Study of dimensional changes during washing process for 1:1 interlock cotton yarns

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Abstract. The paper proposes a study regarding the dimensional changes during washing process for the 1:1 interlock structures made of 100% cotton yarn with Nm 58/1. The interlock 1:1 structures which are studied are made of 100% cotton yarns, with Z torsion, on Monarch circular knitting machines, with diameter of 30 inch, fineness 20E and 72 knitting systems. Tubular meterage knitwear resulted from this process. After the knitting, the structures were laid for relaxation, and then they were subjected to the washing, drying and relaxation operation. The loosening of the knits for 72 hours was done in air-conditioned areas respecting the parameters of the standard atmosphere to balance the internal tensions introduced into the structures during the knitting and washing operations. The structure parameters of the knitwear modify after the relaxation before finishing process, after finishing and after washing process. The machines where the structures were produced are new generation knitting machines and finishing. After knitting and relaxation of the fabrics, the finishing and washing processes were applied with a minimum tension of the structures, de-watering was made with uniform pressure air-blowing installations on entire length and surface of the tubular knitting, in this way replacing the classical centrifugation machines, which had a dynamic action on knitwear and increased the wrinkling.

1. Introduction
In the case of knitted structures, a washing process is carried out in the process of finishing the cotton knitwear, which has the purpose both of removing the technological companions of paraffin used for knitting and of maximum fiber expansion to relax the existing latent tensions in knit.

From the dimensional stability point of view, the first washing has a great importance, therefore it is very important the selection of the washing agents used, the washing temperature, the duration of the process and the intensity of the mechanical action.

These preparation processes are also accompanied by additional washing processes, in order to remove natural or technological companions, and as well the reaction products resulted from different treatments. For washing, mixtures of anionic and non-ionic detergents are used. Cationic detergents give residues that are deposited on machines and therefore are not used. Surfactants are adsorbed on the surface of the dirt particles on the knit surface, and then due to the dispersing and protective colloid nature, the impurities are passed from the knit in solution and remain there in dispersed state [1-3]. The sequence of operations for cotton knitwear preparation is generally given by the impurity removal order:
1. degreasing and removing greasy/oily substances used as lubricants in the knitting process which might have been deposited on the yarn.

2. acid extraction, to remove metal ions which are the companion binders of natural cotton

3. alkaline treatment that has the role of removing most of the natural companions

4. bleaching, which has the purpose of destroying natural pigments [1, 2, 4].

We consider dimensional stability a quality parameter of knits that presumes optimizing the parameters of the finishing technological operations in order to obtain the maximum values of this parameter. Dimensional stability of knits is a consequence of their structural elements resulted from design and knitting, as well as changes in structural elements that occur during finishing operations [5-8]. The structural elements of a knit that are closely related to both the knitting and finishing technologies and as well the dimensional stability obtained are the fineness and structure of the yarn, the density in vertical direction of the knit, the knit structure [8, 9].

The fineness of the thread determines the thickness of the knit, the mass per square meter, the minimum and maximum density of the knit that can be obtained on the knitting machine, and to a lesser extent the structure used. Thread structure elements such as thread twist, thread type (ring spinning machine or open-end machine) influence the structure only indirectly in terms of the possibility of using or not a thread type for a particular structure as well as by the possibilities of applying or not applying a particular finishing technology. The twist direction of the yarn and the spinning process influences the dimensional stability through internal stresses that can be introduced into the structure or through the spirality of the tubular knit feature [10, 11].

Knitting density influences both dimensional stability and requires the feasible finishing process to be adopted as well as its parameters. These parameters are correlated with the dimensional stability obtained after finishing. The knitted fabric is one of the aspects with a particular influence on the dimensional stability of the knitwear. The structure is determined either by the aesthetic aspects or by the functional aspects of the designed product.

The finishing processes should be chosen taking into account the structure, which is important in terms of the possibilities of uniform penetration with the treatment solutions, the possibility of affecting the elements of the structure in general and the tensions introduced or the elimination of the existing ones. The interlock structures 1:1 made of 100% cotton yarns are the most dimensionally stable structures. The yarn-yarn contact points and the contact surfaces are multiple and the frictional forces which develop in the structure are relatively high. The study proposes an experimental program with 2 variables which represent the input data. The regression equation coefficients are established, the equations are written and the response surfaces are represented and also the sections through the response surfaces. The study made on interlock 1:1 structures made of 100% cotton yarns, Nm 58/1 have proven that for a maximum dimensional stability, the highest influence represents the wale density of the knitting machine. The results of the experimental program which was proposed have practical applicability because by knowing the fineness of the cotton yarns, the technical characteristics of the knitting machines, the turn of the needle bar and the wale density of the machine, then it can be determined the dimensional modifications of the knitted fabrics on stitch course direction and stitch course in vertical direction.

2. The experimental part

The 1:1 interlock structures studied were made of 100% Z-twisted cotton yarns on high diameter circular machines, Monarch, finesse 20 E and 30 inch needle bar diameter. Tubular knits were produced. After knitting the structures were laid for relaxation, and then subjected to the washing,
drying and relaxation operation. The loosening of the knits for 72 hours was done in air-conditioned enclosures respecting the parameters of the standard atmosphere to balance the internal tensions introduced into the structures during the knitting and washing operations.

To determine the influence of knitting parameters on dimensional stability, we established a mathematical model of the correlation between dimensional changes after washing, considered as the dependent variable (response) and as well the wale density and the speed of the needle bar considered independent variables.

For statistical processing of results for 1:1 interlock knitted yarns made of 100% cotton, Nm 58/1, an experimental program was proposed with two variables \( x_1 \) and \( x_2 \) constituting the input data, where \( x_1 \) represents the vertical density on the knitting machine [stitches/cm] and \( x_2 \) the speed of the needle bar of knitting machine [rot/min]. The proposed program is a central routable mathematical model with two variables. The significance of the coefficients was tested with the T test, and the suitability with the Student test.

We determined the coefficients of the regression equations in the stitch course direction, \( D_x \), and stitch course in vertical direction, \( D_y \). We wrote the equations and plotted the response surface and the sections by the response surface on the two directions of the knit, the stitch course direction and the stitch course in vertical direction.

In table 1 are presented the dimensional changes during washing process, of the 1:1 interlock structures made of 100% cotton yarn, Nm 58/1.

| \( x_1 \) encoded | \( x_2 \) encoded | \( D_x \) (stitches/cm) | \( n \) (rot/min) | \( D_x \) (%) | \( D_y \) (%) |
|------------------|------------------|------------------------|------------------|-------------|-------------|
| 1 -1             | -1               | 9.45                   | 10.90            | 3.70        | -4.25       |
| 2 1              | -1               | 11.60                  | 10.90            | 2.40        | -2.20       |
| 3 -1             | 1                | 9.45                   | 15.10            | 4.00        | -4.50       |
| 4 1              | 1                | 11.60                  | 15.10            | 2.50        | -2.15       |
| 5 -1.414         | 0                | 9.00                   | 13.00            | 4.20        | -4.90       |
| 6 1.414          | 0                | 12.00                  | 13.00            | 1.80        | -2.00       |
| 7 -1             | -1.414           | 10.50                  | 10.00            | 2.20        | -1.70       |
| 8 1              | 1.414            | 10.50                  | 16.00            | 2.30        | -1.60       |
| 9 0              | 0                | 10.50                  | 13.00            | 2.40        | -1.70       |
| 10 0             | 0                | 10.50                  | 13.00            | 2.30        | -1.65       |
| 11 0             | 0                | 10.50                  | 13.00            | 2.30        | -1.70       |
| 12 0             | 0                | 10.50                  | 13.00            | 2.20        | -1.70       |
| 13 0             | 0                | 10.50                  | 13.00            | 2.00        | -1.60       |

2.1. Study regarding the dimensional changes during washing process, in stitch course direction, for interlock structures 1:1 made of 100% cotton yarn, Nm 58/1

The regression equation describing the behavior of 1:1 interlock knits made of 100% cotton yarn Nm 58/1, in stitch course direction, after washing is given by equation (1):

\[
f(x, y) = 2.24 - 0.774 \cdot x + 0.511 \cdot y + 0.068 \cdot x^2 + 0.136 \cdot y^2 - 0.05 \cdot x \cdot y
\]

In figure 1 is presented the response surface, which is the dependence \( U=f(x, y) \), in the case of shrinkage contraction after washing in the stitches course direction for the 1:1 interlock knitted fabrics.

The response surface has an elongated saddle shape. The curves which generate it are hyperbolas. In figure 2 are presented the sections through the response surface, represented in figure 1, for the finishing contraction in the stitch course direction for the 1:1 interlock knitted fabrics.

From the interpretation of the graphic in figure 2 it follows:
- level curves are portions of hyperbolas;
- for the entire range of variance of stitch course direction and of the turn of the needle bar, the values of the washing contractions are positive, so elongation of the knitted fabrics during washing appear in this direction;
- once the wale density increases, the elongation during washing in stitch course direction decreases;
- it can be obtained knitted fabrics with the same dimensional stability by working with high speed of the needle bar and large wale density or with low speed of the needle bar and small wale densities. Accordingly, knits with different mass on square meter will be obtained.

**Figure 1.** Response surface in the shrinkage contraction during washing, on stitch course direction, for the 1:1 interlock, 100% cotton yarns, Nm58/1.

**Figure 2.** Sections through the response surface in washing contraction, in stitch course direction, for 1:1 interlock, 100% cotton yarn, Nm 58/1.

In figure 3 is represented the dependence of Z = f(y) for x = constant. From the graphical representation analysis of figure 3 it follows:

- together with the increase of the wale density, the washing contraction decreases in stitch course direction
- the curves present approximate the same evolution for the entire variation domain of the wale density, if the speed of the needle bar is kept constant.

**Figure 3.** Variation Z=f(y) for x=constant in the case of dimensional changes during washing, in stitch course direction, 1:1 interlock structures, 100% cotton yarn, Nm 58/1.

From the interpretation of the graphic in figure 4 it follows:

- once the speed of the needle bar increases, the washing contraction in stitch course direction increases as well, for the 1:1 interlock structures
• the transition from one level to another is made with the same effort for the entire variation domain of the speed of the needle bar.

Figure 4. Variation $T = f(x)$ for $y = \text{constant}$ in the case of dimensional changes during washing, in the stitch course direction, for 1:1 interlock structures made of 100% cotton yarn, Nm 58/1.

2.2. Study of the dimensional changes during washing in stitch course in vertical direction, for 1:1 interlock structures made of 100% cotton yarn, Nm 58/1

The regression equation which describes the behaviour of the 1:1 interlock structures, 100% cotton yarn, Nm 58/1, in the stitch course in vertical direction, after washing is given by the equation (2)

$$f(x, y) = -1.67 + 1.063 \cdot x - 1.072 \cdot y - 0.007326 \cdot x^2 - 0.171 \cdot y^2 + 0.075 \cdot x \cdot y$$ (2)

In figure 5 is presented the response surface, which is the dependence $U = f(x, y)$, in the case of shrinkage contraction after washing in the stitches course in vertical direction for the 1:1 interlock knitted fabrics.

The response surface is an elongated saddle shape. The curves which generates it are hyperbolas. In figure 6 are presented the sections through the response surface, represented in figure 5, for the washing contraction in the stitch course direction for the 1:1 interlock knitted fabrics studied.

Figure 5. Response surface in the contraction during washing, on stitch course in vertical direction, 1:1 interlock knitted fabrics, 100% cotton yarns, Nm58/1.

Figure 6. Sections through the response surface in washing contraction, in stitch course in vertical direction, 1:1 interlock, 100% cotton yarn, Nm 58/1.
Figure 7. Variation $Z=f(x)$ for $y=\text{constant}$ in the case of dimensional changes during washing, in the stitch course in vertical direction.

Figure 8. Variation $T=f(x)$ for $y=\text{constant}$ in the case of dimensional changes during washing, in the stitch course in vertical direction, for 1:1 interlock structures, Nm 58/1.

From the interpretation of the graphic in figure 6 it follows:

- the level curves are portions of hyperbolas;
- for the entire variation domain of wale densities and of the speed of the needle bar, there are noted washing contractions in stitch course in vertical direction;
- together with the increase of wale density, the washing contractions decrease;
- there can be obtained knitted fabrics with the same dimensional stability by working with large wale densities and high speed of the needle bar, or with small wale densities and low speed of the needle bar.

In figure 7 is represented the dependence $Z=f(y)$ for $x=\text{constant}$. In figure 8 is represented the dependence $T=f(x)$ for $y=\text{constant}$. From the analysis of the graphic design form figure 8, results:

- Once the speed of the needle bar is increased, the elongation during washing in stitch course in vertical direction increases as well, for the 1:1 interlock structures studied;
- The curves have the same evolution for the entire variation domain of the wale density;
• The transition from one level to another is made with the same effort as for the entire variation domain of the wale density.

3. Conclusions
Knitted fabrics with the same dimensional stability can be obtained by working with high speed of the needle bar and large wale densities or with low speed of the needle bar and small wale densities. The same, knitted fabrics with different mass per square meter will be obtained.

Knitted structures with the best dimensional stability are those for which dimensional changes after relaxation are minimal.

The greatest knit deformations occur after the washing and finishing process, as these phases intervene vigorously in wet and high temperature on knitwear.

1:1 interlock structures have the appropriate dimensional stability, within ± 2% due to the way the structure is achieved, the spatial layout of the structure elements and the large number of yarn-yarn contact points.

Adopting the technological parameters of the knitting washing process and conducting the minimum tensioning process will result in the achievement of knits of maximum dimensional stability. Minimal tensioning of knits throughout the technological processing processes leads to knitted fabrics with dimensional stability and maximum shape.

In order to obtain knitted fabrics with good dimensional stability, from the structure parameters of knits, the greatest influence is the wale density on the knitting machine.

In the case of establishing a certain wale density on the knitting machine, the technological parameters of the knitting operations have considerably less influence on the unfinished dimensional changes of the knits.

The method of obtaining the 1:1 interlock structure made of two 1:1 rib structures, leads to a balanced structure, the high number of yarn-yarn contract points and of a high number of yarn-yarn contact surfaces leads to creating high friction forces between the elements of the structures and in the same time leads to an easier dimensional stability.

Experimental programs provide information on the behaviour of knits in the entire range of variation of wale densities and speed of the needle bar.

The program is designed so that dimensional changes can be provided after knitting, finishing and washing of knits, depending on the values f the wale density and the speed of the needle bar, for the types of knitting machines on which the structures were made.

4. References
[1] Ursache M, Loghin C, Muresan R, Cerempei A and Muresan A 2011 Investigation on the Effects of Antibacterial Finishes on Dyed Cotton Knitted Fabrics Tekstil ve konfeksiyon 21(3) 249-256
[2] Harpa R, Curteza A, Cristian I and Piroi C 2008 Optimizing The Yarn Quality By Means Of Cotton Mixture Design ITC&DC: 4th International Textile Clothing & Design Conference - Magic World Of Textiles 763-768 Dubrovnik Croatia
[3] Ciobanu L, Ionesi D and Ciobanu A R 2011 Design of fashioning lines in 3D knitted fabrics Industria Textila 64(4) 198-201
[4] Abramiuc D, Cerempei A, Muresan E and Ciobanu L 2011 – Development of new materials and therapeutical characteristics 7th International Conference on Management of Technological Changes 1-5 Alexandroupolos Greece
[5] Negru D, Buhu L, Loghin E C, Dulgheriu I and Buhu A 2017 Absorption and moisture transfer through knitted fabrics made of natural and man-made fibers Industria Textila 68(4) 269-274
[6] Harpa R 2012 Cotton Yarns Weavability Assessment: Investigation On Raw Material Properties For Denim ITC&DC: 6th International Textile Clothing & Design Conference - Magic World Of Textiles 505-511 Dubrovnik Croatia
[7] Radu C D, Tulbure A, Agafitei G, Popescu V, Piroi C and Harpa R 2007 Knitted Structures For Dermatological Diseases 5th International Conference on the Management of Technological Changes 1 435-439 Alexandroupolis Greece

[8] Dulgheriu I, Ionescu I, Ionesi D and Dragomir A 2015 Evaluation and calculation model for heat transfer equilibrium through clothing articles Industria Textila 66 59-66

[9] Ciobanu L, Ionesi S D and Ciobanu A R 2011 Design of fashioning lines in 3D knitted fabrics Industria Textila 4 198-201

[10] Ionesi D, Ciobanu A R, Blaga M and Budulan C 2010 Knitted preforms for composite materials 7th International Conference – TEXCI Liberec, Czech Republic

[11] Ciobanu L and Filipescu F 2015 Experimental Study of the Mechanical Behaviour of Knitted Fabrics FTEE 20(91) 34-39