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Influence of Fabric Structure on Its Weavability

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In the present article the problems of the fabric designing theory in connection with fabric weavability are analysed. A close relation has been determined to exist between fabric structure and weavability. It is maintained that fabric formation conditions to make uniform fabric structure and predetermine the constant fabric structure factor can be achieved weaving the fabric of maximum density, in this case, it's the maximum weft setting of the fabric. The reciprocal relation has been determined experimentally between fabric structure parameters, and the coefficients of variations of the fabric structure parameters were evaluated. The data showed that weavability of fabric is better reflected by Brierley's group factors than those of Peirce's group. The earlier proposed fabric firmness factor φ is used like most precise and convenient as an indicator for different fabric weaves.

Keywords: fabric structure, fabric weave factors, integrated fabric structure factors, maximum weft setting.

INTRODUCTION

When new fabrics are designed it is important to know their predetermined application properties and technology of their formation. Fabric weavability characterises fabric technological properties in addition to other ones. It is known that limit density of fabric depends on raw material, construction of loom and fabric structure [1, 2]. It is determined that woven fabrics can be denser when using threads of stronger fibres. For example, comparing viscose fabric with polyester fabric it is evident that increasing the weft density the breaking of viscose threads becomes unacceptable before that of polyester ones, i.e. the weavability of polyester threads is higher. In this case the weavability of fabric is predetermined by the properties of used raw materials. The impact of thread's raw material can be estimated by treatments of thread breakage during weaving [2]. It is necessary an individual investigation, however.

In the present paper the stress is made on fabric weavability influenced by loom construction. In weaving technology many ways exist for making the denser fabric structure. It can be proved that an application of all these methods is limited by the construction of loom beat-up mechanism and the beat-up force developed. Thus it can be proved that all types of loom have its specific limited fabric structure factor resulted by fabric weave as well as other structure parameters, which can be used for estimating fabric weavability. It is assumed that weaving of different fabrics under the same weaving conditions gives the same fabric structure tightness [1]. Estimating fabric weavability such uniform weaving conditions are accessible by using maximum weft setting during weaving. These maximum fabric settings depend on maximum possibilities of loom, i.e. the parameters of loom construction. Thus, limited maximum beat-up process parameters must exist for any type of loom because the fabric structure is formed namely during the beat-up process [3, 4].

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The main parameters of beat-up process are beat-up force, beat-up duration and beat-up force impulse [4].

The objective of this article is to find out the relation between fabric structure parameters and parameters of the beat-up process depending on the loom construction. At present time seven parameters are considered to be important to fabric structure: warp and weft raw materials, warp and weft linear density, warp and weft settings and fabric weave [3].

FABRIC WEAVE FACTORS

The greatest problem between all fabric structure parameters is to estimate the fabric weave, which is not a digital but a graphical fabric structure picture.

Fabric weave can be represented as the matrix [5] where "1" labels the float of warp and "0" labels the float of weft. This method is the most popular due it's convenience and possibility to apply computer.

Special weave matrix parameters for reflecting weave influence to fabric properties are used. The average float length $F_{1(2)}$ proposed by Ashenhurst and often used for evaluation for warp and weft respectively is equal to the repeat $R_{1(2)}$ divided by intersection of warp and weft in the repeat $t_{1(2)}$ [6]:

$$F_{1(2)} = \frac{R_{1(2)}}{t_{1(2)}}. \quad (1)$$

Galceran's weave factor $Kl_{1(2)}$ [7] and Neves warp and weft interlacing coefficients *CCWA* and *CCWE* are similar to it [8]:

$$Kl_1 = CCWA = \frac{t_1}{R_1 R_2}, \quad (2)$$

and

$$Kl_2 = CCWE = \frac{t_2}{R_1 R_2}. \quad (3)$$

The shortcoming of these factors is that they estimate only a single thread and do not take in account interlacing of adjacent threads.

Brierley suggested evaluating the weave by the empirical function F^m. The power m was determined experimentally by weaving fabrics of various weave types of maximum their density. It depends on a weave type [9].

Skliannikov [1] proposed the following equation of weave tenseness factor:

$$C = \frac{6R_1R_2 - \left(2n_f + \sum_{i=1}^{6} K_i n_{fi}\right)}{6R_1R_2}, \quad (4)$$

where R_1 and R_2 are the warp and weft repeat of the weave, respectively, n_f is the number of free fields, n_{fi} – the number of free fields belongs to group i (all free fields are distributed into 6 groups), K_i – elimination factor of group i.

Milašius [6] has marked that there is a close relation between Skliannikov's weave tightness factor c, which evaluates a mutual position of threads, and Brierley's factor F^m:

$$F^m = \frac{1}{\sqrt{c}}. \quad (5)$$

Basing on this equation Milašius [6] suggested a new weave factor:

$$P_{1(2)} = \frac{1}{\sqrt{C_{1(2)}}} = \sqrt{\frac{3R_1R_2}{3R_1R_2 - \left(2n_{f1(2)} + \sum_{i=1}^{6} K_{1(2)i} n_{f1(2)i}\right)}}. \quad (6)$$

These factors evaluate not only a single thread float but an interlacing of adjacent threads too and can be calculated for all the types of the weaves (the PC programme is proposed), meanwhile, the Brierley's factor F^m can be calculated only for those types of weaves Brierley investigated.

As it has been mentioned seven parameters estimate the fabric structure and all these parameters are evaluated by integrated fabric structure factors.

INTEGRATED FABRIC STRUCTURE FACTORS

The integrated fabric structure factors are used for estimation of fabric structure tightness. Newton [10] distributed integrated fabric structure factors into two groups: some of them refer to the Peirce theory, others – to the theory of Brierley. In the first case it is a ratio of a surface covered by one or two threads systems with the whole fabric area. In the second case it is a ratio of the setting of the "square" analogue of the given fabric with the setting of the standard "wire" plain weave fabric.

Peirce [11] introduces determination of cover factor, which is equal to a ratio of thread's diameter $d_{1(2)}$ with a distance between threads $p_{1(2)}$:

$$K_{1(2)} = \frac{d_{1(2)}}{p_{1(2)}}. \quad (7)$$

Seyam and El-Shiekh [12] suggested to estimate fabric structure by using determination of fabric tightness. Their fabric geometry is composed from threads racetrack shape geometry and Ashenhurst's end-plus-intersections geometry. This structure factor is calculated by an equation:

$$TS_{1(2)} = \frac{S_{1(2)}}{F_{2(1)}} d_{1(2)} \left(\frac{\pi\left(F_{2(1)} - 1\right)}{4} + 2\right), \quad (8)$$

where $d_{1(2)}$ are warp and weft diameters, respectively, $F_{1(2)}$ are warp and weft average float lengths, respectively, $S_{1(2)}$ are warp and weft settings, respectively.

Newton suggested calculating fabric tightness as a distance between the point corresponding to the fabric and the nearest point on the Peirce "maximal density curve" [10]. This factor can be calculated by an equation:

$$L = \sqrt{\left(K_1 - K'_1\right)^2 + \left(K_2 - K'_2\right)^2}, \quad (9)$$

where

$$K_{1(2)} = \frac{d_{1(2)}}{\frac{F_{2(1)}}{S_{1(2)}} - \frac{\pi d_{1(2)}}{4}\left(F_{2(1)} - 1\right)}. \quad (10)$$

$K'_{1(2)}$ can be calculated from the curve, which was plotted by Peirce according his formula of maximal setting for the fabric.

Galceran [7] calculates the fabric structure factor as a ratio of the coefficient of the setting of the given fabric with the coefficient of the maximal setting. His structure factor is calculated as follows:

$$OG = \frac{\frac{S_1\sqrt{T_1}}{\sqrt{1000}} + \frac{S_2\sqrt{T_2}}{\sqrt{1000}}}{\frac{5\sqrt{\pi\rho_1}}{1 + 0{,}73Kl_1} + \frac{5\sqrt{\pi\rho_2}}{1 + 0{,}73Kl_2}} 100, \quad (11)$$

where $T_{1(2)}$ are warp and weft linear densities, respectively, $\rho_{1(2)}$ warp and weft raw material densities, respectively, $Kl_{1(2)}$ are warp and weft weave factors by Galceran, respectively.

The main shortcoming of Peirce's group factors is their establishing on the average float length F or Kl, which do not estimate exactly the weave.

Brierley proposed the setting of the given fabric to compare with the "standard" plain weave "wire" fabric of the maximum density [9].

Galuszynski has noticed that Brierley's formula needs additional correction of the coefficient g for warp and weft ribs [13]. Galuszynski established that there is a relation between Brierley's tightness factor and weaving resistance. This factor can be used to establish the weavability of fabric.

Brierley's and Galushynski's fabric structure factors can be calculated as follows:

$$MS/MD = TG = \sqrt{\frac{12}{\pi}} \frac{1}{F^m} \sqrt{\frac{T_{av}}{\rho \cdot 1000}} S_2^{\frac{1}{1+g\sqrt{T_1/T_2}}} S_1^{\frac{g\sqrt{T_1/T_2}}{1+g\sqrt{T_1/T_2}}}, \quad (12)$$

where

$$T_{av} = \frac{T_1S_1 + T_2S_2}{S_1 + S_2} \quad (13)$$

and

$$\rho = \frac{\rho_1S_1T_1 + \rho_2S_2T_2}{S_1T_1 + S_2T_2}. \quad (14)$$

The main shortcoming of these factors is that empirical coefficients m and g are established experimentally and they depend on the type of weave but sometimes it is difficult to assign the weave to suitable type of weave. For this reason Brierley's and Galuszynski's fabric structure factors can be calculated not for all types of the weave.

The method proposed by Milašius [1] like that of Brierley is based on the comparison of the setting of the given fabric with "wire" "square" fabric woven by plain weave of "standard" maximal density. This method differs from that of Brierley because $g = 2/3$ is for all the weaves (i.e. it does not depend on the type of the weave) and instead of F^m weave factor P_1 is used, which estimates the mutual location of threads in the weave. Then the new integrated fabric structure factor φ can be calculated as follows:

$$\varphi = \sqrt{\frac{12}{\pi}}\frac{1}{P_1}\sqrt{\frac{T_{av}}{\rho}}S_2^{\frac{1}{1+2/3\sqrt{T_1/T_2}}}S_1^{\frac{2/3\sqrt{T_1/T_2}}{1+2/3\sqrt{T_1/T_2}}}, \quad (15)$$

where

$$\rho = \frac{S_1\rho_1 + S_2\rho_2}{S_1 + S_2} \quad (16)$$

and

$$T_{av} = \frac{S_1T_1 + S_2T_2}{S_1 + S_2}. \quad (17)$$

The priority of fabric structure factor φ in comparison with *MS/MD* and *TG* is that φ can be calculated in warp and weft directions depending on characteristics of the fabric. There are emphasized the properties of fabrics differ in warp and weft directions.

EXPERIMENTAL RESULTS

A series of experiments were carried out to establish the weavability of the fabric. The fabrics were woven by Zulcer type gripper looms, the warp and weft – PES 29.4 tex twisted multifilament yarns, the warp set 284 dm^{-1}. It was woven 12 different weaves with maximum weft setting. The experimental methods and the weaves used are described in [3].

It is believable the most important in appreciating the fabric structure would be the weave of the fabric whereas the maximal loom properties would reflect the maximum of weft setting. As it is mentioned above the various factors weave of matrix describe the weave of the fabric. In this case we are more interested in the weave factors calculated in warp direction because the fabric structure must be formed along the fabric; in spite of that often the average weave factors are used. Out of our interest in the fabric properties in weft direction the weft weave factors are not analysed.

In this investigation of the weavability of the fabric there were defined relations of different weave factors upon maximal weft setting.

Fig. 1 shows the dependence of weave factor F_1 on maximal weft setting.

Dependence is represented by power equation good enough. Such curve equations were used according the former investigations of the fabric structure [13]. From Fig. 1 it can be seen that increasing the weave factor F_1 the maximal weft setting increases too. The determination coefficient of the curve is equal to 0.9603, i.e. it is high indeed. The weave factor can help to predict the maximal weft setting, i.e. the maximal possibilities of loom.

As it is mentioned above important is to ascertain the direction for the better weave factor, which defines the weavability of the fabric. For this reason it was defined the

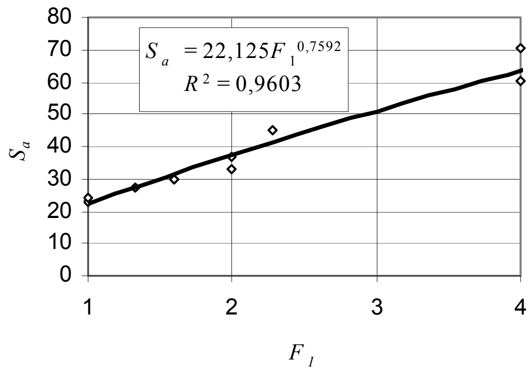

Fig. 1. Dependence of weave factor F_1 on the maximal weft setting S_a

dependence of weft setting on average weave factor *F*. This dependence is shown in Fig. 2. It can be seen that the accuracy of the dependence is lower than the former one, i.e. its determination coefficient is equal to 0.9097 and it is lower than the weave coefficient F_1. It indicates that the values of the weave factor F_1 calculated in warp direction are more suitable for establishing the weavability of the fabric.

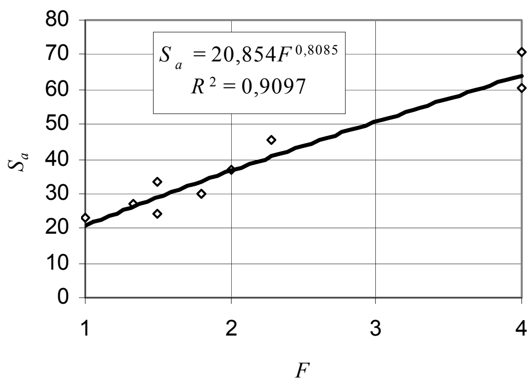

Fig. 2. Dependence of the weave factor *F* on the maximal weft setting S_a

Fig. 3 shows the dependence of Galceran's weave factor Kl_1, which is compatible to Neves, weave factor *CCWA* calculated in warp direction on the maximal weft setting.

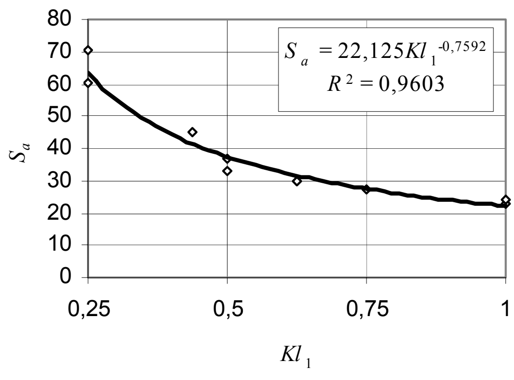

Fig. 3. Dependence of the weave factor Kl_1 on the maximal weft setting S_a

We can see that the type of the curve is different from the former factors curves. This is due to the fact that the factors are reverse proportional to the factor F_1. Hence, when the weave factor Kl_1 is increasing the maximal weft setting is decreasing. The determination coefficient is equal to 0.9603. It is quite the same as of another factor F_1 defined in warp direction, so it refers the weavability quite the same exactly. But its determination coefficient is higher than the average fabric structure factor's F, which determination coefficient reaches only 0.9097.

Fig. 4 shows the dependence of Galceran's average weave factor Kl corresponding Neves average weave factor *ACC* on maximal weft setting. Its character is the same as the weave factor Kl_1, i.e. when the weave factor increases the weft setting decreases. We can see that the determination coefficient of the weave factor Kl_1 calculated in warp direction are higher than the average weave factor Kl as in the case of the factors F_1 and F. However, in both cases Galceran's and Neves's determination coefficients of the weave factors are lower than Ashenhurst's weave factors.

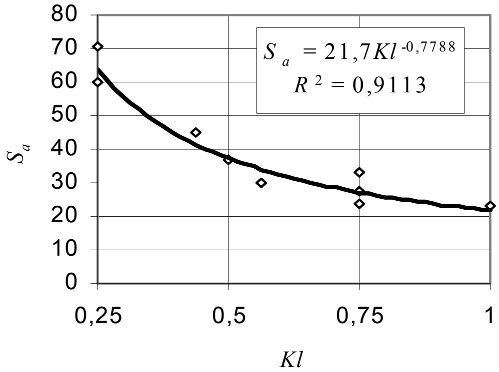

Fig. 4. Dependence of the weave factor Kl on the maximal weft setting S_a

Fig. 5 shows the dependence of the weft setting on Brierley's weave factor F^m It should be emphasised that Brierley's weave factor can't be calculated separately in warp and weft directions – it is typical for the whole fabric.

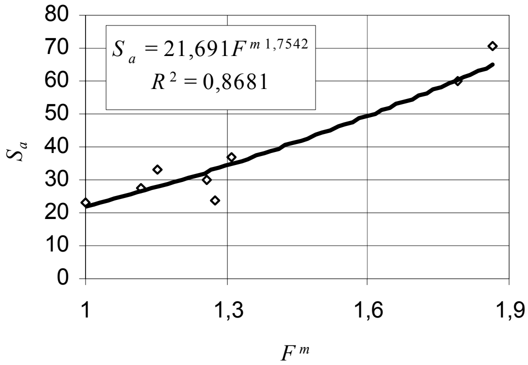

Fig. 5. Dependence of the weave factor F^m on the maximal weft setting S_a

The character of the curve is the same as in the cases of the weave factors F_1 and F, i.e. when the weave factor is increasing the maximal weft setting increases too. According to the values of the determination coefficient which is equal to 0.8681 we can see that this weave factor defines the weavability of the fabric better than the weave factors F and Kl but worse even than the weave factors F_1 and Kl_1, i.e. worse than the factors calculated in warp direction.

Fig. 6 shows the dependence of the weave factor P_1 on the maximal weft setting. When this weave factor is increasing the maximal weft setting increases too. The determination coefficient of the dependence equal to 0.9792 is the highest.

The dependence of the average weave factor P on the maximal weft setting is presented in Fig. 7. It can be seen that the determination coefficient of this dependence equal to 0.936 is lower than the one of the weave factor P_1 calculated in warp direction.

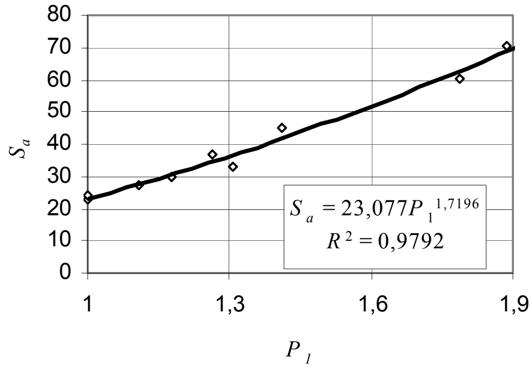

Fig. 6. Dependence of the weave factor P_1 on the maximal weft setting S_a

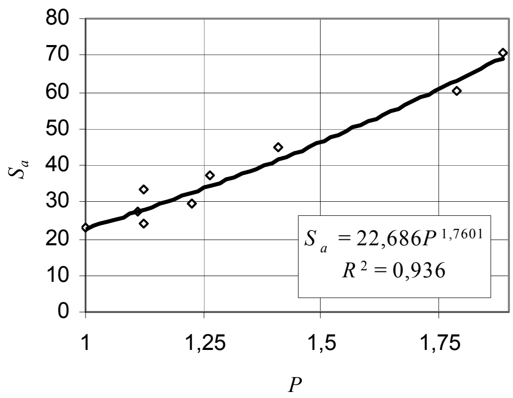

Fig. 7. Dependence of the weave factor P on the maximal weft setting S_a

In the Table 1 the equations of the dependencies of maximum weft setting on the fabric weave factor as well as determination coefficients of these equations are represented.

It is clear, the weave factors calculated in warp direction are better for definition of loom possibilities because in any case their determination coefficients are higher, i.e. the dependences are more precise. On the other hand, the values of separate weave factors vary in rather close limits 0.87 – 0.98.

However, as it has been mentioned the structure of the fabric depends not only on the weave but also on the other six parameters, and whole the fabric structure can be evaluated by integrated the fabric structure factor. The same conditions of the weaving should promote the steady structure of fabric and herewith the steady fabric structure factor. Hence, the weavability of the fabric can be reflected the best by that factor which dispersion i.e. the variation coefficient, would be lowest.

Table 1. Equations of the dependence of maximum weft setting on the fabric weave factor

Weave factor	Equation	R^2
F^m	$S_a = 21.691F^{m1.7542}$	0.8681
F	$S_a = 20.854F^{0.8085}$	0.9097
Kl	$S_a = 21.7Kl^{-0.7788}$	0.9113
P	$S_a = 22.686P^{1.7601}$	0.936
F_1	$S_a = 22.125F_1^{0.7592}$	0.9603
Kl_1	$S_a = 22.125Kl_1^{-0.7592}$	0.9603
P_1	$S_a = 23.077P_1^{1.7196}$	0.9792

In Fig. 8 Newton's fabric structure factor L and fabric structure factor φ are plotted on different axis for better evaluation the difference of their points dispersion. It is evident that the dispersion of the points of Newton's fabric structure factor L is considerably higher than those of the fabric structure factor φ. The points of the square weave are distributed approximately uniformly in respect to average line. Properties of square weaves are similar in warp and weft directions, i.e. $P_1 = P_2$. The points with $P_1 < P_2$ are disposed in opposite sides of the average line of the structure factor φ. In the case of the average line of Newton's structure factor L these points are located on the left side. The points with $P_1 > P_2$ are disposed below the average line of the structure factor φ and on the right of the average line in the structure factor L respect.

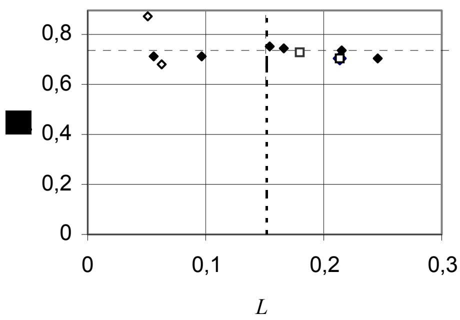

Fig. 8. The comparison of the points of fabric structure factor φ with those of Newton's fabric structure factor L: the average values of the fabric structure factors are labelled by dotted lines; the points of square weave are labelled (♦); the points of the weaves with $P_1 < P_2$ are labelled (◊); the points of the weaves with $P_1 > P_2$ are labelled (□)

In Fig. 9 there are shown the points by comparing the fabric structure factor φ with Brierley's fabric structure factor *MS/MD*. In this figure there are less points than in the pictures before because Brierley's method can't estimate all the weaves used in this investigation. The dispersion of the given points is similar in the respect of both fabric structure factors. Here it is to be mentioned that the determination coefficient of Brierley's weave factor F^m evaluates the weavability of the fabric worse than other ones but the results obtained are considerably better by estimating the all others technological parameters of the fabric. It means that Brierley's method more exactly estimates the influence of all rest technological parameters.

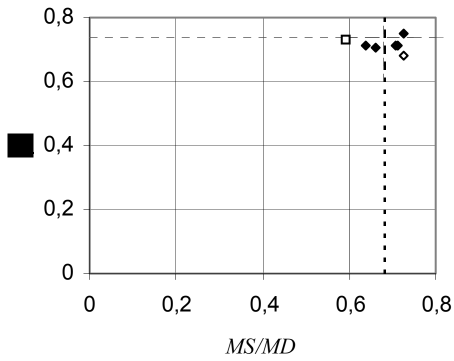

Fig. 9. The points of comparison the fabric structure factor φ with Brierley's fabric structure factor *MS/MD*: the average values of the fabric structure factors are respected by dotted lines; the points of the square weave are labelled by (♦); the points of the weaves with $P_1 < P_2$ are labelled by (◊); the points of the weaves with $P_1 > P_2$ are labelled by (□)

In the Table 2 the variation coefficients of the fabric structure factors are presented for the comparison of the obtained results for the various integrated fabric structure factors.

Table 2. The variation coefficients of the fabric structure factors

Group of factors	Factor	Variation coefficient
Peirce's	Newton's	0.48
	Seyam's	0.2
	Galceran's	0.13
Brierley's	Brierley's	0.08
	Galuszynski's	0.06
	Milašius's	0.07

From the table it can be seen that Brierley's group factors distinguish their selves considerably by less variation than Peirce's group structure factors. Their variation coefficients are less than 0.1 while those of Peirce's group are considerably more than 0.1. It must needs stress the Brierley's and Galuszynski's fabric structure factors variation coefficients were calculated from the less number of points than that of Milašius's because these factors can not be defined for some weave used in the experiment.

The investigations presented let to put forward the assumption that the weave factors can be used for weavability evaluation as express method due to the right enough accuracy of results. Of course, for definite answer the fabric firmness factor for evaluation of the weavability is preferable.

CONCLUSIONS

The weave of the fabric was evaluated by seven weave factors and the weavability of the fabric was evaluated by the maximal possible weft setting, which can be developed due the given type of loom. The weavability of the fabric was related with the weave of the fabric realizing the dependence of weave factors on the maximal weft setting.

According to the determination coefficients of these dependencies it was defined that the warp direction weave factors are the best for estimation of the weavability of the fabric because their determination coefficients are highest. The best between them is P_1. It can be proposed for express evaluation of the fabric weavability.

The fabric structure was evaluated by six integrated factors. Having carried out experiments with maximal weft settings for different weave fabrics at the same conditions of the weaving, which make certain the steady structure of fabric and herewith the steady fabric structure factor the variation coefficients of various integrated fabric structure factors were defined for their mutual comparison. Hence, the weavability of the fabric can be reflected the best by that factor which dispersion i.e. the variation coefficient, would be lowest.

It has been established that though Peirce's group fabric structure factors are used more often Brierley's group fabric structure factors are more suitable for estimation of weavability of the fabric because the variation coefficients of these factors are considerably less. The most convenient from them is to use the structure factor φ proposed by Milašius because of its universality. No regularities in the location of the structure factor φ points of non-square weave were noticed because these points are distributed at random for every fabric structure factor.

The results obtained can be applied in new fabric designing because the limited values of fabric structure factors allow select the best loom for a given fabric.

REFERENCES

1. **Milašius, V.** An Integrated Structure Factor for Woven Fabrics. Part II: The Fabric-firmness Factor *The Journal of the Textile Institute* 2 2000: pp. 277 – 283.
2. **Behera, B. K., Joshi, V. K.** Weavability of Unconventional Yarns *3rd Autex World Conference "Textiles-Necessary Condition for Development of Civilization"* Gdansk, Poland, 25 – 27 June, 2003: pp. 162 – 168.
3. **Kumpikaitė, E., Milašius, V.** Analysis of Interrelation between Fabric Structure Factors and Beat-up Parameters *Materials Science (Medžiagotyra)* 9 (2) 2003: pp. 228 – 232.
4. **Nosek, S., Jonak, R.** Factors Determining the Stress of High-speed Beat-up Mechanisms *International Conference 'New Trends in the Techniques, Technology and Organization of Weaving Mills'*, Brno, Czech Republic, 1972.
5. **Fujita, T.** Warp Lifting Plan of Weaving Calculated with Matrices *J. Text. Soc. Japan (Eng. Ed.)* 1 1961: pp. 29.
6. **Milašius, V.** An Integrated Structure Factor for Woven Fabrics. Part I: Estimation of the Weave *The Journal of the Textile Institute* 2 2000: pp. 268 – 276.
7. **Galceran, V.** Seccion Segunda: Relation Entre La Densidad y el Ligamento Sin Variar el Numero del Hilo *Technologia del Tefido* 1961: pp. 232 – 247 (in Spanish).
8. **Neves, J., Neves, M.** The Influence of the Interlacement Degree of Woven Fabrics on the Ultraviolet protection Factor *3rd Autex World Conference "Textiles-Necessary Condition for Development of Civilization"* Gdansk, Poland, 25 – 27 June, 2003: pp. 229 – 236.
9. **Brierley, S.** Cloth Setting Reconsidered *The Textile Manufacturer* 79 1952: pp. 349 – 351.
10. **Newton, A.** The Comparison of Woven Fabrics by Reference to Their Tightness *The Journal of the Textile Institute* 2 1995: pp. 232 – 240.
11. **Peirce, F. T.** The Geometry of Cloth Structure *The Journal of the Textile Institute* 28 1937: pp. 145 – 196.
12. **Seyam, A., El-Shiekh, A.** Mechanics of Woven Fabrics. Part IV: Critical Review of Fabric Degree of Tightness and Its Applications *Textile Research Journal* 4 1994: pp. 653 – 662.
13. **Galuszynski, S.** Fabric Tightness: A Coefficient to Indicate Fabric Structure *The Journal of the Textile Institute* 1 1981: pp. 44 – 49.