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# Analysis of Changes in the Internal Structure of PA6.6/PET Fabrics of Different Weave Patterns under Heat Treatment

**Abstract**
*Conveyor belts are widely used in almost all fields of industry, agriculture and architecture. They are also used in mines of raw materials and minerals, in the cement and lime industry, in paper and sugar mills, as well as in agriculture, power and etc. Conveyor belts consist of a woven fabric carcass and rubber covers. In the production process, polyamide polyester vulcanised fabrics are subjected to high temperatures. The aim of the study was to examine how the process of heat treatment affects the internal geometry of synthetic fabrics and what the impact of the weave on these changes is. An experiment was performed by subjecting nine samples of polyester and polyamide fabrics of different weave to heat treatment at 160 °C for 5, 10 and 15 minutes. The scheduled study was to mirror the conditions prevailing in the vulcanisation. Analysis of the measurements of the basic parameters characterising the internal structure of fabric shows that the weave affects the size of their changes during exposure to high temperatures.*

**Key words:** *woven fabric, internal structure, high temperature, conveyor belt.*

## Introduction

Examples of flexible textile composites are tyres, inflatable rafts or conveyor belts, where the textile component provides stability for the distribution of forces over the entire length and width of the finished product.

Taken separately, textiles and rubber do not meet the durability requirements in the above examples. The fabric would be strong enough, but is not resistant to mechanical damage, such as punctures or abrasions. It is flexible composite material of high strength properties that gives textile reinforcement together with the rubber [1, 2].

Conveyor belts are a highly reliable means of transport for bulk and granular materials. They have a simple construction and consume a relatively small amount of energy. Such transport is being constantly improved and for a long time has raised great interest both in the mining and power industry, metallurgy, and other industries such as chemical plants, ports, handling and storage yards.

Currently conveyor belts are able to work with a yield of up to 50,000 tons per hour. One particular belt can manage a route of up to 30 km and difference in levels of up to 1 km [3]. A conveyor belt operates with a flexible tape rewinding endless feedback through rollers, out of which at least one is driven. There are two types of conveyor belts: those with a textile carcass and those with a steel one. Conveyor belts with a textile carcass may be one-layer, two-layer or multi-layer, and the carcass may be of materials such as cotton, viscose or other cellulose fibres, silk, polyamide, polyester, aramid or glass fibres.

In the case of rubber, fabric conveyor belt layers forming the carcass move the main longitudinal and transverse forces [4]. Covers of flat running and bearing as well as those of side edges are used to protect fabrics from damage. The construction of conveyor belts is shown in **Figure 1**.

In order to increase the strength of the conveyor belt, the number of layers is increased, respectively. However, this increases the thickness of the conveyor belt, resulting in an increase in weight and a reduction in its transverse flexibility, which, in turn, increases the resistance movement of the belt when scrolling through the rollers. Therefore, particularly with conveyor belts of high strength and those used in severe operating conditions, there is intensive research being conducted on new types of fibre, weave and layer systems that would meet the growing needs of users in this respect [5, 6]. In production, vulcanisation is done at a temperature of 160 °C under tension for about 10 minutes. The high temperature process brings about intense shrinkage, thus resulting in recrystallisation in a preferred direction of the fibre axis. Researchers [7] revealed different recrystallization responses of the fibres to the thermal annealing applied, and consequently different shrinkage mechanisms. The recrystallisation of Nylon 6.6 fibre was accompanied by the growth and perfection of pre-existing crystals. Also the researchers analysed the influence of add-on finish and process variables on the recovery properties of polyester
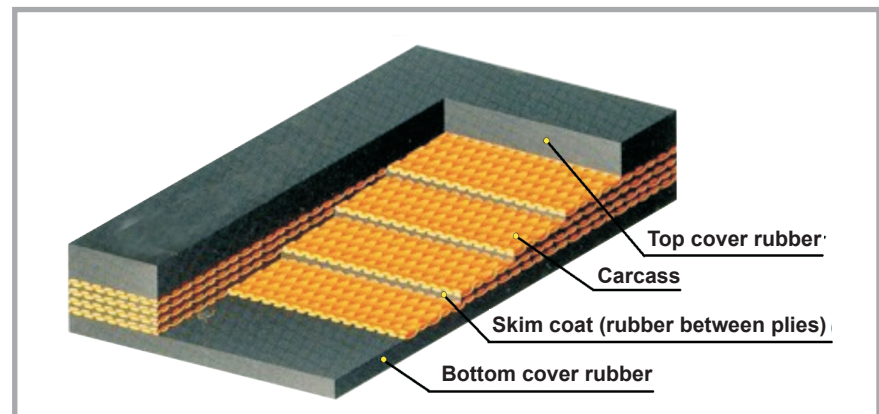


**Figure 1.** *Structure of multi-layer conveyor belt [4].*

yarns. The add-on finish plays a key role in determining the immediate elastic recovery of polyester yarns [8]. The behaviour of polyamide and polyester fibres as well as various textiles made from these fibres under high temperatures both in terms of shrinkage and the change in mechanical properties has been widely studied by many authors [9 - 14], but this paper focuses on technical fabrics used in conveyor belts.

This work tackles the subject of the vulcanisation of polyester – polyamide fabrics and shows the influence of the weave on the change in their internal geometry under high temperature, which will enable understanding of the operation of the textile carcass in the production process of conveyor belts.

Polyester - polyamide fabrics were subjected to heat treatments for 5, 10 and 15 minutes, at 160 °C. This operation imitated the original vulcanization conditions of fabrics similar to those using a rubber blend at 160 °C for 10 min. [15].

## ■ Material

Polyester and polyamide fibres are inexpensive, extremely durable and resistant to many factors such as stretching, tearing, moisture and a wide range of chemicals [16 - 19].

The maximum temperature of using polyester is about 160 °C and for polyamide - 180 °C [20, 21].

They are used, among others, in the textile, automotive, food, transportation and other industries. Polyester, polyamide or polyester and polyamide fabrics are, for example, used in the manufacture of tents, covers of various products, advertisements (roll-up), umbrellas or clothing and even furniture. They are also used as a reinforcement of composite materials, for example in the production of tyres and conveyor belts used in mining, among other things.

Nine samples of fabrics were made which varied in the weave, although each of them had the same setts of polyester warp and polyamide 6.6 weft (*Figure 2*). The weaves were also classified according to the bending rigidity of the fabrics and length of the thread overlap. This was the criterion of weave diversity. Fabrics were made of different weaves with PES 2200 tex × 4/60 warp, 120/dm sett and PA6.6 1400 tex × 5/90 weft, 33/dm
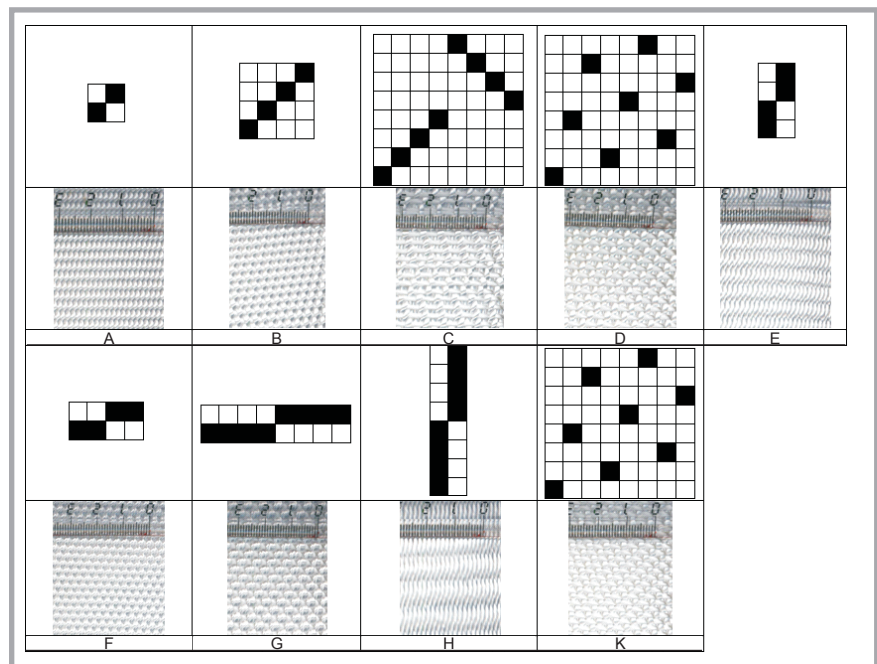


***Figure 2.*** *Weaves and surfaces of particular fabrics: A) plan weave; B) twill weave; C) twill cross weave; D) satin weave; E) warp rep weave and H; F) weft rep weaveand G); K) satin weave with higher density of weft.*

sett. The weft sett was defined empirically as the maximum sett of wefting for a linen weave on a Dornier loom.

The fabrics were made by the "Metso Fabrics" company in Lodz on a Dornier loom with a harness machine. The fabrics chosen and produced have the following weaves: A) plain weave; B) twill weave; C) twill cross weave; D) satin weave; E) warp rep weave and H); F) weft rep weave and G); K) satin weave with higher density of weft then D).

The fabric after weaving goes through vulcanising process and becomes conveyor belts [22].

## ■ Experiment

In the normal production of a conveyer belt, first of all the woven fabrics are covered by latex in order to increase rubber adhesion to the synthetic fibres, and then they are vulcanised. The tension during impregnation is controlled by two sets of gauge rollers regulating the speed difference between the drive stations, and vulcanisation is done at a temperature of 160 °C under tension for about 10 minutes. Analysis of the mechanical properties of conveyor belts for the three main stages of production has been done and published [23]. This study showed differences in the mechanical properties of products at different stages of conveyor belt production and the dependence of

the properties on the intersection numbers of yarns in woven fabrics.

In order to verify and assess changes in parameters in the internal structure of the fabric occurring during vulcanization, samples tested were heated at 160 °C for 5, 10 and 15 minutes. Samples of 10 × 10 cm were heated in an oven with a thermostat. Nine samples were prepared for each fabric, and three for each heating period.

Basic parameters of the internal structure of the fabrics were tested by using an optical microscope at the laboratory of the Institute of Textile Architecture, Faculty of Material Technologies and Textile Design, Lodz University of Technology.

Also using X-ray tomography techniques, a cross section of the fabrics was created. This is a non-destructive technique that allows the obtaining of information about the internal microstructure of an object with high definition and resolution. Micro-CT usage in the field of materials science has great potential because this technique allows the making of 3D observation inside the sample, which is not possible with standard microscopy techniques [24 - 27]. *Figure 3* shows an example of the cross section of satin weave (D fabric), and weft rep weave (G fabric) before heat treatment.

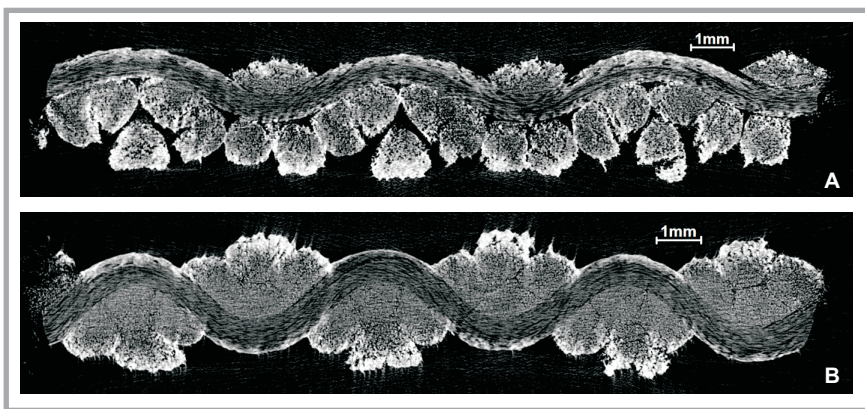Ten measurements were made in each case for calculation of the crimp and lin-

***Figure 3.*** *Cross-section of fabrics along the weft before heat treatment: A) satin weave (D fabric), B) weft rep weave (G fabric).*

ear density of the warp and weft threads [28 - 30]. The apparent length of thread segments tested was 10 cm. The results presented are average values of the measurements conducted. The areal density of the fabrics was tested experimentally (ISO 3801:1993P Textiles, Woven fabrics, Determination of the mass per unit length and mass per unit area) by weighing and calculating the ratio of the fab-
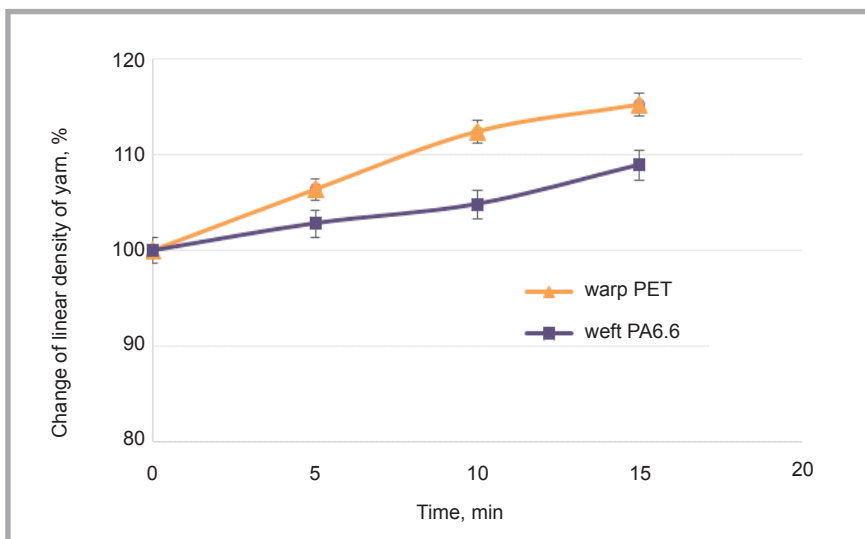
ric weight to its size. The samples were weighed on scales accurate to 0.01 g. The fabric cover with warp and weft threads depends on the diameter and number of these threads. For calculation of the fabric cover, the following formula was used: $Fabric_{Cov} = Warp_{Cov} + Weft_{Cov}$ where $Warp_{Cov}$ and $Weft_{Cov}$, being, respectively, the product of the diameter and the number of these warp and weft threads. Fabric cover with the warp and weft in the fabrics tested was over one hundred percent, which was caused by the large deformation of warp threads and their accumulation (***Figure 3***). The analysis of weave influence on the properties analysed using digital estimation of weave by weave factors will be done in next paper.
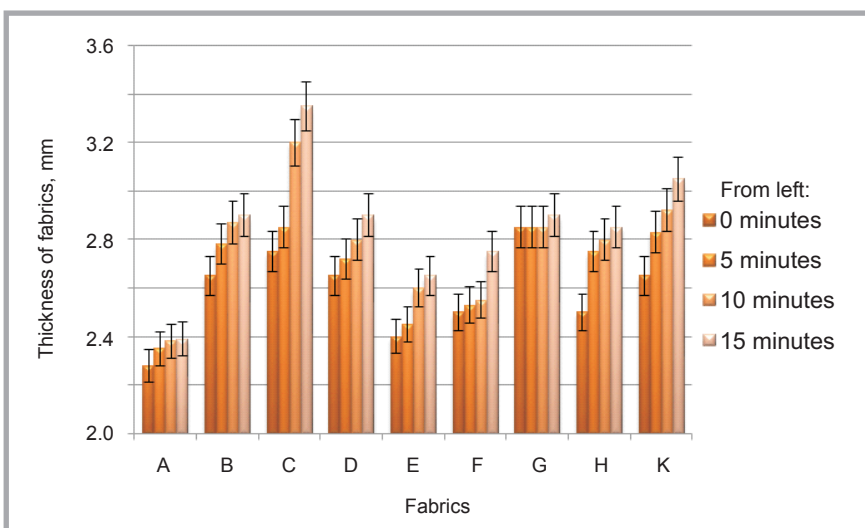
■ **Results and discussion**

When analysing the results of the tests on heat-treated yarns PA6.6 and PET, you can observe a clear change in the parameters of the warp and weft threads. The yarns were taken from the bobbin before weaving. It was assumed that the output linear density of threads before heat treatment is 100%. Both the linear density of the warp and weft increased (***Figure 4***).

It is visible that the linear density of the PET warp increased more (15%) than the linear density of the PA6.6 weft (9%). The increase in the linear density and diameter of threads of the fabrics causes changes in their internal structure parameters.

The thickness of the fabric is a function of the diameter and thread deflection arrows in the fabric. One parameter of all the fabrics which increased evenly was the thread diameter. The graph (***Figure 5***) shows that the increase in the fabric thickness was the most even for fabrics D and K - 19% and 15%, respectively. The smallest change in thickness was for plain fabric A - 4.8%, which is a result of the dense internal structure.

For fabric C with long interlaces, the increase in thickness was the biggest - 21%. In this weave, free threads, as well as changing their thickness, also had the possibility of additional build-up during heat treatment.



***Figure 4.*** *Effect of the heat treatment time on the linear density of warp and weft threads.*



***Figure 5.*** *Change in fabric thickness after heat treatment according to their weave.*

In general, it can be said that for fabrics with a dense structure, a change in their thickness under heat treatment is limited comparing to those with a loose structure. For twill or satin fabrics it is possible to easily shift and build-up threads, which does not limit the possibility of increasing the thickness during heat treatment.

When taking the warp thread number, a relatively large "jump" in the value of this parameter after 5 minutes was observed, and subsequently it stabilised. The biggest change in the thread number happened in fabrics F and G (4.8%), which is a result of the fact that the warp is grouped in weft rep weaves (*Figure 3.B*) and builds-up under heat treatment.

Longer heat treatment did not cause a further change in the warp number, due to locking of the fabric structure and the lack of opportunities for further shrinking.

A similar trend was observed when analysing the changes in the number of weft threads. This value is dependent on the free opportunity of warp threads to shrink and crimp as well as on the possibility of weft threads grouping and building up. The highest values of change in the number of weft threads, up to 24%, were observed for the warp thread rep weave. Heat treatment causes the locking of the fabric structure, no longer allowing its shrinking, nor warp and weft thread build up, which increases the thickness and surface weight of fabrics while reducing their longitudinal and transverse dimensions.

Warp and weft crimp is determined by the weave of the fabric. For warp threads A and F the crimp increased the most (*Figure 6.A*), because the initial crimp of these fabrics was relatively high. In these fabrics, values of thread displacement in the raw material were the highest and heat treatment caused an even greater surge of these threads.

As with other parameters of the internal structure, after the first five minutes of heating, for the majority of fabrics there was a "jump", and after a further 10 and 15 minutes the increase was not significant, the reason for which was the blockage of the fabric structure.

Fabrics A, B, E and H showed a low value of weft thread crimp (*Figure 6.B*) before high temperature, and heating did not increase their crimp, but caused shrinkage along their axis, sliding between the warp threads.
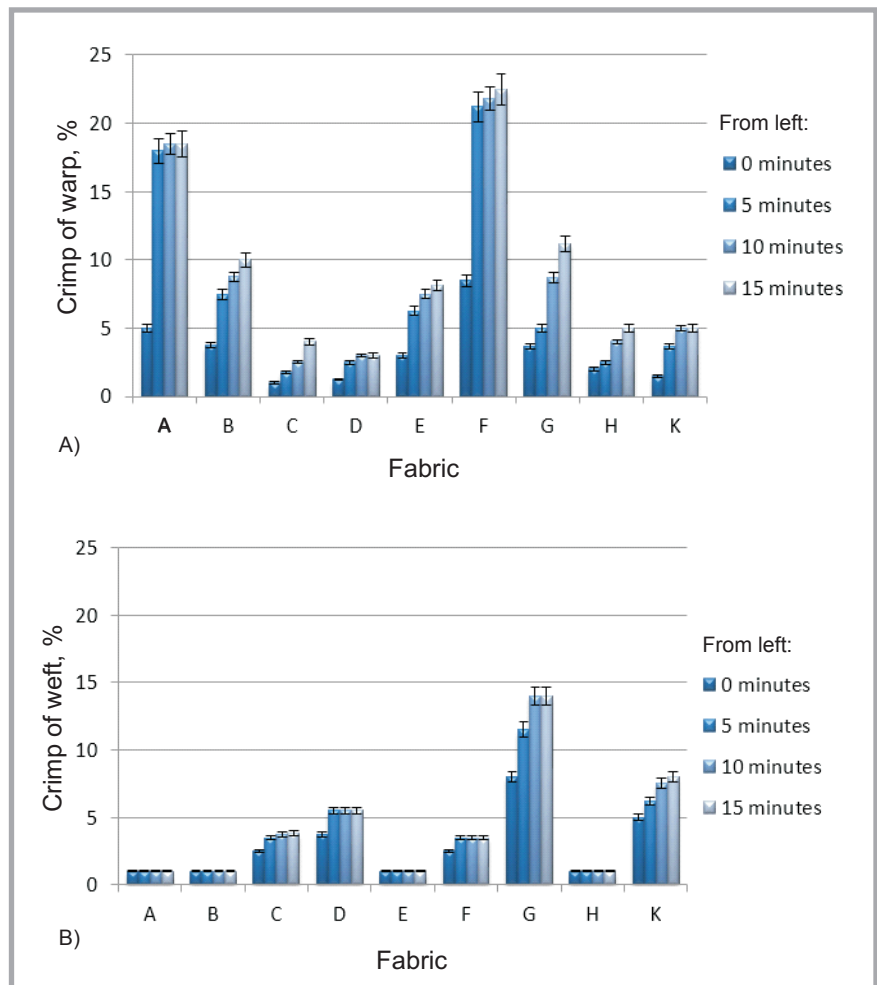


*Figure 6. Influence of heat treatment time on the crimp of warp A) and weft B).*

Generally it can be said that straightened threads do not tend to bend or wave in the fabric structure, while threads that originally have big crimps and are wavy, when subjected to heat treatment, bend increasingly.

Stopping the growth of crimp of fabric wefts C, D (*Figure 3.A*) and G (*Figure 3.B*) was caused by the lack of opportunities for further increasing the number of warp threads of these fabrics. The fabric areal density depends on many parameters of the internal structure of fabrics such as the linear density, sett and crimp of the component threads. The highest increase in areal density for the majority of fabrics could be observed during the first 5 minutes of heating. After this time, the value of the warp and weft sett was limited and the increase in the areal density was only influenced by that in the linear density and crimp of threads.

During the growth of the diameter and sett of the warp threads, the fabric cover with threads also increased in relation to the normal state (*Figure 7*, see page 50).

The fabric cover tested with warp and weft threads was already over 120% (in relation to a normal cover) in the rough. This meant that the warp threads in every fabric closely adhered to each other, often accumulating and deforming their cross-sectional shape (*Figure 3*). This explains the locking of the structure of most fabrics along the weft threads, and hence no increase in the value of the number of the warp threads after the first 5 minutes of heating.

*Figure 7* illustrates the fabric cover with warp and weft and its change during heating. The fabric cover with warp and weft depends on the cover with component threads, and this is influenced by the change in the diameter and sett of these threads. Analysis of the fabric cover charts and changes in the setts shows a relation between these parameters. With an increasing sett of threads during heat treatment, it is clear that the cover with these threads also grows.
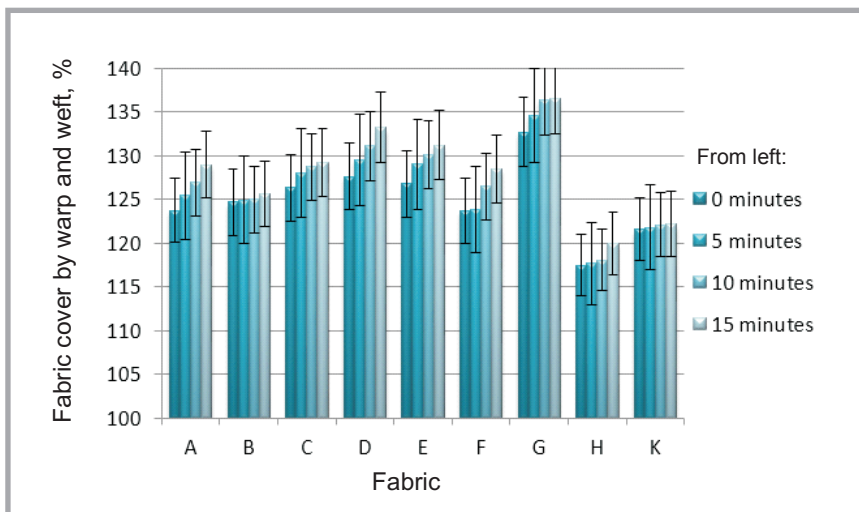
**Figure 7.** *Influence of heat treatment time on the fabric cover with warp and weft threads.*
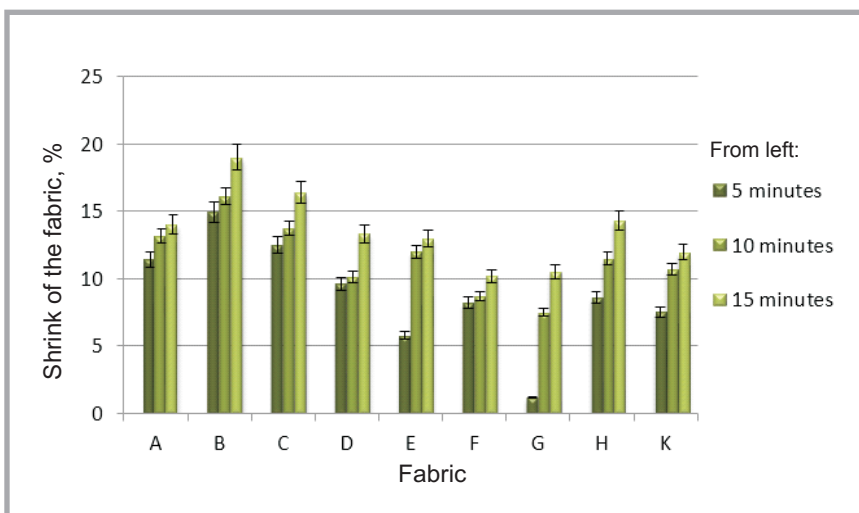


**Figure 8.** *Shrinkage of the fabric during heat treatment.*

The highest increase in shrinkage for the majority of fabrics could be observed during the first 5 minutes of heating (even 15%). After this time, the value of the warp and weft sett was limited. The highest shrinkage was observed for twill fabric (***Figure 8***).

Longer heat treatment did not cause further change in the yarn number, caused by locking of the fabric structure and lack of opportunities for further shrinking.

Given the above changes in the structure, an experiment will be conducted to determine the mechanical properties of the fabrics used in conveyor belts and how individual processes of creating belts affect these properties. Analysis of the mechanical properties of conveyor belts at the three main stages of production will be presented in the next paper.

## ■ Conclusions

The above analysis shows how the basic parameters of the internal structure of PA6.6/PET fabrics change during heat treatment occurring during the vulcanization and formation of conveyor belts.
■ When analysing the results of the research, you can observe a distinct change in the parameters of the internal structure of heat-treated fabrics.
■ The fabric weave significantly affects its internal structure parameters and the receptivity of these parameters to the influence of heat treatment.
■ The parameters of the internal structure of fabrics are closely related, changing one of which results in varying the others.
■ The most important and significant changes occur during the first 5 minutes. After this time the changes subsequently stabilised.

■ The locking of the fabric structure due to the swelling of component threads and shrinking of the fabric may affect the nature of changes occurring in the fabric.
■ Selection of the weave of fabric for vulcanization to be used as carcass of a conveyor is dependent on the structure and the strength of the conveyor belt.

The research presented above may, in the future, explain how these changes affect the vulcanisation process as well as the mechanical properties of PA6.6/PET fabrics and finished conveyor belts, which will be presented in the next article [23, 31].

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