Influence of the sample dimension and yarn type on the washing relaxation process of knitted fabrics

Andrea Ehrmann, PhD[1]
Prof. **Tomasz Blachowicz**, PhD[2]
Frank Heimlich[1]
Andrea Brücken, Dipl.-Ing.[1]
Prof. **Marcus O. Weber**, PhD[1]
[1]FTB, Niederrhein University of Applied Sciences
Mönchengladbach, Germany
[2]Institute of Physics, Silesian University of Technology
Gliwice, Poland
e-mail: andrea.ehrmann@hsnr.de
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While tailoring a garment or a technical textile, relaxation processes of a knitted fabric after production have to be taken into account. Such dimensional changes can occur during a long time of dry relaxation, during wet relaxation, or during washing relaxation, the latter having the strongest influence on a fabric. Besides fabric construction and yarn material, the dimensions of a knitted fabric also strongly influence the relaxation process. This paper shows a detailed analysis of the first 50 washing cycles for different fabric dimensions and yarn parameters, comparing conventional yarns and a conductive yarn used in sensory technologies. Stitch width in different locations in fabric samples were considered for analyzing the relaxation behavior.
Key words: *washing relaxation, knitted fabric, stainless steel fibre yarn, polyester yarn, dimensions, structural properties*

1. Introduction

In the knitting process, the yarn is forced into an unrelaxed state – it is being bent and strained. Relaxation of a single stitch into a relaxed state is prevented by the neighboring stitches which act in a similar manner. The whole system aims at minimizing its energy. This process leads to local energy minima, while the absolute energy minimum, i.e. the fully relaxed state, is blocked by energy barriers. These barriers can be overcome by spontaneous fluctuations or by supplying energy from outside.

The relaxation process starts directly after the knitted fabric has been taken out of the machine. While even dry relaxation leads to a significant dimensional change (especially in the first hours after the knitting process), wet relaxation leads to a more relaxed state. By immersing the fabric in water for some time, the yarn-yarn friction in the fabric is reduced, resulting in decreased energy barriers. In a washing process, however, the combination of further reduced friction due to the washing detergent and mechanical energy supplied to the fabric enables even stronger relaxation.

Despite the strong influence of washing relaxation on the dimensions of a knitted fabric, only a few examinations of up to maximum 10 washing cycles have been reported in literature. The dimensional changes have been reported, e.g., for different structures of 80 % lambs wool and 20 % polyamide [1] and especially for Milano rib and half Milano rib [2] for 1 washing cycle only. A lyocell blend has been reported to enhance washing shrinkage during 5 washing cycles

[3], while cotton fabrics have been examined during 5 laundry cycles after enzymatic and alkaline scouring [4] and after 6 laundry cycles [5]. Plain knitted fabrics of silk, cotton, and polyester with varying cover factors [6] have been investigated as well as single jersey and 1x1 rib silk and cotton fabrics [7], each during 10 laundry cycles each. The relaxation procedure of conventional non-elasticized and elasticized basic single and double weft knitted structures has recently been described for 5 washing and tumble drying cycles [8].

These small numbers of washing cycles are motivated by other examinations claiming the fully relaxed state to be reached after a few washing cycles. Silk knitted fabrics, e.g., have been found to be fully relaxed after 1 [7] or after 10 [9] laundry cycles. Similarly, wool knitted fabrics are reported to reach a fully relaxed state after 1 cycle of wetting-out, briefly hydro-extracting to remove excess water, and tumble-drying for 1 hour [10], or after 10 washing and tumble dry cycles [11]. For a wide range of natural and synthetic fibers, a combination of high temperature and wet treatment has been found to lead to full relaxation [12].

The idea of a fully relaxed state being reached after a few washing cycles is correlated with the theoretical description of the dimensional change using an exponential curve [13,14]. Measurements of the fabric width during 100 laundry cycles, however, have shown that the relaxation process can in certain cases also be described by a logarithmic function [15], which is not consistent with a fully relaxed state – i.e. the absolute energy minimum – that could ever be reached.

While a recent examination has also proven the strong influence of the sample dimensions on the relaxation behavior of a knitted fabric [15], most of the cited papers do not even mention the size of the samples under examination.

This paper analyzes the influence of fabric height and width on the relaxation process during 50 washing cycles for three different yarns and examines in which cases the knitted fabric can be regarded as fully relaxed after this amount of washing cycles, in order to determine which mathematical description should be used for which combinations of structure and material.

2. Experimental

The double face fabrics used in this study have been produced on a flat knitting machine CMS-302 TC by Stoll. The fabrics consist of three different yarns: the conductive staple fibre yarn "S-Shield" (3 x Nm 50/2) made by Schoeller, Bregenz (Austria), which contains 20 % of thin stainless steel fibres and 80 % polyester (PES) fibres and which has also been used in a previous examination [15]; a PES staple fibre yarn (3 x Nm 50/2); and a textured PES filament yarn (4 x dtex 150 * 2). All three yarns have the same linear density and have been knitted with the same machine parameters (take-down, machine speed, yarn tension etc.) to enhance comparability.

With this combination, we can examine the difference between staple fibre yarn and filament yarn as well as the influence of the additional conductive stainless steel fibres.

For each series of measurements, a small ensemble of 5 nominally identical samples has been examined in order to reduce the influence of random variations. Measurements of the fabric width were conducted in the middle of the fabric height in order to avoid edge effects. The first measurement, referred to as "0 washing cycles", has been taken (23±3) hours after taking the sample out of the machine. Measurements of the fabric height are not shown here since the relaxation effects are too small and correspondingly too error-prone.

Washing cycles have been performed in a household washing machine with heavy-duty detergent at 40 °C and subsequent spin cycle at 1200 min^{-1}. For drying, the samples were spread on a flat, smooth surface for (20 ± 2) hours at room temperature.

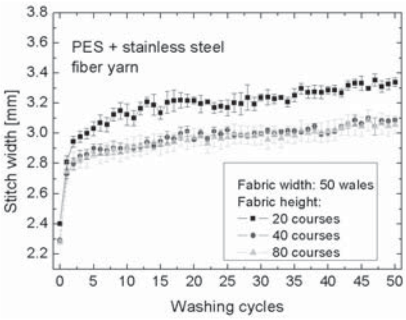
3. Results

Fig.1 shows the stitch widths, measured after 0-50 washing cycles, in samples produced of PES staple fibre yarn with 20 % stainless steel, for different fabric widths and heights. For this material, earlier experiments have shown that in broad, flat samples no fully relaxed state exists for up to 100 washing cycles, correlated with logarithmic behaviour. For approximately square samples, however, the slope of the curve could not be identified as logarithmic, while a fully relaxed state was nevertheless not reached [15].

The recent, more detailed analysis allows for a deeper insight into the influences of fabric height and widths on the relaxation process. In each graph of Fig.1 we can see that the shortest samples (20 courses) start with the largest stitch width and also show the largest stitch width after 50 washing cycles. It should be mentioned that the absolute increase in stitch width is not definitively correlated with the shortest samples (Fig.1c).

While the stitch width after 50 washing cycles grows with increasing fabric width, the stitch widths before washing do not show such a clear trend. This inconsistent behaviour may be attributed to slightly different times of dry relaxation between the end of the knitting process and the beginning of the measurements.

Comparing the curves, it can be recognized that the "rounder" slopes are correlated with lower fabric heights, while the higher samples show a sharper bend after the first washing cycle and an approximately linear correlation between stitch width and number of washing cycles after the first few laundry cycles. Apparently, a mathematical description which is



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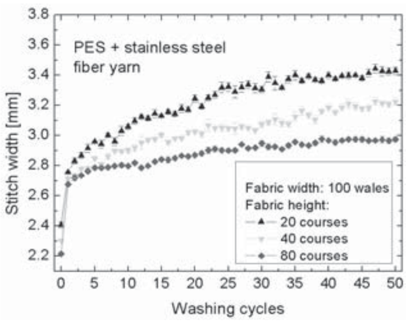

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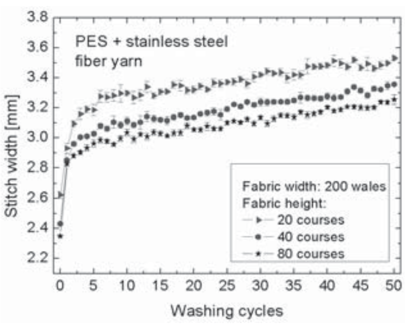

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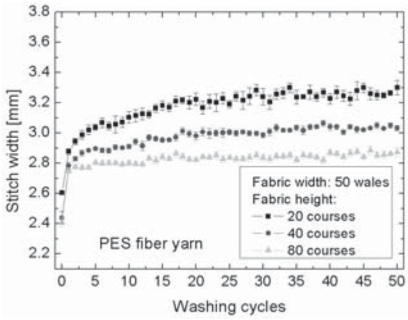
Fig.1 Stitch widths, measured after 0-50 washing cycles, for PES and stainless steel staple fibre yarn fabrics with: a) widths 50 wales, b) 100 wales, and c) 200 wales for different numbers of knitted courses



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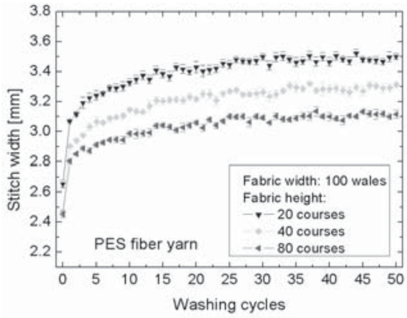

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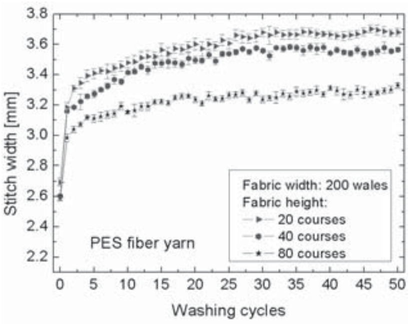

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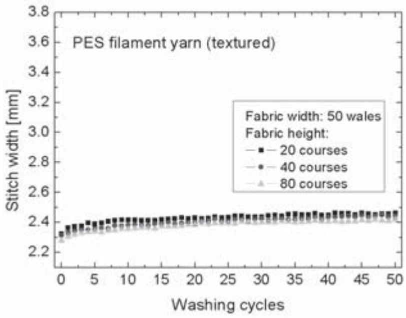
Fig.2 Stitch widths, measured after 0-50 washing cycles, for PES staple fibre yarn fabrics with: a) widths 50 wales, b) 100 wales, and c) 200 wales for different numbers of knitted courses.



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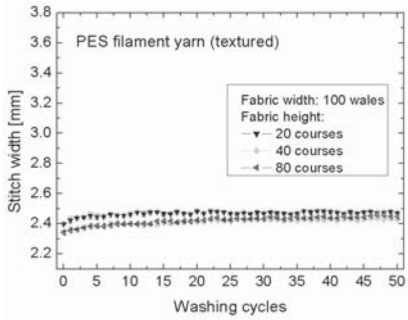

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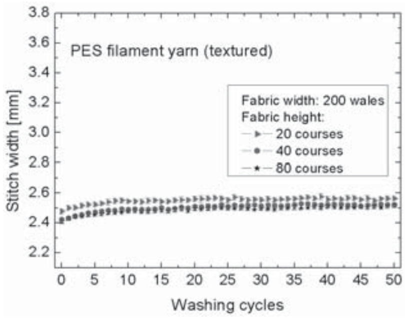


c)

Fig.3 Stitch widths, measured after 0-50 washing cycles, for textured PES filament yarn fabrics with: a) widths 50 wales, b) 100 wales, and c) 200 wales for different numbers of knitted courses

valid for all fabric dimensions could, e.g., include a logarithmic as well as a linear term.

To examine the influence of the stainless steel fibres in the first sample series, Fig.2 depicts the respective measurements on samples produced from PES staple fibre yarn *without* stainless steel. The basic findings described above can be found here, too: The shortest samples start and end with the largest stitch widths; the stitch width after 50 washing cycles grows with increasing fabric width; and the "rounder" slopes are correlated with lower fabric heights. As already stated in a previous publication [15], the additional stainless steel fraction does not qualitatively change the relaxation processes of the knitted fabrics.

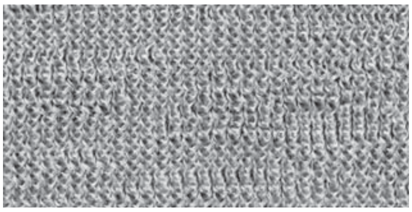
In comparison with the experimental results of the two different staple fibre yarns, the textured filament yarn directly after knitting shows similar stitch widths (Fig.3). The values after 50 washing cycles, however, are significantly smaller than those measured in the staple fibre yarn samples. This finding can be attributed to the texture of the yarn which enhances the yarn-yarn friction and thus diminishes the possibilities of overcoming energy barriers. On the other hand, staple fibre yarns are – opposite to filament yarns – known to lose weight during washing, by losing either fibre ends or whole fibres which are drawn out of the fabric. This effect might slacken the knitted fabric and thus lower the friction-induced energy barriers, resulting in increased relaxation.

However, even the textured PES filament yarns lead to relaxation processes which do not stop after 10 or even less washing cycles.

In order to find an adequate description for the systems under examination, Fig.4 shows a macroscopic picture of the three samples. Especially the fabric produced from PES and stainless steel staple fibre yarn (upper panel) shows areas with apparently differing stitches. In some parts, the stitches look flat and two-dimensional, while in other parts, the original clear and three-dimensional stitch structure is still evident.

This effect is also detectable in the other two pictures; however, it is most pronounced in the sample including stainless steel fibres, probably due to a shape memory effect of the metal which retains effects of forces during washing on the fabric.

A closer look at the stitches in the different areas of the fabric from PES and stainless steel staple fibre yarn reveals the microscopic differences (Fig. 5): While the stitches originally have an upright position (upper panel), they are strongly tilted to alternating sides in the relaxed state (lower panel). The tilting orientation (to the left or to the right side) does not show a correlation with the knitting direction of the respective course; the yarn torque is always identical and thus can neither define the tilting orientation. Comparing scans of the PES and stainless steel knitted fabrics after the 1st and the 50th washing cycle (not shown here), it can be recognized that the areas with the relaxed stitches grow in dimension and number with increasing numbers of washing cycles. This effect can similarly (although less pronounced) be found in the fabrics produced from pure PES staple fibre yarn, while it is nearly invisible in the textured PES filament yarn fabrics. This finding may be attributed to the denser stitches in the latter sample which – additional to the increased friction – suppress the possibility of a diagonal shift in the stitches.



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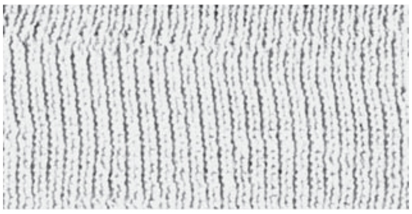

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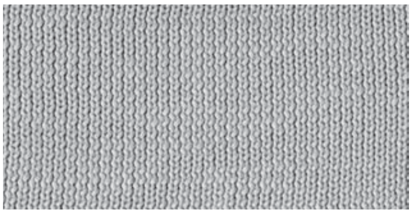

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Fig.4 Scans of samples with width 100 wales and height 20 courses after 50 washing cycles for: a) PES and stainless steel staple fibre yarn, b) PES staple fibre yarn, and c) textured PES filament yarn

a)

b)

Fig.5 Microscopic pictures of different stitches after 50 washing cycles for PES and stainless steel staple fibre yarn: a) originally-shaped stitches and b) relaxed stitches

4. Discussion

The shape of the relaxation curves depicted in Figs. 1-3 is heterogeneous. Some of the curves fit to a logarithmic behaviour, others can probably be better described by two exponential functions with different dependencies on the number of washing cycles. Both mathematical descriptions are not unknown in physical processes.

For example, some relaxation processes like relaxation of a spin ensemble sensed by Nuclear Magnetic Resonance (NMR) are known to include two separate exponential relaxation processes with two different time constants. Similarly, such a mathematical function could describe better the relaxation of the higher fabrics (i.e. 80 courses) with the strong first dimensional increase followed by an almost linear slight increase after the first few washing cycles.

On the other hand, some relaxation processes in physics and other sciences can be adequately described by the stretched exponential function $\exp(-(t/\tau)^{\beta})$ with the stretching exponent β and the time constant τ [16]. A stretched exponential function $[1-\exp(-(t/\tau)^{\beta})]$ with $\beta < 1$ can look similar to the logarithmic function. Due to the large error bars, more than the 50 washing cycles depicted in this paper would be necessary to distinguish definitely between both mathematical descriptions. Nevertheless, although exponential and logarithmic curves can be shaped similarly for the first 50 or more washing cycles, the difference between them is not only of academic nature: While an exponential function has a boundary which will not be crossed, a logarithmic function can grow without limits. Thus, finding the correct mathematical description is identical with the possibility to decide whether the relaxation process of a knitted fabric has a final state or not – which is also important to know for knitters and textile engineers.

Due to the described challenges in finding the answer to this question by further experiments, the next step will be to perform an Ising simulation [17] which includes yarn-yarn friction, elastic moduli, bending stiffness of the yarn and the knitted structure. Each washing cycle corresponds to one simulation step, in which each single stitch can relax with a certain probability if the randomized external energy due to washing at this position exceeds the node energy due to yarn-yarn friction and tensions in the yarn. The model parameters can be fitted to the experimental results and allow for predictions of the systems after more than 50 simulation cycles. The stability of these predictions according to small changes in the model parameters can be used as an indicator for the confidence level of the simulation. This theoretical approach will help to understand the complex relaxation process in knitted fabrics.

5. Conclusions

The washing relaxation process of double face fabrics from polyester staple fibre yarn with 20 % stainless steel fibres, pure polyester staple fibre yarn and textured polyester filament yarn has been experimentally examined during the first 50 washing cycles. Depending on the sample dimension, different shapes of the relaxation curves have been observed. Samples from textured filament yarn have been shown to relax significantly less than staple fibre yarn samples. For the latter, our experiments could prove that the relaxation process is not finished after 50 washing cycles for all fabric dimensions. Additionally, microscopic examinations of the samples containing stainless steel fibres depicted that the relaxation in these double face fabrics is correlated with a tilting of the stitches in growing areas of the fabric.

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