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The Influence of Woven Fabric Structure on the Woven Fabric Strength

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In this article, the methods of assessment of the woven fabric structure are described, the weave factors of woven fabric and integrated fabric structure factors suggested by different scientists are presented, the differences and advantages of the above factors are analyzed. The dependence of the woven fabric breaking force and elongation at break on different weave factors have been obtained within the period of the research. The obtained diagrams of points show that the correlation between the breaking force and the weave factors of the woven fabric does not exist, though the elongation at break depends on the weave of the woven fabric, i.e. with the increase of rigidity of woven fabric, the elongation at break increases. Thus the dependence of breaking force and elongation at break on the weft setting has been determined. It has been determined that with the increase of weft setting the breaking force slightly decreases, while the elongation at break increases. It has been determined from the breaking force and elongation of break of the woven fabric dependence on the integrated fabric structure factors that the correlation between the breaking force and the integrated fabric structure factors does not exist, while the elongation at break increases with the rigidity of the woven fabric structure.

Keywords: woven fabric, weave factors, integrated fabric structure factors, breaking force, elongation at break.

INTRODUCTION

Woven fabric is a material of sophisticated structure, the features of which are influenced by its structure. There are seven parameters influencing its structure: the raw material of the warp and the weft, the linear density of warp and weft, the warp and weft setting and fabric weave. Different fabric factors estimate seven parameters mentioned above.

It has been determined [1 – 3] that weave factor P_1 calculated along the warp direction, as well as the integrated fabric structure factor φ best estimates the technological properties of the woven fabric.

The influence of the woven fabric structure on some of its mechanical and end use properties has been researched. The newest researches in this area have been carried out by Milašius et al [3], who have been researching the effect of woven fabric structure on air permeability and abrasion resistance. It has been determined that with the woven fabric structure getting denser air permeability decreases, and with woven fabric weave getting more rigid abrasion resistance increases.

The tensile properties (the breaking force and elongation at break) are of very great importance, though relation with the parameters of woven fabric structure has been found just in a few previous works. Nikolic et al [4] suggested fabric strength to estimate as yarn strength, fabric setting and yarn strength coefficient function. It has been established that when increasing the yarn strength, fabric strength also increases. Plain weave fabric is the strongest, and the strength is higher in warp than in weft direction. Frydrych et al [5] investigated the influence of fabric finishing, weft density, and row material on the elongation at break value. Wang et al [6] analyzed the mechanical interaction of warp and weft yarns in shearing deformation and established theoretical equations expressing the relationship between the shearing rigidity and the fabric structures. For the short-float fabrics they found the approximately linear relationships between the rate of friction change and the contact area of warp and weft yarns. In the other articles it was estimated tear strength [7] and bending rigidity [8]. So it was just few articles which analyzed the relationships between fabric structure and their strength. So we analyzed these problems in the article.

FABRIC FACTORS

The most difficult is to characterize weave, as it is a graphic view of the woven fabric structure. To estimate the weave, different weave factors have been suggested, which might be distributed into two groups: some of them estimate only the interlacing of a single thread, while the others characterize weave as a whole.

Ashenhurst's [9] and Galceran's [10] weave factors may be allocated to the first group. The Ashenhurst's [9] weave factor $F_{1(2)}$, alternatively called the average float length, has been used most often. It can be measured along the directions of warp and weft:

$$F_{1(2)} = \frac{R_{2(1)}}{t_{1(2)}}, \tag{1}$$

where $R_{1(2)}$ are repeats of warp and weft, respectively, $t_{1(2)}$ are the numbers of intersections of warp and weft, respectively.

Galceran's [10] weave factor Kl is similar. It is calculated by:

$$Kl_{1(2)} = \frac{\sum_{i=1}^{R_{2(1)}} t_{1(2)i}}{R_1 R_2}. \tag{2}$$

The shortcoming of such weave factors is that they characterize only the interlacing of a single thread, and it is difficult to estimate all the weaves by them.

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Brierley [11], having analyzed different types of woven fabric, has suggested using the F^m weave factor, where the m index depends on the weave group excluded by Brierley. The shortcoming of this factor is that m is experimentally determined, and not in all weave cases it is clear to which weave group the analyzed weave should be allocated. Besides, difficulties arise when evaluating rib weaves [12].

Milašius [13] suggested his own weave factor P which may be calculated according to the weave matrix and evaluates weave as a whole.

The properties of woven fabric also depend on the other parameters of the woven fabric structure, which are all evaluated by the integrated fabric structure factors. Such factors have been distributed into two groups [14]: Peirce's and Brierley's. The factors of Peirce's group are calculated as a ratio between the whole woven fabric area and the area covered by threads.

The Newton's [14] integrated fabric structure factor L belongs to this group and is expressed as a distance of the point, corresponding to the analyzed fabric, to the nearest point on the Peirce's "curve of maximal setting". So it shows how far the woven fabric is from its maximal setting.

Also Seyam and El-Shiekh [15] suggested integrated fabric structure factor TS, which belongs to Peirce's group, that may be calculated following the directions of warp and weft:

$$T_{1(2)} = \frac{S_{1(2)}}{F_{2(1)}} d_{1(2)} \left(\frac{\pi \left(F_{2(1)} - 1 \right)}{4} + 2 \right), \tag{3}$$

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

The Galceran's [10] integrated fabric structure factor OG is calculated according to the formula:

$$OG = \frac{\left(1 + 0.73 Kl_1\right)\left(S_1\sqrt{T_1} + S_2\sqrt{T_2}\right)}{5\sqrt{1000}\left(\sqrt{\pi\rho_1} + \sqrt{\pi\rho_2}\right)}, \tag{4}$$

where $T_{1(2)}$ are the linear densities of warp and weft, respectively, $\rho_{1(2)}$ are densities of raw materials of warp and weft, respectively, $Kl_{1(2)}$ are Galceran's warp and weft weave factors.

Brierley's [11] group integrated fabric structure factors are calculated as the ratio between settings of standard woven fabric and the analyzed one. Standard woven fabric is plain weave fabric of square structure and maximum setting, woven out of "wire" threads with $\delta = \rho$. The Brierley's [11] integrated fabric structure factor MS/MD is calculated according to the formula:

$$MS/MD = \sqrt{\frac{12}{\pi}} \frac{1}{F^m} \sqrt{\frac{T_{av}}{\rho \cdot 1000}} S_2^{\frac{1}{1+g\sqrt{T_1/T_2}}} S_1^{\frac{g\sqrt{T_1/T_2}}{1+g\sqrt{T_1/T_2}}}, \tag{5}$$

where T_{av} is average linear density of the fabric, m, g are empiric indices, experimentally determined and depending on the weave type.

The shortcoming of the factor is that indices m and g may not be determined for more sophisticated weaves, because it isn't clear to which of the weave groups distinguished by Brierley they should be allocated. Therefore Milašius [16] suggested a new integrated fabric structure factor φ, where weave is estimated by the theoretical weave factor P_1, which may be directly calculated from the weave matrix, while the g factor is constant and does not depend on type of weave:

$$\varphi = \sqrt{\frac{12}{\pi}} \frac{1}{P_1} \sqrt{\frac{T_{av}}{\rho}} S_2^{\frac{1}{1+2/3\sqrt{T_1/T_2}}} S_1^{\frac{2/3\sqrt{T_1/T_2}}{1+2/3\sqrt{T_1/T_2}}}. \tag{6}$$

The above integral weave factor may be calculated along the warp and weft directions.

METHODS

To research the influence of the fabric structure on the fabric strength, woven fabrics have been woven using STB gripper weaving loom from PES 29.4 tex multifilament yarns.

The warp setting was 28.4 cm^{-1}. Several weaves have been woven with five different weft settings within the limits of the range of their weavability. The warps were drawn-in into 8 harnesses by straight draw. 12 weaves have been used for woven fabrics that may be woven without resetting of the weaving loom. Also the weave factors of all weaves were different and distributed within the range of values of weave factors. Part of weaves (3, 8, 9, 10, 11, 12) were with the more or less expressed across stripiness. The floats of other weaves (1, 2, 4, 5, 6, 7) were evenly distributed within the whole width of the woven fabric. The weaves used for the experiment are presented in Fig. 1.

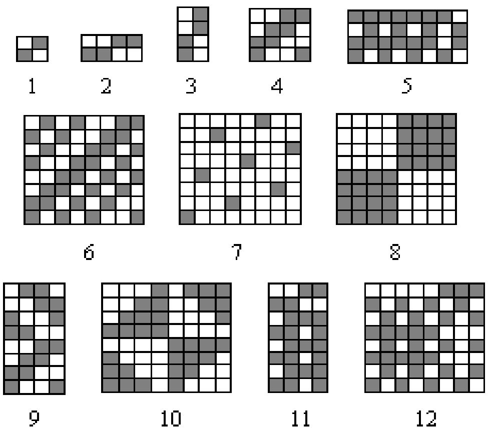

Fig. 1. The weaves using for experiment: 1 – plain weave; 2 – weft rib; 3 – warp rib; 4 – twill 2/2; 5 – weft direction Bedford cord; 6 – fancy twill; 7 – sateen; 8 – basket weave; 9 – broken twill; 10 – crape weave; 11 – warp direction Bedford cord; 12 – mock leno

The woven fabric tensile tests have been carried out according to the international standard ISO 13934-1 [17] with a tensile testing machine Zwick/Z005. The speed of stretching was 100 mm/min, the distance between clamps was 200 mm. The tests were carried out in standard weather conditions. The test samples were being cut only along the warp direction, because woven fabric is being formed along the warp, and it had been shown by previous researchers [12] that the properties of woven fabric along the direction of warp are more important than those along the direction of weft. The coefficient of variation of tests results was 5 %.

INVESTIGATION RESULTS

When researching the effect of weave on the strength properties of woven fabric, dependences of breaking force and elongation at break on different weave factors (Ashenhurst's F_1, Galceran's Kl_1, Brierley's F^m and Milašius's P_1) have been obtained. Two of these factors (F_1 and Kl_1) estimate interlacing of a single thread, while the two others (F^m and P_1) estimate weave as a whole. All the weave factors with the exception of F^m have been defined along the direction of warp, because the strength of the woven fabric has been researched only along this direction. F^m is the Brierley's weave factor, which may be determined only common for all the woven fabric. The obtained diagram of breaking force points from the weave factor P_1 has been presented in Fig. 2.

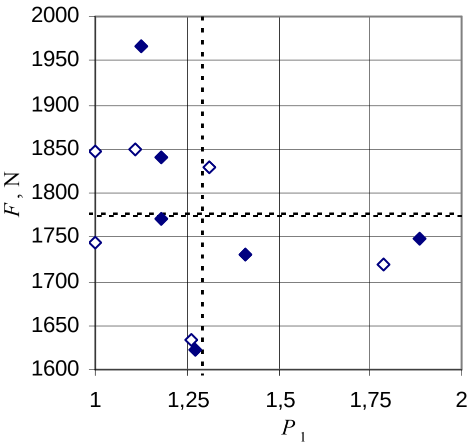

Fig. 2. The dependence of the breaking force F on the weave factor P_1: ◊ – weaves, the floats of which are evenly distributed within the whole area of the woven fabric; ♦ – across striped weaves; the dotted line shows the average of values of the breaking force and weave factor P_1

We can see from the diagram of points that the points are distributed at random, i.e. the correlation between weave factor and breaking force does not exist, though the breaking force depends on fabric weave because the breaking force varies within the limit of 25 %, but the dependence of breaking force on these weave factors was not established. It has been observed during the experiment that the weaves may be distributed into two groups according to the character of the break, i.e. the across striped weaves broke within the whole length of the test sample, while the weaves with evenly distributed floats within the whole woven fabric area have broken at the definite site of the test sample (localized). So it is possible to notice from the points diagram that both groups of weaves with evenly distributed floats and across striped weaves are equally distributed with regard to the average line, i.e. 3 points on both average line sides. It also proves that the points of all the weaves are situated at random and the character of weave has no effect on distribution of points.

The dependence of elongation at break on weave factor Kl_1 is given in Fig. 3. It is seen that the elongation at break of the woven fabric is influenced by the weave, though the coefficient of determination is small.

Therefore, having deducted the results of warp and weft rib weaves (Fig. 4), the coefficient of determination increases significantly. The deduction of these weaves is based by the fact that they have been analyzed by Brierley [4] as special. Thus the research carried out in this work has also confirmed the peculiarity of these weaves. We can see that with rigidity of the woven fabric weave its elongation at break increases. The dependence is precisely described by the second degree polynomial equation.

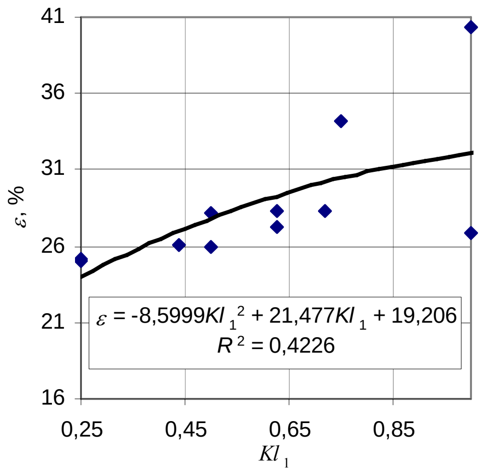

Fig. 3. The dependence of elongation at break ε on the weave factor Kl_1

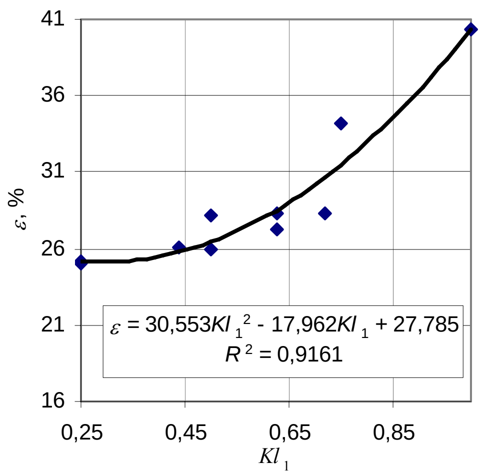

Fig. 4. The dependence of ε elongation at break on the weave factor Kl_1 having deducted the warp and weft rib weaves

Similar dependences have also been obtained from the other weave factors.

The values of all the dependences coefficients of determination are given in Table 1. We can see that the values of all the dependences coefficients of determination are large, so all the weave factors describe the elongation at break precisely enough. The largest is the value of the coefficient of determination of the Galceran's weave factor Kl_1. The smallest is the value of the coefficient of determination of the Brierley's weave factor F^m. This may be due to the fact that this weave factor is empirically set and calculated as general for the whole woven fabric. It may not be calculated only along the direction of warp. There are no conspicuous differences between the results of both weave groups, because the values of their coefficients of determination vary in rather close limits.

Table 1. Coefficients of determination of dependences of elongation at break on the weave factors

Factor's group	Weave factor	Coefficient of determination
Weave factors evaluating separate thread	Kl_1	0.9161
	F_1	0.8039
Factors evaluating weave as a whole	P_1	0.8077
	F^m	0.7698

Another parameter of the woven fabric structure, which could be changed during the experiment, is the weft setting. So dependences of breaking force and elongation at break on the weft setting were established. Dependence of breaking force of plain weave fabric on the weft setting is presented in Fig. 5. We can observe that the value of coefficient of determination is 0.6672, i.e. medium. It has been established that when the weft setting increases, the breaking force has a tendency to decrease. That could be explained by the fact that in the case of bigger weft setting the adjacent threads press each other more and in the places of contact the woven fabric becomes weaker. The curve is described by second degree polynomial equation. Similar curves have been obtained in the cases of other weaves.

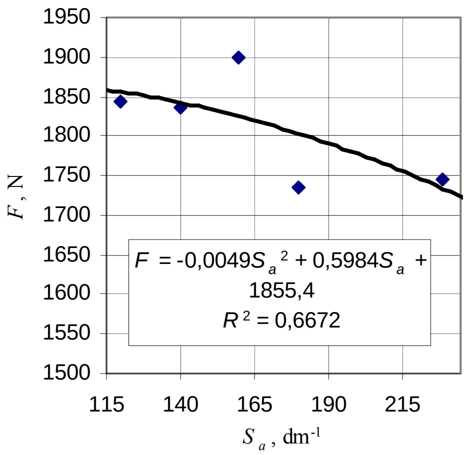

Fig. 5. The dependence of breaking force F of plain weave fabric on weft setting of woven fabric S_a

In Fig. 6 the dependence of elongation at break of plain weave woven fabric on the weft setting has been presented. We can see that with the increase of the weft setting the elongation at break increases. That can be explained by the fact that with larger weft setting the threads squirm more and during the stretching they are apt to straighten. The dependence is described by second degree polynomial equation – the value of coefficient of determination is 0.9914, i.e. extremely big.

To unite the influence of all the parameters of woven fabric structure on the factors of strength, the dependences of the factors of woven fabric strength on various factors of integral structure of the fabric have been established. The newest integrated factor φ of woven fabric structure is offered by Milašius. The diagram of points of breaking force on the factor φ is presented in Fig. 7. We can see that, as in the case of weave factors, there is no correlation between the analyzed parameters, i.e. the points are located at random on both sides of the average line. So, although the weft setting influences the breaking force, that influence disappears by evaluating all other parameters of woven fabric structure.

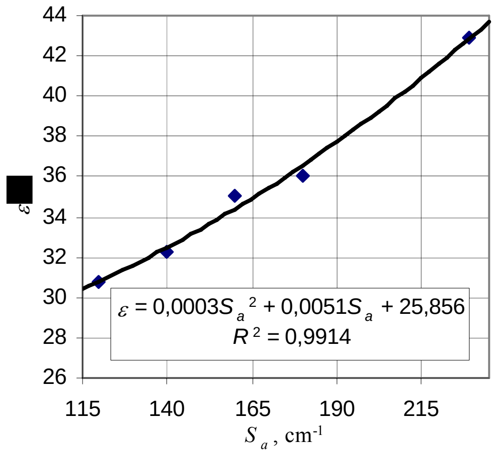

Fig. 6. The dependence of elongation of break ε of plain weave fabric on weft setting of woven S_a

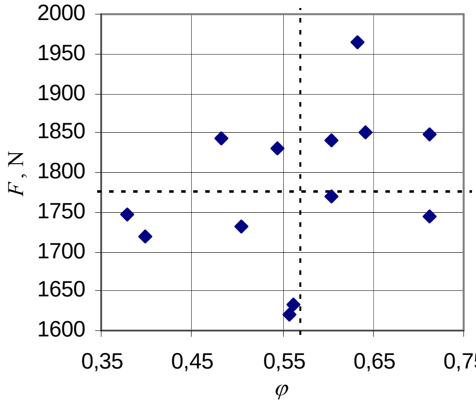

Fig. 7. The dependence of breaking force F on the factor φ of integral woven fabric structure

In the case of other integrated factors of fabric structure, similar point diagrams have been obtained as well, i.e. correlation between the breaking force of the woven fabric and integrated factors of structure of woven fabrics does not exist.

The dependences of the elongation at break on various integrated fabric structure factors have been established. One of them is presented in Fig. 8. We can see that as the structure of woven fabric becomes more rigid, i.e. factor φ of the woven fabric structure increases, the elongation at break increases. The same tendency, obtained in the case of separate woven fabric structure parameters (weave of woven fabric and weft setting), confirms that. Second degree polynomial equation reflects the dependence – value of coefficient of determination is 0.8897.

The dependences of elongation at break on other integrated fabric structure factors were obtained as well. The coefficients of determination of these dependences are presented in Table 2. We can see that in the case of all integrated fabric structure factors the coefficients of

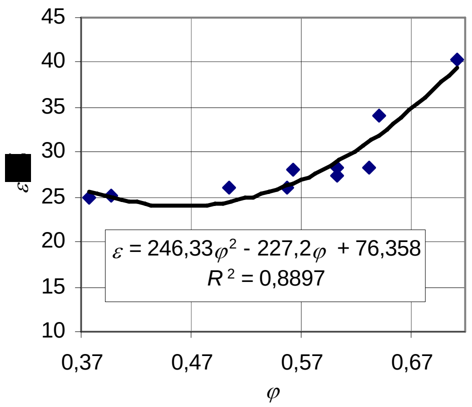

Fig. 8. The dependence of elongation at break ε on the integrated fabric structure factor φ

Table 2. Coefficients of determination of dependences of elongation at break on various integral woven fabric structure factors

Factor‘s group	Factor	Coefficient of determination
Peirce's	Newton's	0.9545
	Galceran's	0.9507
	Seyam's	0.9161
Brierley's	Brierley's	0.9337
	Milašius‘s	0.8897

determination vary in rather close limits and their values are large, so we cannot distinguish indicators of a certain group as reflecting the mentioned dependences more exactly.

CONCLUSIONS

For fabrics woven by different weaves and different weft settings, after performing tensile tests and establishing the breaking force and elongation at break of the woven fabrics, we conclude the following:

1. The influence of weave on the breaking force and elongation at break has been established. From the diagram of points of breaking force on various weave factors, it has been established that correlation between the breaking force and various weave factors does not exist. The obtained dependences of elongation at break on the factors of weave indicate that in the case of increase in weave rigidity the elongation at break increases.

2. The influence of the weft setting on the factors of woven fabric strength has been established. It has been found out that during the increase in weft setting the breaking force slightly decreases, and the elongation at break increases.

3. Considering the influence of all the woven fabric structure parameters on the factors of strength of woven fabric, the dependences of breaking force and elongation at break on various integrated fabric structure factors have been obtained. After evaluating all the parameters of structure, it has been established that correlation between breaking force of the woven fabric and integrated fabric structure factors does not exist. If the structure of woven fabric becomes more rigid, the elongation at break increases.

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