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Investigation of Fabric Impact Behaviour and its Relationships with Mechanical Parameters and Hand Evaluation

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The investigation of fabrics impact behaviour is based on the registration of pendulum vibration process. To describe fabrics impact behaviour the values of impact and bounce angles of each stroke are used and the relationships of impact angles with uniaxial deformation are determined. The evaluation is performed on the basis of two groups of cotton fabric, treated by commercial stiffener. The concentration of stiffener in each group differed by 3 ml/l and by 7 ml/l, respectively. The qualified judge panel carried out subjective evaluation of textiles hand. Thus quality words such as "stretchability" and "resiliency" were used for textile hand evaluation. Relationships between subjective hand parameters and mechanical properties of the fabrics were determined. The results have shown that sufficiently close relationship exists between subjective assessment and impact behaviour of fabrics.

Keywords: impact behaviour, vibration process, judge panel, subjective assessment: stretchability, resiliency.

INTRODUCTION

The behaviour of textile materials under conditions of impact loading is important in many spheres, e.g.: pneumatic tires, off-the-road equipment, military supply systems. The later items are armor clothing and climbing ropes, the adequate performance of which depends up on the ability of the component yarns to withstand the effects of impact loading. However, fabrics in certain garment production processes are compressed dynamically, e.g. by fabric feeding mechanisms in sewing machines, gripping of single or multiple plies of fabric or certain fabric ply separation devices.

Fabrics in ready-made garments also experience multicycle dynamic impact loadings and must not loose their stable shape, e. g. in the zones of elbows or knees, thus maintaining garment's quality during all wear period.

P. M. Taylor and D. M. Pollet analyzed a new technique to measure low force impact compression on fabrics and compared the obtained results with the static compression characteristics [1].

Objective evaluation of textiles impact behaviour can also be based on the registration of vibration process of pendulum by defining the decreasing angle of vibration [2].

Nowadays many attempts are known to correlate textiles objective measurements with subjective judgements [3].

K. L. Yick, K. P. S. Chang and Y. L. How [4], S. L. Paek [5] studied the relationship between the judges' preferences and the fabric mechanical parameters. Quality words such as "smoothness", "stiffness", "weight" and etc. were analyzed for textile hand evaluation in the works published by R. L. Barker and M. M. Scheininger [6], C. J. Kim and K. Piromthamsiri [7].

X. Zeng, L. Koehl described a new method for modeling the relationship between objective and subjective fabric hand evaluation and analyzed the quality of objective and subjective data obtained from physical measurements and human panels, respectively. Fuzzy techniques and Principal Component Analysis were used in this method [8].

No information has been found concerning subjective evaluation of textiles in respect to its "stretchability" and "resiliency" yet. It is expected that such hand properties can correlate with certain parameters of fabrics impact behaviour.

So, the aim of this research was to find the parameters able to describe impact behaviour of fabrics with sufficient accuracy, also to find their relationship with the parameters of uniaxial deformation, e. g. bending rigidity, and to investigate correlations between subjective evaluation and impact behaviour of fabrics.

EXPERIMENTAL

Investigations were performed with 100 % cotton plane wave fabric: surface density (LST EN 12127:1999) – 140 g/m^2; thickness (LST EN ISO 5084:2000) – 0.38 mm; bending rigidity in warp direction – 12.22 μN·m, in weft direction – 7.39 μN·m, in bias direction by 45° angle – 9.48 μN·m. Bending rigidity was determined in accordance with FAST testing conditions.

Samples for testing were prepared in such a way: they were soaked for 15 min in stiffener (PVA dispersion) solutions of 30 ºC ±2 ºC temperature and dried at 20 ºC ±3 ºC temperature. Specimens were divided into two groups. The concentration of stiffener solution in each group differed by 3 ml/l and by 7 ml/l. Thus stiffener concentrations for both groups of samples were 0; 3; 6; 9 ml/l and 0; 7; 14; 21 ml/l, respectively. The main characteristics of treated fabric are presented in Table 1. Before testing specimens were exposed to standard atmospheres (temperature – 20 ºC ±2 ºC, humidity – 65 ±2 %) not less than for 24 h.

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Table 1. Characteristics of tested cotton fabrics treated with different concentration of stiffener

Stiffener concentration, ml/l	Surface density, g/m^2	Thickness, mm	Bending rigidity, μN·m		
			in warp	in weft	in bias
0	140.5 ±1.8	0.38 ±0.007	12.2 ±0.4	7.4 ±0.2	9.5 ±0.2
3	145.8 ±0.9	0.41 ±0.004	32.5 ±0.5	16.3 ±0.2	19.8 ±0.6
6	147.7 ±1.4	0.41 ±0.008	55.9 ±2.1	21.1 ±0.6	30.7 ±0.9
7	148.3 ±1.1	0.42 ±0.006	61.9 ±0.8	23.8 ±0.7	31.2 ±0.5
9	149.4 ±1.4	0.42 ±0.006	75.0 ±0.7	25.3 ±0.6	38.6 ±1.1
14	153.9 ±0.9	0.42 ±0.006	105.9 ±1.7	47.2 ±1.1	49.2 ±0.9
21	154.3 ±0.8	0.43 ±0.007	131.1 ±2.4	47.9 ±1.2	85.5 ±1.1

The investigations of sample's behaviour under conditions of impact loading were based on the registered decreasing process of pendulum vibration (see Fig. 1). Testings were performed using the testing base presented elsewhere [9].

The pendulum consists of a bar suspended at one end at a pivot point, which is free to rotate in vertical plane, and has a bob at the other end, where most of assembly mass is concentrated (Fig. 1). In operation the bar is inclined at an angle α_0 from its vertical (free hanging) position and clamped. After the release the bar and the mass swing downward. At the lowest point of its path the pendulum applies impact load to the specimen. After touching the specimen, the pendulum continues its swing and declines at an angle β_1, which is less than α_0. The energy available for extending the specimen is kinetic energy of the pendulum at the point of impact [2].

The process of pendulum vibration was digitally registered as a vibration curve [10]. To describe fabrics impact behaviour the values of impact ($B_1, B_2, \ldots, B_n$) and bounce ($A_0, A_1, \ldots, A_n$) angles of each stroke were used (Fig. 2.).

Testing conditions of fabrics impact behaviour were: initial angle α_0 of the pendulum – 5.1°; duration t of one vibration process – 20 s; mass m of the bob – 106.95 g; radius r of the bob – 13.5 mm; pendulum length l – 1.5 m; radius R of the specimen – 50 mm.

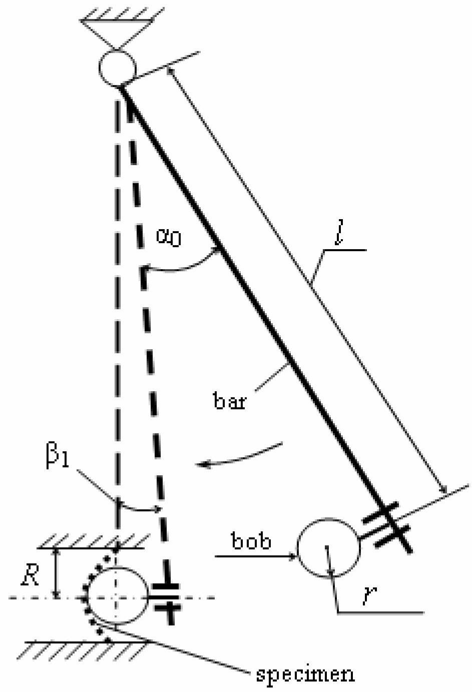

Fig. 1. Testing scheme of fabrics impact behaviour

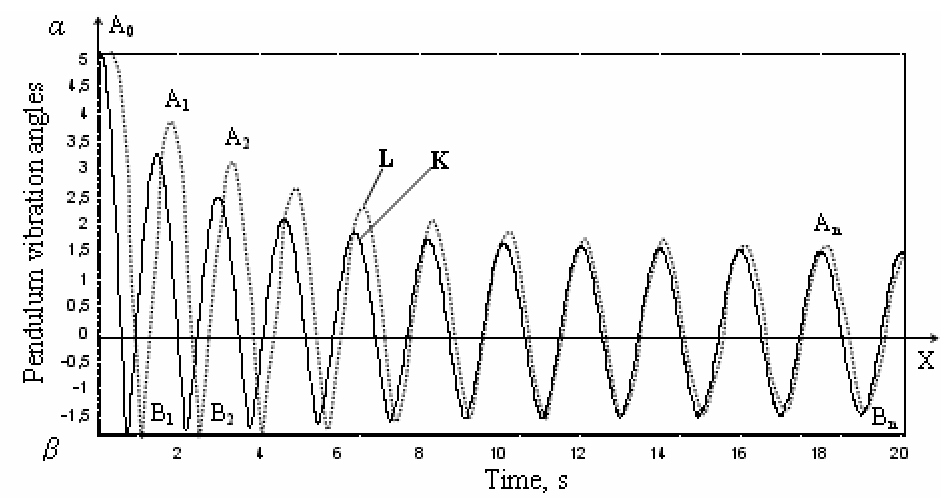

Fig. 2. Registration of pendulum vibration process (K – sample treated with 7 ml/l stiffener concentration, L – non-treated sample)

One of the aims of this research was to define the correlation between properties of subjective assessment and fabrics impact behaviour.

For this, judge panel consisting of ten experts (researchers and students from the textile and clothing sectors) was chosen. Subjective evaluation was performed in standard atmosphere conditions with two groups of samples treated with different concentrations of stiffener (sample size was 300×300 mm).

Experts were provided with specimens given one by one in mixed order. They were asked to rank the fabrics from less stretchable to more stretchable.

"Stretchability" and "resiliency" were chosen for subjective evaluation of fabrics. Experts were provided with explanatory and visual information how to assess these features.

Subjective evaluation of "stretchability" was performed holding the edges of the sample with both hands then stretching it three times in the same direction and evaluating the strain of the sample. "Resiliency" was assessed in the following way: holding sample in hands it was stretched three times and without unhanding it the sample was allowed to return to initial position. Experiments were performed in warp and in weft directions.

Kendall's coefficient of concordance W [11] was used to determine the level of agreement of experts:

$$W = \frac{12\left[\sum_{j=1}^{n}\left(Rj - \overline{R}\right)^2\right]}{r^2 n(n-1)(n+1)},$$

where R_j is the sum of the ranks given to each object (fabric); $\overline{R}$ are the means of these rank sums; r is the number of experts; n is the number of fabrics.

RESULTS AND DISCUSSION

Impact behaviour of fabric, treated with industrial stiffener was investigated by registering decreasing pendulum vibration process in $x - y$ coordinate system, and by defining impact (B_{1-n}) and bounce (A_{0-n}, where n – number of the impact) angles of the pendulum (Fig. 2.).

After the release of pendulum from clamped position (angle $A_0 = 5.1°$) the specimen is stretched at the angle β_1 (peak of first impact B_1). The first bounce angle of the pendulum is described by the second peak A_1 of the vibration curve. During pendulum vibration numerical values of the bounce and impact angles decrease and after 5 – 6 impacts become similar for all tested fabrics. The bounce angle of the pendulum gradually decreases till the beginning of free vibrations of the pendulum because of energy losses in the cycle. Absolute values of bounce and impact angles of pendulum's vibrations are given in Table 2. Curves of decreasing vibration process in time are given in Figure 3 and Figure 4. In order to determine accuracy and reliability of the pendulum, two groups of fabrics are investigated (stiffener concentration in each group differed by 3 ml/l and by 7 ml/l).

Testing results have shown that bounce angle α_{1-n} of the pendulum is not sensitive to the changes of stiffener concentrations, neither in the group where it differed by 3 ml/l, nor in the group with 7 ml/l difference. It must be noted also, that fabrics without the stiffener treatment give slightly bigger value of bounce angle of the pendulum. The stored compressive energy of these fabrics is released back to the pendulum giving it kinetic energy, which causes the pendulum arm to bounce back to a certain angle. This angle is bigger than the angle of fabrics with stiffener treatment, because during the treatment shape stabilizing substances are removed and their stored energy becomes less.

Values of the first impact angle (first peak, i.e. point B_1), after releasing the pendulum from stationary position distinguishes impact behaviour of tested fabrics more evidently, because impact angle β_1 of the pendulum show bigger difference for different concentrations of stiffener. Also, value of the impact angle increases with the increase of stiffener concentration. The difference of impact angles of the pendulum for different concentrations becomes negligible within the decrease of vibration process. The process of impact continues until the initial potential energy of the pendulum is totally consumed by the energy losses. Meantime the group of fabrics with difference of stiffener concentration by 7 ml/l showing considerable difference between impact angles of the pendulum.

Vibration process and changes of bounce angles of the pendulum for all concentrations of stiffener is described by power equation $y = a + bx^c$ with coefficient of determination $R^2 = 0.99$, while for impact angles of pendulum's vibrations – $R^2 = 0.98 \div 0.99$.

Table 2. Absolute values of bounce (A_{1-n}) and impact (B_{1-n}) angles of pendulum's vibrations

Amplitudes	Angles of pendulum's vibrations (at stiffener concentrations of samples, ml/l)						
	0	3	6	7	9	14	21
A_1	3.92 ±0.04	3.32 ±0.08	3.25 ±0.09	3.40 ±0.03	3.33 ±0.08	3.45 ±0.10	3.46 ±0.01
A_2	3.20 ±0.02	2.56 ±0.08	2.51 ±0.08	2.61 ±0.03	2.53 ±0.08	2.67 ±0.10	2.68 ±0.01
A_3	2.64 ±0.03	2.07 ±0.09	2.08 ±0.03	2.15 ±0.01	2.06 ±0.02	2.17 ±0.01	2.22 ±0.01
A_{12}	1.54 ±0.02	1.47 ±0.02	1.50 ±0.02	1.53 ±0.05	1.47 ±0.03	1.45 ±0.01	1.39 ±0.03
B_1	–2.06 ±0.03	–1.89 ±0.03	–1.85 ±0.02	–1.83 ±0.02	–1.83 ±0.01	–1.79 ±0.08	–1.79 ±0.02
B_2	–1.99 ±0.03	–1.79 ±0.09	–1.76 ±0.02	–1.73 ±0.10	–1.74 ±0.04	–1.71 ±0.05	–1.69 ±0.04
B_3	–1.92 ±0.03	–1.68 ±0.09	–1.67 ±0.02	–1.66 ±0.10	–1.65±0.01	–1.66 ±0.05	–1.62 ±0.04
B_{11}	–1.54 ±0.02	–1.43 ±0.09	–1.45 ±0.02	–1.53 ±0.10	–1.43 ±0.01	–1.42 ±0.05	–1.39 ±0.09

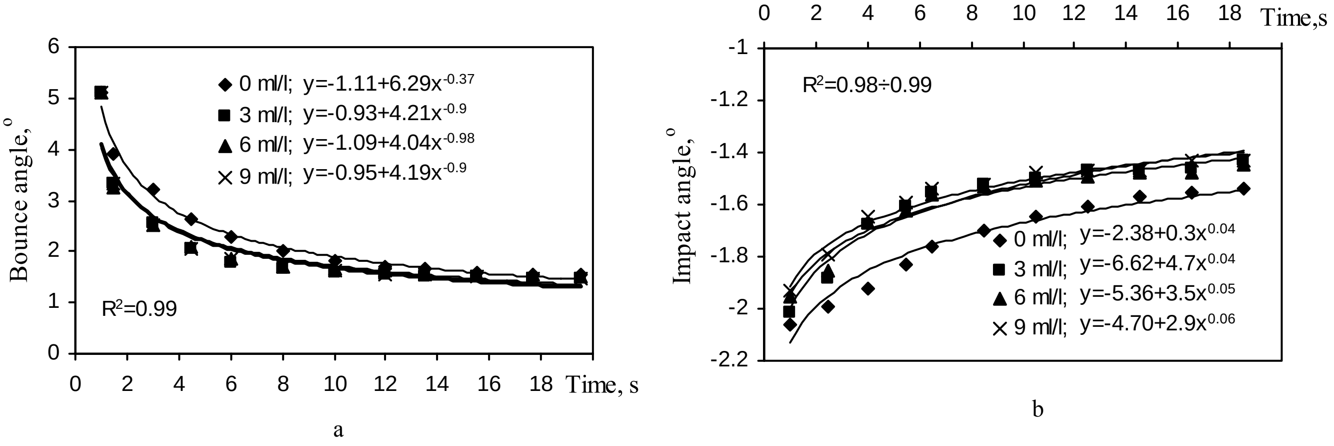

Fig. 3. Bounce (a) and impact (b) angles of pendulum's for the group of samples differed by 3 ml/l

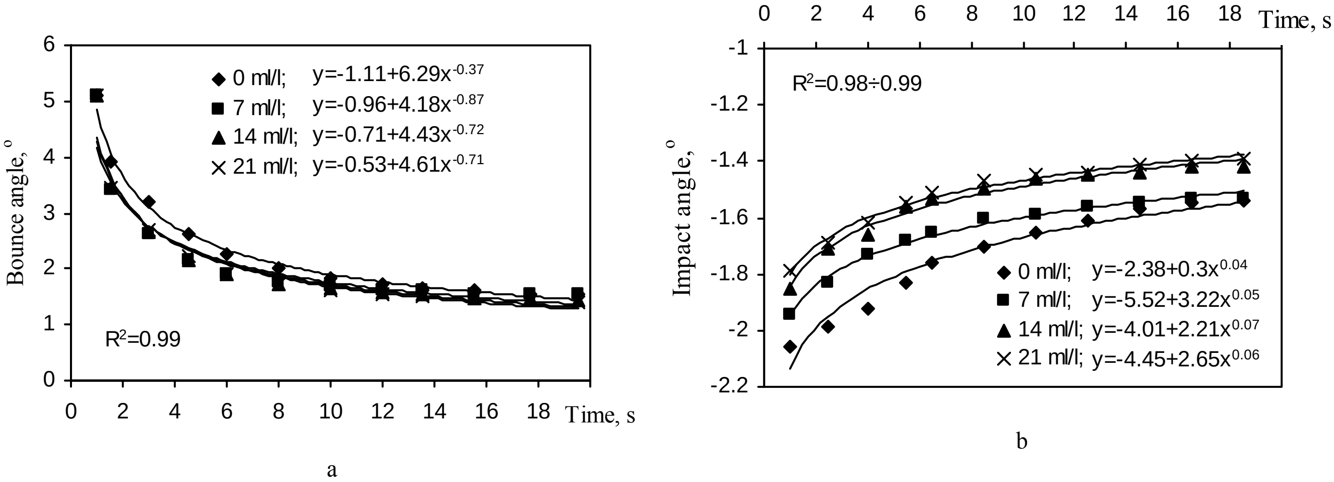

Fig. 4. Bounce (a) and impact (b) angles of pendulum's for the group of samples differed by 7 ml/l

Figure 5 illustrates correlation between samples uniaxial bending rigidity in warp, weft and bias directions and their stiffener concentration.

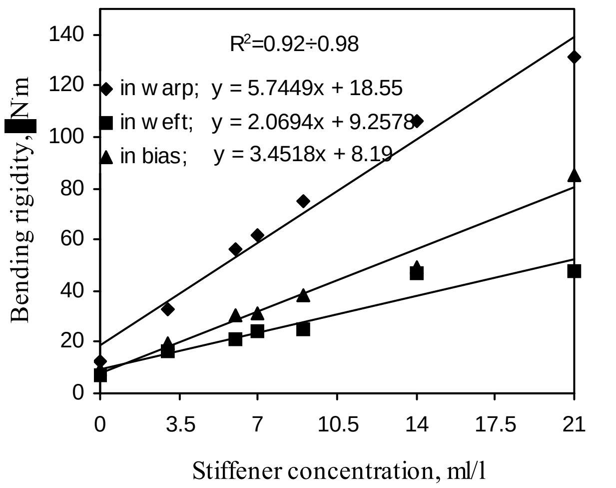

Fig. 5. Relationship between bending rigidity of the tested fabrics and stiffener concentration

The relationship between uniaxial bending rigidity in warp, weft and bias directions and stiffener concentration is linear ($y = a + bx$; coefficient of determination – $R^2 = 0.92 \div 0.98$), i. e. bending rigidity of the fabrics increases with the increase of stiffener concentration.

Whereas the change of stiffener concentration by 3 ml/l and by 7 ml/l is not essential, measuring the bounce angle of the pendulum at a certain moment of time it was effective to determine the influence of textiles bending rigidity to impact behaviour of fabrics.

Impact behaviour of fabrics and the energy absorbed by the fabric during a stroke, depends on its surface density, thickness and bending rigidity.

The dependencies of impact angles of the pendulum during the stroke B_1 versus bending rigidity in warp, weft and bias directions are given in Figure 6.

As stated above, first peak B_1 distinguishes impact behaviour of the fabric most evidently and during this impact the dependency of impact angles of the pendulum and bending rigidity in all directions can be described by polynomial equation $y = a + b/\ln x$ with a coefficient of determination $R^2 = 0.97 \div 0.99$.

The impact angles of the pendulum increases with increase of bending rigidity of the fabrics.

After summarizing the results of subjective evaluation of judge panel it was found that agreement level of experts on "stretchability" and "resiliency" of the fabrics was higher assessing specimens in weft direction ($W = 0.63$). Assessing these features in warp direction, experts showed lower agreement ($W = 0.23 \div 0.30$). Comparing these two

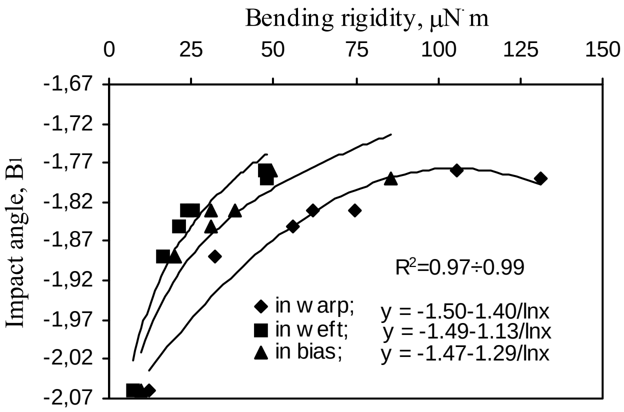

Fig. 6. Impact angle B_1 versus bending rigidity of the tested fabrics

properties, experts showed better agreement in a case of "resiliency". The best agreement level was reached assessing "resiliency" of the fabrics in weft direction ($W = 0.63$) for the group of specimens where the change of stiffener concentration is 3 ml/l.

To determine the extent to which the objective data can explain the subjective handle assessments of fabric characteristics made by the judge panel the power regresion ($y = a + bx^c$) analysis was applied to establish whether there were any relationships existing between the preference of the judges and the impact behaviour of fabrics.

"Stretchability" shows good relationship with impact angle of the pendulum β_1 during the impact B_1 and with bounce angle of the pendulum α_0 at the moment A_1 when the change of stiffener concentration in a group of fabric is 3 ml/l. The best relationship of "stretchability" subjective evaluation was obtained with the bounce angle (A_1) of the pendulum in weft direction for the group of sample, when the change of stiffener concentration is 3 ml/l ($R^2 = 0.99$). The relationship of "resiliency" with textiles impact behaviour is lower. The highest relationship of "resiliency" was obtained with the bounce angle (A_1) of the pendulum in a weft direction for the group of sample, when the change of stiffener concentration is 7 ml/l ($R^2 = 0.98$).

CONCLUSIONS

Experimental method, based on pendulum vibrations, was established to measure the impact behaviour of fabrics. The pendulum impacts the fabric and gradually reduces its potential energy during a number of swings, because of energy losses during the stroke. The bounce angle α_{1-n} of the pendulum is not sensitive to the changes of stiffener concentration, neither in the group where it differed by 3 ml/l, nor in the group by 7 ml/l difference. The group of fabrics with stiffener concentration changes by 7 ml/l show considerable difference between impact angles of the pendulum. The first impact of the pendulum on the specimen (point B_1) distinguishes the impact behaviour of tested fabrics most evidently.

Impact behaviour of fabrics and the energy absorbed by the fabrics during a stroke cohere with its bending rigidity. Bending rigidity of the fabrics increase with the increase of stiffener concentration – relationship between uniaxial bending rigidity in all directions and stiffener concentration is linear ($y = a + bx$; $R^2 = 0.92 \div 0.98$).

The dependency of impact angles of the pendulum and bending rigidity in all directions was described by polynomial equation $y = a + b/\ln x$ with a coefficient of determination $R^2 = 0.97 \div 0.99$.

The relationships between subjective hand parameters and impact behaviour of fabrics were established. The closed relationship of "stretchability" was obtained with the bounce angle (A_1) of the pendulum in weft direction for the group of sample, when the change of stiffener concentration is 3 ml/l ($R^2 = 0.99$). "Resiliency" shows the closest relationship with the bounce angle (A_1) of the pendulum in weft direction, when the change of stiffener concentration is 7 ml/l ($R^2 = 0.98$). Coefficients of determination between the subjective values: "stretchability", "resiliency", and physical hand properties are sufficiently high.

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