DESCRIPTION OF MUTUAL THREADS INTERLACING IN BINDING WAVE

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Abstract
Input parameters of two sets of threads (warp and weft) create the fabric with specific properties from the aspect of its geometry as well as final mechanical and end-use properties. Generally woven fabric weave determines the manner of the thread's interlacing in the fabric. Weave is given by the size of interlacing (the width and the depth of pattern repeat) as well as the manner of interlacing (the number of thread's transition and the length of non-interlacing part in the binding repeat). Weave consists from the interlacing – curved parts and non-interlacing – float parts. In the binding repeat exist only four structural models of interlacing. These structural models are: full interlacing model, partial interlacing model, double and full float structural interlacing model. Generally we can distinguish only two kinds of weaves in woven fabric, weaves with identical and different interlacing in the longitudinal as well as transverse section.
Key words: fabric, geometry, weave, diameter, interlacing, binding wave,

1. Introduction

Mutual interlacing of two sets of threads creates woven fabric. The manner of the mutual interlacing of threads defines the final fabric structure and mechanical and end-use properties. The shape of the binding wave and basic geometry of the binding cell changes according to the dimension and number of threads in the weave repeat or in the binding cell [1].

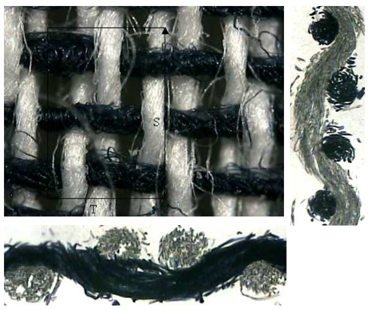

Figure 1. Depiction of real woven fabric and its longitudinal and transverse cross section

2. Description of fabric geometry in cross section

Threads interlacing and fabric structure in the longitudinal cross section and in the transverse cross section is defined on the basic of fabric geometry parameters [1, 3, 4]. For description of fabric geometry is possible to use:

1. Experimental method
2. Theoretical mathematical models

2.1 Selected fabric parameters form fabric geometry description

Dimension is given by the distances of both systems of threads AxB. The distances of threads for others than plain weaves:

$$A_{\min} = \sqrt{4.d_2^{\,2} - d_2^{\,2}}\ ,\ B_{\min} = \sqrt{4.d_1^{\,2} - d_1^{\,2}} \tag{1}$$

The distances of threads for others than plain weaves [1]:

$$A = \frac{\left(\frac{100}{D_2}.n_2\right).\sqrt{4.(d_s)^2 - (d_s)^2}}{pp_1.\sqrt{4.(d_s)^2 - (d_s)^2} + d_2.(n_2 - pp_1)},\quad B = \frac{\left(\frac{100}{D_1}.n_1\right).\sqrt{4.(d_s)^2 - (d_s)^2}}{pp_2.\sqrt{4.(d_s)^2 - (d_s)^2} + d_1.(n_1 - pp_2)} \tag{2}$$

where:

$n_{1,2}$ – number of ends and picks in weave, $D_{1,2}$ – warp and weft sett,
$pp_{1,2}$ – number of warp and weft transitions in binding wave.

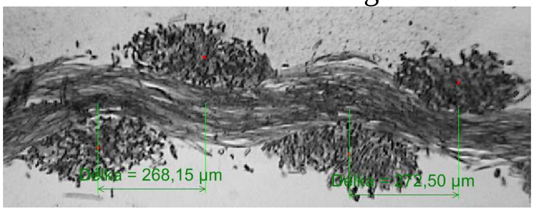

Figure 3. Evaluation of warp distances in transverse cross section

2.1.1 Description of heights of binding waves h_1 and h_2

The interlacing of warp and weft is defined by the heights of binding waves h_1 and h_2. Important parameter for fabric geometry description and fabric geometry prediction is height of binding wave (h_1 -warp, h_1 –weft) see Fig.4. Relations between heights of binding wave and yarn diameter $d_{1(warp)}$, $d_{2(weft)}$, is given $h_1 + h_2 = (d_1 + d_2)/2$ [2].

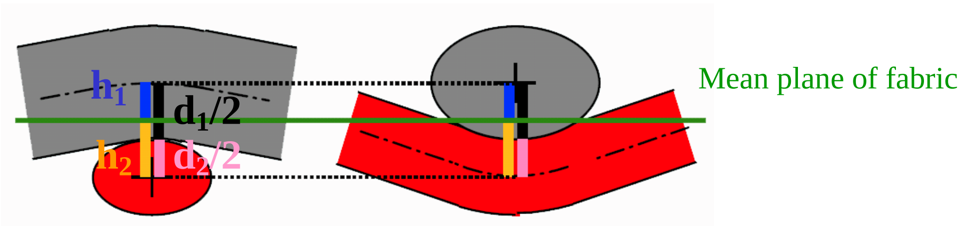

Figure 4. Description of heights of binding wave and yarn diameters in binding wave

Relative waviness of warp e_1 and weft e_2:
h_1,h_2 – heights of binding wave (h_1 -warp, h_1 –weft), d_s – the mean diameter of threads:

$$e_1 = \frac{h_1}{d_S}\ ,\ e_2 = \frac{h_2}{d_S}\ ,\ d_s = \frac{d_1 + d_2}{2} \tag{3}$$

Warp and weft waviness is given by mutual threads interlacing in woven fabric. Waviness we can describe on the bases of individual phases. On under mentioned pictures we can see three cases (A, B case is extreme)[2].

A) $e_1 = 0$… the warp thread is straight ($e_2 = 1$… the weft thread has maximal waviness)
B) $e_1 = 1$… the warp thread has maximal waviness ($e_2 = 0$… the weft thread is straight)
C) $e_1 = 0{,}5$

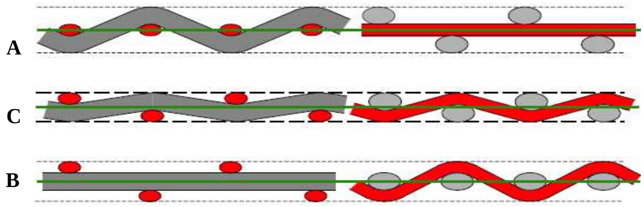

Figure 5. Selected phases of threads waviness

3. Analysis of binding wave and yarn shape in cross section - Experimental methods

Description of interlacing from the real fabric (real longitudinal and transverse sections) on the basis of image analysis (using the software NIS Elements) [4, 5, 6, 7].

The shape of binding wave and yarn deformation changes on the basis of fabric parameters (threads sett, weave, threads tension on the weaving loom, etc.).

This shape of binding wave is possible to evaluate from real woven fabric cross section [8, 9, 10] on the basis of

- central line (central line is important for determination of real length of binding wave as well as for threads crimp),
- individual coordinates of binding wave, see Fig. 6, 7 (individual coordinates are important for simulation of threads interlacing as well as for comparison with theoretical models) [10].

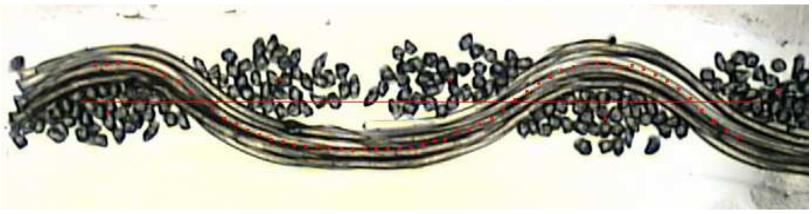

Figure 6. Image of binding wave coordinates in longitudinal cross section in woven fabric (PES threads)

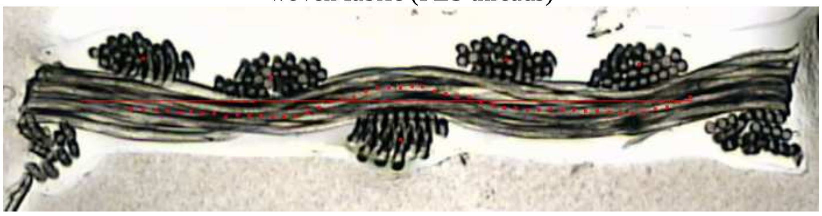

Figure 7. Image of binding wave coordinates in transverse cross section in woven fabric (PES threads)

The shape of individual threads in woven fabric and their deformation

- yarn shape in interlacing can change on the basis of input parameters; generally we can obtain bigger or smaller compression in comparison with diameter of free yarn. Generally, the shape of in weave yarn (free yarn) is possible to substitute on the basis of mentioned models of yarn deformation in cross-section – circular shape, Kemp model, ellipse, lens model [10,11,12].

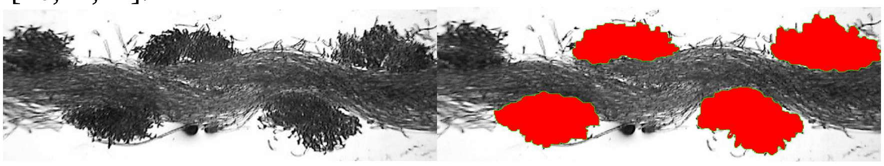

Figure 8. Real cross section (image analysis Software NIS Elements) – real shape

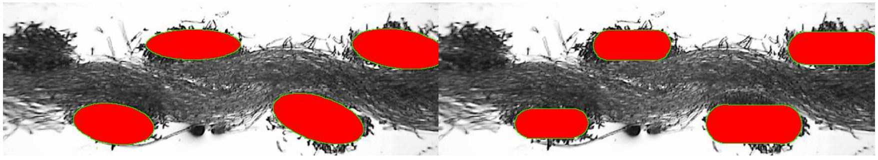

Figure 9. Substitution of real yarn in cross-section – ellipse, Kemp model

4. Analysis of binding wave - Theoretical models

Many attempts have been done in the past to find a suitable model describing the binding cell, i.e. to express mathematically the shape of the binding wave in a given thread crossing in the fabric in the steady state. Peirce model [13], Ollofsson model [14], hyperbolic model, sine shape are known as the most used models. These models are related to the plain weave [15, 16]. Other than plain kinds of interlacing could theoretically rise from models created before. The form and number of repeated section in the binding wave is specified by number of warp and weft in the binding repeat, which is repeated regularly in whole fabric width.
All rank of attempts was created to find suitable model describing binding cell (binding point). Why is necessary to deal with geometrical description of the fabric interlacing. Geometric parameters that we obtain from models influence final mechanical properties (elongation) and end-use properties (areal weight, warp and weft crimp, etc.) [1, 17, 18].

4.1 Selected models for description of binding wave

Linear model

Description of plain and non-plain interlacing [19]. The shape of linear model as we can see doesn't correspond with real shape of binding wave. But the final expression of length of individual threads is comparable with real value of real binding wave. The float part is substituted by abscissa for other than plain weave – model for non-plain interlacing [20].

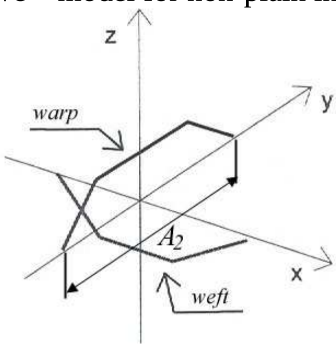

Figure 10. Linear model for description of binding wave

Parabolic description

This transcendental model is possible to use for description of one binding point only. Analytical continuation to next interval of thread's interlacing doesn't correspond with real shape of binding wave [3]. Under-mentioned expression of interlacing we can use for description of plain weave. The float part is substituted by abscissa for other than plain weave.

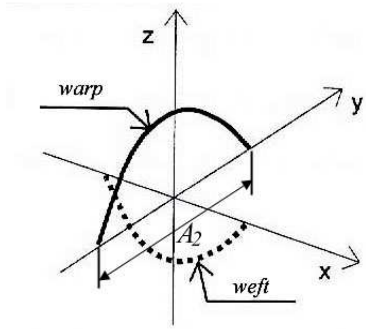

Figure 11. Parabolic model for description of binding wave

Hyperbolic description

This transcendental model is possible to use for description of one binding point only. Analytical continuation to next interval of thread's interlacing doesn't correspond with real shape of binding wave [3]. Under-mentioned expression of interlacing we can use for description of plain weave. The float part is substituted by abscissa for other than plain weave.

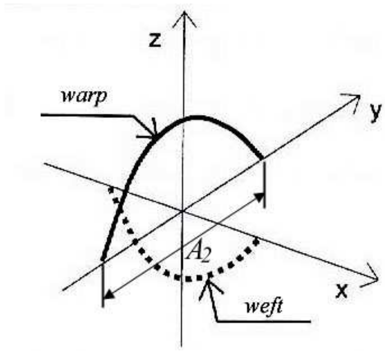

Figure 12. Hyperbolic model for description of binding wave

Peirce model

For description of the fabric structure this model is one of best-known models. For description of specific kind of woven fabric Peirce model [13] is acceptable from the geometrical viewpoint (this model we can't use for fabric with tight sett). This model is not acceptable if we want to evaluate mutual connection of the fabric structure and mechanics. For fabric geometry description is possible to use corrected Peirce model [19].

For determination of the basic mathematic equations we have this precondition:

- yarn diameter in cross section in the fabric is a circle,
- warp or weft binding wave is substituted by arc of circle and straight line,
- this model is for description of the fabric with plain weave. For other than plain weave the float part is substituted by abscissa.

For description of fabric with plain weave using Peirce model is necessary to know next parameters:

- diameter of individual threads d_o, d_u, d_{mean},
- warp and weft distances A, B,
- height of waviness h, h_o, h_u.

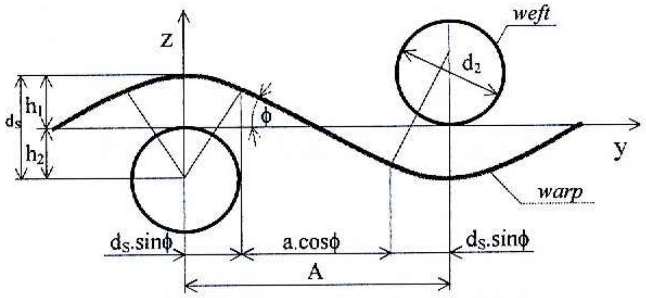

Figure 13. Peirce model for description of binding wave

Under-mentioned expression of interlacing we can use for description of plain weave. The float part is substituted by abscissa for other than plain weave.

Fourier mathematical model for description of binding wave in the fabric

The shape of binding wave in woven fabric is specific fictive accidental process with basic period (pattern repeat) and all spectrums other periods [1]. The pattern of binding is then repeated regularly (periodically) across whole fabric width.

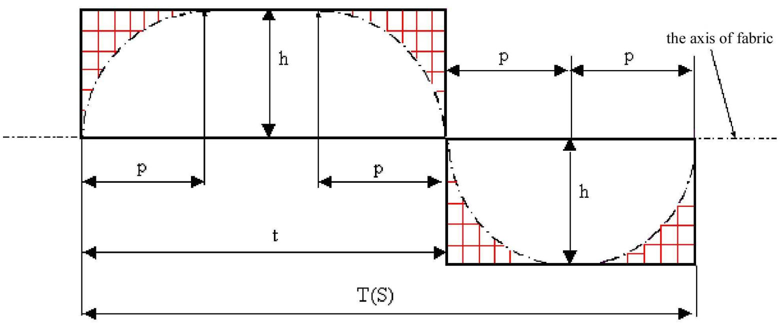

Figure 14. Description of binding wave in fabric for Fourier mathematical model

5. Conclusion

For description of real fabric structure is necessary to know behaviour of individual threads in woven fabric. Mutual relations between warp and weft threads during weaving on weaving loom together with input fabric parameters define position of warp and weft threads in woven fabric as well as mechanical and end-use properties. Important fabric parameters connected with fabric geometry is warp and weft crimp. Warp and weft crimp influence on threads waviness as well as threads set and weave.

For comparison of theoretical and real threads crimp were used woven plain fabrics with above-mentioned parameters. An experimental value of warp and weft crimp is possible to obtain on the basis of different experimental methods. This method is based on the tension of warp and weft unstitches threads. Is necessary to define the yarn preload and time of tension. Predicted warp and weft crimp was calculated from experimental yarn parameters in cross section (real value of warp and weft diameter, waviness, real value of heights of binding wave, etc.). Comparison of predicted and experimental warp and weft crimp is plotted in figure 15 - 16.

Table 1. Basic parameters of individual woven fabrics

fabrics	warp count [tex]	weft count [tex]	warp diameter [mm]	weft diameter [mm]	Warp set [/10cm]	Weft set [/10cm]	warp waviness	weft waviness
P10R	10	10	128	128	485	309	0,704	0,296
E10R	10	10	128	128	484	311	0,629	0,371
P20R	20	20	185	185	258	233	0,572	0,428
R20R	20	20	185	185	249	243	0,564	0,436
E20R	20	20	185	185	256	237	0,572	0,428
P29,5R	29,5	29,5	231	231	236	212	0,597	0,403
R29,5R	29,5	29,5	231	231	237	205	0,638	0,362
E29,5R	29,5	29,5	231	231	241	196	0,566	0,434

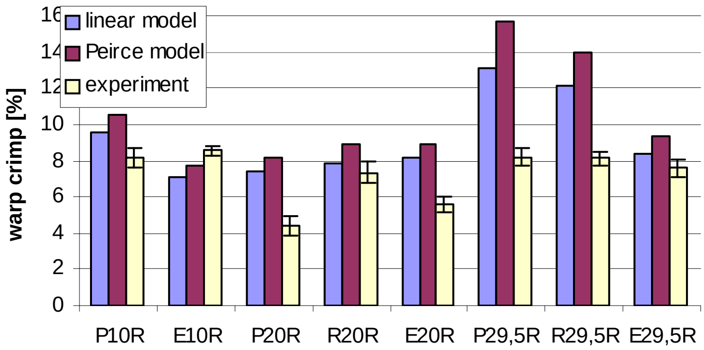

Figure 15. Comparison of theoretical and experimental warp crimp

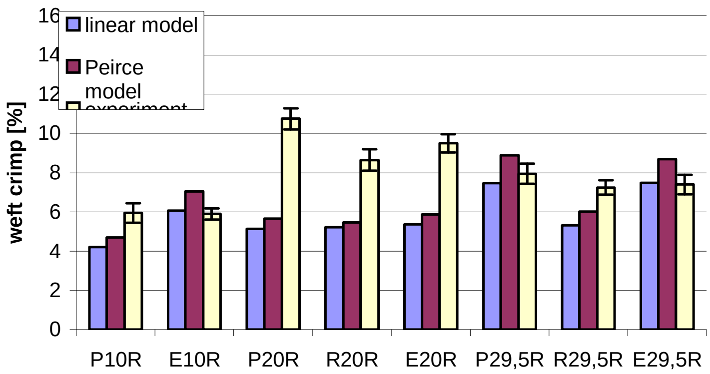

Figure 16. Comparison of theoretical and experimental weft crimp

Crimp of individual threads (warp and weft) influence on threads waviness. If is warp waviness increasing than is weft crimp decreasing. If warp waviness is higher than weft waviness then is necessary to obtain higher warp crimp than weft crimp. On above-mentioned graphs we can see that fabrics P20R, R20R, E20R have different behavior of warp and weft waviness versus warp and weft crimp, we can assume mistake in measurement of real waviness in cross section. Comparison of behaviour of warp and weft waviness versus warp and weft crimp is plotted in figure 17 - 18.

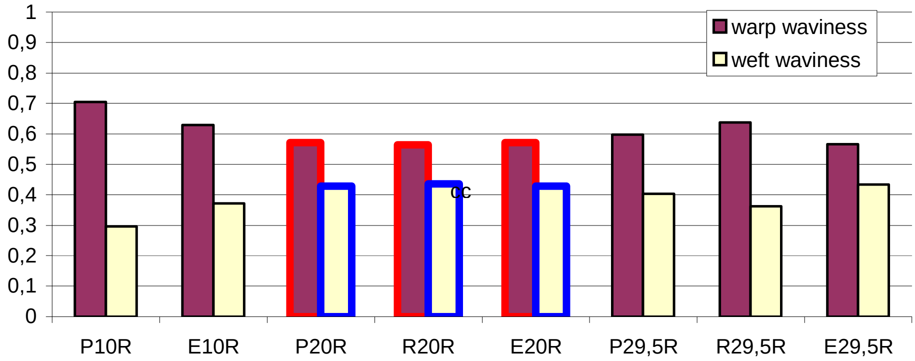

Figure 17. Comparison of warp and weft waviness

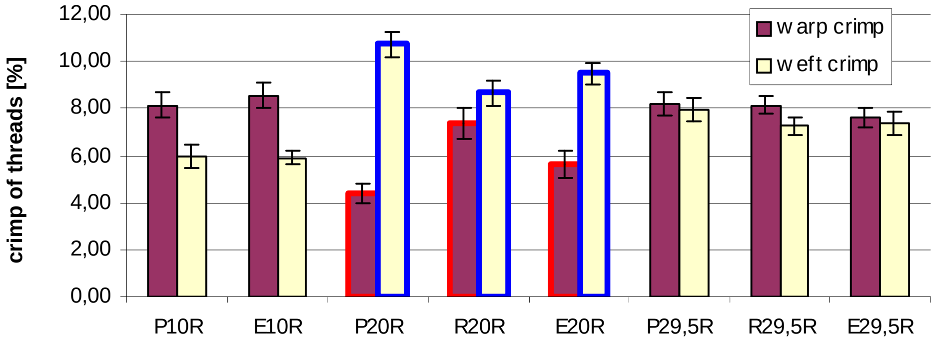

Figure 18. Comparison of warp and weft crimp – experimental values

6. Acknowledgement

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