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Influence of Weaving Loom Setting Parameters on Changes of Woven Fabric Structure and Mechanical Properties

Aušra ADOMAITIENĖ *, Greta RAVINIENĖ, Eglė KUMPIKAITĖ

Faculty of Design and Technologies, Kaunas University of Technology, Studentų g. 56, Kaunas

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During the manufacturing of fabric of different raw material there was noticed, that after removing the fabric from weaving loom and after stabilization of fabric structure, the changes of parameters of fabric structure are not regular. During this investigation it was analysed, how weaving loom technological parameters (heald cross moment and initial tension of warp) should be chosen and how to predict the changes of fabric structure parameters and its mechanical properties. The dependencies of changes of half-wool fabric structure parameters (weft setting, fabric thickness and projections of fabric cross-section) and mechanical properties (breaking force, elongation at break, static friction force and static friction coefficient) on weaving loom setting parameters (heald cross moment and initial warp tension) were analysed. The orthogonal Box plan of two factors was used, the 3-D dependencies were drawn, and empirical equations of these dependencies were established.

INTRODUCTION

It is known, woven fabric is material of sophisticated construction, the structure of which influences its properties. It is important to predict prospective end-use properties of the fabric and technological parameters of its manufacturing (heald cross moment and initial warp tension) during the designing of new fabric. Elasticity of the fabric depends not only on the fabric weave and rigidity, but also on decrease of warp tension during heald cross [1 – 5]. The new shed are started to form for new weft during the beat-up, weaving with heald cross [6 – 8]. Crossed warp presses beated-up weft next to the cloth fell and does not let to move back the weft when reed moves back. When fabric is weaved with heald cross, the beat-up conditions are better and by this reason the higher weft setting can be achieved without higher breakage of warp. The warp tension increases when the heald cross moment increases. Warp sustains the multiplex deformations when the beat-up force is bigger [1 – 8].

Different initial force, which depends on the fabric purpose, weave and weft setting, can be given for warp [1 – 3]. High initial tension can influence high cyclic deformation of thread and high fluctuation of tension of whole system. When initial warp tension increases, the amplitudes of changes of warp tension and deformations of loom setting system are almost constant [4 – 7]. Just their absolute values increase proportionally to the growing of initial tension during dynamic conditions. So, the change of initial force influences only the structure of element of fabric during its weaving. The put down phase of fabric structure can be achieved, when initial force is combined with heald cross moment [1 – 7].

The initial warp tension and heald cross moment influence the structural and mechanical properties of woven fabric [9 – 12]. The parameters of fabric cross-section changes with the alteration of weaving loom setting parameters.

During earlier investigations [12] the regularities between properties of fabrics structure (weft setting, fabric thickness and cross-section parameters) when fabric structure stiffens, were not established. So, the aim of the article is to predict, how the mentioned fabric structure and mechanical properties change with changes of basic parameters of weaving loom setting, when the fabric structure is stable.

MATERIALS AND METHODS

The object of investigation was half-wool fabric (the raw material is 55 % wool and 45 % polyester) weaved with plain weave. The linear density of yarn was 18 tex × 2. Warp setting was 240 dm^{-1}, weft setting was 160 dm^{-1}. Fabric was weaved with STB-1-180 gripper weaving loom.

Two parameters of weaving loom setting (heald cross moment and initial warp tension) were changed according to the orthogonal Box plan of two factors, the matrix of which is shown in Table 1.

The weft setting was established according to the standard ISO 7211-2:1984 using counting glass. Fabric thickness was established according to the standard LST EN ISO 5084 with device Automatic – Micrometer (Louis Schopper, Leipzig).

The parameters of fabrics cross- and longitudinal sections were measured after stabilization of its structure and after biaxial tension, imitating forces, affecting the fabric in weaving loom. The specimens were spread in both sides with achromatic silicon, which was used to stop fabric decomposition, and preserved 24 hours, while silicon became rigid. The specimen of the fabric after stabilization was spread with silicon and was dried in loose state. Imitating behaviour of fabric in weaving loom, biaxial tension was done for the specimens, adding in warp and weft directions force of 10 cN/tex, which was

* Corresponding author. Tel.: +370-37-353862; fax.: +370-37-353989.
E-mail address: *ausra.adomaitiene@gmail.com* (A. Adomaitienė)

preliminary chosen according to the earlier investigations [12]. The specimens of fabric are shown in Fig. 1.

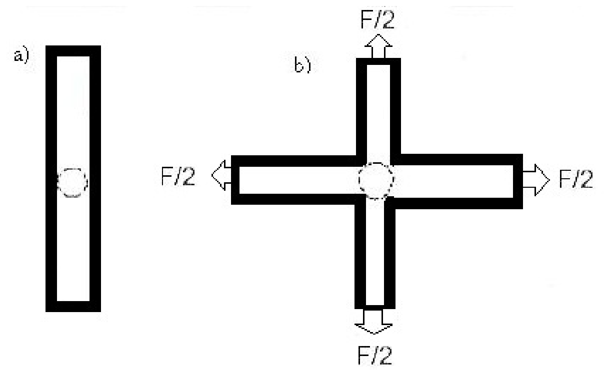

Fig. 1. The specimens of fabric: a – after stabization of fabric structure; b – after biaxial tension

The fabric cross-section parameters (the longitudinal projection of thread *a*, the cross projection of thread *b* and wave height *c* are shown in Fig. 2.

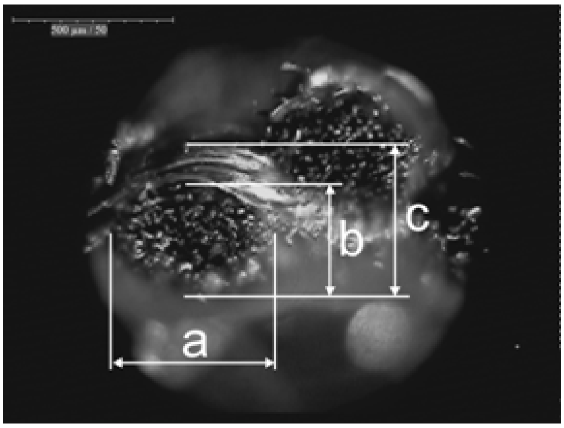

Fig. 2. The fabric cross-section parameters

Breaking force and elongation at break were established with universal tension machine Zwick/Z005 according to the standard LST EN ISO 13934-1. Dimension between clamps was 200 mm, the speed of tension was 100 mm/min. The friction tests to the leather and half-wool material were made with the same universal tension machine Zwick/Z005 according to the standard LST EN ISO 21182:2007, the dimensions of trolley were 60 mm × 60 mm.

The changes of weft setting, fabric thickness and fabric cross-section parameters were calculated according to the formula:

$$\Delta a = \frac{a_1}{a_2}, \qquad (1)$$

where: Δa is the change of parameter analysed, a_1 is the value of parameter analysed of tensioned fabric, a_2 is the value of parameter analysed of fabric of stable structure.

The mathematical analysis of experimental results was made with the software "Statistica", which was used for drawing the 3-D dependences and for establishing their regression equations and determination coefficients. The informativeness of mathematical models was inspected according to the dates of software. All models analysed in article were informative. The software also examined the significance of equation coefficients and eliminated not significant coefficients.

Table 1. Matrix of orthogonal Box plan of two factors

Number of experiment	Coded values of factors		Real values of factors	
N	X_1	X_2	x_1 (initial warp tension, mN/tex)	x_2 (heald cross moment, degrees)
1	+1	+1	7	45
2	+1	–1	7	15
3	–1	–1	3	15
4	–1	+1	3	45
5	+1	0	7	30
6	–1	0	3	30
7	0	+1	5	45
8	0	–1	5	15
9	0	0	5	30

EXPERIMENTAL RESULTS

It was investigated, how the changes of fabrics structure parameters (weft setting, fabric thickness and cross-section parameters) and mechanical properties (breaking force, elongation at break, static friction force and static friction coefficient to the leather and half-wool suit fabric) depend on the changes of weaving loom setting parameters. The changes of different fabric structure parameters and properties can be predicted according to 3-D graphs and their regression equations, when the values of weaving loom settings parameters are certain.

In Fig. 3 the dependence of changes of weft setting on warp initial tension and heald cross moment is shown. It can be seen, that when warp initial tension increases till 6 mN/tex, the change of weft setting increases till maximum value (1.038), and after further increase of initial tension till 7 mN/tex the change of weft setting is settled and decreased slightly. When the initial tension increases, the warp are more tensioned in weaving loom, and when fabric is taken away from the loom, warp relaxes and more crimps and the change of weft setting increases. The tendencies of changes, when the values of heald cross moment are low or high, are similar. When warp initial force is critical, the change of weft setting decreases a little, because warp can not to crimp more, when the fabric is taken away from the loom. When the heald cross moment changes, warp crimps already in weaving loom in proper magnitude and weft setting stays almost similar, when taking fabric away from the loom. So, it can be stated, that the change of weft setting of half-wool fabric does not depend on heald cross moment of weaving loom, when fabric structure is stable. The relative error of experiments varies from 6 % till 12.4 %. The dependence is medium strong, because the determination coefficient is 0.7211, i. e. it is of middle value. These results are similar to the ones of Galuszynski and Ellis [1, 2], who investigated influence of fabric structure on the beat-up process parameters. Jeon, Chun and Hong [10] received also similar results about the structural properties of fabric and explained them by fabric geometry.

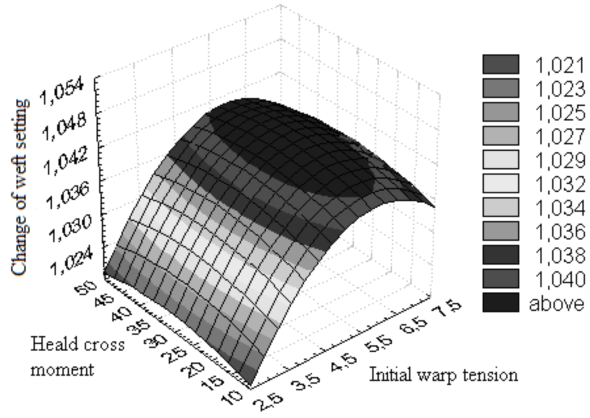

Fig. 3. The dependence of change of weft setting of half-wool fabric on initial warp tension and heald cross moment

In Fig. 4 the dependence of fabric thickness on initial warp tension and heald cross moment is presented.

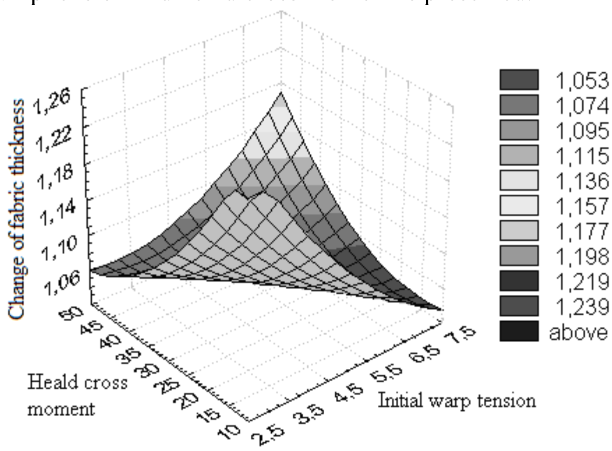

Fig. 4. The dependence of change of fabric thickness of half-wool fabric on initial warp tension and heald cross moment

It can be seen from Fig. 4, that when the warp initial tension varies from 3 mN/tex to 7 mN/tex, the change of fabric thickness increases from 1.053 till 1.177. It happens when the warp is more tensioned and then crimps more difficult. The fabric taken away from the loom is more packed and its thickness decreases. The tendency of change of 3-D dependence is similar, when of heald cross moment is changing, i. e. when heald cross moment increases, the change of fabric thickness decreases. When heald cross moment increases, shed starts to close later, warp stronger presses weft thread and fabric become thinner. The relative error varies from 5.6 % till 10.2 %. The determination coefficient of dependence is 0.7564, i. e. the dependence is medium strong and the change of fabric thickness can be predicted in the middle accuracy. Investigations of fabric inner structure during weaving were made by Malčiauskienė, Rukuižienė and Milašius [11]. They also established that the weaving conditions have influence to the structural parameters of woven fabric. Gu [3] established also warp tension influence on conditions of fabric formation and his results are similar to the results described.

In Fig. 5 the dependence of change of weft longitudinal projection on initial warp tension and heald cross moment is shown. It can be seen, that when warp initial tension increases and heald cross moment is 10 degrees, the weft longitudinal projection increases, just when values of warp initial tension are the highest (about 7 mN/tex), the graph has a small tendency to decrease. When the value of heald cross moment is 45 degrees and the initial warp tension is about 5 mN/tex, the 3-D dependence bows. When the initial warp tension increases, warp is more tensioned, it presses the weft threads from bottom and top, and the weft projection in longitudinal direction increases at first. However, when the initial warp tension increases further, warp more covers the weft and presses it also in cross direction. Because of this reason the weft longitudinal projection starts to decrease. When the initial warp tension is 5 mN/tex, the longitudinal projection of weft increases from 0.99 till 1.052, because when warp is low tensioned and the heald cross moment increases, warp covers and presses weft threads more and weft longitudinal projection increases. When warp initial tension is 7 mN/tex, the 3-D dependence bows and weft longitudinal projection has tendency to decrease, because when warp are strong tensioned, it crimps more and starts to press weft in longitudinal direction. The relative error varies from 5.6 % till 10.8 %. The determination coefficient is 0.8276, i. e. it is the medium. Investigations of fabric cross-section parameters were made by Jeong and Kang [8], who analysed compresional deformation of fabric and used finite element method. They also have got similar results.

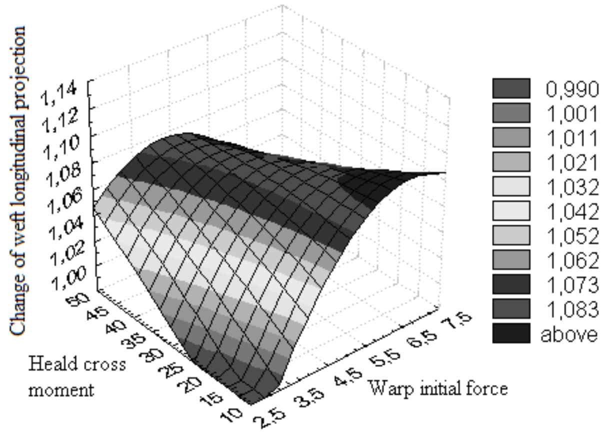

Fig. 5. The dependence of change of weft longitudinal projection on initial warp tension and heald cross moment

In Fig. 6 the dependence of change of weft cross projection on warp initial tension and heald cross moment is shown. It can be seen from 3-D graph, that the change of weft cross projection changes similar in respect of initial warp tension and heald cross moment, i. e. when the both factors increase till middle values (5 mN/tex for initial warp tension and 25 degrees for heald cross moment), the change of weft cross projection decreases till 0.881, and then it starts to increase again till maximum value (1.132). The reason of this phenomenon is that when the initial warp tension and heald cross moment increase, weft is pressed at first, because warp is more tensioned and more presses the weft thread. However, from the certain value of weaving loom setting parameters warp increasingly covers the weft and the weft cross projection increases. The influence of fabric formation to its inner structure was investigated by R. Milašius and V. Milašius [9]. They also established, that parameters of weaving loom influence fabric geometrical properties.

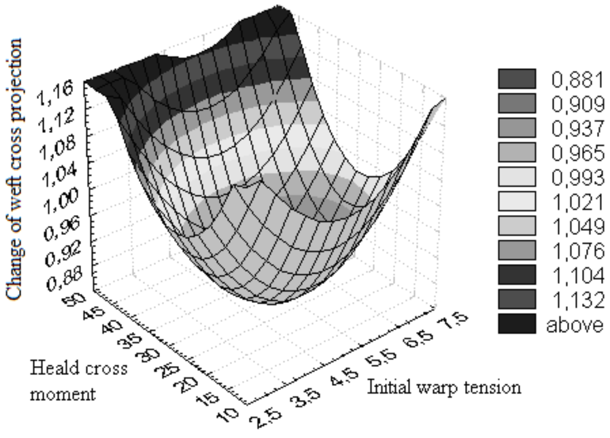

Fig. 6. The dependence of change of weft cross projection on initial warp tension and heald cross moment

In Fig. 7 the dependence of change of weft wave height on initial warp tension and heald cross moment is shown. When the initial warp tension increases and the value of heald cross moment is 15 degrees, the change of weft wave height seeks to increase not significant from 1.114 till 1.183. The tendencies of change of this projection are similar, but less bowed, when the values of heald cross moment are high (about 45 degrees). When initial warp tension increases, warp is more tensioned, presses the weft more and wave height increases. When the heald cross moment changes from 15 till about 25 degrees, the wave height decreases, but after that it starts to increase till maximum value (when the warp initial tension is 5 mN/tex, this value is 1.16). This phenomenon can be explained by the heald cross moment increase. Warp covers weft threads more at first, warp crimps and wave height decreases. However, when heald cross moment increases, warp presses weft increasable, weft projections are packed more tightly and the wave height increases. The relative error varies from 4.3 % till 9.6 %. The determination coefficient of dependence is 0.7345, i. e. it is of medium magnitude. Adomaitienė, Lazarevičiūtė and Kumpikaitė [12] investigated changes of fabric cross-section parameters according to their raw material and established, that the geometrical properties of all these fabrics changed, when conditions of fabric formation are different, i. e. their results are similar to the results described.

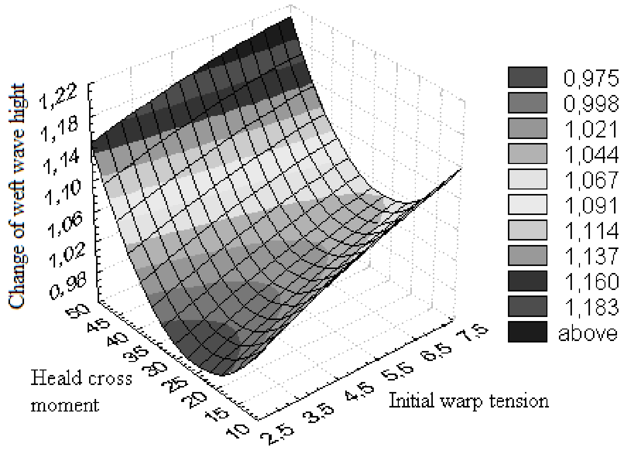

Fig. 7. The dependence of change of weft wave height on initial warp tension and heald cross moment

3-D graphs of warp threads have similar tendencies with weft projections, but tendencies are not so expressed. The equations and determination coefficients of changes of fabric geometrical properties are presented in Table 2.

The equations and 3-D dependencies of fabric mechanical properties, when the weaving loom setting parameters change were established during investigation.

In Fig. 8 the dependence of breaking force in weft direction on initial warp tension and heald cross moment is presented.

From Fig. 8 it can be seen, that when warp initial tension increases and heald cross moment is 15 degrees, the 3-D graph increases not significant, and after that have tendency to decrease. When the initial warp tension increases, warp is more tensioned and some time fabric breaking force increases and when the critical point is

Table 2. The equations and determination coefficients of changes of fabric geometrical properties

The change of property	Equation	Coef. of det.
Weft setting	$Y = 0.973 + 0.022 \cdot X_1 - 0.002 \cdot X_1^2 + 0.00000347 \cdot X_1 \cdot X_2 - 0.000005864 \cdot X_2^2$	0.7211
Fabric thickness	$Y = 1.698 - 0.128 \cdot X_1 - 0.017 \cdot X_2 + 0.006 \cdot X_1^2 + 0.002 \cdot X_1 \cdot X_2$	0.7564
Longitudinal weft projection	$Y = 0.613 + 0.138 \cdot X_1 + 0.006 \cdot X_1 - 0.01 \cdot X_1^2 - 0.001 \cdot X_1 \cdot X_2 - 0.00001292 \cdot X_2^2$	0.8276
Cross weft projection	$Y = 1.916 - 0.236 \cdot X_1 + 0.032 \cdot X_2 + 0.024 \cdot X_1^2 + 0.001 \cdot X_2^2$	0.7652
Weft wave height	$Y = 1.062 + 0.038 \cdot X_1 - 0.015 \cdot X_2 - 0.001 \cdot X_1^2$	0.7345
Longitudinal warp projection	$Y = 1.166 + 0.046 \cdot X_1 - 0.008 \cdot X_2 + 0.004 \cdot X_1^2$	0.774
Cross warp projection	$Y = 1.078 - 0.056 \cdot X_1 + 0.002 \cdot X_2 + 0.008 \cdot X_1^2 + 0.00003901 \cdot X_2^2$	0.7612
Warp wave height	$Y = 1.346 - 0.006 \cdot X_1 - 0.027 \cdot X_2 - 0.001 \cdot X_1^2 + 0.001 \cdot X_1 \cdot X_2$	0.8001

Table 3. Equations and determination coefficients of fabrics mechanical properties

Property	Equation	Coef. of det.
Breaking force, weft dir.	$Y = 421.065 + 16.857 \cdot X_1 - 1.533 \cdot X_2 - 2.717 \cdot X_1^2 + 0.503 \cdot X_1 \cdot X_2 + 0.002 \cdot X_2^2$	0.7695
Elongation at break, weft. dir.	$Y = 29.463 + 0.001 \cdot X_1 - 0.153 \cdot X_2 - 0.046 \cdot X_1^2 + 0.015 \cdot X_1 \cdot X_2 + 0.002 \cdot X_2^2$	0.8111
Breaking force, warp. dir.	$Y = 643.685 + 56.382 \cdot X_1 + 2.613 \cdot X_2 - 5.174 \cdot X_1^2 + 0.043 \cdot X_2^2$	0.7895
Elongation at break, warp dir.	$Y = 36.828 + 4.188 \cdot X_1 - 0.721 \cdot X_2 - 0.473 \cdot X_1^2 + 0.019 \cdot X_1 \cdot X_2 + 0.012 \cdot X_2^2$	0.8256
Stat. friction force to leather	$Y = 1.178 - 0.003 \cdot X_1 - 0.004 \cdot X_2 + 0.00001667 \cdot X_1 \cdot X_2 + 0.0000563 \cdot X_2^2$	0.812
Stat. friction coef. to leather	$Y = 0.479 + 0.007 \cdot X_1 + 0.015 \cdot X_2 - 0.01 \cdot X_1^2 + 2.287 \cdot 10^{-18} \cdot X_1 \cdot X_2$	0.798
Stat. friction force to fabric	$Y = 1.589 - 0.024 \cdot X_1 - 0.005 \cdot X_2 - 0.006 \cdot X_1^2 + 0.002 \cdot X_1 \cdot X_2 - 0.000077 \cdot X_2^2$	0.799
Stat. friction coef. to fabric	$Y = 0.811 - 0.016 \cdot X_1 - 0.003 \cdot X_2 - 0.002 \cdot X_1^2 + 0.001 \cdot X_1 \cdot X_2 - 0.00003556 \cdot X_2^2$	0.8142

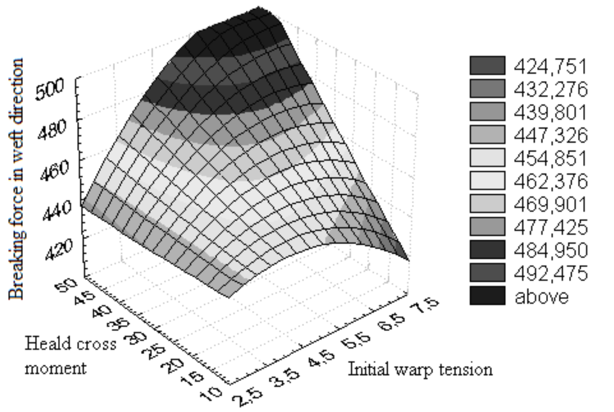

Fig. 8. The dependence of breaking force in weft direction on initial warp tension and heald cross moment

achieved (about 5 mN/tex), warp is tensioned too high and the strength of fabric starts to decrease. When the values of heald cross moment are 45 degrees, the tendencies of graph increases, because warp covers the weft more and it is more crimped. So, when the initial warp tension increases, fabric is stronger. The heald cross moment does not influence the fabric breaking force in weft direction, when initial warp tension is 5 mN/tex. However, when the initial warp tension is 7 mN/tex and heald cross moment increases, warp cover weft more closely, crimps and when fabric is stretched, the warp threads become straighter and just after that the structure of fabric is started to act. The relative error varies from 5.8 % till 15.8 %. The determination coefficient of dependence is equal 0.7695, i. e. it is medium. Shih, Mohamed, Bullerwell and Dao [4] established that beat-up process parameters influence fabric mechanical properties during investigation of beat-up process. These results are similar to the results investigated.

In Fig. 9 the dependence of elongation at break in weft direction on warp initial tension and heald cross moment is presented. It can be seen, that elongation at break depends on the both weaving loom setting parameters. When the initial warp tension increases and heald cross moment is 15 degrees, the elongation at break decreases. When the values of heald cross moment are about 45 degrees, the dependence bows and when initial warp tension increases, the elongation at break also increases. When heald cross moment is 15 degrees and initial warp tension increases, warp is straighter, weft crimps more about warp and when the fabric is stretched, weft stretches, while become straight. When the heald cross moment is 45 degrees, warp is more crimped and extensibility in weft direction has tendency to decrease. When heald cross moment increases, elongation at break starts to increase, because warp is straighter and weft is more crimped. By this reason the extensibility of fabric in weft direction increases. The relative error of measurements varies from 8.8 % till 12.3 %. The determination coefficient of dependence also is medium and is equal 0.8111. Zhang and Mohamed [5] established that parameters of fabric formation influence fabric strength parameters and these results sustain the results described.

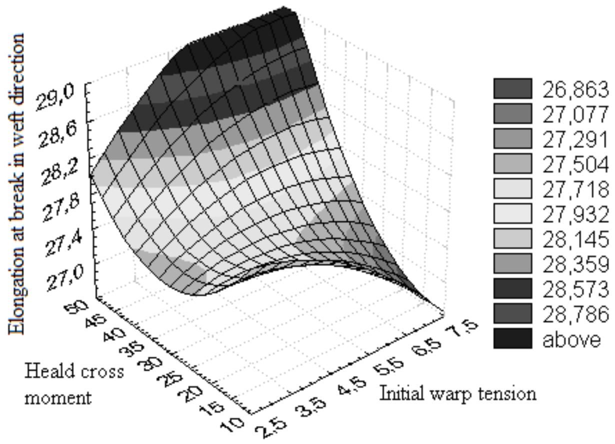

Fig. 9. The dependence of elongation at break in weft direction on warp initial tension and heald cross moment

In Fig. 10 the dependence of static friction force to leather on initial warp tension and heald cross moment is shown. It can be seen, that static friction force almost does not depend on initial warp tension. However, when heald cross moment increases till 30 degrees, friction force decreases till minimum value (1.113 N) and after that the dependence bows and starts to increase again. The reason of this phenomenon is, that when heald cross moment increases, at first warp covers weft more closely, crimps and surface of fabric becomes not plane, fabric overcomes the static friction more hardly. When heald cross moment increases more, threads from one of systems start to dominate in the fabric and friction is overcome easier. The relative error of measurements is from 2.9 % to 13.5 %. The determination coefficient of dependence is medium and equal 0.812. During theoretical and experimental investigation of beat-up process Katunskis [7] also established that the parameters of fabric formation influence mechanical properties of woven fabric.

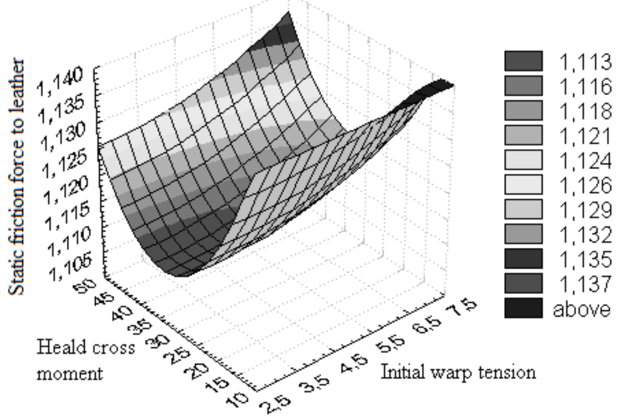

Fig. 10. The dependence of static friction force to leather on warp initial tension and heald cross moment

The character of the dependence of static friction coefficient on warp initial tension and heald cross moment is similar to static friction force, because this coefficient is in direct ratio with static friction force. The relative error of this dependence varies from 5.9 % till 12.5 %. The determination coefficient of the dependence is 0.798, i. e. the dependence is of middle strength.

The tendencies of change of static friction force as well as static friction coefficient to fabric are different, but in this article just the equations and their determination coefficients are shown.

The equations and determination coefficients of fabrics mechanical properties are presented in Table 3.

So, values of changes of fabric structure parameters and mechanical properties, when the weaving loom setting parameters (initial warp force and heald cross moment) are certain, can be predicted in the middle accuracy according to the 3-D graphs and their equations.

CONCLUSIONS

1. The changes of fabrics structure parameters depend on warp initial tension and heald cross moment in middle strength, because when these parameters change, the behaviour of warp changes as well.
2. The mechanical properties of fabric also depend on weaving loom setting parameters in the middle strength, because fabric surface properties changes.
3. The values of changes of fabric structure parameters and some mechanical properties can be predicted in the middle accuracy according to the given 3-D dependencies.

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