The Peculiarities of New Textile Hand Evaluation Method

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Abstract: The paper presents information concerning metrological and technical characteristics of KTU-Griff-Tester device, the optimization of its parameters and the cases of its application. It was defined that the behaviour of textile material during its extraction through a rounded hole depends upon its structure. Variations of geometrical shape of woven and knitted specimens can be described by mathematical expressions of shortened epicycloids and Cassini ovals. It is shown that waving process of disc shaped specimen can be predicted on the basis of the law of sine curve. The examples of textiles treatment with different types of commercial softeners are presented, herewith showing the suitability (sensitiveness) of the new device to detect the changes of textile hand. Meantime it is shown that the level of materials anisotropy can be decided on the basis of transformations of specimen's geometrical shape.

Keywords: Textile hand, Evaluation methods, The extraction through a hole, Geometry transformations, Anisotropy, Mathematical models

Introduction

Hand is one of the most important serve properties of textiles, which decides the attitude of consumer. Textile hand is associated with the senses that are received by the person while touching the material. For a long textile hand was evaluated by subjective methods, i.e. questioning the panel of judges [1,2]. Simultaneously the attempts were made to evaluate the hand objectively, i.e. through the suit of experimentally defined textile properties. With the appearance of KES-F and FAST equipment the evaluation quality of these parameters has evidently improved [3]. However, this equipment in many cases was inaccessible due to rather complicated interpretation of obtained data, long testing durations and high testing prices.

It must be noted that several testing devices of specimen's extraction through a rounded hole already exist on the basis of which the evaluation of hand is much more simple in the sense of methodology [4-6]. Though the first data concerning this type of testing was presented sufficiently long ago, deeper investigations in this sphere were not done. More reliable testing base was created only some years ago [7-10].

In this research the main attention is paid for so called restrained extraction of specimen through a rounded hole. According to testing principle it reminds punching test, which in textiles material science is used to determine strength properties and shape stability of textiles in biaxial loading [11]. The difference between these testing methods is that in extraction test smaller punch is used and the outer contour of the specimen is not restrained, only limited by certain spacing in which the specimen slides changing its geometrical shape. The regulation of spacing height is an additional mean enabling to control the extraction process. It

allows choosing the right testing mode in more wide range compared to "free" extraction tests [4-6].

The aim of this research was to present the possibilities of KTU-Griff-Tester device to evaluate such important textiles properties as hand, performance peculiarities and anisotropy level on the basis of disc shape specimen's restrained extraction through a rounded hole.

Methodics

KTU-Griff-Tester device was created to realise the restricted extraction of disc shaped specimen through a rounded hole. The general view and principal scheme of it are presented in Figure 1 [10-16].

Experimental approbation of the device was performed on the basis of more than 40 examples of woven and knitted materials and their fused systems, different in structure and end use. In this work only the most typical of them are presented (Table 1).

The extraction process is evaluated referring to the parameters of the extraction curve $H - P$ (height – force) and the indicators of the variations of specimen's geometrical shape (Figure 2). The device KTU-Griff-Tester can be mounted in the clamps of any type of tensile testing machine, the force scale of which must be not less than 100 N. Tension rate must be 100 mm/min. On the basis of the extraction curve four parameters are registered, i.e. maximum force P_{max}, slope angle of curve's initial part tg α, extraction work A and maximum extraction height H_{max}. The fifth parameter - $\Delta\delta$, which enters the complex criterion Q for textile hand evaluation is determined by thickness gauge assessing the compression level of the material measured at two pressures differing by ratio 1/5.
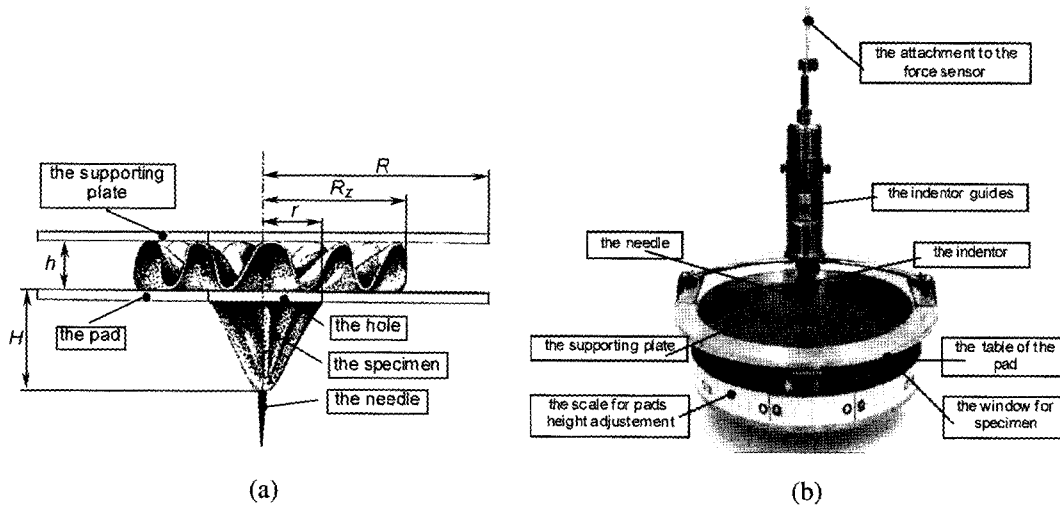
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(a)   (b)

Figure 1. Principal scheme of KTU-Griff-Tester device (a) and its general view (b).

Table 1. Characteristics of investigated materials

Symbol	Composition	Structure	Thickness δ, mm	Surface weight, g/m^2	Anisotropy level, K_a
W	Wool, polyester	Hopsack	0.63	252	2.7
W-3	Polyester (wale dir.), viscose (warp dir.)	Hopsack	0.39	124	0.2
K-2	50 % cotton, 50 % viscose	Interlock	1.00	260	3.1
K-0	100 % cotton	Interlock	0.89	247	7.3
K-R	100 % cotton	Interlock	0.87	214	6.5
K-V	100 % cotton	Rib	0.79	143	12.5
K01	100 % cotton	Plain jersey	0.53	157	...
K02	100 % cotton	Rib	0.76	180	...
K04	95 % cotton, 5 % lycra	Plain jersey	0.60	206	...

Note: The first letter of symbol indicates woven fabric – W or knitted material – K. $K_a = \varepsilon_t/\varepsilon_l$, where ε_t – elongation in transverse direction (weft or course); ε_l – elongation in longitudinal direction (warp or wale).
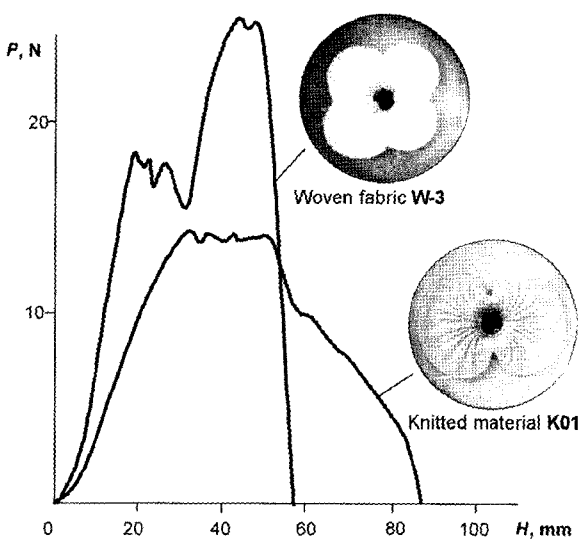

Figure 2. Typical extraction curves $H - P$ of woven fabric W-3 and knitted material K01, and the shapes of their specimens at $H = 30$ mm.

$$\Delta\delta = \frac{\delta_1 - \delta_5}{\delta_1} \cdot 100\% \qquad (1)$$

Complex criterion Q is defined on the basis of polar diagram in which five (or four) parameters are laid in a strict order as it is shown in Figure 3. This order in clockwise direction is always the same: P_{max} - tg α, - A - $\Delta\delta$ - H_{max}. Thus, criterion Q enables to compare different fabrics according to their total hand evaluations.

Optimization of the main parameters r and h of the device is based referring to the specimen's jamming conditions in the rounded hole and between the limiting plates [12]. The dangerous zone in which the specimen can jam during its extraction locates at the outer contour of the pads hole. The jamming phenomenon is related with the thickness δ and the radius R of the specimen. In KTU-Griff-Tester device the size of the specimen is similar to those used in other devices of the same type, i.e. $R = 56.5$ mm (100 cm^2) [7,8].
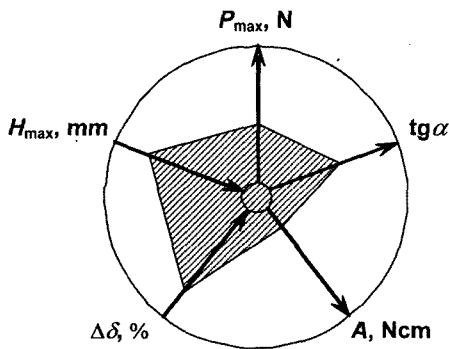
The specimen doesn't jam in the hole of the pad when:

Figure 3. The scheme of complex criterion Q determination for textiles hand evaluation.

$$r \geq \sqrt{2R\delta} \qquad (2)$$

and it doesn't jam between the limiting plates when:

$$h \geq \frac{R}{r} \cdot \delta \qquad (3)$$

Additionally the device has a set of changeable pads with the holes of different radiuses the values of which are $r =$ 7.5; 10.0; 12.5; 15.0 and 20.0 mm, respectively. The shape of the holes upper edge significantly affects the resistance of the material during extraction. For this reason in all cases its chamfer angle was $\rho = 1.0$ mm. Each value r corresponds to a certain range of thicknesses δ of tested materials, while parameter h for all pads can be changed gradually taking into account the value of δ from the (3) equation with the accuracy of 0.05 mm.

Both limiting plates (supporting and pad) are made of transparent materials, which allow to observe and to capture the variations of specimen's shape during the extraction.

Theoretical Analysis

It was assumed that in the case of idealised (isotropic) material at the initial stages of extraction process the outer contour of the specimen waves and obtains the shape, which reminds the sine curve (Figure 4). On the basis of later assumption the number of waves N can by calculated using the equation [17]:

$$N = \frac{2\sqrt{2}}{C}\sqrt{3(2R^2 - RR_z) - (4R - R_z)\sqrt{2R^2 - R \cdot R_z}} \qquad (4)$$

where $C = 0.5\ h$.

It was defined that in the case when $R_z = 0.95 \div 0.9\ R$ the experimental and calculated number of waves N practically coincides for most of the materials [12].

However geometrical shapes of real materials during extraction through a hole deviates from idealised shapes, i.e. from the shape of a rounded disc. In this respect two cases can be analysed, i.e. knitted materials and woven fabrics.
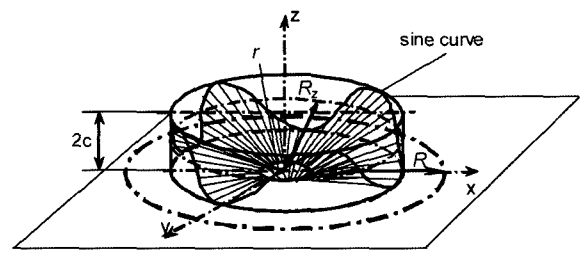

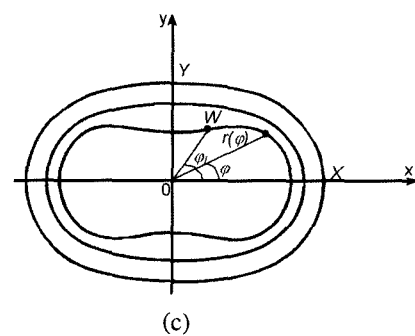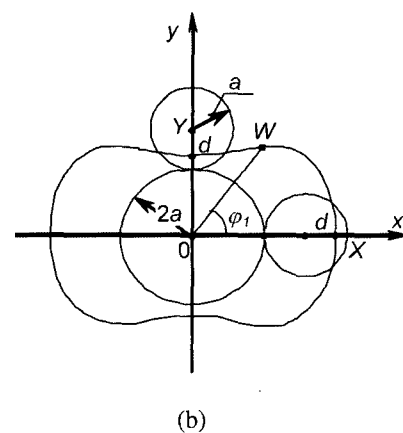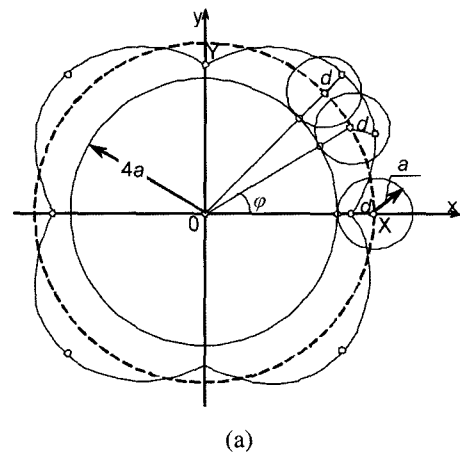**Figure 4.** Wrinkled surface of the tested specimen.

(a)

(b)

(c)

Figure 5. The schemes of shortened epicycloids when radiuses of circles equals to $4a$ and a (a) and $2a$ and a (b); Cassini ovals (c).

The difference between them is essential. The shapes of knitted materials transform into ovals, while the shapes of woven fabrics – into the shape of four-leaved clover. Intermediate shapes between mentioned are obtained for fused textile systems [16].

In the case of restrained extraction when rounded specimen is pulled through the hole of the pad an interesting transformations of specimens shape are taking part. These changes become significant when outer contour of specimen approaches the hole of the pad, i.e. R_z approaches the value of r. The analysis of specimens projections at different stages of deformation have shown that geometrical shapes of woven fabrics can be mathematically approximated with sufficient accuracy using the expressions of shortened epicycloids, while the shapes of knitted materials – using the expressions of Cassini ovals and shortened epicycloids [18,19]. The results of distance measurements from specimen's contour to its centre (defined at the angles $\varphi = 15°$) in the captured views of real materials (Figure 2) showed close relationship with the above mentioned models (Figure 5(a) and (b)) and that parameters a and d can approximate the outer contour of woven or knitted specimen with sufficient accuracy. When specimen's outer contour approaches the pad's hole the accuracy of approximation worsens, especially for those materials the anisotropy coefficient of which is high. A vivid example of such material can be knitted fabric K-V (Table 1) the anisotropy coefficient of which is $K_a = 12.5$. In the partway of extraction process the stiffer system (wale direction) of this material gets into the zone of the hole and the specimen looses its typical shape.

The calculations have proved that the application of shortened epicycloids to describe geometrical transformations of the specimen at different stages of its extraction is fairly close to the parameters of geometrical variations of real materials in the same conditions [16]. Surely, except those cases when specimen's outer contour approaches the pad's hole, i.e. at the final stages of extraction. So, the results of the investigations of shape's geometrical transformations allow supposing that it can be applied not only to solve the problems of textiles hand objective evaluation, but also to model certain performance properties of technical textiles (parachutes, sails, filters, specialised clothing, etc.).

Control of Textile Hand after Technological Treatment

This section is intended to illustrate the application possibilities of KTU-Griff-Tester for the evaluation of chemical softeners effect upon the changes of textiles hand.

Four widely known commercial surface activating softeners (cationique) LENOR (Czech), SILAN (Hungary), SOUPLINE (France) and DOSIA (Poland) were used in washing process of three knitted materials (Table 1). The results of the investigation are presented in Table 2. It can be seen that after specimen' treatment by mentioned softeners the values of parameters P_{max}, tg α and A decreases compared with the controlled (original) samples and those that were washed in pure water. In most case the decrease is essential because the sum of errors is less the difference of parameter changes. It also can be seen that the values of parameters $\Delta\delta$ and H_{max} increase.

The data in Table 2 shows that all five parameters (except H_{max}) vary in a fairly wide range. It can be explained by the fact that treatment with commercial softeners significantly changes the initial parameters of investigated textile materials.

Analysis of variation limits of each parameter separately reveals different tendencies. The variation of parameter P_{max}

Table 2. The summary of investigation results

Symbol	Type of treatment	P_{max}, N	tgα	A, Ncm	$\Delta\delta$, %	H_{max}, mm	Q
K01	C – Control	10.12 ± 0.16	4.41 ± 0.11	37.6 ± 0.7	21.3 ± 0.9	62.1 ± 0.8	1.00
	L – Lenor	9.60 ± 0.54	4.40 ± 0.10	36.1 ± 0.9	26.5 ± 0.9	62.1 ± 0.8	0.74
	S – Silan	9.24 ± 0.24	4.36 ± 0.25	35.0 ± 1.5	26.5 ± 0.8	62.1 ± 1.8	0.48
	Su – Soupline	10.30 ± 0.20	4.67 ± 0.19	49.4 ± 1.1	35.3 ± 1.0	62.6 ± 0.5	0.74
	D – Dosia	9.72 ± 0.37	4.60 ± 0.22	47.4 ± 1.2	34.0 ± 1.2	62.4 ± 0.8	0.51
	W – Fresh water	11.84 ± 0.22	5.48 ± 0.24	46.6 ± 1.4	26.5 ± 0.8	63.8 ± 0.8	1.27
K02	C – Control	12.98 ± 0.29	5.36 ± 0.12	78.4 ± 3.0	17.1 ± 0.7	83.7 ± 0.9	1.00
	L – Lenor	10.29 ± 0.40	3.98 ± 0.13	52.0 ± 1.9	20.3 ± 0.7	84.7 ± 2.6	0.13
	S – Silan	10.10 ± 0.24	3.96 ± 0.12	50.0 ± 1.9	22.5 ± 1.0	84.1 ± 2.9	0.09
	Su – Soupline	11.97 ± 0.50	4.76 ± 0.14	74.4 ± 2.8	23.0 ± 0.9	85.6 ± 1.4	0.17
	D – Dosia	11.28 ± 0.26	4.57 ± 0.14	69.4 ± 1.0	23.0 ± 0.8	85.1 ± 1.2	0.15
	W – Fresh water	15.08 ± 0.52	6.19 ± 0.33	89.1 ± 5.1	20.3 ± 1.2	84.0 ± 5.1	1.10
K04	C – Control	21.44 ± 1.21	7.29 ± 0.22	113.7 ± 6.8	30.0 ± 1.2	71.3 ± 1.5	1.00
	L – Lenor	17.48 ± 0.67	5.95 ± 0.18	97.8 ± 4.09	28.3 ± 1.6	74.4 ± 1.2	0.15
	S – Silan	15.58 ± 0.37	5.73 ± 0.21	87.8 ± 3.0	24.2 ± 1.6	71.8 ± 1.2	0.29
	Su – Soupline	17.52 ± 0.47	5.85 ± 0.18	98.0 ± 3.5	25.0 ± 1.4	72.6 ± 1.5	0.31
	D – Dosia	16.64 ± 0.45	5.79 ± 0.19	91.8 ± 3.2	23.8 ± 0.8	71.8 ± 1.2	0.43
	W – Fresh water	17.44 ± 0.28	6.46 ± 0.18	95.6 ± 1.8	28.6 ± 0.9	72.0 ± 0.6	0.36

for all five technological treatments is the most significant for K02 material – 33.2 %, while the most negligible it is for the material K01 – 22.0 %. The parameter tg α significantly changes for K02 material – 36.6 % and negligibly for K01 – 20.4 %. The parameter $\Delta\delta$ in the case of all materials varies in the most wide limits (for K04 – 57.7 % and for K02 – 25.7 %). Hence, it is the most sensitive for the effect of softener. Meantime, analysing these five parameters it is hard to say which softener is the most effective. The most suitable in this sense is complex criterion Q, which in Table 2 is presented in relative form. Namely this criterion shows the most significant differences between the types of treatment. In accordance with complex criterion Q the effectiveness of softeners ranges like this: S – L – D – Su.

The Correlation between the Uniaxial Deformation and Extraction Through a Rounded Hole

The behaviour investigations of woven and knitted materials during their extraction through a hole have shown that this type of textile material's testing is more close to their performance compared to standard strip tension tests in uniaxial direction. The prime example of this is tension deformation of bias strip, i.e. when a narrow strip is stretched at the angle of $45 \pm 15°$ no threads of the specimen are fitted in the clamps of tensile testing machine by both ends. It is evident that in such a case the behaviour of a bias strip is concerned only with a shear deformation and does not have much similarities with the deformation of specimen in main directions.

During the extraction of a disc shaped specimen through a hole all the directions of the material affect each other and the obtained deformation distribution is different. Though the extraction through a rounded hole belongs to the group of biaxial testing methods, still certain similarities between the strip and disc shaped specimen exist. Firstly the directions of minimal and maximal deformations remain the same, secondly certain similarities between polar diagrams of these two testing methods exist, also [16]: in the case of knitted materials – reduction with bend point in wale direction, while in the case of woven fabrics – the minimal value of displacement R_z is obtained at the angle of $45°$, as it can be seen from captured images presented in Figure 2 and theoretical models shown in Figure 5. Thirdly – coefficient of anisotropy K_a for four knitted materials K-2, K-0, K-R and K-V, determined experimentally by uniaxial tension test at low values of external loading is closely related with calculated parameter d (Figure 5b), defined on the basis of specimens extraction through a hole results and applying the model of shortened epicycloids. The later especially suits for the knitted materials (Figure 6). It can be seen from this figure that parameters K_a and d are related by liner relationship. Hence, the dependency exists between the level of material anisotropy K_a defined by uniaxial testing and the parameter d determined during restrained extraction of a specimen through a hole at the similar
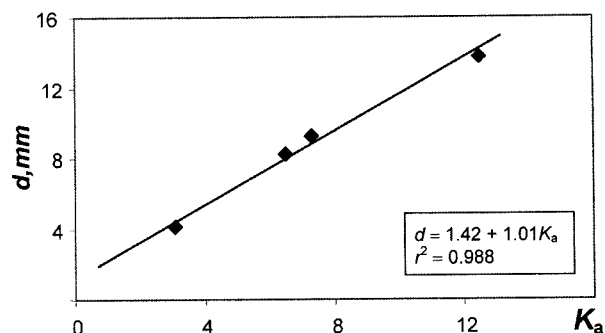

Figure 6. The dependency between the anisotropy coefficient K_a of knitted materials (Table 1) and parameter d of shortened epicycloids.

conditions of loading intensity.

Conclusion

The presented results show that KTU-Griff-Tester is technically simple and methodologically reliable instrumental device suitable to control hand properties of textile materials.

Simple (with small number of parameters) and reliable mathematical models are proposed to describe the process of disc shaped specimen's extraction through a hole. The best models for this purpose are those of shortened epicycloids and Cassini ovals at the most reliable loading conditions – initial stages of extraction deformation.

The proposed testing method based on the restrained extraction reveals the inequality of textile material properties in different directions is simple in the sense of its realisation and provides new information about the behaviour of textile materials. The developed testing method can be suitable to evaluate the effect of softeners and other types of textiles finishing.

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