EVALUATION OF YARN LATERAL DEFORMATION

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Abstract:

The article focuses on a new approach for characterization and evaluation of lateral yarn deformation. A small review about theoretical description and measurement possibilities will be introduced. The evaluation of yarn compression will be done by three innovative methods (lateral deformation of yarn between two parallel plates, simulation of binding point of fabric, cross-sectional analysis of real fabric). The analysis of yarn deformation will be carried out for a set of samples in combination of fiber material, yarn count and given fabric structure.

Key words: yarn diameter, lateral deformation of yarn, innovative measurement principals.

1. Introduction to fabric structure

The woven fabrics structure is complicated due to their complex hierarchy. There are no models, which are able to describe the structure from the fibers throw the yarns to the fabric. Usually the yarn is used as an elementary building unit of the structural model of the fabric. The fineness T, twist Z and diameter d are the basic geometrical characteristics describing the yarn. The diameter is considered only as a theoretical idea. For evaluation of the yarn diameter, it is necessary to know the packing density μ [1, 2].

The simplified assumption, that the yarn is compact, solid and circular cross-section, is implemented for a description of binding point geometry. The troubles with the yarn diameter establishing originate in the incompactness of yarn structure. Some air gaps are found between fibers also the yarn cross-section (especially in binding point) is not a circle. In binding points, the deformation of cross-section and the compression of fibers are considered.

In the stretched state of fabrics, yarns compress each other at their cross-over points. The lateral compression force at the cross-over points is generated by the yarn tension. Internal tension in fabric structure is given by forces balance, which depends on different types and levels of deformation during fabric production stages and in its use. The typical deformation of yarn cross-section is generally caused by the combined effect of compression, extension, bending and torsion.

Main aim of this work is to report about possibilities, which can be used for measuring lateral deformation of yarn. The evaluation of yarn compression will be done by three innovative methods (lateral deformation of yarn between two parallel plates, simulation of binding point of fabric, cross-sectional analysis of real fabric). The experimental results for selected material, yarn count and fabric structure will be present.

2. Yarn cross-section deformation

The nearly circular yarn cross-section is due to compression changed to more flat profile. A lot of geometrical models do not include this phenomena and so-called free yarn geometry is assumed. Yarn flattening is important from the point of view of selected fabric parameters evaluation, modeling and design. It is for example fabric porosity, air permeability and mechanical characteristics in terms of ultimate and user range loading.

2.1 Models

The width *a* and the height *b* are defined for the description of the yarn cross-section deformation. The circular cross-section of "free" yarn (fig. 1a) is changed into a shape, which can be substituted by Kemp´s cross-section (oval of two half-circles with semi-diameter *b* and two abscissas of length *a*-*b*, fig. 1b), elliptical or lens shape (fig. 1c, d) [2].

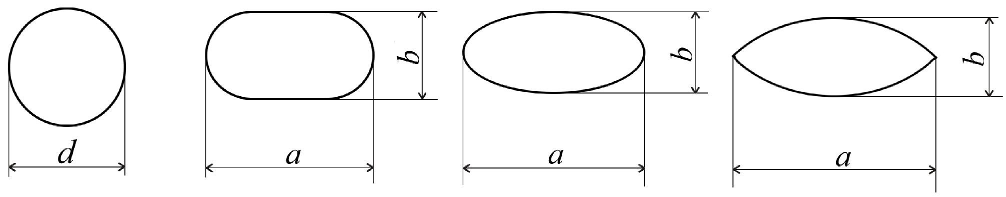


Figure 1 Shape of yarn cross-section
a) „free“ yarn b) Kemp c) ellipse d) lens

It is possible to define relative enlargement and relative compression:

$$\varepsilon_2 = (a-d)/d \,, \tag{1}$$

$$\varepsilon_1 = (b-d)/d \,. \tag{2}$$

The area *S* and the perimeter *L* of these shapes can be calculated in very simply way.

2.2 Geometrical hypothesis

For the relationship between the shapes, two alternative hypotheses are proposed, about constant area and constant perimeter. This hypothesis can be described as a function of relative enlargement ε_1 and relative compression ε_2.

A) Constant area (cross-sections before and after deformation have the same area). Subsequently hold:

$$S = \frac{\pi d}{4} = S_{deformed\ yarn} \,. \tag{3}$$

The relation between relative enlargement and relative compression is derived:

Kemp $$\varepsilon_2 = \left(\varepsilon_1^2\left(1-\pi/4\right)+\varepsilon_1\left(1-\pi/2\right)\right)\Big/\left(\varepsilon_1+1\right), \tag{4a}$$

ellipse $$\varepsilon_2 = -\varepsilon_1\big/\left(\varepsilon_1+1\right). \tag{4b}$$

It is impossible to express the relative enlargement explicitly for lens, therefore the equation was solved numerically:

lens $$\varepsilon_2 = 1{,}11\big/\left(\varepsilon_1+1\right)^{1{,}06}-1\,. \tag{4c}$$

B) Constant perimeter (cross-sections before and after deformation have the same perimeter). Subsequently hold:

$$L = \pi d = L_{deformed\ yarn} \,. \tag{5}$$

The relation between relative enlargement and relative compression is derived:

Kemp $$\varepsilon_2 = \varepsilon_1 (1 - \pi/2), \tag{6a}$$

ellipse $$\varepsilon_2 = \sqrt{2 - (\varepsilon_1 + 1)^2} - 1, \tag{6b}$$

lens $$\varepsilon_2 = \sqrt{(\pi/2)^2 - 4/3(\varepsilon_1 + 1)^2} - 1. \tag{6c}$$

Lomov [3] proposes relation between relative enlargement and relative compression empirically:

$$\varepsilon_2 = 1/(\varepsilon_1 + 1)^n - 1 \; (n = 1..2). \tag{7}$$

The estimation of these hypotheses is based on the assumption of circular cross-section of "free" yarn. Circle has for the same area minimal perimeter and for the same perimeter maximal area, compared to other plane figures. Cross-section changes are caused not only by shape changes but also due to relaxation of radial forces. These forces originate from helix structure of the fibers in the yarn.

From the 1st hypothesis of "constant area", we conclude: the perimeter of the deformed cross-section must be increasing; the volume of inter-fibres pores does not change, it means that the packing density decreases. It would be a particular effect, which eliminates the action of radial forces relaxation.

From the 2nd hypothesis of "constant" perimeter: the area of the deformed cross-section must be decreasing; the packing density increases, because the number of inter-fibres pores decreases and the contacts of fibres increase. It means the destruction of the original (primary) yarn structure turn up.

3. Experimental methods

There exist various methodologies for evaluation changes in yarn cross-sections. A change of yarn diameter under tension in yarn axis direction was studied by many researches. They are mostly based on optical system or mechanical detection. Only few of them are described and their results are shown in this article.

There are a group of methodologies, which is based on fabric analysis. One of them is judgment of fabric thickness before and after biaxial tension, which is described in [4]. The cross-sectional analysis of fabric in freeze state is the other approach to have the information about yarns deformation. Fabric can be fixed by soft or hard methods. The experiment is based on analysis of frozen fabric structure in terms of cross-sectional analysis or surface analysis in the third main fabric direction [5]. The improved possibility of novel stress-freezing technique for studying the compression behavior of fabrics is described in [6]. The biggest advantage of this modified method is possibility of deformed fabric fixing.

Fixing of fabric in stressed state is limited and therefore the simplified approaches were found to see the influence of selected factors and forces. Methodologies, which take not only compression but also bending in to consideration, are wire method, V wire method, three rod unit and simulation of binding point in hollow block [4] and [7].

The deformation of yarn between two parallel plates is the highest simplification of a real state in forces balance at cross-over point. In this case, only complexional forces cause the deformation of yarn. There are several methods, by which yarn thickness can be measured. Using of a rotation drum and feeler, in which the yarn thickness was measured by passing the yarn around the drum's circumference with the feeler pressed very gently against the yarn is mentioned in [9]. KES F3 system allows the measurement of yarn compression in terms of yarn thickness as a function of compression load [10], [4]. In case, that the information about yarn thickness (minor yarn diameter *b*) is not enough and the knowledge of yarn widening (major yarn diameter *a*) is demanded than it is possible to use special equipments, which offer measuring the yarn diameter change in both main directions under higher pressure [7].

3.1 Analysis of weave cross-sections

The method used for the detection of the internal weave structure is based on the analysis of the weave cross-sections. The method used for the detection of the internal weave structure is based on the analysis of the weave cross-sections [3], [4], [5]. The measuring parameters are shown on fig. 2. The fabric cross-sections were prepared by the method of "soft" cross-sections, where the blend of bee wax and paraffin as fixing medium was used [1] and [2]. These cross-sections have usually thickness 30 mm.

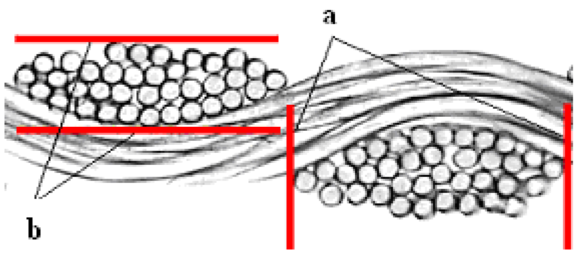


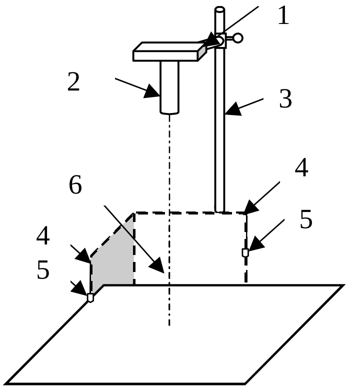
Figure 2 Measured values

3.2 Assessment of yarn flattening caused by compression and bending

The wire and V wire method is simplification of real state in fabric binding point. One of cross-over yarn is substituted by absolute stiff wire because of influencing factors elimination. A steal wire is usually fixed on a horizontal base and yarn is hanged on the wire with tension. The angle between the yarn and the horizontal level is 30°, which is approximately equal to the averaged yarn-intersecting angle in various weaves. V shaped groove at the cross-over area is more close the real intersecting state of yarn in fabric binding point. Yarn thickness is measured by needle sensor contacting at he top of the yarn surface with a small compression force [4], [1].

The alternative possibility based on V wire method is using three-rods unit mounted for example on Instron Tensile Tester. The three-rods unit consists of a rod fixed to a horizontal base and two rods of the same diameter placed parallel to the bottom one. It is spaced as a center the three-rods form an equilateral triangle. The unit enables measurement to be made of the changes in both minor and major diameters of a yarn bent over the three-rods unit and subjected to increasing extension [4].

Simulation methodology of real fabric binding points goes out from idea, that the yarns are crossed in hollow block and various forces realize their deformation. Arrangement of experiment is shown in fig. 3. The hollow block is placed under macro-scope and measurement of yarns diameters change is realized in system of image analysis [7]. Yarn is guided in between two opposite corners and they are placed in position of block diagonals. One end of yarn is fixed by clumps and the other is guided over the small ideal pulley with a small pretension. The simulated binding point is placed in the hollow block center. The loading of yarn sample is realized by various weights.

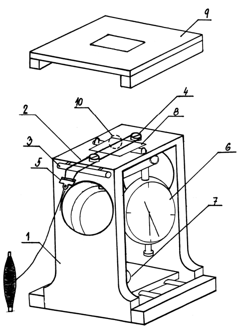


1 camera
2 macro-scope objective
3 tripod
4 pulley
5 weight
6 simulated binding point

Figure 3 Hollow block

3.3 Yarn compression between two parallel plates

The other method for the simulation of the stress in the binding point is based on the yarn compression between two parallel plates [5], [8]. First prototype is shown in the fig. 4. This device is placed under macro-scope holder. Yarn is guided though measuring zone between two glass parallel plates and it is pretended proportionally to their count. The deformation of yarn is the result of loading realized by upper frame. Upper frame can be connecting with various pieces of defined weight and seven level of loading is available. Sequence of yarn longitudinal views before and after deformation at same place is scanned and the absolute values on scales of two contact thickness meters are read. Sequences of yarn macro-images before and after deformation in terms of yarn diameter *d* and yarn characteristic proportion *a* are evaluated. Characteristic proportion *b* in other words yarn thickness after deformation is equal to the value, which describes difference between the absolute value on scale of thickness meter without and with deformed yarn between parallel plates under pressure.



1 main frame
2 yarn
3 guide
4 brake
5 straightening load
6 contact thickness meter
7 lighting system
8 lower plate with calibrated ruler
9 frame with upper glass plate
10 measuring area

Figure 4 Measuring device for yarn compression

4. Experimental material and results

Main idea of this experiment was to use selected methodologies used for evaluation of yarn deformation and apply them to set of fabrics and yarns, which were used for fabric weaving. The results should be discussed and compared with expectations and the influencing factors should be identified.

A set of experimental gray relaxed fabric in plain weave was used for the experiment. Fabrics were produced from 100% CO, 100% PP and 50CO/50 PP 29,5tex staple single ring yarns with a given set of warp (25 thread cm^{-1}) and three level of set of weft (8,8 thread cm^{-1}, optimum 13 thread cm^{-1} and 17 thread cm^{-1}). One gray relaxed fabric produced with comparable geometrical structure in plain weave from 100%PET 16,5tex staple single yarn was added to experiment. Analysis of yarn deformation was realized according to cross-sectional technique described in paragraph 3.1 for both main direction of fabric (warp and weft). Experimental results are shown in fig. 5a.

Estimation of level of yarn deformation based on evaluation of simulated binding point described in paragraph 3.2 was realized for a set of yarn used for fabric production. Yarns were spun by classical ring spinning technology with 29,5tex yarn count from 100% CO, 100% PP and 50CO/ 50 PP staple fiber material. Three levels of loading force were applied to simulate yarn deformation (1,8 g, 6,8 g and 11,8 g). Obtained data are present in fig. 5b.
Yarn deformation was also simulated by deformation between two plates mentioned in paragraph 3.3. 100%CO 29,5tex staple single ring spun yarn, which was used for fabric production, was analyzed and an experimental set of 100% CO single staple yarn was added to lab measurements. It was a set of typical ring spun yarn produces with 16,5tex, 20tex and 38tex yarn count. Seven levels of deformed forces were used for simulation of yarn deformation (10N, 15N, 20N, 25N, 30N and 40N). Summarization of data is given in fig. 5c.

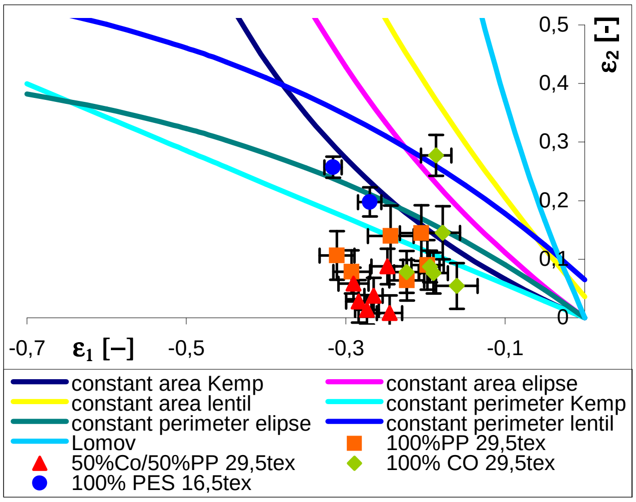


Figure 5 a Experimental results – method 3.1

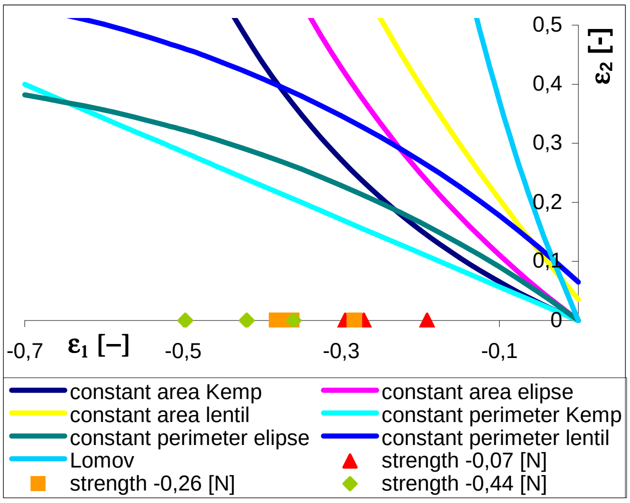


Figure 5 b Experimental results – method 3.2

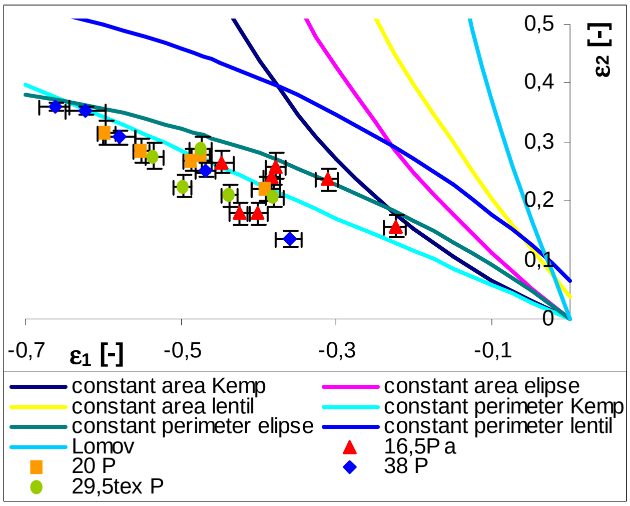


Figure 5c Experimental results – method 3.3

5. Discussion

Figures 5 a, b, c show relationships between relative enlargement and relative compression. The hypothesis for constant perimeter and constant area are compared with experimental data.

The generally known results could be expected. Experimentally analyzed yarn deformations in fabric binding point are located in the low levels of relative yarn enlargement and compression. It is not possible to decide, if they follow the hypothesis of constant perimeter or constant area. Calculated curves described the limited cases are very close each other in this range of deformations. Experimental data should be placed in delimited area of both hypotheses. Most of them are under hypothesis of constant perimeter. It is probably caused by the precision of original yarn diameter estimation. The influence of evaluated factors was in accordance with previous experience. Higher deformations in terms of relative enlargement and compression were found for the main fabric warp dimension. From the point of view of weft analysis, it can be said, that the deformation increases when the weft set increases. The behavior of fabric produced from blended yarn is more close to behavior of 100% PP fabric. Differences among experimental data were very small. The verification of significance power of these factors is limited, because the data is very sensitive to original yarn determination.

Using of hollow block for analysis of yarn deformation is limited from the point of view of estimation of relative compression only. In other words, it is not possible to measure the second parameter describing the level of relative enlargement. Therefore the second coordinate of experimental data is equal to zero in the figure 5 b. Increased loading force causes the increase of yarn relative compression in contact point. The statistical significance of fiber material used for yarn production is very low and for their verification the repeating measurement should be realized. The blended yarn behavior is more close to behavior of 100%PP yarn. The reason can be hidden in yarn production because of used mass fibers mixing. There is higher number of polypropylene fibers in yarn volume than cotton fibers. It confirms the outputs from the methodology 3.1. The interesting conclusion arises from comparison of relative deformation obtained form fabric analysis and this method. It seems that the level of normal force in gray relaxed fabric is very close to first level of loading force realized here by the weight 1,8 g.

Simulation of yarn between two parallel plates is the most simplification of real deformation in real binding point. Based on previous experiments and solving force balance it can be expected, that for description of deformed yarn cross-section Kemp model and hypothesis of constant perimeter will be suitable. It means in other words, that the yarn is due to deformation compressed and the pacing density of yarn increases. It can be also expected, that the deformation will increase when the yarn count or loading force will increase. The obtained experimental results are in a good agreement with expectations. Differences among experimental data are higher for higher applied forces. On the other hand, the statistical significance of data differences wasn't verified.

6. Conclusion

The influence of various factors was studied. The experimental data obtained from three selected methodologies was compared. The influence of selected factors was roughly evaluated. There was: used methodology, fiber material, yarn count, applied level of deformation force and fabric structure in terms of set of warp and weft.

Thanks to realized experiment it can be concluded that the methodologies give us comparable results, which can be background for precise modeling of structure and mechanical parameters of fabric. Yarn flattening is important for example for estimation of fabric porosity, air permeability and mechanical characteristics in terms of ultimate and user range loading.

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