This paper analyzes the impact of the yarn linear density used in the dimensional stability of the 1x1 RIB knitwear made on the same circular knitting machine. The used samples of raw knitwear are made from 100% cotton yarn with different linear densities of 19, 17, 15 and 13 tex. Dimensional stability of these samples was analyzed by FAST 4. The results show that the most stable knitwear is made of 100% cotton yarn with the linear density 19 tex. The values of the tightness factor in the dry relaxation stood at 14, 93, 15, 14 under wet, 16,32 under total and 16,20 under air conditioned conditions. The knitwear with the highest values of dimensional instability is a raw knitted fabric made of 100% CO, and the yarn with the linear density of 13 tex. The values of the tightness factor in the dry relaxation stood at 16,20 under wet, 15,14 under total and 12,53 under air conditioned conditions.

Keywords: 1x1 rib cotton knitwear, knitwear dimensional stability, dimensional constants, the tightness factor

Introduction

One of the most important indicators of knitted products is their dimensional stability. Knitted fabrics have a structure which offers a stretch ability and the elasticity of knitwear. These advantages make knitwear comfortable and fit well to body contours, providing transpiration as well[1].

In the yarn which has formed a loop, a certain amount of potential energy is accumulated. This energy causes a certain pressure yarn against yarn in places where these yarns intersect in knitwear. In these places, frictional forces appear between the yarns and prevent their displacement. The yarn tends to get rid of deformations that have occurred in the shaping of the loop which causes shrinkage of knitwear. The knitwear shrinkage stops when these deformation and friction forces are in balance[2].

The impact of the raw material is significant for dimensional stability, i.e. the fiber type, the shape, intersection and linear density of fibers, a spinning process, a linear density of the yarn, a type and number of twists of the yarn. The fiber characteristics significantly influence the knitting [2].

The impact of the water treatment is also significant. During the penetration into intermicellar spaces in cellulose fibers, water molecules lead to swelling of fibers and as a result the yarn diameter in the loop increases by 20 to 30% [3]. Wet processing is usually accompanied by the increase of the temperature of processing agents. The result is the increase of the yarn thickness, to which shape of the loop need to adapt[4]. All this leads to knitwear shrinkage.

When designing clothing products a big issue is the prediction of the dimensional stability of knitwear. This problem is expressed during the exploitation of knitted products, as well as during their washing, because very often there are significant dimensional changes in clothing products that reduce their quality[3].

The purpose of this paper is collecting relevant information in the form of the dimensional stability of knitwear in order to obtain the results that will make future clothes projecting easier in order to fulfill the customer demands.

Experimental

The experimental part of this paper analyses the dimensional stability of the 1x1 RIB knitwear made of 100% CO yarns used in four linear densities: 19, 17,15 and 13 tex. Raw state samples were examined (Table 1).
20 samples of the same type and in the measurement result that follows, the arithmetic mean values of these 20 samples is represented.

Determination of the dimensional stability by the FAST 4 method
Dimensions of the sample were 300 x 300 mm. The samples with the 5cm minimum distance from the edges of the knitwear were taken. The FAST 4 method has several stages [5]. First, the conditioned samples of the knitwear has to be exposed to heat at the temperature of 105 °C in a dryer for the period of 60 min, after which the dimensions of the samples have to be taken in the longitudinal and transverse direction for a period of 30 seconds (length L1) (Dry relaxation S). This is followed by immersion of a dry sample in water for 30 minutes, at the temperature of 25 °C to 30 °C with the addition of 0.1% detergent. After that, the sample has to be placed on a smooth surface with gentle pressing in order to remove the excess water, after which the sample should be measured again (length L2) (Wet relaxation W). The sample is then returned to the dryer to be exposed to heat at the temperature of 105 °C for 60 min. The dried sample is measured over a period of 30 seconds to obtain the length L3 (Full relaxation F). At the end, the sample is left for relaxation, and after conditioning in a room with standard atmospheric conditions according to ISO 139, the sample is measured (length L4) (Climatization - C) (Figure 1).

According to the method FAST 4, relaxing shrinkage is defined as percentage change of the dimension of the knitwear sample after the heat and wet processing. It can be described as the ratio of the difference between the dry sample length after the heat treatment (length L1) and the dimension of the dried sample after relaxation at the wet state (length L3) and the dimension of the dry sample after the heat treatment (length L1). Relaxation shrinkage of the knitwear sample can be represented by the following expression 1 [6]:

$$RS = \frac{L_1 - L_3}{L_1} \cdot 100\%$$

FAST 4 method defines relaxing stretching in a wet condition as the percentage change of the dimension of the knitwear sample upon the wet treatment, and is calculated according to the following expression 2[6]:

$$HE = \frac{L_2 - L_4}{L_2} \cdot 100\%$$

Results and discussion
In Figures 3 and 4, we can see that raw samples of knitwear made from finer yarns have more shrinkage of the knitwear which are made of the coarser and stronger yarn.

Dimensional constants K-values
In order to monitor the stability of the knitted structure through different states of relaxation, dimensional
constants can be used. Usually, the following Munden's geometrical correlations are used [1] for calculating the dimensional constants of the knitwear relaxation conditions:

\[ K_c = \frac{D_h}{I} ; \quad K_w = \frac{D_v}{I} ; \quad K_r = \frac{K_c}{K_w} ; \quad K_s = S \cdot I^2 \]

I - the mean value of the yarn length in a loop, 
Kc, Kw, Kr, Ks - dimensional constants, S - the loop density, Dh - number of loops in horizontal, Dv - number of loops in vertical, I - yarn length.

K values are important for the prediction of structural behavior, for creating a material with better stability and for determining the minimum/lower energy level of loops after treatment. K constants can interconnect the values Dh, Dv and the yarn length in a loop. Kw and Kc are constants of Dv and Dh. Kr constant represents the ratio of the constants Kc / Kw. This is a direct measure of the shape and it is called the shape factor of the loop. Ks is a constant overall density of loops. It is the product constants Kc and Kw [1]. Table 2 shows the value of dimensional constants for the test samples.

|        | C1         | C2         | C3         | C4         |
|--------|------------|------------|------------|------------|
| I      | 0.280±0.0111 | 0.292±0.005 | 0.293±0.0121 | 0.269±0.0063 |
| D      | 4.06±0.0581  | 3.81±0.0122 | 3.76±0.0456 | 3.88±0.0107 |
| W      | 4.19±0.0465  | 3.97±0.0185 | 3.95±0.0479 | 3.77±0.0239 |
| F      | 4.27±0.0475  | 4.00±0.0191 | 4.05±0.0490 | 3.89±0.0241 |
| C      | 4.19±0.0466  | 3.97±0.0189 | 4.02±0.0487 | 3.73±0.0237 |
| D      | 6.30±0.0901  | 6.46±0.0207 | 6.62±0.0801 | 6.8±0.0200  |
| W      | 6.34±0.0704  | 6.53±0.0312 | 6.70±0.0811 | 6.14±0.0516 |
| F      | 6.55±0.0727  | 6.68±0.0319 | 6.73±0.0815 | 7.92±0.0502 |
| C      | 6.52±0.0724  | 6.81±0.0316 | 6.71±0.0813 | 7.91±0.0501 |
| D      | 1.55±0.0222  | 1.70±0.0054 | 1.76±0.0213 | 1.86±0.0054 |
| W      | 1.51±0.0168  | 1.69±0.0081 | 1.70±0.0205 | 2.16±0.00137|
| F      | 1.53±0.0170  | 1.67±0.0080 | 1.66±0.0202 | 2.08±0.0132 |
| C      | 1.55±0.0173  | 1.67±0.0080 | 1.67±0.0202 | 2.12±0.0134 |
| D      | 25.58±0.3658 | 24.65±0.0789 | 24.82±0.3014 | 25.20±0.0735 |
| W      | 26.54±0.2949 | 25.30±0.1207 | 26.49±0.3207 | 30.69±0.1945 |
| F      | 27.98±0.3108 | 26.76±0.1276 | 27.24±0.3299 | 30.08±0.1907 |
| C      | 27.33±0.3036 | 26.25±0.1252 | 27.00±0.3270 | 29.50±0.1871 |

Legend: D - dry relaxation, W - wet relaxation, F - Full relaxation, C - conditioned sample, I - the mean value of the length of the yarn in a loop (cm).

The results shown in Table 2 indicate that the values of dimensional constants increase with the increase of relaxation, except for the conditioned samples where the values decrease. The values of the constants rise with the knitwear which is made of thinner cotton yarns, comparing with the ones made of thicker cotton yarns.

Also, with the change of the relaxation condition, it can be seen that Kr constant or a loop shape factor is significantly reduced as a result of achieving a stable condition. With the increase of relaxation, the minimum energy is produced so that the loop cannot be changed further and occupies the envisaged state in the space.

In Figures 5 to 8, the change in K is shown graphically in relation to the length of the yarn in the loop.

Figure 5. Changes in K in relation to the yarn length in a loop (l0) for sample C1

Figure 6. Changes in K in relation to the yarn length in a loop (l0) for sample C2

Figure 7. Changes in K in relation to the yarn length in a loop (l0) yarn for sample C3

Figure 8. Changes in K in relation to the yarn length in a loop (l0) for sample C4
Tightness factor variations

Tightness factor represents a measure of the knitwear density and it can be calculated by the following equation [1]:

\[
\text{Tightness factor} (TF) = \frac{\sqrt{\text{tex}}}{l}, \ (\text{tex}^{12} \text{cm}^{-4})
\]
or it can be represented as:[1]:

Structural tightness factor (STF) = TS · KS (tex^{12} cm^{-4})

where: TF – Tightness factor, tex; l - yarn’s length in a loop, cm.

Table 3. Values of the tightness factor for the measured samples

| Sample | D | W | F | C | D | W | F | C |
|--------|---|---|---|---|---|---|---|---|
| C1     | 14.93 | 15.14 | 15.92 | 16.20 | 381.97 | 299.05 | 341.77 | 329.72 |
| C2     | 14.78 | 14.98 | 15.34 | 16.14 | 364.38 | 379.10 | 406.47 | 397.31 |
| C3     | 14.42 | 14.49 | 14.27 | 13.66 | 330.26 | 330.78 | 347.37 | 341.92 |
| C4     | 12.48 | 12.40 | 12.57 | 12.53 | 330.49 | 380.62 | 378.30 | 396.72 |

Table 3 shows that the value of the TF decreases from full, through wet to dry relaxation. It shows that thicker knitwear provides a greater value of TF comparing with the knitwear made of the thinner yarn.

Mathematical model for describing the relation between TF and the value of the yarn's length (l_0) in the knitwear loop

To determine TF dependencies from the length of the yarn in the knitwear loop, a specific mathematical model is introduced. In order to represent the method of non-linear regression, a polynomial model is used.

For a given set of data pairs \((x_i, y_i), (x_2, y_2), ..., (x_n, y_n)\) the following relation should be found, \(y = a_0 + a_1x + ... + a_mx^m\), whereby \(m \leq n-2\), so experimental data can be best represented.

The results of the experimental research have been approximated by a non-linear model fitting data which has a form of polynomial of degree 4:

\[
TF = a_0 + a_1l_0 + a_2l_0^2 + a_3l_0^3 + a_4l_0^4 \quad .................(5)
\]

where \(a_0, a_1, a_2, a_3, a_4\) are constants, \(l_0\) independent variable i.e. the length of the yarn in the loop twists. As \(l_0\) in knitwear changes depending on relaxation, the TF value changes according to the previous formula. Table 4 gives an overview of calculated coefficients of the empirical formula for the TF value changes depending on the length of the yarn in the loop.

Table 4. Overview of calculated coefficients of the empirical formula for TF changes depending on the \(l_0\)

| Sample | \(a_0\) | \(a_1\) | \(a_2\) | \(a_3\) | \(a_4\) |
|--------|--------|--------|--------|--------|--------|
| C1     | 81.92  | -570.21 | 2011.48 | -3538.55 | 2533.35 |
| C2     | 71.49  | -482.65 | 1654.8  | -2833.57 | 1940.8  |
| C3     | 65.91  | -451.05 | 1338.51 | -2625.48 | 1792.16 |
| C4     | 67.61  | -498.7  | 1849.46 | -3437.64 | 2555.89 |

Conclusion

This paper analyzes the impact of linear density of the yarn for raw cotton 1x1 RIB knitwear, made on the same circular knitting machines by using the FAST method. The results obtained show that the most stable knitwear is made of 100% cotton with the yarn fineness 19 tex. The values of the tightness factor in the dry relaxation stood at 14.93, in wet 15.14, in total 16.32 and 16.20 under air conditioned conditions. The knitwear with the highest values of dimensional instability is raw knitwear made of 100% CO, and the yarn with the linear density of 13 tex. The values of the tightness factor in the dry relaxation stood at 16.20, in wet 15.14 , in total 12.66 and 12.53 under air conditioned conditions.

Also, the impact of the length of the yarn in the loop on the dimensional stability of the knitwear during dry, wet and complete relaxation, and relaxed samples in the conditioning chambers after the treatments were analyzed in the paper. It was noted that the differences in the length of the yarn in the loop linearly related to the length of the yarn in the loop at different stages of relaxation.

It can be also concluded that values \(K_c\) and \(K_w\) increase in the knitwear which is made of the thinner yarn. \(K_r\) decreases with the increase of relaxation which means that the loop reaches its stable state and it has a minimal ability to change the shape. \(K_s\) factor rises significantly with the increase of relaxation and with the increase of the TF.

In complete relaxation, all samples recorded the largest dimensional change and for sample C1 the shrinkage on vertical is 12.91, and on horizontal 3.94%, while \(K_r\) is in dry relaxation 1.55±0.0222, in wet relaxation 1.51±0.0168, and in full relaxation 1.53±0.0170. The amount of \(K_s\) factor in dry relaxation is 25.58±0.3658, in wet 26.54±0.2949, in full 27.98±0.3108. The most instable knitwear is sample C4 and here the vertical shrinkage is in the amount of 14.21%, horizontal shrinkage is 5.97% , while \(K_r\) in dry relaxation is 1.86±0.0054, in wet 2.16±0.0137, in full 2.08±0.0132, \(K_s\) factor in dry relaxation is 25.20±0.0735, in wet 30.69±0.1945 and in full 30.08±0.1907.
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Izvod

ANALIZA DIMENZIJSKE STABILNOSTI 1X1 REBRASTIH PAMUČNIH PLETENINA

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U radu je analiziran uticaj finoće pređe na dimenzijsku stabilnost 1x1 rebrastih pletenina izrađenih na istokružnoj mašini za pletenje. Upotrebili su sirovih pletenina izrađenih od 100% pamučne pređe različitih finoća i to 19, 17, 15 i 13 texa. Analiza je sprovedena metodom FAST 4. Dobijeni rezultati pokazuju da su najstabilnije pletenine izrađene od pređe finoće 19 tex-a. Vrednosti pokrivnog faktora u svom relaksaciji iznosile su 14,93, u mokroj 15,14, u potpunoj 16,32 i u klimatizovanim uslovima 16,20. Pletenine sa najvećim stepenom dimenzijske nesabilnosti su sirove pletenine od 100% pamuka, izrađene od pređe finoće 13 tex-a. Vrednosti pokrivnog faktora u svom relaksaciji iznosile su 16,20, u mokroj 15,14, u potpunoj 12,66 i u klimatizovanim uslovima 12,53.