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Investigation of Initial Warp Tension and Weave Influence on Warp Yarn Diameter Projections

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Abstract
The influence of initial warp yarn tension and fabric weave on warp yarn projections are investigated in this article. Fabrics were woven with different initial tensions and weaves. The warp yarn projections were measured beside the floats in the central part of fabrics. The dependencies of warp yarn projections on initial warp yarn tensions and dependencies of warp yarn projections on different weave factors were also determined. According to the coefficient of determination, it was determined that the average weave factor F, which was proposed by Ashenhurst, evaluates the geometric variations of the fabric the best. During the investigation, the dependencies of warp yarn projections on initial warp yarn tensions of different fabric weaves were established. The decrease in warp yarn values with increasing initial warp tensions was determined.

Key words: *weave factor, initial warp yarn tension, warp yarn projection, fabric geometry.*

Notations

$F_{1(2)}$ – *average float length in warp and weft directions;*
$R_{1(2)}$ – *weave repeats in warp and weft directions;*
$t_{1(2)}$ – *number of intersections of warp and weft in the repeat;*
F – *general average float length;*
i – *index which shows the factor of a certain group i;*
$Kl_{1(2)}$ – *Galceran weave factors in warp and weft directions;*
N_f – *number of free fields;*
N_{fi} – *number of free fields belonging to group i;*
K_i – *coefficient of space elimination;*
C – *general weave tightness factor, by Skliannikov;*
$P_{1(2)}$ – *fabric firmness factor, by Milašius, in warp and weft directions;*
$C_{1(2)}$ – *weave tightness factors, by Skliannikov, in warp and weft directions;*
$N_{f1(2)}$ – *number of free fields in warp and weft directions;*
$K_{1(2)i}$ – *coefficient of space elimination belonging to i group in warp and weft directions;*
$N_{f1(2)i}$ – *number of free fields belonging to i group in warp and weft directions;*
P' – *balanced weave factor by Milašius.*

Introduction

If you want to weave a fabric, the warp should be extended, i.e. an initial setting tension should be given for it. The value of the initial warp tension is one of the most important parameters of the fabric setting. A different initial tension, which according to the fabric purpose, weave and weft setting can vary from 5 mN/tex till 20 mN/tex, can be given for the warp. The initial tension should be constant during all the time of warp unwinding from the warp beam [1].

Katunskis established the influence of fabric weave on the changing of warp tension and deformation. Three parameters – warp tension, law of heald shaft moving and the weft beat-up moment – were fixed during the experiment. It was concluded that when the fabric tightness factor increases, warp tension and the amplitude of its vibration also increase. In such a case, it could be predicted that during forming fabrics with a higher weave tightness factor, warp breakage can arise and weaving productivity decrease. After theoretical and experimental investigations of warp tension it was noticed that theoretical and experimental curves are very similar. Thus it can be stated that further investigation of warp tension according to the fabric weave formed can be extended only theoretically, i.e. using computer-aided software. In such a case, the effectiveness of economical investigation becomes very definite [2].

During fabric formation, yarns in the fabric are bent, tensioned, turned, their cross-sections compressed, and friction forces appear between yarns. It can be stated that all changes in the fabric structure follow till a balance of forces acting on the fabric element is achieved. Thus yarn cross-sections before deformation

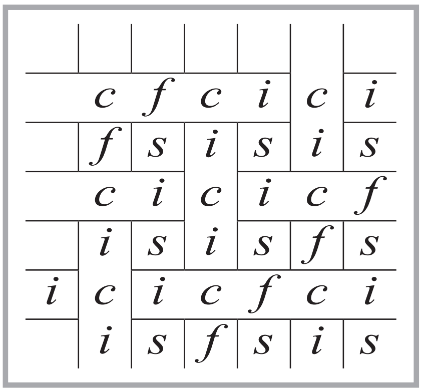

Figure 1. *Fields of fabric weave by Selivanov [9].*

are circular, and after deformation they can be in the shape of a racetrack, ellipse or lens [3].

J. Masajtis and M. Barburski [4] applied more modern methods for the investigation of fabric tension behaviour. When one yarns system is tensioned and the yarn cross-section is decreased, yarns gradually take the shape of a plated ellipse till the moment when the second yarn system increases. After extension, the cross-section gradually comes back to the shape of a circle.

In fabrics with different weaves and woven in different initial warp tensions the fabric geometry (also the projections of the warp yarn diameter, which is one of the fabric geometry components) can change because the initial warp tension and fabric weave influence the yarn comprehension to different degrees; but the laws of this comprehension are not investigated in detail herein. The main aim of this investigation is to investigate the influence of the initial warp tension and weave on the fabric geometry. The dependencies of warp yarn projections established for different weave factors will show which weave factor is the best for establishing the warp projection in woven fabric. The investigation allows to choose the best weave factor in the case of changes in fabric geometry.

Fabric weave factors

Evaluation of weave is the most difficult of all parameters of the fabric structure because the weave represents the fabric structure in a graphic way and does not have a concrete numerical value. Therefore the weave can be evaluated by different weave factors.

The average float length $F_{1(2)}$, proposed by Ashenhurst, and often used for the evaluation for warp and weft, respectively, is equal to the repeat $R_{1(2)}$ divided by number of intersection of warp and weft in the repeat $t_{1(2)}$ [5]:

$$F_{1/2} = \frac{R_{2/1}}{t_{1/2}} \qquad (1)$$

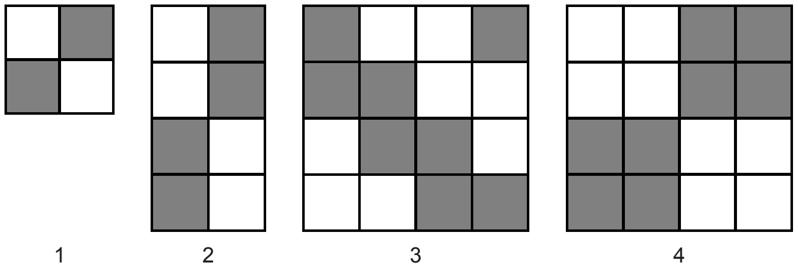

Figure 2. *Weaves used during investigation: 1 – plain, 2 – warp rib 2/2, 3 – twill 2/2, 4 – basket 2/2.*

Table 1. *Technical data of PC-20 plate processing.*

Indication	Value
Analogical input	8
Analogical output	2
Digital channel	2 × 16
Measurement range	± (10, 5, 1) V of input channel; ± (10, 5) V of output channel
Accuracy of measurement	12 bit ± 1 of statical measurements; ± 2 of dynamic measurements
Total impulse transmission	10 μs ... 10 s
Fixing time	10 s
Required PC	16 bit

At first, it looks like a very simple and clear factor, but a problem occurs when $F_1 \neq F_2$, and all the weave must be definable. Then it can be accepted that [5]:

$$F = \frac{F_1 R_1 + F_2 R_2}{R_1 + R_2}, \qquad (2)$$

Another problem occurs when separate yarns of one system have different medium lengths of floats [5]. Then:

$$F_{1/2} = \frac{\sum_{i=1}^{R_{1/2}} F_{(1/2)i}}{R_{1/2}} \qquad (3)$$

The Galceran weave factor $Kl_{1(2)}$ [6] is similar to it [5]. Weave factor Kl can be calculated [6]:

$$Kl_1 = \frac{\sum_{i=1}^{R_1} t_1}{R_1 R_2} \qquad \text{and } (4)$$

$$Kl_2 = \frac{\sum_{i=1}^{R_1} t_1}{R_1 R_2} \qquad (5)$$

If $F_1 = F_2 = F$, then $Kl_1 = Kl_2 = Kl$ and $Kl = \frac{1}{F}$. In other ways Kl differs from F.

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

Brierley suggested evaluating the weave using the empirical function F^m [7, 8]. The power m was determined experimentally by weaving fabrics in different weaves in the maximum setting. It depends on the weave, hence according to Brierley twill 2/2, basket 2/2, warp and weft ribs 2/2 have the same F value; however, their weave factors F^m are different because of different power m values.

Another weave evaluation method is proposed by Selivanov [9]. His suggestion was for all the weave zone to be divided into different fields (***Figure 1***): contact field – part of weave, shown as a projection of the horizontal plane, which is occupied by both systems of yarns (indicated by letter c); the float field is a projection of any part of yarn in the horizontal plane, occupied by yarn between the same two contact fields (indicated by letter *f*); the space field is a part of the fabric projection in the horizontal plane without any yarn (indicated by letter *s*). When the weave has free fields (only plain weave does not have them), there is the possibility to combine two yarns of the same system and eliminate the space field.

Skliannikov divided all free fields into six groups [10] according to different ways of free field elimination. The weave tightness factor equation was obtained by eliminating the free field coefficient *K*, and accepting that the free field is occupied by all eight fields of spaces:

$$C = \frac{6R_1R_2 - \left(2N_f + \sum_{i=1}^{6} K_i N_f\right)}{6R_1R_2} \qquad (6)$$

V. Milašius [12] calculated factor *C* in the warp and weft directions and proposed a new weave factor $P_{1/2}$:

$$P_{1/2} = \qquad (7)$$

$$= \sqrt{\frac{3R_1R_2}{3R_1R_2 - \left(2N_{f1(2)} + \sum_{i=1}^{6} K_{1(2)i} N_{f1(2)i}\right)}}$$

This weave factor can be used to investigate weave density and to evaluate some fabric properties too [11].

V. Milašius et al. [12] investigated the influence of fabric weave on beat-up process parameters. Dependencies of the beat-up force, beat-up duration and beat-up impulse on the weft setting when weaves are different show that the curves do not ascend so steeply when the weave factor P_1 decreases. The change in the curve becomes more intensive when the setting increases. X. Chen established that a higher tension leads to a smaller yarn crimp, and a lower tension results in a larger yarn crimp [13]. Kumpikaitė and V. Milašius defined the warp direction weave factors to be the best for estimation of fabric weavability, the best of which was weave factor P_1. It can be proposed for express evaluation of fabric weavability [14].

To compare F^m and $P_{1/2}$, it is vital that factor F^m is general for all the fabric, whereas factor $P_{1/2}$ can be determined separately for the warp and weft directions. This is an advantage when compared with F^m because some of the weave properties are different in the warp and weft directions. Both factors evaluate the interlacing of adjacent yarns.

V. Milašius [14] proposed a new weave factor P'. Weave factors P and P_1 can be calculated directly from the weave matrix, which was the same with experimental factor F^m.

Supposedly the balanced weave factor P' is calculated according to the new formula and must be equal to factor P.

$$P' = 0.712P_1 + 0.288P_2 + \\ + [ABS(P1 - P2)]^{3.02} \qquad (8)$$

The new weave factor P' showed good results between experimental and theoretical values.

Materials and methods

The objects of investigations were fabrics woven with STB projectile looms, with a straight pass of warp to four heald frames. The raw material of the warp and weft of the fabric was half-wool yarns (45% wool, 55% PES), with their linear density being 18 tex × 2. The setting of the warp was 240 dm^{-1}, and weft 200 dm^{-1}. Four weaves were chosen (***Figure 2***) which could be woven with the same setting of the loom. Every weave was woven with four different initial tensions of warp (5, 7, 9 and 11 mN/tex). The warp tension was regulated by changing the position of the back rest and measured with a tensiometer - "Rotschield", whose output signal is amplified by an amplifier. It also has a power supply that provides tension to the warp stress strain gauge. The free frequencies of the strain gauge are 300 Hz. The signal entered into the data processing card, which makes the signals measured, could be observed on the PC monitor. Technical data of PC-20 plate processing are presented in ***Table 1***. Technical data of the tensometric amplifier are as follows: line voltage – 110/230 V, line frequency – 50/60 Hz, capacity demand – 15 W, measurement frequency – 300 kHz. The warp yarn stress measurement scheme is presented in ***Figure 3***. The warp yarn stress strain gauge was mounted between the lamella and the back rest. The total tension of four warp yarns was measured, because the warp repeat of all weaves was equal to 4. In addition, the measurement was limited by the number of warp yarn stress strain gauges and the maximum possible load (4000 mN). The warp yarn setting scheme for the stress measurement strain gauge is presented in ***Figure 4***. Yarns, marked with the letter S, are bent between static 2 and moving roller 1 so, that the influence of warp yarns tension, pushing moving roller 1 to the right and at the same bending the cantilever beam inside the housing of the strain gauge, on which are glued strain gauge resistance. Static roller 2's axes are set and play the role

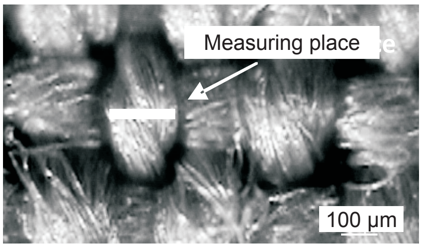

Figure 3. *Measuring place of warp yarn projection in plain weave fabric.*

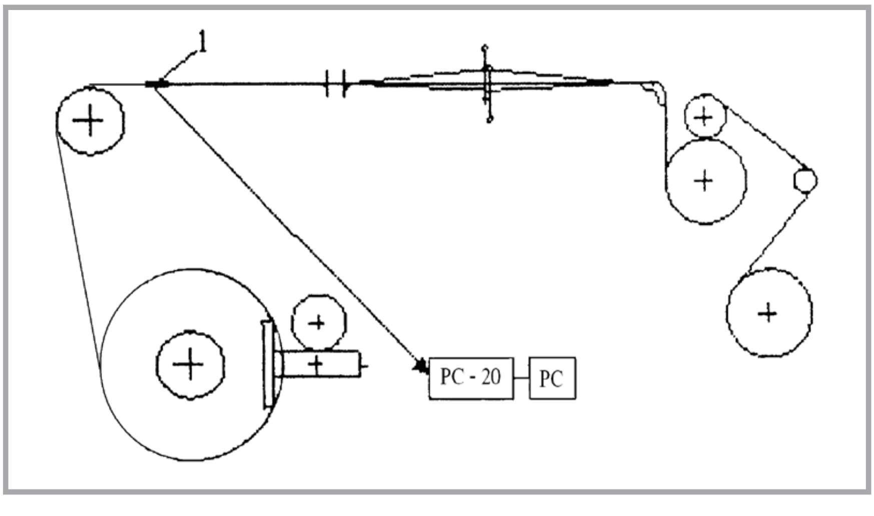

Figure 4. *Fixing scheme of warp yarn tension by strain gauge 1.*

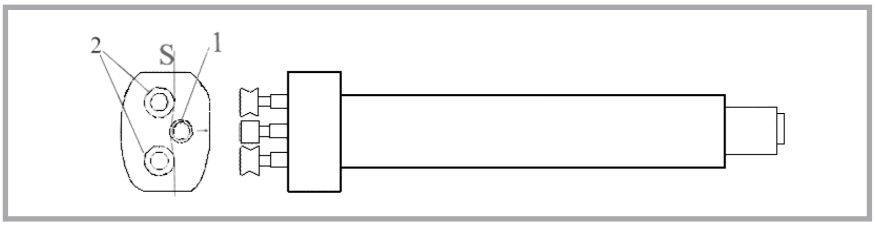

Figure 5. *Scheme of warp yarn tension measurement by strain gauge; s) sensor, 1) sensitive element, 2) guid rolls.*

of restraints. During the measurement, all healds were in the heald cross position, i.e. at one level. The warp yarn tension was measured in ten different warp beam locations, but each time measuring the tension of the same yarns.

Projections of ten warp yarns of each fabric woven with different initial tensions were measured with a microscope - „ASKANIA" and the program *Metric.* The optical magnification was ten times. We supposed that the cross-section of the warp yarn assumes the same shape, because the all fabrics investigated were of the same raw material, linear density of yarns, and warp and weft settings. Thus only one projection of warp yarn in the horizontal plane was measured in the investigation. Measuring of warp yarn floats was done in the central part of the fabric. Projections of warp yarns were measured in ten different places. The place of warp yarn projection measuring is presented in ***Figure 5***.

Experimental results and discussions

Three parameters were measured or calculated during the investigations: initial warp tension, weave factors of woven fabrics and warp yarn diameter projections.

During the investigation, the dependencies of warp diameter projections of different initial warp tensions, using different weave factors for weave evaluation, were drawn (***Figure 6***).

In ***Table 2***, weave factors of the fabrics calculated are represented. The values are calculated according to the formulas mentioned above.

Figure 6.a shows the dependence of warp yarn projections on the average weave factor *F*, with different values of warp yarn initial tensions. The dependence can be quite well described by the linear equation, which is chosen because of the small amount of points investigated. The warp projections of yarns decrease with an average weave factor *F* increase. The maximum determination coefficient was 0.9808, when the initial warp tension was 11 mN/tex. It shows that using this weave factor, the rather precise variation of warp yarn projections can be predicted, with the highest initial warp yarn tension. The coefficients of determination were high or medium.

Table 2. *Fabric weave factors.*

Fabric weave	Weave factor							
	F	F_1	Kl	Kl_1	F^m	P	P_1	P'
Plain	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Warp rib 2/2	1.500	2.000	0.750	0.500	1.186	1.124	1.309	1.249
Twill 2/2	2.000	2.000	0.500	0.500	1.310	1.265	1.265	1.265
Basket 2/2	2.000	2.000	0.500	0.500	1.366	1.359	1.359	1.359

Table 3. *Statistical indices of fabrics*

Weave	Factor	5 mN/tex	7 mN/tex	9 mN/tex	11 mN/tex
Plain	**V,%**	6.57	8.66	10.78	8.03
	U,μm	9.25	11.39	13.34	9.55
	E,%	4.57	6.02	7.50	5.58
Warp rib 2/2	**V,%**	11.28	12.64	17.2	10.52
	U,μm	15.62	16.86	20.55	11.58
	E,%	7.84	8.78	11.96	7.31
Twill 2/2	**V,%**	9.9	12.51	13.04	10.79
	U,μm	11.07	13.15	13.41	10.6
	E,%	6.88	8.7	9.06	7.5
Basket 2/2	**V,%**	13.23	5.35	8.2	7.49
	U,μm	14.41	5.72	8.44	7.59
	E,%	9.2	3.72	5.7	5.21

The relation between the warp yarn projections and weave factor F_1 shows that this factor cannot be used for warp yarn projection evaluation because the weave is estimated as not enough good, i.e. only two values of the weave factor are given. The small determination coefficients (0.3814 – 0.4885) also show the bad suitability of weave factor F_1 for warp yarn projection evaluation.

Figure 6.b shows the dependence of the average Galceran weave factor *Kl* on warp yarn diameters projections. It is seen, that the character of dependencies differs from other weave factor curves. Consequently this weave factor is inversely proportional to weave factor *F*. Thus with an increase in factor *Kl*, the warp projection also increases. Linear equations also describe dependencies well enough. The highest coefficient of determination is the same as the average coefficient of weave factor *F*. When the warp yarn initial tension is 11 mN/tex, the coefficient of determination is the highest, i.e. 0.9808. Hence factors *F* and *Kl* specify fabric properties during its formation equally.

The relation between the Galceran weave factor Kl_1 and warp yarn diameter projections is as bad as in the case of weave factor F_1, because these are inversely proportional. Hence it can be stated that these two factors cannot be used for estimation of warp yarn diameter projections. This also shows the small determination coefficients of dependencies (0.3814 – 0.4885).

Figure 6.c shows the dependence of warp yarn diameter projections on the Brierley weave factor F^m. It is seen that the character of the dependence is the same as for weave factors *F* and F_1, i.e. when the weave factor increases, values of warp yarn diameter projections decrease. According to the highest value of

the determination coefficient (which is equal to 0.9184), it is seen that this factor describes the fabric weave better than the F_1 and Kl_1 weave factors, but worse than the F and Kl weave factors. The Brierley weave factor cannot be calculated in the warp and weft directions because it is determined in general for all fabrics, obtained by experiment according to set weave type.

Figure 6.d shows the dependence of warp yarn diameter projections on the average weave factor P when the initial warp tensions of yarns are different. The tendency of dependencies are the same as for the weave factor, mentioned above, i.e. when weave factor P increases, values of warp yarn diameter projections become lower. Linear equations also describe dependencies quite well. The determination coefficient of the strongest dependence is equal to 0.9098. In comparison with other weave factors, it mainly applies to evaluating diameter projections of warp yarns because its values of the determination coefficient are average compared to the weave factors mentioned above.

In the cases of weaves factors P_1 and P' weak dependencies were also established, i.e. coefficients of determination were just 0.2668 – 0.626 for P_1 and 0.4353 – 0.7523 for P'. Thus the dependencies show that these weave factors cannot be used for evaluation of warp yarn diameter projections.

Hence from all mentioned dependencies of warp yarn projections on each weave factor the weave factor most suitable for fabric geometrical property evaluation should be chosen. Almost in all cases of weave factors, the values of warp yarn diameter projection decrease when the weave factor and initial warp yarn tension increase. Only for the Kl and Kl_1 weave factors, the character of curves is different. Evaluating the determination coefficients of dependencies, their maximum values (0.9808) are for average weave factors F and Kl. The smallest determination coefficient value (0.2668) of all weave factors is for weave factors F_1 and Kl_1, i.e. they evaluate the geometrical properties of fabrics the worst of all weave factors. Therefore in summary it can be said that weave factor F evaluates the warp yarn diameter the best, because its determination coefficient is the highest and it is used more frequently than weave factor Kl.

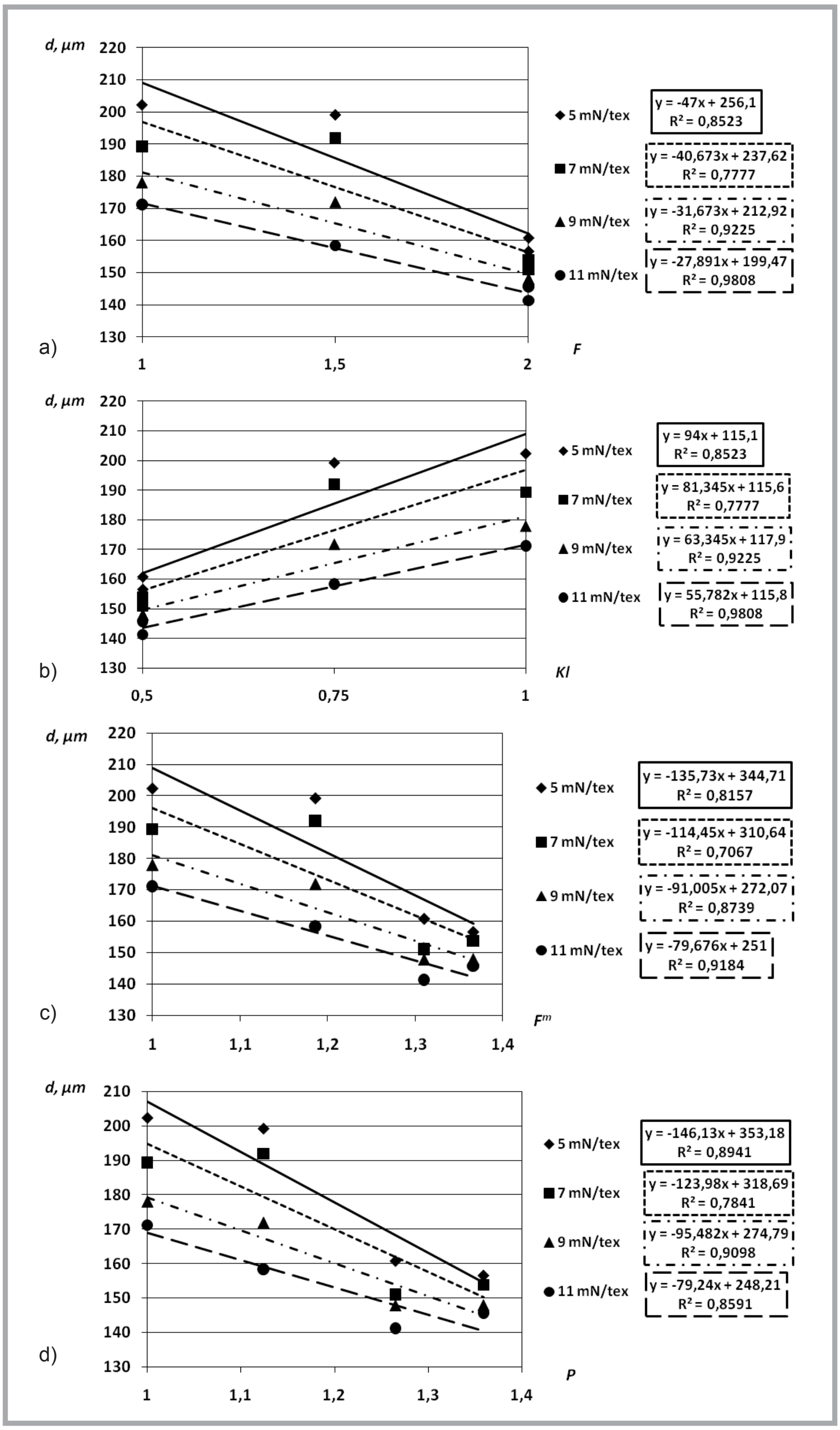

Figure 6. *Dependencies of warp diameter projections on weave factor; a) F, b) Kl, c) F^m, and d) P.*

Statistical indices (coefficient of variation, absolute random error and relative random error) of the investigation results are presented in ***Table 3***. The values of the variation coefficient calculated vary from 5.35 to 17.2%. Thus it can be stated that the variation of results varies from rather low till medium. The absolute random error varies from 5.72 to 20.55 µm, which means that with probability a 0.95 error does not exceed the value calculated. The relative random error varies from 4.57 to 11.96%. Hence the accuracy of the results measured changes from small to medium. The larger errors and variation coefficients are influenced by

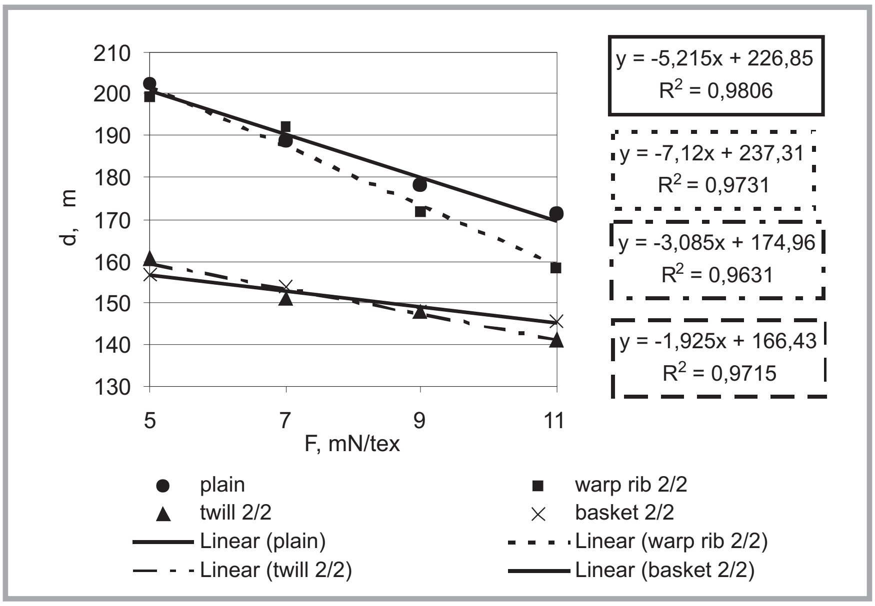

Figure 10. *Dependencies of warp diameter projections of fabrics of different weave on initial tensions.*

the raw material of the fabrics investigated, i.e. they are woven from wool fibre yarns, which are usually uneven. Also the measuring errors are influenced by different factors, for example, the error and resolving power of the measuring device, the human factor etc.

Figure 10 shows the dependencies of warp yarn diameter projections on different initial warp yarns tensions when the weaves of fabrics are different.

The values of warp yarn diameter projections decrease when the initial warp yarn tension increases, which can be explained by the fact that the more the warp yarns are tensioned, the more they squeeze the weft yarns; and there is less possibility of their cross-section and projections in floats changing. Warp projections of plain and warp rib 2/2 weaves vary very similarly, as well as those of twill 2/2 and basket 2/2 weaves, when the initial tensions of the warp are different. The more flexible the fabric weave is, the lower the values of warp diameter projection are in comparison with tighter fabric weaves. The linear equations describe dependencies very well. Their determination coefficients are from 0.9631 till 0.9820, i.e. they are rather high, which shows that the dependencies determined are exact. It can be assumed that the fabric structure depends not only on the initial warp tensions but also on the fabric weave chosen. Thus the conclusion is that the fabric structure during its formation depends not only on the initial warp tension but also on the weave chosen.

Conclusions

1. The investigated dependencies of warp yarn diameter projections on different weave factors showed that the average weave factor *F* proposed by Ashenhurst evaluates fabric geometric variations the best, with the determination coefficient of which being the maximum (0.9808).
2. Warp yarn diameter projections decrease from 20.5% (for warp rib 2/2 weave) till 7% (for basket 2/2 weave) when the initial tension of warp increases.
3. The value of warp yarn diameter projections decrease when the fabric weave is more flexible (basket 2/2), i.e. warp yarns are deformed more than in more tightly (plain) woven fabrics.
4. The dependencies of warp yarn projection variation on various weave factors for fabrics woven with different weaves were determined: in many cases, the values of warp yarn projections decrease when the weave factor increases.
5. The tighter the fabric weave and the higher the initial warp yarns tension, the lower the value of warp yarn projections. The determination coefficients of these dependencies are from 0.9631 till 0.9820, i.e. they are high. This result shows that the dependencies are right.

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