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The Evaluation of Yarn Slippage at the Sewn Seam in Woven Fabrics Using the New Methods

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In the present study, the new methods for the investigation of the yarn slippage at the sewn seams in woven fabrics and for the determination of the parameters of yarn pulling out from woven fabrics were suggested. The original test methods capable to imitate similar to the real clothing wearing conditions, to evaluate the influence of external friction, of deformation method and of the position of seam allowances in respect to stitching line on the yarn slippage parameters were designed. Applying the new method based on the yarn pulling out from woven fabric with sewn seam, the analysis of the friction that occurs between warps and wefts during their sliding was done. Consequently, the behavior of the sewn seams in woven fabrics was analyzed applying the linear regression model which describes the dependence between the parameters such as: yarn pull out force $F_{pull\text{-}out}$, yarn pull out displacement $\varepsilon_{pull\text{-}out}$, the woven fabrics' mechanical characteristics such as: bending rigidity in warp direction *B1*, fabric elongation in warp direction *E100-1* and yarn slippage at sewn seam parameter (seam opening *d*). The created three-cluster model enabled to split the investigated woven fabrics into three statistically different groups.

Keywords: yarn slippage, friction, woven fabric, sewn seam, method.

1. INTRODUCTION

The yarn slippage at the sewn seam in the woven fabrics significantly influences the garment quality and appearance during their wearing under quite low tension forces. It is known, that the yarn slippage at the sewn seam in the woven fabrics depends on the woven fabrics' structure parameters, such as: fabric density, yarn linear density, composition and others, on fabric finishing, on sewing parameters and on seam type [1 – 7]. But the influence of mechanical characteristics of woven fabrics on the yarn slippage at the sewn seams was not investigated so widely.

Some standard methods for the investigation of the yarn slippage at the sewn seams in the woven fabrics are known [8]. They are constantly developed, e. g. it is known, that application of standard method did not provide accurate results about the yarn slippage at the sewn seams in the lining woven fabrics and it was complemented with additional analysis of the captured images of the deformed sewn seams [9, 10]. The other research works [11 – 14] are committed to develop the more realistic imitation of clothing wearing conditions.

It is known, that the most important factor, which influences the yarn slippage at the sewn seams in the woven fabrics, is the friction between warps and wefts. So, the test methods suitable to analyze these aspects are of very high importance. Consequently, the literature review has shown that the tests suitable to determine the parameters of yarn pulling out from woven fabric are very important as they are actual for the analysis of the friction between fabric warps and wefts [15 – 21]. These methods are based on the yarn pulling out from the woven fabric specimen without seams clamped in the grips.

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The aim of this work was to develop the original test methods capable to imitate similar to the real clothing wearing conditions, suitable to investigate the yarn slippage at the sewn seam in the woven fabrics and to analyze the friction between fabric warp and weft yarns.

2. EXPERIMENTAL

2.1. Materials

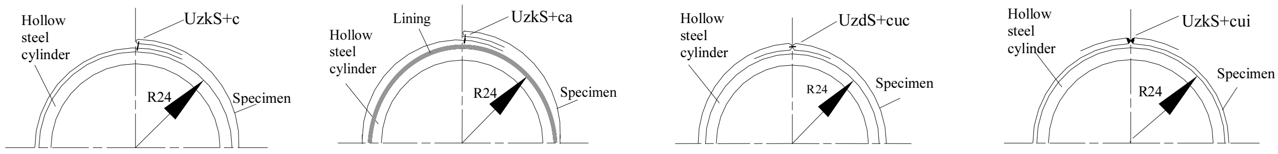
The plain weave raw (z) lining fabrics with different industrial finishing (dyed (d), dyed and softened (d+m), dyed and treated with non-slip finishing (d+n)) [10] and the purposely weaved non stabilized fabrics: plain weave (D), twill weave (R) and combined twill weave (KR) were investigated in this research (Table 1).

2.2. The newly created method for the determination of the yarn slippage at the sewn seams in the woven fabrics

A new test method for the investigation of yarn slippage at the sewn seams in woven fabrics and was created and an original technical device for its realization was constructed for different deformation cases (Fig. 1).

The clamping device consists of 50 mm length and 48 mm diameter steel hollow cylinders (see 2 and 4 in Fig. 2). They are fixed on steel plates covered with rubber. These plates are clamped in the standard clamps of tensile machine. The specimens mounted on cylinders are extended at 50 mm/min rate. The influence of different deormation modes and external surface friction are investigated applying the different deformation cases (Fig. 1).

The images of the specimens deformed up till 100 N tension force were captured using digital photo camera (Fig. 2, b, c). The seam opening was calculated according to the following equation: $d = d_a + d_v + h$ (mm) (Fig. 3).



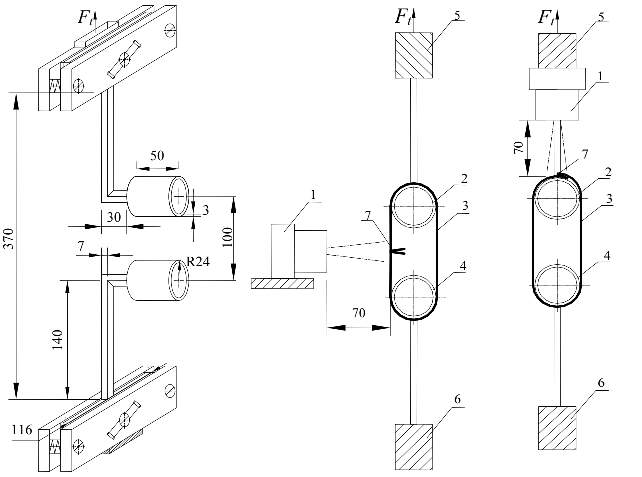
a b c d

Fig. 1. The principal schemes of the seams' deformation modes (front views): a – seam with the seam allowances bent to one side in respect to stitching line lying on the surface of steel cylinder (UzkS+c); b – seam with the seam allowances bent to one side in respect to stitching line and lying on the surface of steel cylinder covered by lining fabric (UzkS+ca); c – seam with the seam allowances opened to both sides in respect to stitching line and lying on the steel cylinder surface (UzdS+cuc); d – the seam with unrestricted seam allowances and placed on the surface of steel cylinder (UzkS+cui)

Table 1. Woven fabrics structure characteristics

Woven fabric characteristics	P11d+m	P11d	P11z	P14d+n	P12d	P4	D	R	KR
Composition	VI	VI	VI	VI	VI	PES	Warps: 70 % CO; Wefts: 30 % PES		
Surface density, g/m^2	76	72	66	72	61	56	155	153	155
Thickness, mm	0.09	0.09	0.17	0.12	0.09	0.09	0.43	0.47	0.54
Fabric density in warp direction, cm^{-1}	48	45	42	53	45	33	28	28	28
Fabric density in weft direction, cm^{-1}	25	25	25	33	27	28	20	20	20
Warp linear density, tex	8.7	10.7	7.8	10.6	8.4	6.2	39.9	39.9	39.9
Weft linear density, tex	14.1	13.1	13.5	12.9	8.4	7.68	18.1	18.1	18.1

Note: z – raw woven fabric; d – dyed woven fabric; d+m – dyed and softened woven fabric; d+n – dyed and treated with non-slip finishing woven fabric; VI – viscose; PES – polyester; CO – cotton. Surface and linear density was measured according standard LST ISO 3801:1998 [22], thickness – LST EN ISO 5084:2000 [23], warp/weft density – LST EN 1049-2:1998 [24].



a b c

Fig. 2. The scheme of the original technical device for specimen fixation in the clamps of tensile machine (a) and the schemes of deformed specimen image capturing using digital photo camera (b, c): b – unrestricted seam (UzdS+c); c – seam with opened or bent to one side seam allowances lying on cylinder (UzkS+c); 1 – digital photo camera; 2 – upper cylinder; 3 – specimen; 4 – bottom cylinder; 5 – the fixation of upper cylinder in the upper moving clamp of tensile machine; 6 – the fixation of bottom cylinder in the bottom not moving clamp of tensile machine; 7 – sewn seam

The yarn slippage parameters (Fig. 3) were measured applying AutoCAD2006 software with the accuracy of 0.001 mm.

2.3. The method for the investigation of the yarn pulling out from the woven fabric with the sewn seam

The original technical device was constructed and used to determine (Fig. 4) the yarn pull-out force $F_{\text{pull-out}}$ and yarn pull-out displacement $\varepsilon_{\text{pull-out}}$. The pull-out force-displacement curves were also registered using the standard tension machine.

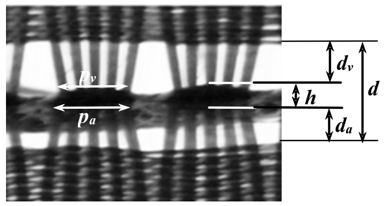
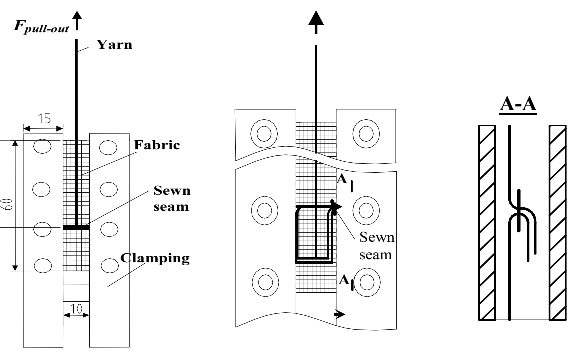


Fig. 3. The scheme of the measurement of the seam opening and its constituents: h – stitch opening width, mm; p_v – the compressed yarns in the upper seam zone, mm; p_a – the compressed yarns in the bottom seam zone, mm; d_v – distance between the slipped yarns in the upper seam zone, mm; d_a – distance between slipped yarns in the bottom seam zone, mm



a b c

Fig. 4. The typical schemes of the device used for the determination of the yarn pull-out force $F_{\text{pull-out}}$ and of yarn pull-out displacement $\varepsilon_{\text{pull-out}}$: front view (a), back view (b); sewn seam fixation section A-A (c)

The sewn specimen was clamped without pretension in the clamps. Each of them consisted of two metallic plates fixed together with screws. Specimen's working width was equal to 10 mm and length was equal to 52 mm. The part of specimen from the clamps to the stitching line was also fixed in perpendicular direction. The width of sewn seam allowances was equal to 12 mm. The seam allowances were unrestricted in the clamps. The middle yarn was pulled out from fabric using a standard tensile machine at 10 mm/min rate. The low width of specimen was chosen to minimize shear deformation and transverse tension induced by the pull-out force.

2.4. The modeling methodology of the investigation of the influence of the woven fabric mechanical properties on the yarn slippage at the sewn seam in the woven fabrics

Modeling methodology of the influence of the woven fabric mechanical properties on the yarn slippage at the sewn seam parameter (slippage opening *d*) has been proven in the context of phenomenology research. Also, the proofed empirically methodology of multivariable linear regression analysis application for the classification of fabrics' mechanical characteristics, and performed empirical validation of k-means method application for the classification of fabrics' mechanical characteristics was suggested [28].

The research is based on the phenomenological theory, which means a theory that expresses mathematically the results of observed phenomena without paying detailed attention to their fundamental significance [25].

In this research the phenomenon is the parameter of the yarn slippage at the sewn seam in the woven fabric – seam opening *d*. Since the phenomenon is characterized by some level of abstractness, it was fulfilled the fabric behavior research carried out to determine and to describe the phenomenal features (woven fabric bending rigidity in warp direction *B1*, yarn pull-out force $F_{\text{pull-out}}$ or/and woven fabric elongation in warp direction *E100-1*, yarn pull-out displacement $\varepsilon_{\text{pull-out}}$).

Since the phenomenological research does not require the fundamental or statistical significance, the performed statistical modeling, based on the investigated fabrics, was used rather as a mean better to cognize the research object and the variation of its features changing the research conditions, than as a way to validate the distribution of these features across the general sample.

To fulfill the phenomenological research in SPSS software the following methods were chosen: multivariable linear regression and *k*-mean cluster method (applied for the z-scale variables). They were chosen because they have integrated tools for the quality evaluation of the set, such as: ANOVA colinearity statistics or the studentized residual analysis in linear regression [26, 27] and the analysis of group mean deviation from the total mean on the z-scale in the case of *k*-mean cluster analysis [28]. Since the indicators have shown, that the simulation results are correct, it was stated, that the designed statistical models of the phenomenon behavior are not just a kind of random phenomenological effect. The indicators revealed that behavior of the phenomenon is regular and statistically valid.

The following woven fabrics' mechanical properties were determined applying FAST methods and they were used for modeling (Table 2) [29]. The created original method for the determination of yarn pulling out from sewn specimen parameters as well as the friction on the yarn slippage at the sewn seam parameter (seam opening *d*) was investigated. Considering the results obtained from the reviewed literature analysis four mechanical characteristics were selected having the highest importance on the yarn seam opening *d*. They were the following: woven fabric bending rigidity in warp direction *B1*, yarn pull-out force $F_{\text{pull-out}}$ or/and woven fabric elongation in warp direction *E100-1*, yarn pull-out displacement $\varepsilon_{\text{pull-out}}$ and their selection validity was proven according to the high values of determination coefficients.

2.4.1. The application of multivariable linear regression for the classification of the woven fabric mechanical characteristics

First of all two independent variables and nine cases were used for the research dependence of attribute – seam opening *d*. Created linear regression model was characterized by a relatively high statistical significance ($p = 0.002$) and by the acceptable model quality indicators.

Trying to collect more information about created regression model quality fulfilled the factorial analysis of the independent variables. The factor analysis was fulfilled using the principal component analysis and Varimax methods. Factorial analysis was used to evaluate the quality of the compilation because of the small set of the research examples, which needs more empirical evidence to be sure that the research results are valid. Comparing regression and factor analysis methods, factor analysis gives more information about additive informativeness of the independent variables and about the quality of their compilation, when regression characterizes the impact of the independent variables on the dependent variable.

Cumulative use of the regression and factor analysis enabled to find that additive informativeness of studied characteristics is insignificantly higher than each of them separately. On the one hand, the result proves the accuracy of both variables inclusion to the model. On the other hand, insignificant higher value shows that here is need the greater number of the cases in order to answer to the question: is this variation regular or trivial? Two additional independent variables were added to the designed multivariate linear regression model. They were used for the explanation of the attribute – seam opening *d* change in the designed multivariate linear regression model. The objective of it was to create model of the – seam opening *d* change factors, which conditionally economically and enough objectively would identify the change factors of the attribute. Factors were selected according to their qualitative features and according to their logical impact on the attribute.

Table 2. Woven fabrics' mechanical properties determined applying FAST methods [29]

Woven fabric mechanical properties	P11d+m	P11d	P11z	P14d+n	P12d	P4	D	R	KR
Bending rigidity in warp direction *B1*, μNm	11.6	9.8	28.9	8.8	9.4	5.1	22.9	19.2	20.4
Elongation in warp direction *E100-1*, %	0.10	0.06	0.12	0.16	0.05	0.22	1.00	0.84	0.95

New model had relatively stronger statistical significance comparing with the previously created one. The estimated significance ($p = 0.039$) and the SSE (sum of square error) were lower than SSR (sum of square regression) (Tables 3 – 6). It proves the good quality of the model. Also, there was performed the validation factor of independent variables, using the principal component analysis and Varimax method. It shows that connection of all independent variables into one additive index is expedient. Connection of the variables into an additive index allows increase the informativeness of any single variable in 2.671 times. Finally, it was proven that created additive index of fabric characteristics „Model_F_REGR“ has the significant impact on the attribute – seam opening *d*.

2.4.2. Application of k-mean for the classification of the woven fabrics mechanical properties

K-mean method was selected because it creates the meaningful groups from selected variables, which statistically differ one from each other. In this research, it is assumed that the application of k-mean method is correct, when the distant in z-scale between cluster centers equals to one or it is greater than one standard deviation. In such cases, even in small samples, the difference can be recognized as statistically significant if it is enough large distance between the cluster centers. It can be interpreted on the basis of empirical research practice, where the correctness of the research method judged on statistic and on scientific logic.

Cluster model, which was created using k-mean method, confirms that "Model_F_REGR" is able qualitatively and statistically to describe the behavior of the woven fabrics, and correctly represents all four independent variables from which it is created.

Fulfilled model of the dependence of the mechanical characteristics (*E100-1*, $F_{\text{pull-out}}$, $\varepsilon_{\text{pull-out}}$, *B1*) on the seam opening *d* had shown, that based on the woven fabrics' mechanical properties linear regression model can be estimated. Moreover, it is statistical sensitive and qualitatively complete even in a small sample.

3. RESULTS AND DISCUSSION

3.1. The influence of the deformation mode on the yarn slippage at the sewn seam in the woven fabrics

The experimental results have shown that relative elongation ε and the performance of the investigated sewn woven fabrics were dependent on the deformation mode (Fig. 5, b). During standard uniaxial deformation the elongation of specimens was lower, e. g. for P11d fabric it was equal to 7.84 %, than the one applying the new method. For example, it was equal to 13.51 % for P11d fabric (see Fig. 5, a, b).

It is obvious, that the stick-slip effect (UzdS+c) did not appear in the tensile curve of fabric sewn specimens mounted on the cylinders of a new clamping device (UzdS-c) (Fig. 5, b). This confirms the well known theory that during standard uniaxial tension the stress and strain distributes uneven in the specimen area [11, 14].

The higher relative elongation (it varied from 9.34 % to 19.89 %) was determined applying UzdS+c deformation mode (Fig. 6, b). During standard uniaxial tension, it varied from 5.27 % to 16.6 % (Fig. 6, a). And conversely, during applying standard tension method (UzdS-c), the seam opening *d* was higher than the one of UzdS+c case (Fig. 6, a, b). These results demonstrate, that during standard tension (UzdS-c) the sewn fabric specimen narrows in the middle part, and it does not narrow in this place during applying new test method (UzdS+c). Here, the deformation is distributed more evenly.

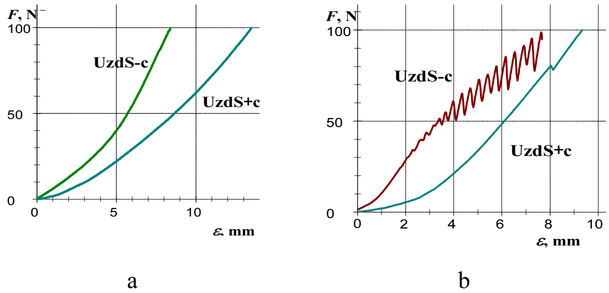


Fig. 5. The tension curves of specimens with sewn seams: a – dyed lining woven fabric P11d; b – raw lining woven fabric P11z; UzdS-c – standard uniaxial tension; UzdS+c – tension applying a new test method using a new clamping device with cylinders

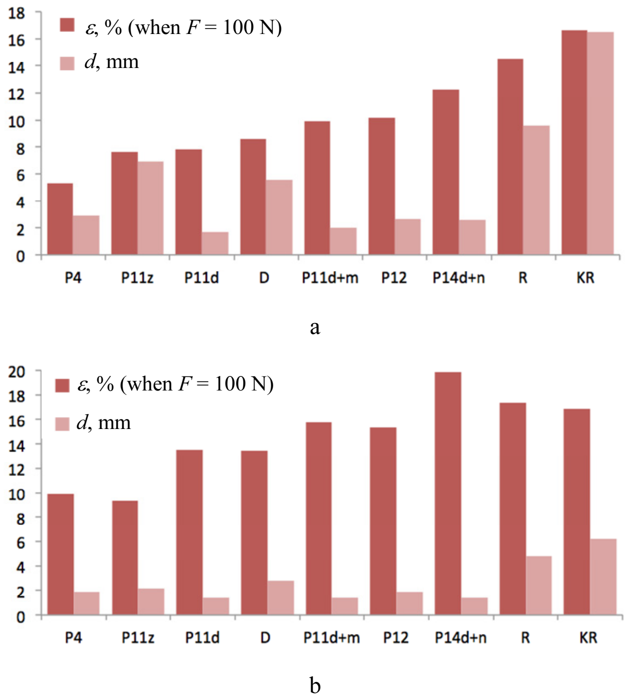


Fig. 6. The influence of the deformation mode on seam opening *d* and on relative elongation ε during standard uniaxial tension (UzdS-c) (a) and applying a new yarn slippage method (UzdS+c) (b)

In the case of UzdS-c deformation the seam opening *d* were higher for all analyzed fabrics and it varied from 1.69 mm to 16.5 mm, and in the case of UzdS+c method – from 1.38 mm to 6.18 mm (Fig. 6, a, b). The high difference between the applied test methods was determined for woven fabrics KR, P11z, D and R. For other fabrics the seam opening *d* was equal to about 10 mm. The reason for this was that the low stability of textile materials without finishing [4, 5, 7].

Two typical cases were determined according to the distribution of fabrics' seam slippage parameters h, d_v and d_a in respect to the total seam opening d (Fig. 7, a). The total seam opening d of twill weave R fabric and of combined twill weave KR fabric were equal to 9.62 mm (UzdS-c), 4.81 mm (UzdS+c) and 16.48 mm (UzdS-c), 6.18 mm (UzdS+c) as well as the parameter h for these fabrics – 1.05 mm (UzdS-c), 1.13 mm (UzdS+c) and 0.89 mm (UzdS-c), 1.14 mm (UzdS+c), respectively. This proved, that the deformation method had the higher influence on the fabric behavior in the specimen zone without the seam comparing with the one in the sewn seam zone. And for the other investigated fabrics the stitch opening width h took larger part in the total seam opening d (Fig. 7, b). It can be stated that the structure of fabric was mostly distorted applying UzdS-c deformation method.

The linear dependence between p_v, p_a parameters and parameter d was determined. After the increase of p_v, p_a, the d decreases applying both test methods. The statistical reliability of determined dependency between p_v and p_a parameters and d parameter was higher for UzdS+c case, notwithstanding that the same number of specimens was used applying both test methods. So, it could be stated that the new test method is more accurate.

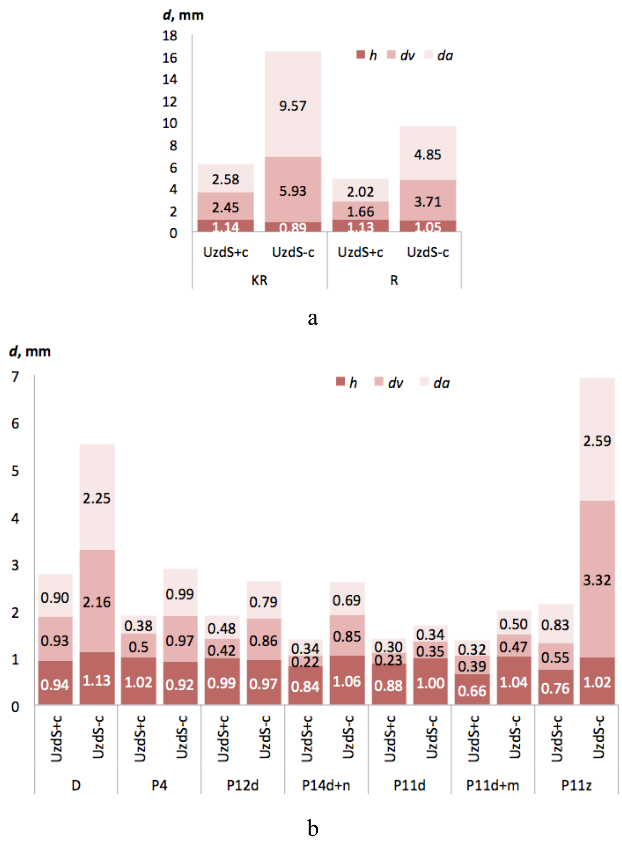


Fig. 7. The values of seam opening d constituents (h, d_v, d_a) (Fig. 3) of all investigated fabrics (a, b)

The obtained results also had shown that the yarn slippage at the sewn seam was dependent also on the position of seam allowances in respect to stitching line or on the friction. When the seam was placed on the cylinder surface with unrestricted seam allowances (UzkS+cui) (Fig. 2, d), it was very complicated to measure the seam opening parameter. Therefore, the parameters d_v, d_a, and their sum d_{va} were analyzed (Fig. 3). In this case, the yarn slippage at the sewn seam in P14d+n, P11d and P11d+n woven fabrics was not determined (Fig. 8). The seam slippage parameter d_{va} does not exceed 0.75 mm for the lining fabrics P4, P12d and P11z due to friction between specimen and cylinder, which initiates the compression of fabric yarns between the stitches as well as influences the lower yarn slippage.

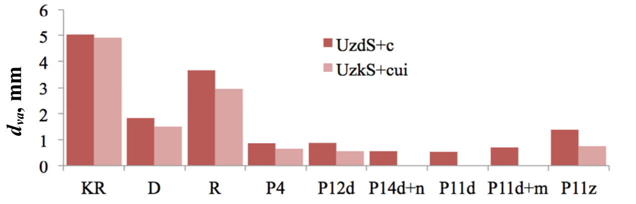


Fig. 8. The parameter d_{va} for the different deformation methods: UzdS+c – sewn specimen with the seam zone which was unrestricted by steel cylinder and UzkS+cui – specimen with sewn seam lying on the surface of cylinder with unrestricted allowances

According to the seam slippage parameter d_{va} it was determined that all investigated fabrics were more resistant to yarn slippage at the sewn seam for UzkS+cui deformation case compared them with the ones of UzdS+c deformation case. The slipped yarns were more deformed than other yarns. These yarns had to overcome not only the tension, compression, but also – the friction, which decreases the yarn slippage in the woven fabrics.

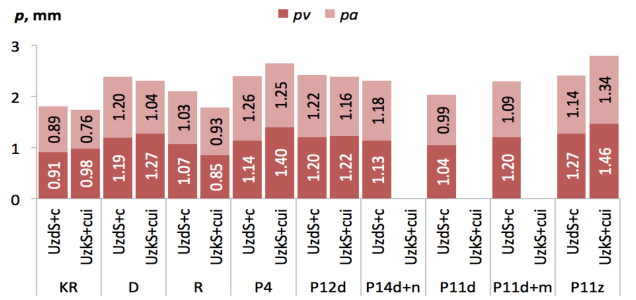


Fig. 9. The parameters p_v and p_a for two deformation methods: UzdS+c and UzkS+cui (Fig. 2)

The analysis of results presented in Figure 9 had shown that, the yarns moved more closely to each other, especially in fabrics KR, D and R, during applying UzkS+cui deformation method comparing with UzdS+c method. This proves, that d_v and d_a parameters increased as well as the p_v and p_a yarn compression parameters decreased, except the opposite tendency for fabrics P4 and P11z during UzdS+cui deformation, supposedly, because of low coefficient of dynamic friction ($\mu_D = 0.03$) between lining fabrics and steel cylinder.

When the seam allowances were bent to on side in respect to the stitching line (UzkS+c (Fig. 2, a) the seam opening was formed due to yarn slippage in the both opposite zones in respect to seam stitching line in the woven fabrics D, R and KR or due to yarn slippage in the zone without seam allowances, e. g. in woven fabric P4. The other investigated woven fabrics were completely resistant to yarn slippage at the sewn seam, similarly to all investigated woven fabrics in UzdS+cuc case. Meanwhile, the yarns slipped at the seam in the woven fabrics D, R and

KR. The seam opening d was highest (1.68 mm) for fabric R and it was the lowest (1.01 mm) for fabric D.

The comparative analysis between UzdS+cuc, UzkS+c and UzkS+ca deformation modes had shown that the highest resistance to yarn slippage at the sewn seam was in the woven fabrics D, R and KR during applying UzkS+c deformation method, supposedly because of the higher specimen thickness in the seam zone with allowances. Therefore the tension and friction forces were distributed irregularly. When the cylinder of clamping device was covered with lining woven fabric P11d (UzkS+ca, Fig. 2, b) the yarn slippage at the sewn seam in the woven fabrics D, R and KR was lower ($d = 0.9$ mm – 1.65 mm) compared with UzkS+c case (Fig. 2, b) ($d = 1.1$ mm – 2.48 mm). Meanwhile, p_v and p_a parameters were almost independent on the friction between specimen and cylinder.

3.2. The determination of the parameters of yarn pulling out from the woven fabrics using the newly created original test method

The pull-out force-displacement curves were recorded during applying the newly created test method. The typical zones of curves were analyzed according to the different behavior of yarns during their pulling out from investigated fabrics (Fig. 10).

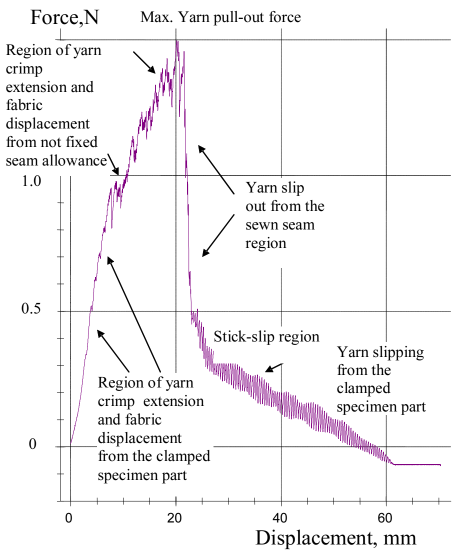
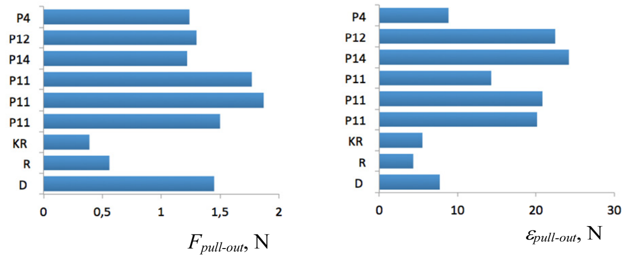


Fig. 10. Yarn pull-out force–displacement curves with the typical zones

These zones were the following: the zone of yarn extension due to its crimp and of fabric displacement in the fixed part of specimen; the zone of yarn extension due its crimp and due to fabric displacement in the unrestricted seam allowance; the maximal pull-out force; the zone of yarn slippage in the sewn seam; the zone of yarn slippage in the specimen part between the clamps – it represents the stick-slip effect.

The yarn pull-out force $F_{\text{pull-out}}$ and yarn pull-out displacement $\varepsilon_{\text{pull-out}}$ were determined (Fig. 11) to explain the yarn slippage process influenced by the friction appeared in the different contact zones.



a b

Fig. 11. The yarn pull-out forces $F_{\text{pull-out}}$ (a) and yarn pull-out displacements $\varepsilon_{\text{pull-out}}$ (b) of woven fabrics

The results have shown, that the lowest yarn pull-out force demonstrate fabrics R and KR which are with longer flats compared with plain weave fabrics [5, 6]. D, K, KR fabrics also had the lowest yarn pull-out displacement because these fabrics were not treated. The polyester fabric P4 has also low $\varepsilon_{\text{pull-out}}$. In this case the finishing has not high influence on PES fibers, which are with reduced charges on the hydrophobic ends and it will have more affinity to the fibre itself. Supposedly, the $\varepsilon_{\text{pull-out}}$ depended also on fabric yarn crimp and on structure parameters [15-20].

3.3. Modeling of the dependence between the mechanical characteristics of woven fabrics and the parameter of yarn slippage at the sewn seam in woven fabrics

Modeling of seam opening d fulfilled selecting different independent variables (mechanical properties). In this part of the paper only the last regression model is described because it was used for classification.

Using the regression four independent variables were chosen (Tables 3-6): bending rigidity in warp direction $B1$, yarn pull-out force $F_{\text{pull-out}}$, elongation in warp direction $E100\text{-}1$, yarn pull-out displacement $\varepsilon_{\text{pull-out}}$.

Table 3. Model summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.939[a]	0.881	0.762	2.37364

a – predictors: (constant), *E100-1*, *B1*, $F_{\text{pull-out}}$, $\varepsilon_{\text{pull-out}}$;
b – dependent variable: seam opening *d*.

Table 4. Coefficients[a]

Model	Unstandardized Coefficients, *B*	Standardized Coefficients, Beta	*t*	Sig.	Correlations			Collinearity Statistics	
					Zero-order	Partial	Part	Tolerance	VIF
(Constant)	10.951		2.108	0.103					
$F_{\text{pull-out}}$	–7.129	–0.728	2.802	0.049	–0.764	–0.814	–0.483	0.440	2.270
$\varepsilon_{\text{pull-out}}$	–0.066	–0.106	–0.335	0.755	–0.724	–0.165	–0.058	0.295	3.395
B1 (recoded)	0.335	0.549	2.423	0.073	0.607	0.771	0.418	0.579	1.727
E100-1 (recoded)	–1.345	–0.114	–0.312	0.770	0.749	–0.154	–0.054	0.225	4.450

a – dependent variable: seam opening *d*.

Table 5. Descriptive statistics

Parameter	Mean	Std. Deviation	N
d	5.6022	4.86838	9
$F_{pull\text{-}out}$	1.2556	0.49702	9
$\varepsilon_{pull\text{-}out}$	14.2544	7.82855	9
$B1$	15.1222	7.97414	9
$E100\text{-}1$	0.3889	0.41102	9

Table 6. ANOVA[b]

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	167.073	4	41.768	7.413	0.039[a]
Residual	22.537	4	5.634	–	–
Total	189.609	8	–	–	–

a – predictors: (constant), *E100-1*, *B1*, $F_{pull\text{-}out}$, $\varepsilon_{pull\text{-}out}$;
b – dependent variable: seam opening *d*.

Correlation between them was high and they had high impact on the seam opening *d*. This means, that they provide the sufficient information about the change of the *d* to the model.

The index „Model_F_REGR“ was created using the factor analysis. For the factor analysis same variables were included in the regression model: *B1* (recoded[1]), $F_{pull\text{-}out}$, *E100-1* (recoded), and $\varepsilon_{pull\text{-}out}$ (Tables 7 – 9). The factor analysis of mentioned variables had shown that all four variables could be connected into one single index.

The created index enabled to classify the investigated woven fabrics, what can be interpreted as particular scientific novelty and is important to the practice. Here, the scientific novelty is the result, which enabled better cognize the combinations of chosen characteristics and gave more information about relationships between fabric properties.

Table 7. KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.675
Bartlett‘s Test of Sphericity	Approx. Chi-Square	13.568
	df	6
	Sig.	0.035

Table 8. Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.671	66.770	66.770	2.671	66.770	66.770
2	0.914	22.854	89.624			
3	0.263	6.570	96.193			
4	0.152	3.807	100.000			

Note: Extraction method: principal component analysis.

Table 9. Component Matrix[a]

	Component
	1
E100-1 (recoded in order to avoid minus)	0.947
$\varepsilon_{pull\text{-}out}$	0.921
$F_{pull\text{-}out}$	0.745
B1 (recoded in order to avoid minus)	0.609

Note: Extraction method: principal component analysis;
a – 1 components extracted.

[1] Recoded in order to get positive meanings in component matrix to be possible to create additive index.

Three-cluster model, which was created using „Model_F_REGR“, enabled to split all nine investigated fabrics into three logical explainable groups, which statistically differ one from each other according to the characteristics of seam slippage. The highest differences were determined between the not sensitive and sensitive fabrics to the yarn slippage at the sewn seam in woven fabrics (Fig. 12).

The group of the medium sensitive according to yarn slippage at the sewn seam fabrics statistically differs from the other groups only according to the bending rigidity in fabric warp direction *B1*, yarn pull-out force $F_{pull\text{-}out}$, elongation in warp direction *E100-1*, yarn pull-out displacement $\varepsilon_{pull\text{-}out}$ parameters. By the seam opening *d* the medium sensitive to yarn slippage at the sewn seam fabric group statistically differ only from the group of sensitive fabrics on investigated yarn slippage at the sewn seam.

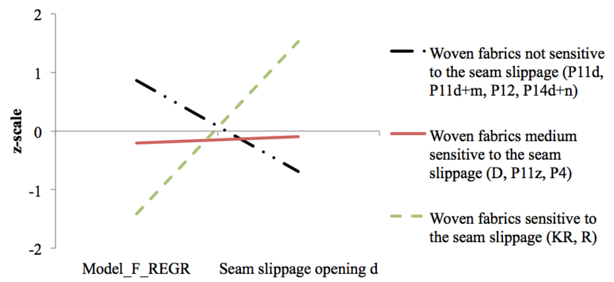


Fig. 12. Classification model based on the analysis of yarn slippage at the sewn seam in woven fabrics

After summarizing all the results it can be stated, that selected four independent variables: bending rigidity in warp woven fabric direction *B1*, yarn pull-out force $F_{pull\text{-}out}$, elongation in woven fabric warp direction *E100-1*, yarn pull-out displacement $\varepsilon_{pull\text{-}out}$ are suitable to describe the change in the main parameter of yarn slippage at the sewn seam (seam opening *d*).

The suggested modeling method can be applied for the characterization of yarn slippage at the sewn seam in woven fabrics not performs standard methods of yarn slippage at the sewn seam. The advantages of the suggested method were the following: the smaller amount of woven fabrics for specimen preparation was needed; and it required the less time input. It also can be used for the more accurate characterization of yarn slippage at the sewn seam in woven fabrics based on the analysis of friction between fabric yarn systems.

4. CONCLUSIONS

The new method for the testing of the yarn slippage at the sewn seam in woven fabrics based on biaxial deformation is capable to imitate more similar to the real wearing conditions of clothing. During applying it, the seam opening can be more accurately measured compared to the case of standard test method, the influence of the friction on the yarn slippage at the sewn seams can be estimated. Applying the original method the sewn fabrics are less sensitive to yarn slippage, but their elongation is higher compared with the one determined using standard method.

The yarn slippage at the sewn seams in the investigated woven fabrics was low when the unrestricted seam allowances were deformed on the surface of cylinder. Additionally, the yarns did not slip at the sewn seam in viscose lining (except polyester lining), when allowances were bent to one side in respect to stitching line because of the high difference in specimen thicknesses and of friction in the opposite sides of stitching line. D, R, KR woven fabrics, which were not treated were not resistant to yarn slippage at the sewn seams.

The obtained results of the yarn pulling out from sewn woven fabric are significant to explain the yarn slippage at the sewn seam in woven fabrics in respect to friction aspect.

Created derivative indicator „Model_F_REGR enabled better study the combinations of chosen characteristics (bending rigidity in warp direction *B1*, yarns pull-out force $F_{\text{pull-out}}$ or/and elongation in warp direction *E100-1*, yarns pull-out displacement $\varepsilon_{\text{pull-out}}$) and gave more information about interrelations of fabric features. Also, this model increases the informativeness of independent mechanical characteristics in 2.671 times. This indicator enabled better cognize the combinations of chosen characteristics and gave more information about interrelations of fabric properties.

Created three-cluster model enabled to split all nine investigated fabrics into three logical explainable groups, which statistically differ one from each other according to the characteristics of the seam slippage: fabrics are not sensitive to yarn slippage at the sewn seam; fabrics that are medium sensitive to yarn slippage; and fabrics that are sensitive to yarn slippage. These findings are significant from the viewpoint of materials' science and practice.

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