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New Representation of the Fabric Weave Factor

Abstract

To design woven fabrics and select the parameters of their structure, it is always necessary to evaluate the two dimensional matrix of the weave by one factor. In this artice possibilities of the employment of the fabric weave factors P and P_1 proposed by V. Milašius are presented. In Brierley's theory weave factor F^m is calculated with different means of index m depending on the type of weave. The index m is estimated in an experimental way. Weave factors P and P_1 are calculated directly from the weave matrix and have excellent correlation with the experimental factor F^m. They cover most of the weaves used but can not be employed for calculating the factors of weaves which are very unbalanced. The aim and innovation of this investigation is the exploration of the employment of factors P and P_1 for all one-layer weaves, including very unbalanced ones. Experimental investigations were made on the basis of Brierley's theory; the maximum pick density was found in an original, more precise way. A suggestion was made to evaluate the integrated weave factor P' by different weights of the factors calculated in the warp and weft directions and by adding this to the formulas of unbalancing factor U. It was also presumed that for balanced weaves the newly calculated factor P' must be equal to P. The model that is proposed shows excellent correlation between experimental and theoretical values of the new weave factor.

Key words: *woven fabrics, weave factor, pick density, unbalanced weave.*

Introduction

To design woven fabrics and select and select their structural parameters, it is always necessary to evaluate the two dimensional matrix of the weave by one factor. This is the main problem that designers face during the construction of a fabric structure. Back in the XIX century, in order to evaluate the two dimensional matrix of a weave, the average float *F* was proposed [1]. Later on was observed that this factor did not reflect all the properties of a weave, which are important from a technological and end-use point of view. This factor could not evaluate the difference between types of weaves (it is well known that the weaves twill 7/1, satin 8/3 and panama 4/4 have a different tightness, but are still counted with the same value, F = 4) and unbalanced weaves, whose average warp float is different from the average weft float (warp rib 4/4 and weft rib 4/4 behave very differently during weaving but still evaluated using the same value, F = 2.5). As Brierley [2] notes, Armitage and Law were the first to take notice of it andintroduced correction factors depending on the kind of weave. The improvements in the weave factor that started at the beginning of the XXth century are still continuing. Other weave factors were proposed by Galceran [3], and Matsudaira [4]. The newest of them is the *FYF* [4], which was proposed by Matsudaira: it evaluates the length of parts of floats. In Brierly's theory of maximum setting [2], the weave factor F^m is proposed. Index *m* is estimated in an experimental way depending on the type of weave. It is different for twills, satins, panamas and ribs. It shows the difference between some unbalanced weaves like warp and weft ribs. The limitation of use of the factor is predicted by the different value of *m* for different types of weaves. It can not be used for evaluation of all weaves nor be employed in CAD fabric systems. V. Milašius [5] proposed the weave factor *P*. It is calculated directly from the weave matrix and has excellent correlation with Brierley's experimental factor F^m. Factor *P* is calculated in the same way for all weaves without special evaluation of the type of weave and can be used in CAD fabric systems. However, factor *P* is very good for balanced weaves but cannot evaluate the difference between unbalanced weaves – warp rib 4/4 and weft rib 4/4 have the same value, P = 1.205. Later on V. Milašius [6, 7] proposed factor P_1, calculated in the warp direction. It covers most of the weaves used but can not be employed for calculating very unbalanced weaves [8] (for example, plain weave and weft rib 4/4 have the same value, P_1 = 1). The aim and innovation of this investigation is to explore various employments of factors P_1 and P for all one-layer weaves, while maintaining the strong sides of both of them.

Methods

Experimental investigations were made on the basis of Brierley's theory of maximum settings [2]. This theory was derived from the weaving of so-called square fabrics, where the linear density

$$P_{exp} = \frac{S_{q\,\max}}{S_{q\,\max\,plain}} = \frac{S_{2\max}^{\frac{1}{1+2/3\sqrt{T_1/T_2}}}\; S_1^{\frac{2/3\sqrt{T_1/T_2}}{1+2/3\sqrt{T_1/T_2}}}}{S_{2\max\,plain}^{\frac{1}{1+2/3\sqrt{T_1/T_2}}}\; S_{1plain}^{\frac{2/3\sqrt{T_1/T_2}}{1+2/3\sqrt{T_1/T_2}}}} = \left(\frac{S_{2\max}}{S_{2\max\,plain}}\right)^{\frac{1}{1+2/3\sqrt{T_1/T_2}}} \left(\frac{S_1}{S_{1plain}}\right)^{\frac{2/3\sqrt{T_1/T_2}}{1+2/3\sqrt{T_1/T_2}}} \quad (2)$$

Equation 2.

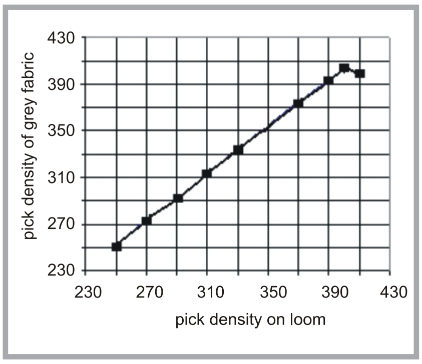

***Figure 1.** Estimation of the maximum pick densities for weft rib 4/4.*

of yarns and density of yarns on the loom in both directions are equal and unchanging. Brierley defined that the experimental value of weave factor P_{exp} can be calculated as:

$$P_{\exp} = \frac{S_{q\max}}{S_{q\max\,plain}} \qquad (1)$$

Brierley later proposed a model for evaluating not square fabrics according to which P_{exp} can be found as Equation (2).

During all weavings performed, the warp density did not change. Moreover, all the experiments were conducted with the same warp and weft yarns. In this case, $T_1 = T_2$ and $S_1 = S_{1plain}$, thus

$$P_{\exp} = \left(\frac{S_{2\max}}{S_{2\max\,plain}}\right)^{0,6} \qquad (3)$$

here S_{2max} – maximum pick density of tested weave, $S_{2max\ plain}$ – maximum pick density of a plain weave.

As the main aim of this investigation was to determine the influence of the level of unbalance of the weaves, the weaves selected presented the main types of balanced weaves (for comparison with earlier experiments of Brierley and other investigators and in order to obtain information on quality of this experiment), and various unbalanced weaves with a difference between P_1 and P_2 of up to 63%, as in the case of warp and weft ribs 4/4. During the experiment, the following balanced weaves were tested: plain, twill, satin and panamas - with F ranged between 1 and 4. Unbalanced weaves can be found in modified basic weaves of all types, such as warp and weft ribs, irregular panamas, broken twills, diagonals, reinforced satin, and diagonal warp and weft ribs. Weaves were tested with a difference in the values of floats in the warp and weft directions from 0.5 (broken twill 2/2 and rib 2/1) to 3 (ribs 4/4).

As was mentioned before, the result of our experiments was the maximum pick density for all tested weaves. It is very important that the maximum pick density will be estimated in a most precise way without any influence of the investigator. In our investigation the following new method was used: by increasing the pick density on the loom, the pick density of the grey fabric also increases. This occurs till the maximum limit of pick density is achieved. This means that permanent fell movement to the side of the reed side takes place till weaving becames impossible. When the limit is reached, a further increase in pick density on the loom does not take place nor an increase in the pick density of the grey fabric. Therefore, the pick density of grey fabric measured is considered as the maximum density of the fabric. In ***Figure 1*** the results of such an experiment for weft rib 4/4 are presented. We can state that the maximum pick density on the loom for weft rib 4/4 is 400/10 cm. This method was used for estimation of the maximum pick density for all tested weaves.

For the evaluation of the results obtained, the following criteria were used:

- a_{max} – maximum deviation of a single result in %

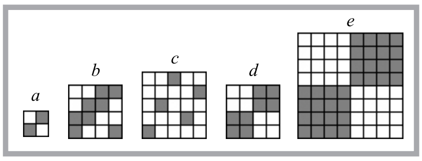

***Figure 2.** Weaves balanced by F: a – plain, b – twill 2/2, c – satin 5/2, d – panama 2/2, e – panama 4/4.*

- r - coefficient of correlation between measured and theoretical values
- dispersion of inadequacy:

$$D_{inadeq} = \frac{\sum \left(P_{\exp} - P'\right)^2}{n - n_{eq}},$$

here n – number of measurements (number of tested weaves),

n_{eq} – number of experimental coefficients in the formula

- δ - and deviation of inadequacy in % according to the mean value:

$$\delta = \frac{\sqrt{D_{inadeq}}}{\overline{P'}} 100$$

Experimental investigations

The fabrics were woven with the following data: the warp density of all samples produced was 354/dm (reed 118/3/dm), warp and weft yarns – filament polyester yarns 16.7 tex × 2. All weaves investi-

***Table 1.** Results of the weaves balanced by F.*

Balanced by F weaves	Fig. 2	P_1	P_2	S_{2max}, dm^{-1}	P_{exp} by (3)
Plain	a	1	1	220	1.000
Twill 2/2	b	1.265	1.265	330	1.275
Satin 5/2	c	1.414	1.414	385	1.399
Panama 2/2	d	1.359	1.359	355	1.333
Panama 4/4	e	1.886	1.886	570	1.770

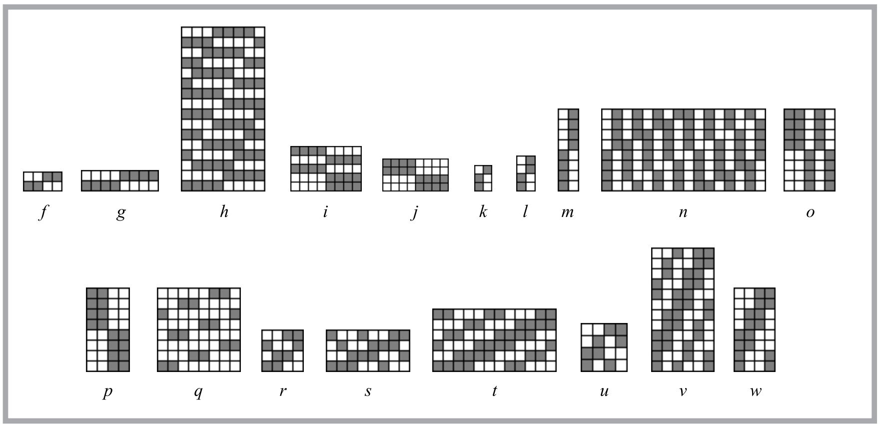

***Figure 3.** Weaves unbalanced by F: f – weft rib 2/2, g – weft rib 4/4, h – diagonal weft rib 4/4, i – irregular panama A (warp 2/1 1/1, weft 4/4), j – irregular panama B (warp 2/2, weft 4/4), k – warp rib 2/1, l – warp rib 2/2, m – warp rib 4/4, n – diagonal warp rib 4/4, o – irregular panama C (warp 4/4, weft 2/1 1/1), p – irregular panama D (warp 4/4, weft 2/2), q – reinforced satin, r – broken weft twill 2/2, s – weft diagonal 3/2 1/2, t – weft diagonal 4/3 2/3, u – broken warp twill 2/2, v – warp diagonal 4/3 2/3, w – warp diagonal 4/4.*

gated were divided into two groups: the first – weaves balanced by F, i.e., weaves with $F_1 = F_2$ (***Figure 2***) and the second - weaves unbalanced by F with $F_1 \neq F_2$ (***Figure 3***).

The data of weaves balanced by F and their maximum pick densities S_{2max} on the loom are listed in ***Table 1***.

The comparison of the experimental value P_{exp} calculated according to (3) with earlier proposed values [6 - 8] of P_1 shows very good results – a_{max} = 6.5 %, r = 0.997, D_{inadeq} = 0.00287, δ = 3.95 %. These parameters prove there is an excellent correlation between the results of this investigation and those obtained by Brierley more than 75 years ago, in which he used a very different loom with very different yarns: Brierley wove worsted yarns on a shuttle loom, whereas our results were obtained from the weaving of synthetic filament yarns on a rapier loom. We stated that the tension of warp and weft threads did not have an influence on the experimental value of the weave factor. It is only important to keep the tension stable during all weavings Undoubtedly, the tensions of yarns during this experiment and those of Brierley were very different, but the results have excellent correlation.

In ***Table 2*** the results of weaves unbalanced by F are listed.

Comparison of the experimental value P_{exp} calculated according to (3) with earlier proposed values [6 - 8] P_1 for weaves unbalanced by F (***Table 2***) shows very great differences between some specific weaves, and low correlation of the model $P_{exp} = f(P_1)$ - a_{max} = -30.1%, r = 0.789, D_{inadeq} = 0.03114, δ = 12.43%. Factor P_1 is workable for the evaluation of all weaves except those, where P_2 is 20-25% higher than P_1. This mainly concernsto weft ribs and irregular panamas made on the basis of weft ribs, with the exception of the following weaves: (marked in Table 2 by *) $P_{exp}=f(P_1)$ - a_{max} = -7.9%, r = 0.973, D_{inadeq} = 0.00306, δ = 3.84%. After elimination of the weaves marked by *, the deviation of results is very close to that of balanced weaves. Therefore, factor P_1 was can be easily implemented into the CAD system [7].

In this investigation a new method of calculating the weave factor P is proposed. It was assumed that for balanced weaves the newly calculated P' must be equal to P. Firstly, two models were evaluated:

$$P' = P_1^{a} P_2^{(1-a)} \tag{4}$$

and

$$P' = a P_1 + (1-a) P_2 \tag{5}$$

here a – experimental coefficient.

In both formulas, in the case of balanced weaves, where $P = P_1 = P_2$, $P' = P$, it was indicated by the least square method, that the best results are obtained by formula (5) with a value of a = 0.712, $P_{exp} = f(P')$ - a_{max} = -17.5%, r = 0.878, D_{inadeq} = 0.01764, and δ = 9.35%.

Notwithstanding the above-mentioned statement, an analysis of the results shows that the greatest difference between experimental and theoretical values was observed for the most unbalanced weaves, in which factor P calculated in one direction exceeds that calculated in another direction by 50% or more. After elimination of these weaves (marked in ***Table 2*** by **), a_{max} = -6.8%, r = 0.976, D_{inadeq} = 0.00266, and δ = 3.82 %.

It is very important that for all significantly unbalanced weaves, the theoretical P' calculated from formula (5) is lower than the experimental one.

Table 2. *Results of weaves unbalanced by F.*

Weaves unbalanced by F	Notes	Fig. 3	P_1	P_2	S_{2max}, dm^{-1}	P_{exp} by (3)
Weft rib 2/2	*	*F*	1.000	1.309	245	1.067
Weft rib 4/4	* & **	*G*	1.000	1.633	400	1.431
Diagonal weft rib 4/4	* & **	*H*	1.050	1.611	390	1.410
Irregular panama *A* (warp 2/1 1/1, weft 4/4)	* & **	*I*	1.112	1.690	430	1.495
Irregular panama *B* (warp 2/2, weft 4/4)	*	*J*	1.386	1.789	455	1.547
Warp rib 2/1		*K*	1.177	1.000	285	1.168
Warp rib 2/2		*L*	1.309	1.000	345	1.31
Warp rib 4/4	**	*M*	1.633	1.000	520	1.676
Diagonal warp rib 4/4	**	*N*	1.611	1.050	510	1.656
Irregular panama *C* (warp 4/4, weft 2/1 1/1)	**	*O*	1.690	1.112	530	1.695
Irregular panama *D* (warp 4/4, weft 2/2)		*P*	1.789	1.386	535	1.704
Reinforced satin	*	*Q*	1.333	1.680	430	1.495
Broken weft twill 2/2		*R*	1.180	1.276	275	1.143
Weft diagonal 3/2 ½		*S*	1.109	1.286	300	1.205
Weft diagonal 4/3 2/3	*	*T*	1.171	1.488	325	1.264
Broken warp twill 2/2		*U*	1.276	1.180	315	1.240
Warp diagonal 4/3 2/3		*V*	1.488	1.171	420	1.474
Warp diagonal 4/4		*W*	1.680	1.333	470	1.577

Table 3. *Comparison of experimental weave factors and those calculated by equation (9) of weaves unbalanced by F.*

Weaves unbalanced by F	P_1	P_2	P' by (9)	P_{exp} by (3)
Weft rib 2/2	1.000	1.309	1.118	1.067
Weft rib 4/4	1.000	1.633	1.434	1.431
Diagonal weft rib 4/4	1.050	1.611	1.386	1.410
Irregular panama A (warp 2/1 1/1, weft 4/4)	1.112	1.690	1.470	1.495
Irregular panama B (warp 2/2, weft 4/4)	1.386	1.789	1.566	1.547
Warp rib 2/1	1.177	1.000	1.131	1.168
Warp rib 2/2	1.309	1.000	1.249	1.310
Warp rib 4/4	1.633	1.000	1.702	1.676
Diagonal warp rib 4/4	1.611	1.050	1.623	1.656
Irregular panama C (warp 4/4, weft 2/1 1/1)	1.690	1.112	1.715	1.695
Irregular panama D (warp 4/4, weft 2/2)	1.789	1.386	1.737	1.704
Reinforced satin	1.333	1.680	1.474	1.495
Broken weft twill 2/2	1.180	1.276	1.208	1.143
Weft diagonal 3/2 1/2	1.109	1.286	1.166	1.205
Weft diagonal 4/3 2/3	1.171	1.488	1.294	1.264
Broken warp twill 2/2	1.276	1.180	1.249	1.240
Warp diagonal 4/3 2/3	1.488	1.171	1.428	1.474
Warp diagonal 4/4	1.680	1.333	1.621	1.577

Table 4. *Statistical data of the results.*

	Note	a_{max}, %	r	D_{inadeq}	δ, %
Weaves balanced by F – $P_{exp} = f(P_1)$		6,5	0,997	0,00287	3,95
Weaves unbalanced by F – $P_{exp} = f(P_1)$	all tested	-30,1	0,789	0,03114	12,43
	not marked by *	-7,9	0,973	0,00306	3,84
Weaves unbalanced by F – $P_{exp} = f(P')$ formula (5)	all tested	-17.5	0,878	0,01764	9,35
	not marked by **	-6.8	0.976	0.00266	3.82
Weaves unbalanced by F – $P_{exp} = f(P')$ formula (9)		5,7	0,984	0,00148	2,71
All tested weaves – $P_{exp} = f(P')$ formula (9)		**6.5**	**0,984**	**0,00181**	**3.03**

Therefore, a factor of unbalancing U was added to formula (5):

$$P' = a\,P_1 + (1 - a)\,P_2 + U \qquad (6)$$

Two models were evaluated for determination offactor U:

$$U = b\,\mathrm{ABS}\,(P_1 - P_2) \qquad (7)$$

and

$$U = [\mathrm{ABS}\,(P_1 - P_2)]^b \qquad (8)$$

here b – experimental coefficient.

It was indicated by the least square method, that the best results are obtained by formula (8) with b = 3.02. Finally, the new model for calculation of the weave factor P' is described by the following equation:

$$\begin{aligned} P' &= a\,P_1 + (1 - a)\,P_2 + \\ &+ [\mathrm{ABS}\,(P_1 - P_2)]^b = \\ &= 0.712\,P_1 + 0.288\,P_2 + \\ &+ [\mathrm{ABS}\,(P_1 - P_2)]^{3.02} \end{aligned} \qquad (9)$$

The results are presented in ***Table 3***.

According to (9), $P_{exp} = f(P') - a_{max}$ = = 5.7%, r = 0.984, D_{inadeq} = 0.00148, and δ = 2.71%. Model (9) shows excellent correlation between experimental and theoretical values of the weave factor. The value can be calculated more simply using equation (10) in order to obtain a quick result:

$$\begin{aligned} P' &= 0.7\,P_1 + 0.3\,P_2 + \\ &+ [\mathrm{ABS}\,(P_1 - P_2)]^3 \end{aligned} \qquad (10)$$

For all the tested weaves – balanced and unbalanced – from formula (9), we obtain $P_{exp}=f(P') - a_{max}$ = 6.5%, r = 0.984, D_{inadeq} = 0.00181, and δ = 3.03%.

In ***Table 4*** statistical data of all the experiments carried out in this investigation are presented. The results show that formula (9) is the most precise for evaluation of all one-layer weaves. All of the other models presented might be used but with a limitations of the area of employment, as was mentioned earlier. Applying these models to all weaves gives unsatisfactory results. The formula proposed (9) provides excellent correlation with experimental results for all weaves tested.

It is worth noting that the new model (9) for calculating the weave factor P' is built by using only two experimental coefficients a and b.

The calculation of weave factors P_1 and P_2 is very complicated and time consuming when done by hand. Free access to a file detailing their calculation can be found on the following website http://www.textiles.ktu.lt/Pagr/En/Cont/pagrE.htm.

Conclusions

A new idea for calculating the weave factor of one-layer weaves balanced and unbalanced by F is presented and proved. Factor P' represents the integrated mean of weave factors calculated in warp P_1 and weft P_2 directions with their different weights, respectively, as well as the mean of unbalancing factor U. Factor U has an absolute mean value irrespective of which factor – (P_1) or (P_2) – has a higher value. The importance of U is sufficient when one of the factors P_1 and P_2 exceeds the other one by 40 - 50% or more. The newly presented factor P' is calculated from the weave matrix by using only two experimental coefficients: a = 0.712 and b = 3.02, which are constant for all one-layer weaves irrespective of the type of weave and degree of unbalancing. Factor P' does not depend on the raw material of yarns nor on the type of loom. Excellent correlation between factor P' between Brierley's factor F^m was indicated, and due to the universality of all one-layer weaves (balanced and unbalanced), it can be used without any variable experimental coefficients for calculation of any of the two dimensional matrices of one-layer weave.

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Received 14.02.2008 Reviewed 05.05.2008