materials, the tensile stress-strain test

should be performed in both directions: warp and weft. Results depend on the specimen's geometry, the fibre type and arrangement as well as the fabric structure. An important factor for the tensile test is also sample preparation.

Preliminary investigations showed that the seersucker effect can influence the results of measurement of some fabric properties [18]. It mostly concerns the properties on which measurement is performed on the basis of small test samples of predetermined dimensions. In the case of tensile strength measurement, the width of the test sample is 5 cm. Depending on the pattern of the seersucker effect – the width of the seersucker strips and distance between them – the test samples for tensile strength and bending stiffness measurement in the warp direction can contain different numbers of seersucker strips. This affects the course of the test and measurement results. However, this problem has not been discussed in detail so far.

Investigations carried out and published till now have concerned mostly the technology [14], structure assessment [19, 20] or comfort related properties of seersucker fabrics, both woven and knitted [21, 22]. There is a lack of investigations and publications aimed at analysis of the influence of the structure of seersucker woven fabrics and the effect of their pattern (repeat) on the results of fabric tensile stress-strain measurement.

The aim of the work was to analyse the mechanical properties of seersucker woven fabrics of different structure as well as the influence of their pattern on the results of measurement of selected mechanical properties of seersucker woven fabrics. Additionally the influence of test sample preparation on the results of measurement of the mechanical properties was the subject of analysis. Differentia-

tion of the structure of the fabrics investigated was achieved by the application of different repeats of puckered strips and various yarns in the weft direction.

■ Materials and methods

In the work presented, 6 variants of cotton seersucker woven fabrics were investigated. The fabrics were manufactured on the basis of the same warp sets made of 20 tex x 2 cotton yarn. In the weft 2 kinds of cotton yarns were applied:
■ 20 tex x 2,
■ 30 tex x 2.

The fabrics were designed in such a way as to obtain puckered and flat strips of predetermined width in the warp direction. Three variants of seersucker effect pattern were applied. They were the following variants:
■ variant 1 (V1) – width of puckered and flat strips, respectively: 5 mm and 8 mm,
■ variant 2 (V2) – width of puckered and flat strips, respectively: 9 mm and 18 mm,
■ variant 3 (V3) – width of puckered and flat strips, respectively: 11 mm and 41 mm,

The basic properties of the fabrics investigated are presented in *Table 1*. The fabrics are characterised by different mass per square meter, which is a consequence of the application of weft yarn of different linear density. The thicker the weft yarn , the bigger the mass per square meter. The number of picks is also different, which is due to the fact that for each kind of weft yarn the number of picks was adjusted in such a way as to obtain a stable and correct seersucker effect.

The fabrics were measured in the range of their mechanical properties: breaking force and elongation at break. The measurement was performed according to the Polish standard PN-EN-ISO 13934-1:12013 using a Hounsfield tensile tester. According to the standard, measurement of breaking force is performed for samples of 5 cm width. The distance between the jaws of the tensile tester is 20 cm. The samples are cut in randomly chosen places of the fabric. However, in the case of patterned fabrics, it is possible that the cut samples can differ from each other in the range of pattern. In this case, the seersucker woven fabrics investigated had flat and puckered strips in the warp direction. Depending on the variant of
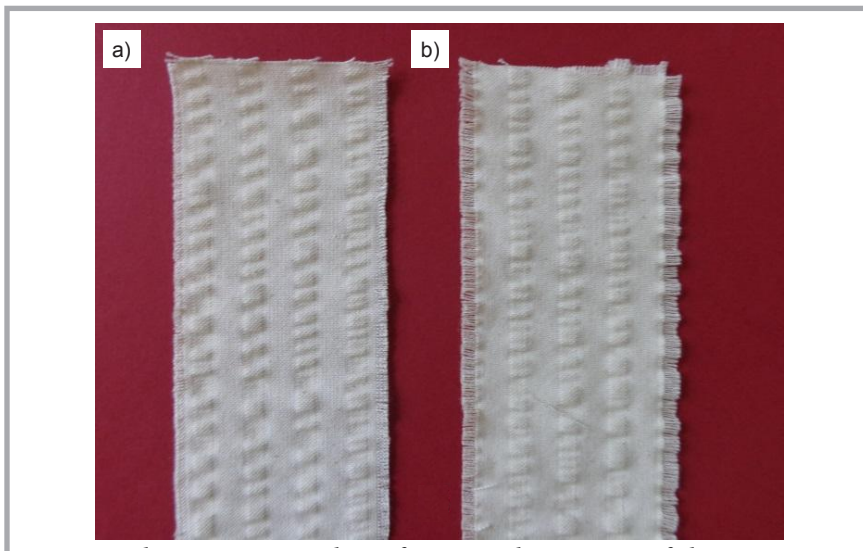
Figure 1. *Exemplary test samples of seersucker woven fabrics – variant V1: a) test samples containing 4 puckered strips, b) test samples containing 3 puckered strips.*
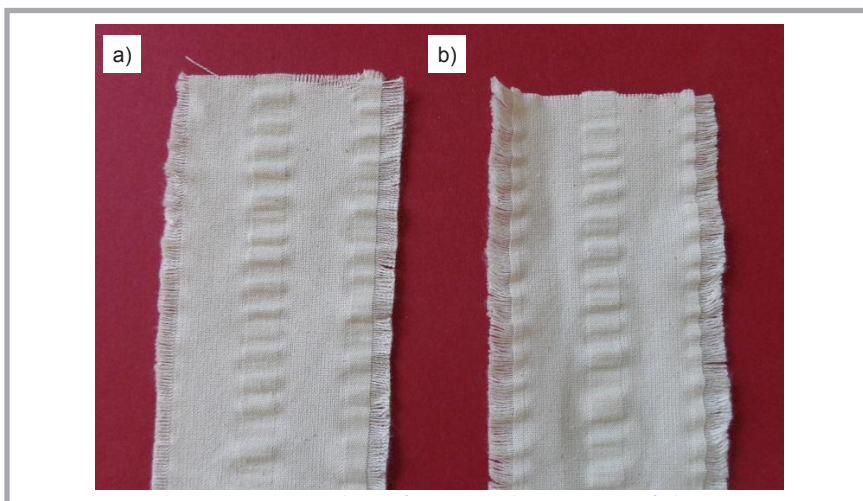

Figure 2. *Exemplary test samples of seersucker woven fabrics – variant V2: a) test sample containing two puckered strips, b) test sample containing 1 full-width and 2 half-width puckered strips.*
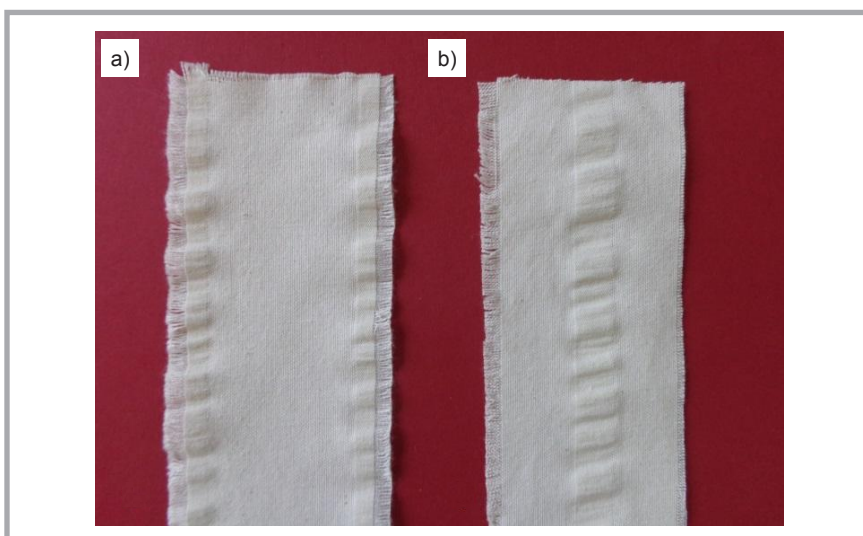

Figure 3. *Exemplary test samples of seersucker woven fabrics – variant V3: a) test sample containing 2 half-width puckered strips on the edges, b) test sample containing 1 puckered strip.*

the seersucker effect, the width of the flat strips is 8 mm, 18 mm and 41 mm, whereas that of the puckered strips is 5 mm, 9 mm and 11 mm, respectively (**Table 1**). Taking this into account, in the sample prepared for tensile strength measurement in the warp direction, the configuration of puckered strips and sometimes their number in the specimen measured can be different. This is due to the fact that at a width of 5 cm different numbers of flat and puckered strips can be placed, depending on the place of cutting. It seems to be obvious that the number of puckered and flat strips as well as their configuration in the sample tested can influence the results of measurement. Due to this fact, in the warp direction the measurement was made twice for samples cut in the following way:

■ for variant V 1 the test samples contained 4 or 3 puckered strips (**Figure 1**),

■ for variant V 2 the test samples contained 2 puckered strips or 1 full puckered strip and two half-width puckered strips on the sample edges (**Figure 2**),

■ for variant V 3 the test specimens contained 1 puckered strip or two narrower puckered strips of a width corresponding to half that of a full puckered strip on both edges of the test specimen (**Figure 3**).

It should be mentioned here that other patterns of the seersucker effect can result in other configurations of puckered and flat strips in test specimens applied in the measurement of the tensile strength of seersucker woven fabrics.

In the weft direction, measurement was made for one type of test sample because in the case of the weft direction the repeat of the seersucker effect does not influence the cutting of samples.

On the basis of the results, statistical analysis was performed in order to analyse the influence of the fabric structure, the kind of weft, and pattern of the seersucker effect on the results of tensile strain–stress measurement. Multifactor analysis of variance (AVOVA), available in STATISTICA software, was applied in the statistical analysis. In general, the purpose of the ANOVA is to test for significant differences between means. According to the software applied. the analysis is based on a comparison of the variance due to the between-group variability (called the *Mean Square Effect* or MS_{effect}) with the within-group variability

(called the *Mean Square Error* or MS_{error}). STATISTICA software compares these two estimates of variance via the *F* test, which tests whether the ratio of the two variance estimates is significantly greater than 1. These latter variance components are then tested for statistical significance, at a significance level of 0.05 [23, 24].

In the statistical analysis the variant of the seersucker effect, the kind of weft yarn and way of sample cutting were applied as the main factors (independent variables), and the tensile strength and elongation at break were applied as dependent variables.

Results and discussion

Results of measurement of the mechanical properties are presented in *Table 2*. As was mentioned earlier, measurement of the tensile strength and elongation at break in the warp direction was performed twice for test specimens containing different configurations of strips (*Figure 1-3*). Due to this fact, in *Table 2* the results in the warp direction are presented for both cases of specimen cutting. The results are marked by symbols *"a"* and *"b"* according to the specimens marking, presented in *Figure 1-3*. The values of standard deviation of the results are presented in brackets.

On the basis of the results, it was stated that all fabric variants differ from each other in the range of their tensile strength properties. It is also clearly visible that in all cases the breaking force in the weft direction is significant – sometimes twice higher than that in the warp direction (*Figure 4*). It is a relation that is opposite to the one usually observed for typical flat woven fabrics of basic or derivative weaves. Due to the different reasons – usually technological and utility (direction of cutting the patterns in the apparel industry), the breaking force of woven fabrics in the warp direction is higher than that in the weft direction. In the case of seersucker fabrics, only a part of threads – creating the flat strips – in the test specimen carries a tensile load in the warp direction. The threads creating puckered strips are much longer than those creating flat strips, which is due to the significantly higher take-up of the threads creating puckered strips in comparison to that of the threads creating flat strips (*Table 1*). It causes that while the threads creating flat strips are already broken, those creating puckered strips are
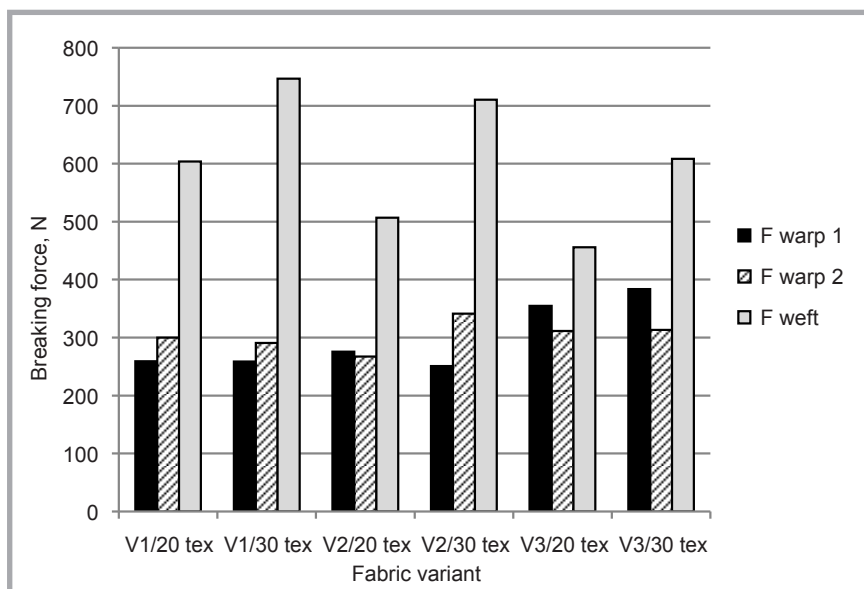

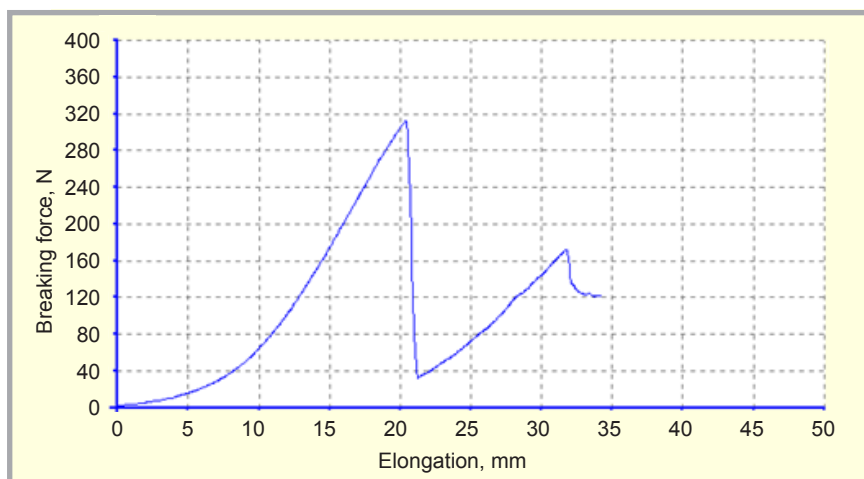**Figure 4.** *Breaking force of seersucker woven fabrics investigated.*

Figure 5. *Exemplary stress-strain curve from tensile test in the warp direction of the seersucker woven fabric investigated.*

Figure 6. *Breaking of seersucker fabrics in the warp direction: a) sample mounted in the clamps of the tensile tester; b) scan of broken sample.*
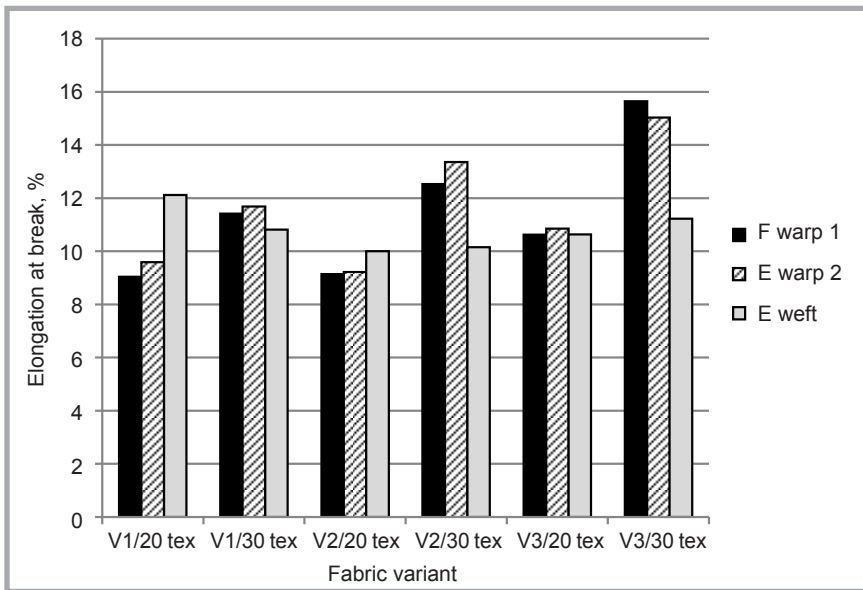
Figure 7. Elongation at break of seersucker woven fabrics investigated.

still straightened. This relation is justified by both the shape of the stress-strain curve (*Figure 5*), and by the appearance of the test specimen after the test (*Figure 6*).

In the warp direction in the majority of cases, two peaks were observed in the stress-strain curve (*Figure 5*). The first peak expresses the maximal force causing the break of thread creating flat strips, and the next – the breaking of threads creating puckered strips.

On the basis of observation of the test sample during and after the tensile test, it was stated that breaks took place in the flat strips (*Figure 6*).

The results obtained showed that a bigger share of flat warp strips in the total area of the specimen tested causes higher tensile strength, which explains the influence of the pattern of the seersucker effect on the

breaking force of seersucker woven fabrics in the warp direction. The width and repeat of puckered strips significantly influence the tensile properties of seersucker woven fabrics (*Figure 7*).

In the case of the elongation at break, differences between particular fabric variants are also observed. However, it is difficult to define any clear tendency. In two cases: variants V1/20 tex and V2/20 tex the elongation at break in the weft direction is higher than that in the warp direction. In the rest of cases the relation is opposite. However, for variants V2/30 tex and V3/30 tex, the differences are much bigger than in the case of variants V1/30 tex and V3/20 tex.

In the case of both the breaking force and elongation at break, differences are also visible in the warp direction between results for specimens of different configuration of puckered and flat strips.

The results show that the relations vary for the different variants of pattern of the seersucker effect. For variant V1 in both cases: fabric with weft 20 tex x 2 and fabric with weft 30 tex x 2, a higher breaking force was noted for test specimens containing a lower number of puckered strips (*Figure 1.b*), as was explained above. In the case of variants V2 and V3, it is not easy to explain the differences, as the test specimens have the same number of puckered strips. In the case of variant V2, test specimens contain 2 puckered strips, but their placement is different (*Figure 2*). In the case of variant V3, due to the repeat of the seersucker effect and relatively big distance (41 mm) between the puckered strips, the test specimen can contain only 1 puckered strip inside the specimen or be divided into two parts placed on the edges of the test specimen. Although in both cases: variants V2 and V3 the number of puckered strips in the test specimens is the same for both ways of cutting (for variant V2 – 2 puckered strips and for variant V3 – 1 a puckered strip in the whole or divided, respectively), differences in the breaking force are observed due to the different arrangement of puckered strips in the test specimen.

In order to assess the significance of the relationships between the mechanical parameters: breaking force and elongation at break of seersucker woven fabrics, their structural factors: kind of weft yarn and pattern of the seersucker effect, and the way of testing the cut specimen, statistical analysis ANOVA was performed. In the warp direction, statistical analysis was performed separately for each variant of pattern of the seersucker effect, e.g. separately for fabric variants V1, V2 and V3. It was done in such a way because the differences caused by the way of cutting brought different consequences for particular variants of the seersucker effect. In the case of variant V1, different ways of cutting resulted in a different number of puckered strips in the test specimens, 3 or 4, respectively. In the case of variants V2 and V3, the number of puckered strips was the same in samples cut in different ways, but the placement of puckered strips in the test specimen was different. Taking the above into account, it was difficult to define the same main factor connected with sample cutting for all variants of seersucker fabrics investigated.

In this part of the analysis, the linear density of the weft yarn (20 tex x 2 and

Table 2. Tensile strain stress properties of the seersucker woven fabrics investigated.

Parameter/ Fabric symbols	Value					
	Breaking force in warp direction, N		Elongation at break in warp direction, %		Breaking force in weft direction, N	Elongation at break in weft direction, %
	"a"	*"b"*	*"a"*	*"b"*		
V1/20 tex	258.95 (22.75)	300.04 (16.70)	9.04 (0.85)	9.59 (0.54)	604.00 (25.79)	12.12 (0.61)
V1/30 tex	258.52 (17.58)	290.68 (22.35)	11.42 (1.80)	11.68 (1.53)	746.90 (65.43)	10.82 (0.83)
V 2/20 tex	275.62 (22.17)	267.39 (24.86)	9.14 (0.49)	9.22 (0.67)	506.89 (68.98)	10.04 (0.82)
V2/30 tex	251.08 (22.94)	341.74 (7.41)	12.53 (0.75)	13.35 (0.53)	710.60 (70.07)	10.16 (0.47)
V3/20 tex	354.84 (23.29)	311.74 (22.70)	10.62 (1.17)	10.85 (0.90)	455.75 (74.54)	10.63 (0.86)
V3/30 tex	383.71 (18.61)	313.20 (18.70)	15.64 (0.64)	15.03 (0.42)	608.50 (119.92)	11.22 (0.41)

30 tex x 2) and the way of cutting (*a* and *b* according to the pictures presented in *Figure 1-3*) were taken as the main factors. Analysis was performed on the breaking force and elongation at break as dependant variables.

Results of AVOVA are presented in *Tables 3-6*. In the software applied, interpretation of the results generated is as follows:

- when $p \leq 0.05$, there is a statistically significant difference between the within-group and between-group variability,
- when $p > 0.05$, the difference between the within-group and between-group variability is statistically insignificant.

In the *Tables 3-6* the effects statistically significant at the level of significance $p = 0.05$ are emphasised in bold italics.

Tensile properties of seersucker fabrics in the warp direction

It was stated that in the case of variant V1, the way of cutting significantly influences the breaking force of fabrics in the warp direction (*Figure 8*). Fabrics cut in the *"a"* way are characterised by a much lower breaking force than those cut in the *"b"* way, which is due to the fact that test specimens cut in the *"a"* way contain 4 puckered strips, whereas those cut in the *"b"* way contain 3 puckered strips. It results in a lower number of threads carrying the tensile load in specimens cut in the *"b"* way in comparison to those cut in the *"a"* way.

The elongation at break of fabrics representing variant V1 is significantly influenced by the weft density. The way of cutting has not any statisticaly significant influecne on the elongation at break. However, it can be seen that samples cut in the *'a'* way are charcterised by higher elongation at break than those cut in the *'b'* way (*Figure 9*).

In the case of seersucker woven fabrics representing V2 variant of the pattern of the seersucker effect, both main factors significantly influence the value of the breaking force. Additionally the interaction between the main factors: the linear density of weft yarn and the way of specimen cutting is also statistically significant.

Generally fabrics representing V2 variant with weft yarn of 20 tex x 2 linear densi-

Table 3. Results of ANOVA for variant V1. **Legend:** MS_{efekt} – mean square of effect expresing between-group variability, MS_{error} – mean square of error expresing within-group variability, df – degree of freedom, F – variable of F-distribution, p – statistical significance.

	df_{effect}	MS_{effect}	df_{error}	MS_{error}	F	p
			BREAKING FORCE			
1 (weft linear density)	1	239.6	36	401.2	0.60	0.44
2 (way of cutting)	*1*	*13413.9*	*36*	*401.2*	*33.43*	*1.35 E-06*
1, 2	1	199.36	36	401.2	0.50	0.48
			ELONGATION AT BREAK			
1 (weft linear density)	*1*	*50.0*	*36*	*1.6*	*30.30*	*3.18 E-06*
2 (way of cutting)	1	1.7	36	1.6	1.02	0.32
1, 2	1	0.2	36	1.6	0.12	0.73

Table 4. Results of ANOVA for variant V2. **Legend:** MS_{efekt} – mean square of effect expresing between-group variability, MS_{error} – mean square of error expresing within-group variability, df – degree of freedom, F – variable of F-distribution, p – statistical significance.

	df_{effect}	MS_{effect}	df_{error}	MS_{error}	F	p
			BREAKING FORCE			
1 (weft linear density)	*1*	*6167.8*	*36*	*422.7*	*14.59*	*0.0005084*
2 (way of cutting)	*1*	*16929.1*	*36*	*422.7*	*40.05*	*2.53 E-07*
1, 2	*1*	*24378.9*	*36*	*422.7*	*57.67*	*5.54 E-09*
			ELONGATION AT BREAK			
1 (weft linear density)	*1*	*141.4*	*36*	*0.4*	*368.03*	*1.72 E-20*
2 (way of cutting)	*1*	*2.1*	*36*	*0.4*	*5.39*	*0.026*
1, 2	1	1.4	36	0.4	3.62	0.065

Table 5. Results of ANOVA for variant V3. **Legend:** MS_{efekt} – mean square of effect expresing between-group variability, MS_{error} – mean square of error expresing within-group variability, df – degree of freedom, F – variable of F-distribution, p – statistical significance.

	df_{effect}	MS_{effect}	df_{error}	MS_{error}	F	p
			BREAKING FORCE			
1 (weft linear density)	*1*	*2299.8*	*36*	*438.5*	*5.24*	*0.028*
2 (way of cutting)	*1*	*32268.1*	*36*	*438.5*	*73.59*	*3.15 E-10*
1, 2	*1*	*1878.3*	*36*	*438.5*	*4.28*	*0.045*
			ELONGATION AT BREAK			
1 (weft linear density)	*1*	*211.5*	*36*	*0.7*	*304.91*	*3.71 E-19*
2 (way of cutting)	1	0.4	36	0.7	0.52	0.48
1, 2	1	1.8	36	0.7	2.61	0.12

Table 6. Results of ANOVA for results in weft direction. **Legend:** MS_{efekt} – mean square of effect expresing between-group variability, MS_{error} – mean square of error expresing within-group variability, df – degree of freedom, F – variable of F-distribution, p – statistical significance.

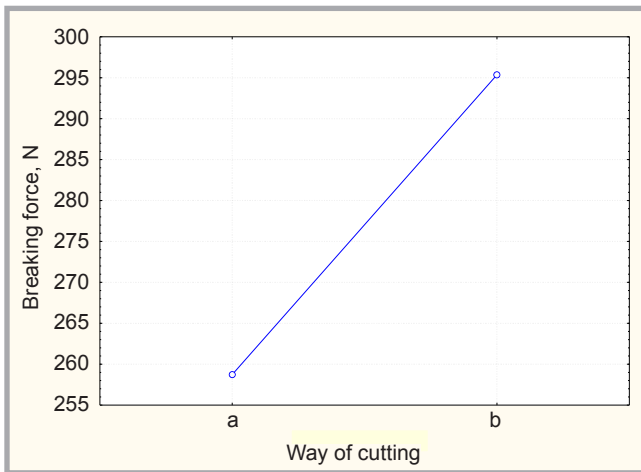|	df_{effect}	MS_{effect}	df_{error}	MS_{error}	F	p
			BREAKING FORCE			
1 (weft linear density)	*1*	*415434.3*	*54*	*4014.1*	*103.49*	*3.71 E-14*
2 (pattern variant)	*2*	*102804.1*	*54*	*4014.1*	*25.61*	*1.51 E-08*
1, 2	2	5338.3	54	4014.1	1.32	0.273
			ELONGATION AT BREAK			
1 (weft linear density)	1	0.5	54	0.5	1.07	0.305
2 (pattern variant)	*2*	*9.8*	*54*	*0.5*	*20.42*	*2.48 E-07*
1, 2	*2*	*4.9*	*54*	*0.5*	*10.22*	*0.00017*

Figure 8. *Influence of the way of cutting on the breaking force in the warp direction of seersucker woven fabrics with a V1 seersucker pattern.*
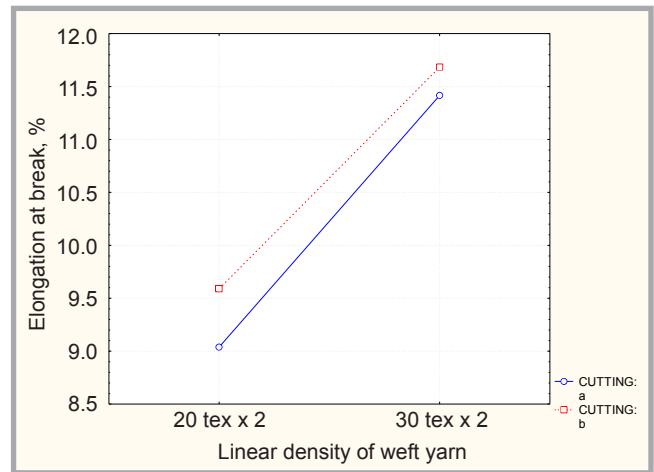

Figure 9. *Influence of the liner density of weft yarn and way of sample cutting on the elongation at break in the warp direction of seersucker woven fabrics of the V1 seersucker pattern.*
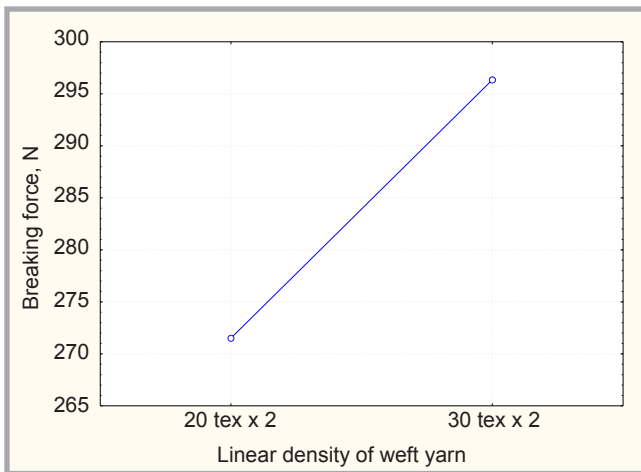

Figure 10. *Influence of weft linear density on the breaking force in the warp direction of seersucker woven fabrics of the V2 seersucker pattern.*
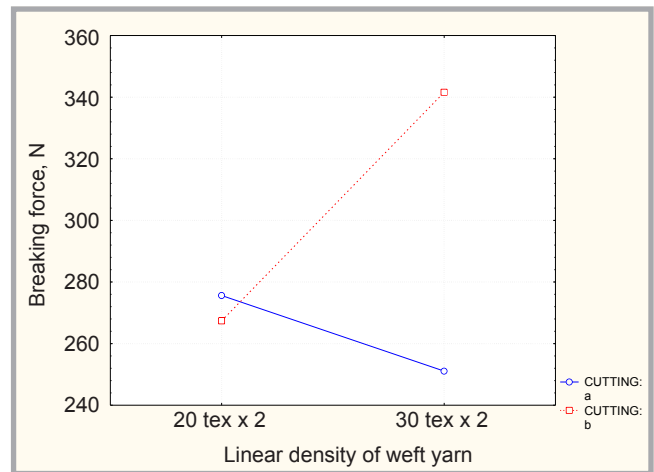
Figure 11. *Influence of the way of sample cutting and weft linear density on the breaking force in the warp direction of seersucker woven fabrics of the V2 seersucker pattern.*

ty are characterised by a lower breaking force than those with a weft linear density of 30 tex x 2 (***Figure 10***). However, the influence of the weft linear density on the breaking force is modified by the way of cutting. For samples cut in the ***"a"*** way, the value of the breaking force is higher for fabrics with 20 tex x 2 weft yarn than for those with 30 tex x 2 weft yarn, whereas for fabrics cut in the ***"b"*** way the relationship is opposite (***Figure 11***).

For fabrics of the V2 variant both main factors also influence the elongation at break. A higher elongation at break occurs for fabrics with weft yarn of 30 tex x 2 linear density than for those with weft yarn of 20 tex x 2 linear density. Higher values of elongation at break were obtained for test samples cut in the ***"b"*** way than for those cut in the ***"a"*** way (***Figure 12***). The influence of both main factors is statistically significant.

The influence of the weft density on the breaking force and interaction between both independent factors: the weft density and way of cutting is statistically insignificant.

For the group of fabrics representing V3 variant of the seersucker pattern, it was noted that the influence of the linear density of weft yarn and way of sample cutting on the results of breaking force measurement as well as the interaction between the main factors are statistically significant (***Table 5***).

The breaking force obtained for test samples cut in the ***"a"*** way is much higher than for those cut in the ***"b"*** way (***Figure 13***). The influence of the weft yarn linear density is more visible for samples cut in the ***"a"*** way than in the ***"b"*** way.

In the case of elongation at break, only the influence of weft density is statistically significant for fabrics representing the V3 variant of the seersucker pattern (***Figure 14***).

Summing up the results of the tensile test in the warp direction, it should be stated that in the majority of cases the main factors: linear density of weft yarn and way of cutting the test samples influence the values of the breaking force. For fabrics representing the V2 and V3 variants of the pattern of the seersucker effect, the influence of both main factors and the interactions between them are statistically significant at the significance level 0.05. For fabrics of the V1 variant of the pattern, the dominative role is played by the way of cutting the test sample. It is a very important remark but according to expectations. Variant V1 of the seersucker effect is characterised by relatively (in
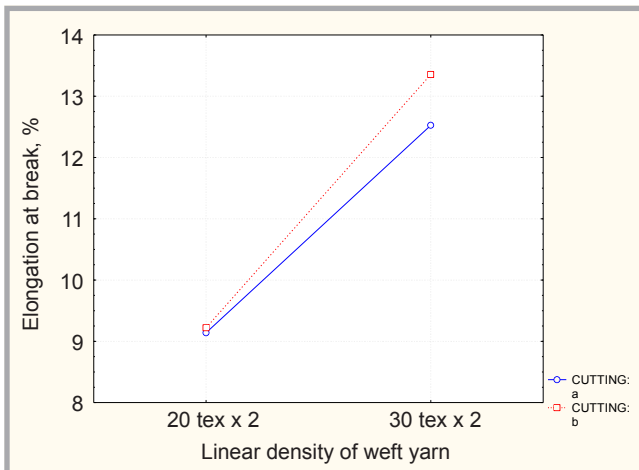
Figure 12. *Influence of the liner density of weft yarn and the way of sample cutting on the elongation at break in the warp direction of seersucker woven fabrics of the V2 seersucker pattern.*
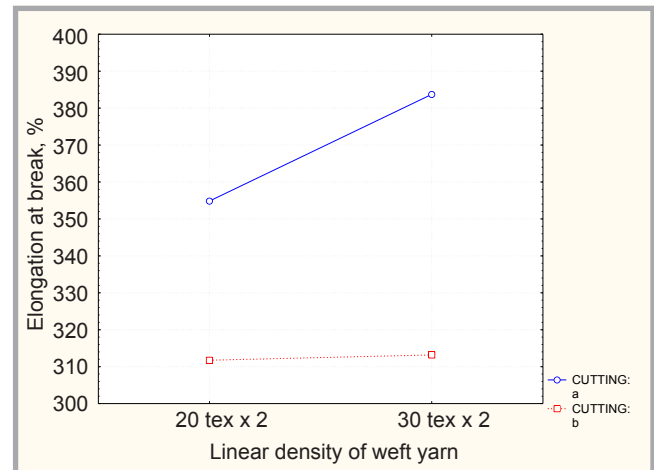

Figure 13. *Influence of the way of sample cutting and weft linear density on the breaking force in the warp direction of seersucker woven fabrics of the V3 seersucker pattern.*

comparison with the V2 and V3 variants) narrow puckered and flat strips, causing that in the test specimen a different number of puckered and flat strips can occur in dependence on the way of cutting. It determines the breaking force because in the first stage of fabric extension only the threads creating the flat strips carry the tensile load (***Figure 6***). A lower number of threads belonging to the flat strips in the total width of the specimen tested means a lower breaking force.

The results for fabrics representing the V3 variant of the pattern are also very interesting and worthy of attention. In this case the number of threads representing the flat strips is rather the same. In dependence on this, the results of statistical analysis showed that the way of cutting significantly influences the breaking force (***Figure 13***). How can this be explained? The way of cutting resulted in a different arrangement of the puckered and flat strips (***Figure 3***), due to which the tensile test ran in different way, causing varied damage to the samples tested (***Figure 15***).

Above should be taken into consideration while preparing samples for measurement as well as when designing seersucker woven fabrics. The crucial question is which results express the real tensile strength of seersucker fabrics and which way of cutting should be chosen for preparation of test specimens for the tensile strain-stress test in order to characterise the fabric in the best way. The questions are open. In the case of the V1 pattern, the solution is rather easy. In our opinion the test specimen should be cut in such a way that the

share of the flat strips in the whole area of the test specimen is the same as that of the flat strips in the whole fabric, which is easy to determine. In the case of the V2 and V3 variants, the problem is more complicated. In the seersucker fabrics investigated, the share of flat strips in the test specimens was the same for samples cut in both the *"a"* and *"b"* ways; but the breaking force was different, especially in the case of fabrics representing the V3 variant. The differences obtained resulted from the different placement of the puckered strips in the test specimens.

This problem concerns not only the seersucker woven fabrics but also other patterned fabrics. Due to the unlimited diversity of patterns of patterned woven fabrics, it is impossible to standardise the procedure of test sample preparation (cutting). In our opinion, in the case of seersucker woven fabrics, the way of test sample cutting should be discussed and agreed between the contractor and

performer of the measurement. It would also be advisable that the laboratory describes the procedure of cutting the test specimen in the report on measurement. The above should make communication much easier between the manufacturer, laboratory and consumer of seersucker woven fabrics and, depending on the pattern, other patterned woven fabrics.

Tensile properties of the seersucker fabrics in the weft direction

In the weft direction results for all seersucker fabrics investigated were analysed together. The linear density of the weft yarn and variant of the seersucker pattern were taken as the main factors. The results of ANOVA for the breaking force and elongation at break in the weft direction are presented in ***Table 6***.

The breaking force in the weft direction is influenced by both the weft linear density and variant of the seersucker pattern. Generally a higher breaking force oc-

Figure 14. *Influence of the liner density of weft yarn on the elongation at break in the warp direction of seersucker woven fabrics of the V3 seersucker pattern.*
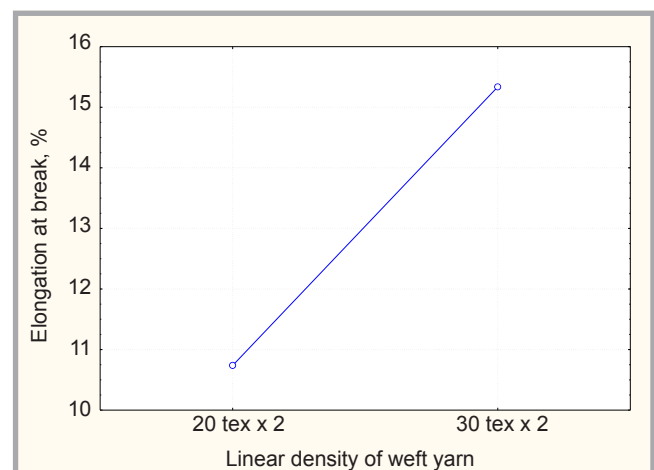
curred for fabrics with 30 tex x 2 weft yarn than for those with 20 tex x 2 weft yarn (*Figure 16*), which is according to expectations.

The highest breaking force was noted for fabrics representing the V1 variant of the seersucker effect, e.g. with the biggest share of puckered strips in the total area of fabric (ca. 38%). The lowest breaking force in the weft direction was noted for fabrics representing the V3 variant of the seersucker effect – with the lowest share of puckered strips (ca. 21 %) in the total area of fabric.

The elongation at break in the weft direction also depends on the linear density of weft yarn and on the variant of the seersucker pattern; but the influence of the weft linear density is statistically insignificant. The influence of the pattern on the elongation at break in the weft direction is statistically significant, and it is modified by the influence of the kind of weft yarn.

For fabrics with 20 tex x 2 weft yarn the highest elongation at break occurred for fabrics representing the V1 variant of pattern, whereas the lowest was for fabrics with the V2 variant. In the case of fabrics with 30 tex x 2 weft yarn, the highest value of elongation at break in the weft direction was noted for fabrics representing the V3 variant of the seersucker pattern (*Figure 17*).

■ Conclusions

Cotton seersucker woven fabrics of different structure were the subject of the investigations. The fabrics were measured
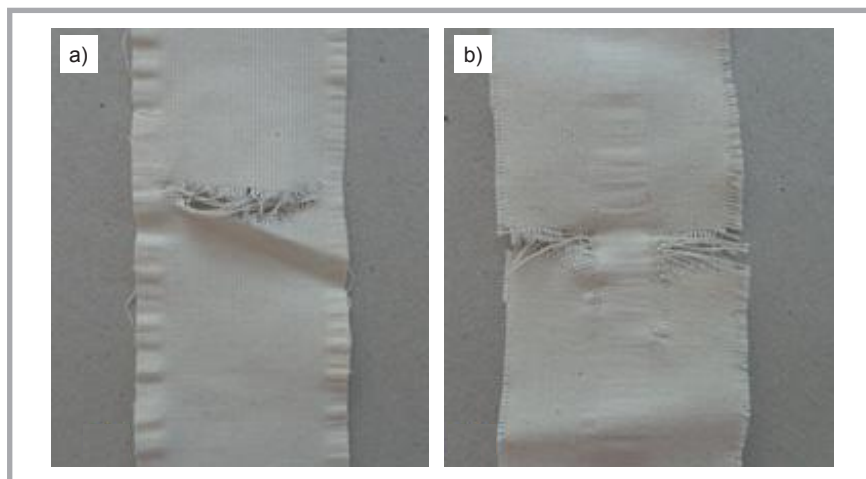

Figure 15. Exemplary pictures of test samples after tensile test – V3 pattern variant: a) test sample containing 2 half-width puckered strips on the edges, b) test sample containing 1 puckered strip.

in the range of their basic mechanical properties: breaking force and elongation at break. On the basis of the results obtained, it was noted that both the tensile strength and elongation at break depend on the kind of weft yarns applied in the fabrics and on the variant of pattern of the seersucker effect. Moreover the investigations performed showed that in the case of such patterned fabrics as seersucker woven fabrics, the repeat of the puckered strips is a very important factor from the point of view of the mechanical properties of fabrics. It was found that the way of test sample preparation, especially the place of cutting them, significantly influences results of the breaking force and elongation at break in the warp direction, due to the fact that test samples cut in different places of seersucker fabrics differ from each other in the range of the number and arrangement of puckered and flat strips. The investigations per-

formed showed that both the number of puckered strips and their arrangement in the test specimen influence the results of the tensile stress-strain test.

This should be taken into consideration while preparing samples for measurement. The problem can also concern other patterned woven fabrics, depending on the kind of pattern. Due to the huge diversity of patterns of patterned woven fabrics, it is impossible to elaborate one procedure of test sample preparation (cutting) appropriate for different kinds of patterned fabrics and to standardise the procedure. In the case of seersucker woven fabrics, it is necessary to take into account the relationships between the puckered strips' repeat and width of specimens tested in the warp direction. Moreover the share of the area of puckered strips in the total area of fabric is an important factor in the process
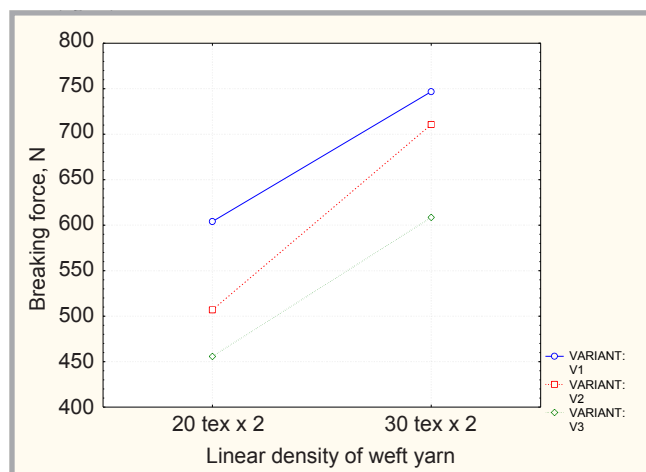

Figure 16. Influence of the variant of the seersucker effect and linear density of weft yarn on the breaking force in the weft direction of seersucker woven fabrics.
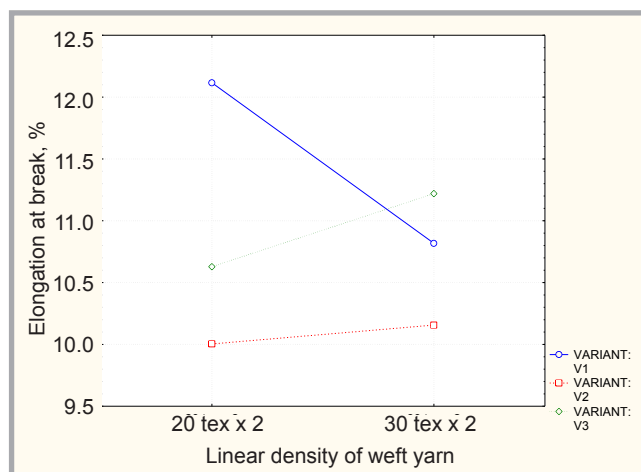

Figure 17. Influence of the variant of the seersucker effect and linear density of weft yarn on the elongation at break in the weft direction of seersucker woven fabrics.

of test sample preparation. In other cases it would be advisable to discuss and agree on the way of test sample cutting between interested parties.

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