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Inequality of Woven Fabric Elongation in Width and Change of Warp Inequality under Axial and Bi-axial Tensions

Abstract
Earlier experimental investigations have shown a particular regularity of warp projection inequality in the loom-state fabric width, while the projections of wefts were steady throughout the whole width of fabric. The changes in the warp projections have a great influence upon some fabric properties. The variation of elongation in warp direction in the fabric width is within the error limits, while the variation of the presented property in weft direction is more important. The reason for these phenomena is the inequality of warp cross-section. Tthe extension of specimens from different places in fabric width under the same loads is unequal. This means that the porosity of fabric in different places in a width under tension is differentalso, and thus influences its filtration characteristics.

Key words: *warp projections, fabric cross-section, elongation ,bi-axial tension.*

Introduction

Technical fabrics are widely used in various areas of application, and so it is very important to establish concrete values for their properties for usage. It is important to know whether these properties are constant throughout the whole fabric width or whether they vary. A significant inequality in different loom-state fabric structure and air permeability in fabric width, dependent on fabric shrinkage in the loom, was determined early on [1]. Warp projection inequality influences many fabric characteristics, such as air permeability, thickness and even fabric strength and elongation. The investigations of 20 different loom-state fabrics (various weaves, raw materials, sets, looms and etc.) showed a particular regularity of fabric structure and properties which were unequal in width. An example of such regular structural inequality in width is presented in Figure 1.

As mentioned earlier, for some fabrics (such as filters, aviation fabrics, fabrics for protective clothing) it is very important to have consistent characteristics throughout the whole width [3]. The main aim of a theoretical analysis of the air permeability of textile materials is usually to find a relationship between air permeability and the structure of the textiles. A number of theoretical and experimental methods exist for determining porosity. Each of these methods includes some simplifying assumptions, which causes inaccuracy. It is therefore very important to know the characteristics of pores (pore size, shape, position and etc.) Fabric porosity and air permeability depend on many factors, such as fabric weave, the yarn stock, the set of yarns and other parameters [4]. In addition, fabric is stretched under certain loads during usage, and its porosity changes as well [5]. Fabric strength and elongation depend not only on yarn stock, but on fabric structure also [6]. This is why any inequality of the fabric structure can also affect its tensile behaviour. On the other hand, the tensile behaviour influences fabric porosity under loading.

The aim of this article is to analyse the elongation inequality in fabric width, and to investigate how axial and bi-axial tension changes the regular inequality of the fabric's structure, i.e. projections of warps on the plane of fabric, and by extension the porosity of the fabric.

Materials and methods

Plain-weave polyester fabric of 158 cm width from multifilament yarns was chosen for further investigation of its properties. The warps of fabric were made from multifilament 29.4 tex yarns (set 244 cm $^{-1}$), and the wefts were made from 27.7 tex multifilament yarns (set 184 cm $^{-1}$). The fabric from multifilament yarns was chosen because of its yarns' uniformity in comparing with spun yarns, so the inequality of multifilament yarns has less influence on the fabric structure's inequality.

During investigation, the measurement of fabric elongation and the projections of yarns on the fabric plane when stretched were carried out. The strip of fabric (width 5 cm) was loaded under various loads and held for 1000 s. When the load is fixed, the fabric extends only at the beginning, and after some time (for woven fabrics, a period of about 200 s) the creep process ends and fabric extension finishes. Therefore, the time 1000 s when fabric is under load was chosen as the creep process ends fully at this time. Thereafter, the stretched fabric was fixed in a frame and the projections of warps were measured. The loads were chosen according to fabric strength in weft, because the strength in weft is less than in warp (F_2 ~ 1600 N, F_1 ~ 1800 N). Further investigations were carried out when the loads were reduced from 800N (50% strength in weft) to 400 N, 200 N and 100 N.

The axial tensile characteristics of polyester fabrics were measured on a Zwick/Z005 tensile-tester by standard tension method ISO 13934-1. The tensile curves of fabric were obtained from the values of five specimens at each experimental

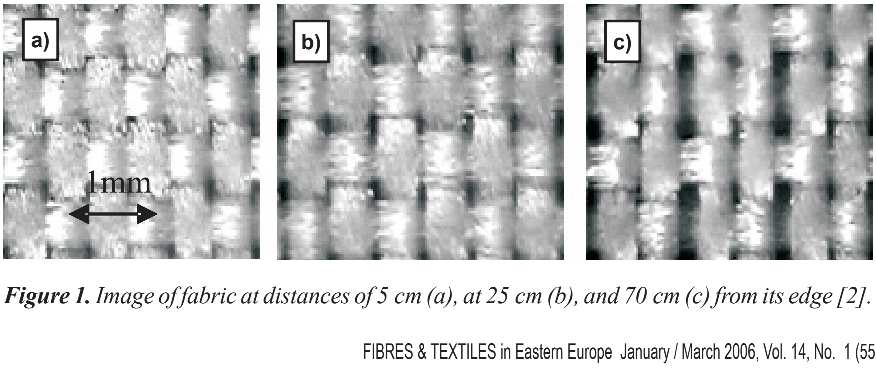

Figure 1. *Image of fabric at distances of 5 cm (a), at 25 cm (b), and 70 cm (c) from its edge [2].*

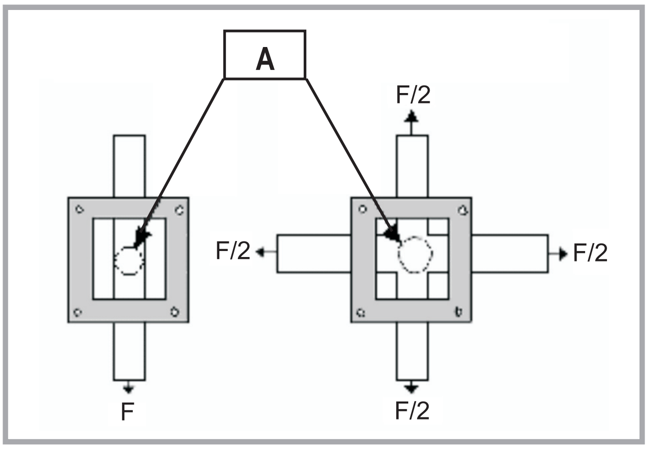

Figure 2. *Axial and bi-axial tension; A - the place of warp projections measuring.*

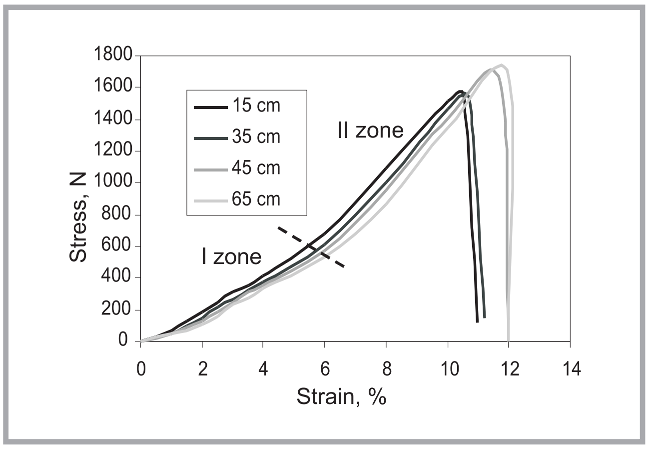

Figure 3. *Tensile curves of fabrics in various places at different distance from fabric edge.*

point. The distance from the medium point of a specimen strip to the fabric edge was taken as the distance from the fabric edge.

The measurements of yarn projections were carried out using a Technik Rathenow microscope (accuracy of measurements is ± 0.001 mm) linked to a PC. Ten warp projection measurements at a certain distance from the left fabric edge were carried out at each experimental point.

The warp projections after bi-axial tension were obtained when the fabric was taken under load, and next 1000 s after the fabric was fixed in the frame (see Figure 2).

Experimental results and discussions

Our experimental investigations confirmed that the inequality of fabric elongation at break in the weft at different places in the fabric depends on unequal fabric structure; the tensile curves of fabric vary from the first zone, which depends only on the fabric structure [7], while elongation in warp is within the limits of error. The reason for this is the shape of the yarns' cross-section in a fabric. If the horizontal axis of warp cross-section decreases, the vertical axis increases, as does the crimp of opposite system of yarns (wefts), and the elongation in weft increases. The stress-strain curves in the weft at various places in the fabric are presented in Figure 3.

In the next stage of the investigation, an analysis of fabric elongation at different places in the fabric was carried out. In Figure 4a the dependence of the fabric elongation in the weft on the distance from the edge to central point is presented. Figure 4b shows the analogous dependence of fabric elongation in the I zone, i.e. in the initial tension stage. The initial elongation for all specimens was measured under a load of 400 N. The value of loading under which the elongation of fabric was measured is chosen by considering the fabric's behaviour under tension, i.e. until the load specimen is only extended due to structural changes in the fabric (see Figure 3). So, the elongation of fabric in weft is unequal due to the inequality of crimp. In the central part of fabric, where the crimp of wefts is higher, the elongation is higher also, and it becomes possible to assert that the inequality of the fabric elongation depends on the inequality of the warp projections.

As seen in Figure 4b, the initial elongation ε_i of fabric increases intensively in the border area of the fabric, and the linear equation confirms this (the coefficient of determination is high: $R^2 = 0.9633$), whereas in the central part of the fabric (55-79 cm from the edge) the values vary very slightly. The low value of the coefficient of determination ($R^2 = 0.0092$) confirms the non-existent dependence, and the initial elongation of this part of the fabric can be described as $\varepsilon = \text{const}$.

In Figure 4c, the residual elongation ε_r is presented.

$$\varepsilon_r = \varepsilon - \varepsilon_i \tag{1}$$

here, ε – the elongation at break,
ε_i – the initial elongation.

The residual elongation mostly depends on yarn properties, and as seen from Figure 4c, no correspondence between the residual elongation and the distance from the fabric's edge has been obtained; the coefficients of determination are low in the border area as well as in the central part ($R^2 = 0.389$ and $R^2 = 0.0013$). We can thus assert that the regular inequality of the elongation of the fabric in the weft and its tensile behaviour depends only on the inequality of warp projections; regular inequality is observable only in the initial part of the tensile curve. On this evidence, if the elongation of specimens from different places along the fabric width under the same loads is unequal,

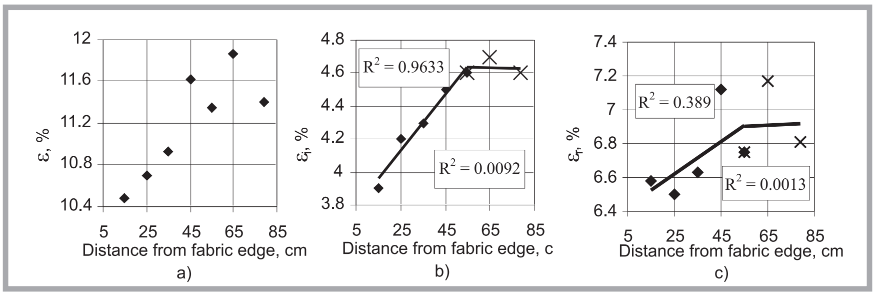

Figure 4. *Inequality of fabric elongation in weft: a) elongation at break, b) initial elongation, c) residual elongation.*

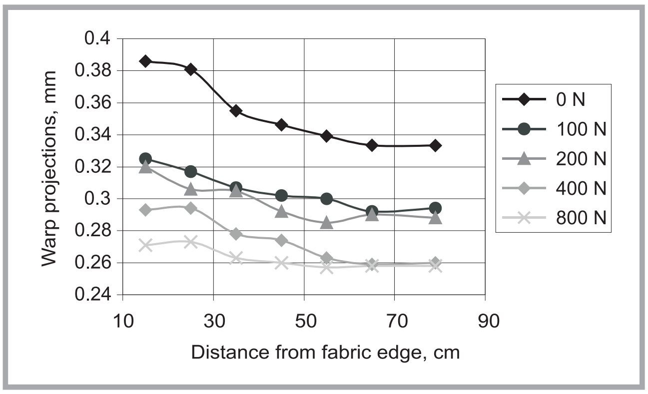

Figure 5. *Inequality of warp projections in fabric width under different axial tension.*

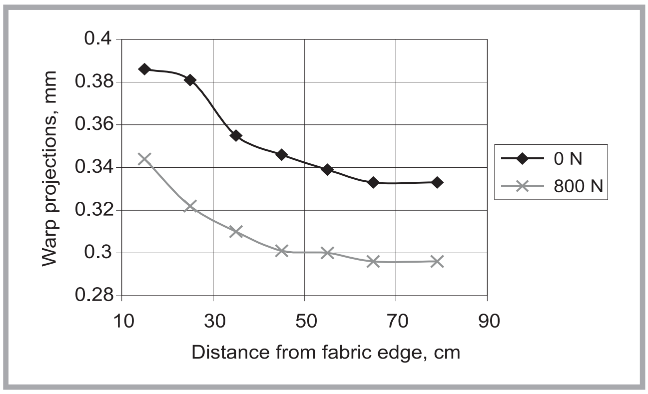

Figure 6. *Inequality of warp projections in fabric width under bi-axial tension.*

the changes in fabric porosity at different places in the width under tension are different also, and so may influence its filtration characteristics.

It was determined that the changes in the warp projections of the stretched fabric in weft are within the error limits, while changes in warp projections after stretching in warp are not only significant but also unequal. As seen in Figure 5, if the load is higher, not only do the warp projections decrease, but the inequality in fabric width decreases as well. The projections of warps at the stretched fabric edge do not vary so significantly from warp projections in the central part of the fabric as those of unstretched fabric. According to formula (2), the width of variation of warp projections values can be calculated:

$$R = x_{max} - x_{min} \qquad (2)$$

The width of variation of warps projections of unstretched fabric is R=0.053 mm, while when the fabric was under 800 N load, the width of variation decreased four times (R=0.013mm). The tension of the fabric therefore decreases the inequality of the warp projections, but it remains even when the fabric is stretched with a value of less than 50% of strength at break. In real usage conditions, the fabric does not only undergo axial tension, but can almost be said to undergo bi-axial tension as well. Therefore, the changes in fabric inequality when it was streched in both directions (warp and weft) were investigated. It was noted that the inequality of warp projections remains as well. In Figure 6, the inequality of warp projections in fabric width under load in bi-axial tension is presented.

As seen in Figure 6, when the fabric in bi-axial tension was under a load of 800 N, the projections of warps decrease, but their inequality in fabric width remains almost identical. If the width of variation of warp projections, when the fabric was not stretched, was R=0.053 mm under a load of 800 N, it decreased slightly, by only 10%, to the value of R=0.048 mm. However, when axial tension is applied, the clearance in the width of variation between 0 N and 800 N was about 400%. The reason for this is that the stretched weft yarn system in bi-axial tension does not permit the shape of the warp yarns' cross-section to be changed. So, the results obtained for axial and bi-axial tension show that if we want to predict the changes in fabric structure inequality during usage, it is important to know the fabric structure's behaviour under bi-axial tension.

Conclusions

- The inequality of warp projections influences the inequality of fabric elongation.
- The regular elongation inequality in the weft is only seen in the initial part of a fabric (the coefficient of determination is high, R^2 = 0.9633); in the central part of the fabric, the initial elongation is constant (as confirmed by the low value of coefficient of determination, R^2 = 0.0092).
- The non-correspondence between the residual elongation and distance from fabric edge has been confirmed; the values of coefficients of determination are low in the border area as well as in the central part (R^2 = 0.389 and R^2 = 0.0013)
- The projections of warps as well as their inequality under different loads in axial tension decreases, but some inequality in fabric width still remains.
- The projections of warps under load in bi-axial tension decreases, but their inequality in fabric width remains the same as when the fabric is not stretched.
- To predict the changes in the inequality of the fabric's porosity during usage, it is important to know the fabric structure's behaviour under bi-axial tension.

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