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Influence of Fabric Structure Parameters on Seam Slippage

Abstract
The slippage resistance of yarns at the seam in woven fabrics is a very important factor and very strict claims are made with respect to this property. It is necessary to know how the fabric structure influences seam slippage quality before manufacturing a fabric. The purpose of this work was to establish which of the fabric structure parameters influence seam slippage. Our previous work investigated the influence of weave on the seam slippage characteristics of a fabric, and a new weave factor was proposed which best characterises the weave from the thread slippage point of view. It was found that the seam slippage influences not only the weave factor in the slip direction but also in the normal direction. In the paper, by means of the design of experiments, the influence of weave, warp density and weft density on seam slippage was investigated. It was found that the warp density has a very low influence on seam slippage characteristics. Only the weft density and weave influence seam slippage.

Key words: *woven fabrics weave factor, seam slippage, fabric structure and density.*

Introduction

Creating new high quality textile products and analysing their properties is an especially pressing and important problem today. When new fabrics are designed it is important to know their various properties. It is well known that woven fabric quality is closely dependent on the structure of the fabric. Each fabric is a complex material and its structure affects its own properties. A fabric's structure can be evaluated by seven basic parameters: the warp and weft raw material, warp and weft linear densities, warp and weft settings and the weave of the fabric [1]. All seven parameters of the fabric's structure can be evaluated by integrated fabric structure factors.

Different researchers have proposed different kinds of evaluation of all these parameters. According to the ways and methods of their evaluation, two groups of integrated factors are identified: those based on Peirce's theories and those based on Brierley's. These groups differ in their physical meaning. In the first case it is the ratio of the surface covered by threads to the whole fabric area. In the second case, it is the ratio of the setting of the 'square' analogue of a given fabric to that of standard 'wire' plain weave fabric [2, 3]. This group also includes the average float length *F,* which was offered by Ashenhurst, and the weave factor *P* offered by V. Milašius.

The average float length *F* was a very simple and widely used factor [4]. However, later it was observed that this factor didnot describe 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 following weaves: twill 7/1, 8 held satin and basket 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 are still evaluated using the same value, F = 2.5).

Weave factor *P* offered by V. Milašius [1] is calculated directly from the weave matrix. Factor *P* evaluates not only a single thread float, but an interlacing of adjacent threads as well and can be calculated for all types of weaves. Weave factor *P* measures the fabric structure, describing some of its properties, such as its elasticity and air permeability, among others [5]. On the other hand, although factor *P* is very good for balanced weaves, it 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 proposed factor $P1$, calculated in the warp direction. It covers most of the weaves used but cannot be employed for calculating very unbalanced weaves [6] (for example, plain weave and weft rib 4/4 have the same value, $P1$ = 1). Moreover it is known that the properties of fabrics with the same setting parameters but woven with not identical technological parameters are different [7]. Therefore all fabrics need to be woven with the same loom. In this way, only the weight of fabric weaves as well as the warp and weft setting can be analysed.

The slippage resistance of yarns at a seam in woven fabrics is a very important factor and very strict claims are made with respect to this property. It is an important parameter for fabric characterisation, especially for garment making. Moreover it is necessary to know how the fabric structure influences seam slippage quality before manufacturing a fabric. This knowledge allows to design fabric with new patterns suitable for clothing that will not slip in its seams. Seam slippage measures the ability of warp yarns to slip over the weft near the seam, which extends in the warp direction, when the fabric is subjected to a given load in the weft direction (and vice versa). This load is applied so as to separate the two pieces of the fabric joins by the seam, and thus an opening, which is the result of yarn slippage, appears near the seam. Many studies have been performed on the slippage of yarns of woven fabric, but this question is still open [8 - 12]. The nnfluence of the weave as well as the warp and setting on the slippage of yarns of woven fabric is not still completely investigated.

In previous works [13, 14] it was found that the determination of models were few in this area, and because of that it was attempted to find a new weave factor which best characterises the fabric structure from the thread slippage point of view. Investigations with balanced weave fabrics showed that the new weave factor *NPR* better describes the influence of the weave on slippage than other known weave factors (V. Milašius's factor *P* or Ashenhurst's factor *F*). According to the coefficient of determination, it was found that the power equation of the new weave factor ($NPR_2^{-0.88}$) characterises well a balanced fabric structure from the

__Table 1.__ Structural parameters of fabrics used in the experiment.

Fabric	Weave	S_1, dm^{-1}	S_2, dm^{-1}	K
1	twill 3/3	360	300	2.63
2	twill 2/1	300	278	1.43
3	twill 3/3	360	200	2.63
4	plane weave	360	200	1.00
5	twill 3/3	240	300	2.63
6	plane weave	240	270	1.00
7	diamond specular broken twill 2/3	300	225	2.55
8	plane weave	240	200	1.00
9	twill 2/2	360	250	1,84
10		240	250	1,84
11		300	300	1,84
12		300	200	1,84
13	twill 3/3	300	250	2,63
14	plane weave	300	250	1
15	twill 2/2	300	250	1,84

thread slippage point of view. It was established that for unbalanced weave fabrics, seam slippage influences not only the weave factor in the slip direction but also in the normal direction. Hence the influence of the weave factor in the slip and opposite directions was investigated $K = 0.81 \times NPR_2^{-0.88} + 0.19 \times NPR_1^{-0.88}$). The weave factor in the slip direction influences seam slippage by 81%, and weave factor on opposite direction by 19%.

The aim of the present work was to analyse how the weave as well as the warp and weft settings together influence the slippage resistance of yarns at a seam in woven fabrics.

Materials and methods

The objects of investigation were fifteen wool fabrics, woven according to the theory of the design of experiments, differing not only in the weave but also in the warp and weft settings. They were all woven on the same rapier looms and had the same linear density of warps and wefts – 12.5 tex×2. Other structural parameters of the fabrics are presented in ***Table 1***. The fabrics were woven in 5 different weaves, which are shown in ***Figure 1***.

The slippage resistance of yarns at a seam in the woven fabrics was measured with a tensile testing machine - Zwick/Z005, according to the international standard 'Determination of the slippage resistance of yarns at a seam in woven fabrics – Part 1: Fixed seam opening method' (LST EN ISO 13936-1: 2004) and according to the Woolmark test method (TM 117 'Seam slippage of woven fabrics') at 78 N force distance between yarns after the slippage had been measured.

Pieces of the test fabric were sewn together using a type 301 stitch (see ***Figure 2***). 100% core spun polyester of 45 tex linear density was used for the seam, stitch density – 50 dm^{-1}, and needle size – 0.90 mm (according to Standard LST EN ISO 13936-1: 2004). The test specimens were stretched until a force of 200 N. Five specimens of each fabric were prepared for the tests.

The analysis of the worsted fabrics' characteristics showed that the warp yarns always slip more over the weft and not vice versa. Therefore, in this research only tests of seam slippage in the weft direction were carried out (warp yarns slipping over weft yarns). All results were statistically processed.

The new weave factor *NPR* [13] was calculated as the proportion of all threads resisting slippage in the warp and weft repeats ***Equation 1***:

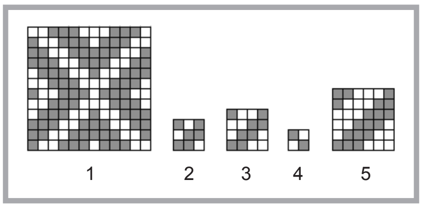

Figure 1. *Weaves used for experiments: 1 – diamond specular broken twill 2/3, 2 – twill 2/1, 3 – twill 2/2, 4 – plane weave, 5 – twill 3/3.*

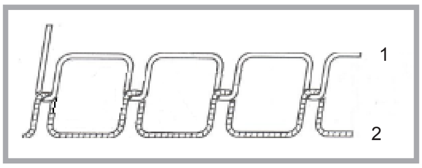

Figure 2. *Stitch type: 1- needle thread, 2 – bobbin thread.*

$$NPR = \frac{\sum i}{R_1 R_2} \qquad (1)$$

Where: $\sum i$ is the sum of all threads which resist slippage, R_1 - warp repeat, R_2 - weft repeat.

This factor is calculated directly from the weave matrix.

The power equation of the new weave factor shows a good correlation between the experimental and theoretical values:

$$K = (NPR_2^{-0.88}) \qquad (2)$$

Experimental results and discussions

All seven parameters of the fabric's structure (the raw material of the warp and weft, the linear density of the warp and weft, the warp and weft setting, and the weave of the fabric) influence the slippage resistance of yarns at a seam in woven fabrics. In order to establish the

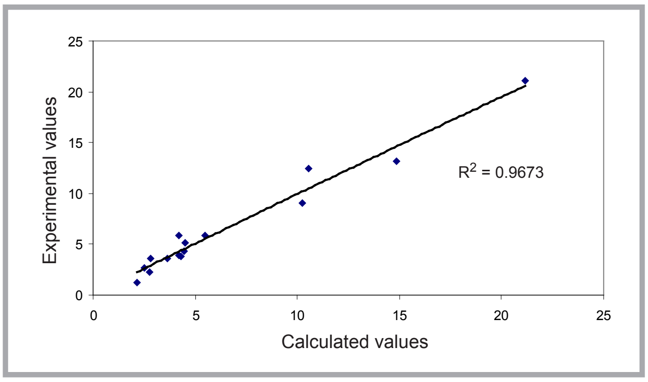

Figure 3. *Correlation between experimental and calculated values of seam slippage.*

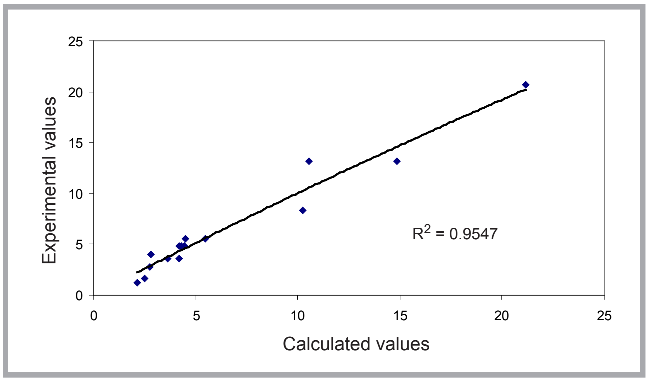

Figure 4. *Correlation between experimental and calculated values of seam slippage according to the simplified equation.*

Table 2. Encoded structure parametervalues of fabrics and experimental slippage resistance thereof.

Fabric	Weave	X_1 (S_1, dm^{-1})	X_2 (S_2, dm^{-1})	X_3 (K)	Slippage resistance of fabric, mm
1	twill 3/3	1	1	1	3.64
2	twill 2/1	0	0.5	-1	2.76
3	twill 3/3	1	-1	1	21.14
4	plane weave	1	-1	-1	4.52
5	twill 3/3	-1	1	1	4.22
6	plane weave	-1	0.4	-1	2.50
7	diamond specular broken twill 2/3	0	-0.5	0.9	10.54
8	plane weave	-1	-1	-1	5.48
9	twill 2/2	1	0	0	4.30
10	twill 2/2	-1	0	0	4.48
11	twill 2/2	0	1	0	2.84
12	twill 2/2	0	-1	0	14.86
13	twill 3/3	0	0	1	10.24
14	plane weave	0	0	-1	2.14
15	twill 2/2	0	0	0	4.18

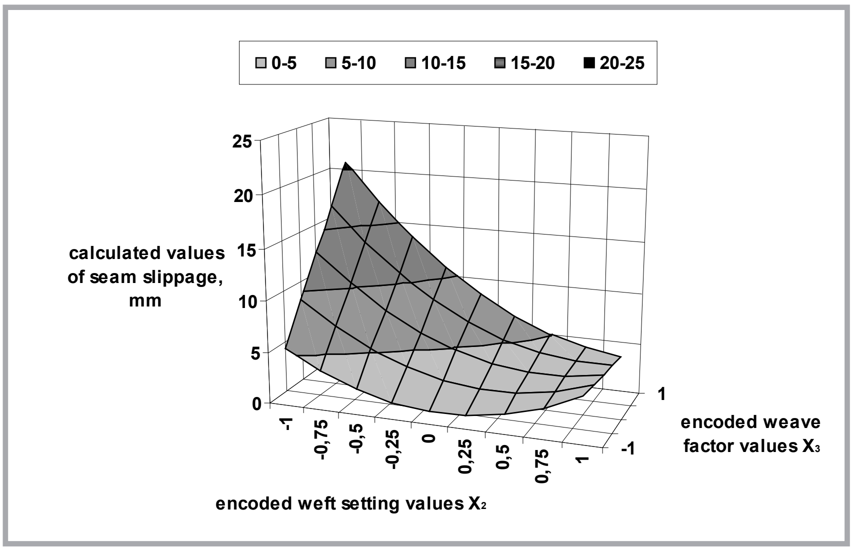

***Figure 5.** Influence of both sufficient parameters (weave and weft setting) on seam slippage.*

influence of the fabric weave as well as the warp and weft settings on the slippage resistance of yarns at a seam in woven fabrics, tensile tests were carried out using fabrics with different weaves and setting parameters. The raw material of the warp and weft was the same for all fabrics, hence its influence was not analysed. The study was carried out with loomstate fabrics in order to avoid the influence of finishing parameters.

3 parameters were chosen (weave – plane weave and some popular twills (***Figure 1***); the warp setting ranged from 240 to 360 dm^{-1}, and the weft setting – from 200 to 300 dm^{-1}) and an experimental plan was made by Box. This plan was slightly modified because there were some non- technological points, which were moved to the center of the plan. According this plan, all values marked with encoded values range from -1 to +1. All these encoded values of the fabrics and their experimental slippage resistance are presented in ***Table 2***.

Thus an experimental matrix was developed with elements which were interesting. The expanded matrix obtained aproximated an equation of polynomial character of second order and next the coefficients were calculated by the least squares method. As a result, the following seam slippage equation was found:

$$Z = 5.86 - 0.25 X_1 - 4.76 X_2 + 3.87 X_3 - 2.75 X_1 \times X_2 + 2.84 X_1 \times X_3 - 1.23 X_2 \times X_3 - 1.82 X_1^2 + 2.54 X_2^2 - 0.71 X_3^2$$

The equation obtained is informative because the Fisher criterion found much more than the tabular: F =10.89, $F_{tabular}$ = 4.64. It was also found that its coefficient of determination is very high, R^2 = 0.9637 (***Figure 3***).

In order to find the most informative and simpler equation, some elements which least influence seam slippage were eliminated. As a result, a simpler equation with the maximum informative was found:

$$Z = 4.82 - 4.53 X_2 + 3.56 X_3 - 4.01 X_2 \times X_3 + 3.77 X_2^2$$

Fisher criterion F = 15.61, $F_{tabular}$ = 2.86. Coefficient of determination R^2 = 0.9547 (***Figure 4***). It shows a good correlation between the experimental and theoretical values.

Analysis of this equation showed that the warp setting parameters have no sufficient influence on the slippage resistance of yarns at a seam in woven fabrics. The weave of a fabric and weft setting parameters have a more substantial influence on the slippage resistance of yarns at a seam in woven fabrics and must be taken in account while designing fabrics in order to achieve the level of seam slippage necessary. The influence of both sufficient parameters (weave and weft setting) on seam slippage is presented in ***Figure 5***. It was also found that seam slippage has a linear dependence on weft setting parameters and a second order polynomial on the weave. As is seen from ***Figure 5***, the influences of both parameters are sophisticated. The greatest influence of the weave exists for fabrics with a lower weft setting, while the influence of the weft setting increases with a decreasing in the weave factor.

Conclusions

- Warp setting parameters do not have a sufficient influence on the slippage resistance of yarns at a seam in woven fabrics.
- The weave of fabric and weft setting parameters have a substantial influence on the slippage resistance of yarns at a seam in woven fabrics and can be described by a two factor polynomial of second order.

- The greatest influence of the weave exists for fabrics with a lower weft setting, while the influence of the weft setting increases with a decreasing in the weave factor.

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