RIB KNITTED FABRICS WITH TUCK STITCHES: STRUCTURE AND PROPERTIES

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Abstract: *Knitted fabrics with tuck stitches are widely used in the manufacturing of knitwear, hats, scarves, etc. due to the variety of patterned effects that can be obtained. It should be noted that the structure and properties of the knitted fabric will depend on the number of tuck stitches in the structure. The goal of this work is to develop a few types of knitted fabrics with different content of tuck stitches and to analyze the effect of tuck stitches on the structural characteristics and deformation properties of the fabric. Two sets of fabrics were produced on a 10-gauge flat-bed knitting machine from 32x2 tex half wool yarn. They are differed by basic interlooping and the number of tuck stitches in the repeat. Dependencies of the structural parameters as well as deformation properties on the number of tuck stitches in the interlooping repeat were set up. They should be taking into account when designing new products from these and similar fabrics.*

Keywords: *rib knitted fabric, tuck stitch, deformation component, full deformation, shrinkage, structure.*

1 INTRODUCTION

Today, the problem of expanding the knitwear range [1] is a topical issue for the vast majority of knitting companies [2]. This problem can be solved in several ways [3]: first, by improving the knitwear design solutions; secondly, to make fuller use of the existing technological potential of knitting machines [4]. Modern knitting equipment allows to create a wide range of interlooping and gets a variety of pattern effects, and electronic needle selection systems contribute to an almost unlimited increase in the pattern repeat size, both in height and width.

According to the variety of patterned effects that can be obtained: lace [4], embossed [6], racked [7], tinted; tuck stitch is occupied one of the first places. Tuck stitches offer many decorative possibilities; they can be used to produce openwork effects, make surface texture effects and improve ladder resistance [7]. Tuck stitches are stitches in which certain loops are drawn through the loops of a previous course and through open loops [9]. Scilicet a tuck stitch is composed of two elements held loop and tuck loop [10]. These loops differ by size and yarn configuration [11]. The tuck stitch may have few tuck loops [4]. Successive tucks on the same needle are placed on top of each other at the back of the head of the held loop and each, in turn, assumes a straighter and more horizontal appearance. Under normal conditions, up to four successive tucks can be accumulated before tension causes yarn rupture or needle damage [4, 10]. The limit is affected by machine design, gauge, yarn count and elasticity, yarn tension and take down tension. From the other side, tucking may occur few adjacent needles [12]. The head of the tuck loop will float freely across these adjacent needles. Dependent upon structural fineness, tucking over six adjacent needles is usually the maximum unit [10].

The uniqueness of the loops` structure of the tuck knit is significantly reflected in the shape, size and disposition of both elements of the tuck stitches as well as conventional loops. So, there are four types of loops in the half cardigan structure (Figure 1): held loop 1 and tuck loop 4 usually at the front side; conventional loops 2 and 3 at the backside [13]. Loop 2 is tightened due to dragging the yarn into held loop 1. Loop 3 has got round shape due to the redistribution of the yarn from the tuck loop 4 and due to the elastic properties of the threads themselves [9].

The properties of knitted fabric are mostly determined by the properties of the basic interlooping (plain, rib or interlock) at the same time changing them. Thus, a single fabric with tuck stitches has a greater thickness, weight [14] and porosity compared to a single jersey [15]. When the tuck stitches give the miss stitch effect in fabric, the weight ant thickness is lower than expected [16]. From the investigation single jersey fabric with tuck loop incorporated with knit loop in wales direction [17] it was found that with the increase of tuck loop percentage in wales direction fabric width and areal density increases. But increasing number of tuck loop does not show any linear relationship with shrinkage and spirality. The fabrics such as lacoste structure having more pores and larger pores show the higher resistance against pilling. Tendency to generate lesser pills will enhance aesthetic property of tuck fabric. Visual investigation shows that tuck stitch was the most beautiful and decorative stitch [15]. The knitted fabric with tuck stitches is less stretchable and has better shape retention than the basic structure. The stretch property walewise is limited due to held loops at the same time the stretch property coursewise is limited due to tuck loops oriented in the stretching direction. Generally, with an increase in the number of tuck stitches the width of the fabric grows and the slackness of the structure increases [18].

In another study [19], the effect of tuck loop on fabric width in grey and finished state, shrinkage, spirality and areal density were investigated when yarn count, stitch length, machine gauge, machine diameter, dyeing and finishing procedures were same. From the investigation it was found that with the increase of tuck loop percentage in wales direction fabric width and areal density increases. But increasing number of tuck loop does not show any linear relationship with shrinkage and spirality.

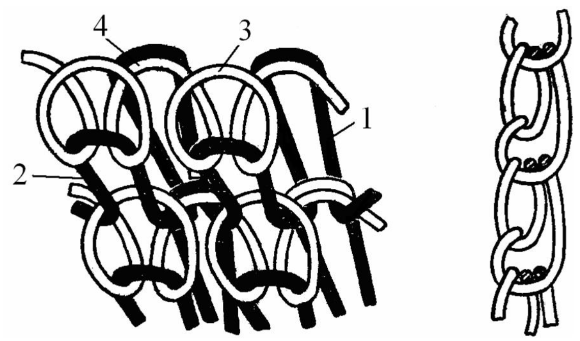


Figure 1 Half cardigan structure

With regard to rib knitted fabric, such common interlooping as a full cardigan and half cardigan are the objects of the vast majority of studies [11-13, 20]. All loops at one or both sides of such fabrics are tuck stitches. It was established that the elongation of half-cardigan is the greatest in wale direction and the elongation of full-cardigan is the greatest in course direction [12]. As a result of the study effects of knit structure on the properties of winter outerwear [20], it was established that the tuck stitch fabrics have the lowest resistance to abrasion. The full cardigan fabric has the lowest resistance to pilling. Half cardigan fabrics have weaker bursting strength performance. At the same time, they are the most permeable to air.

In the other study [21], it was found that the tuck stitches within the structure of composite reinforcement did not have a contributive effect on the tensile and compressive behaviors. But as the tensile and compressive strength values in course and wale directions were much closer to each other for the full cardigan derivative composites than the 1+1 rib composites, the full cardigan derivative composites can still be preferred. The authors conclude that different weft knitted structures which are composed of tuck stitches should be studied. There is also information on the effect of the tuck index on the properties of rib 1+1 knitted fabric [22]. It was concluded that the width, thickness and air permeability successively increase with increasing of tucking course and the length gradually decreases. For drape property, single needle tuck stitch with three tucking courses is biggest and its change presents parabolic curve. In the study [23], the influence of the number of tuck loops in the repeat of the combined interlooping formed by alternation of rib 1+1 and half-cardigan courses in different ratios on the fabric properties was investigated. The increasing the number of tuck stitches in the repeat leads to an increase in the thickness and, accordingly, the surface density. The values for half cardigan are 25% higher than for rib 1+1.The increasing the number of tuck loops in the repeat leads, as well, to a decrease in the difference in the stretchability in different directions. The full deformation of half cardigan is almost the same both course-wise and walewise and it is 140 ÷ 150%.

Therefore, there is a lack of information on the effect of tuck stitches on the properties of rib knitted fabric, when the tuck loops are not formed on each needle of the needle bar. The purpose of this work is to study the rib knitted fabrics with tuck stitches according to repeat and to establish the effect of the tuck stitch number on the properties of developed knitted fabrics.

2 MATERIALS AND METHODS

Rib knitted fabric with tuck loops formed according to the repeat on the needles of one needle bed is the object of this study. All knitted fabrics are manufactured on a 10-gauge flat-bed knitting machine from 32x2 tex half wool (50% wool and 50% polyacrylonitrile fibers) yarn. The tuck stitch is formed by standard method for weft knitting: by holding the old loop and then accumulating new loop in the needle hook. New loop becomes a tuck loop as it and the held loop are knocked-over together at later knitting cycle [10].

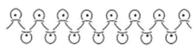
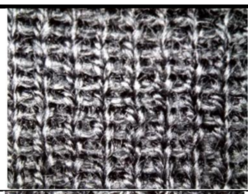
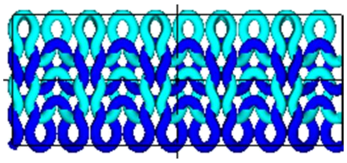
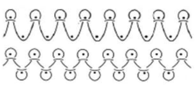
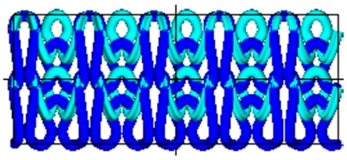
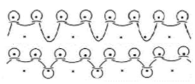
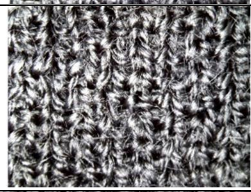
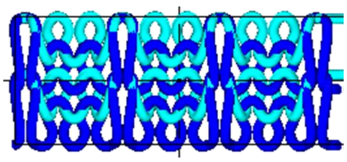
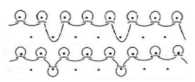
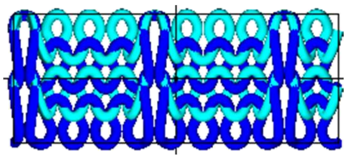
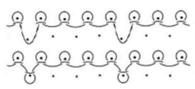
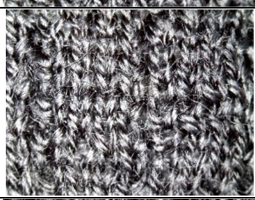
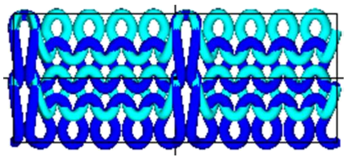
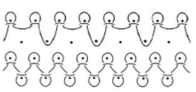
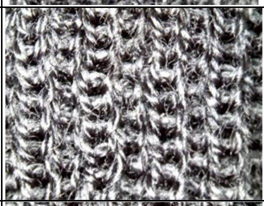
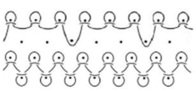
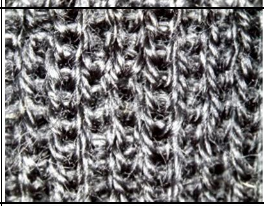
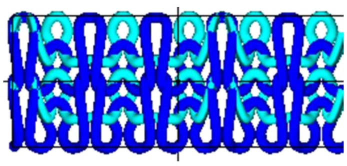
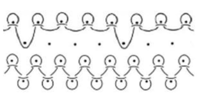
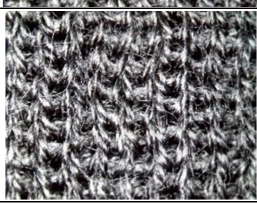
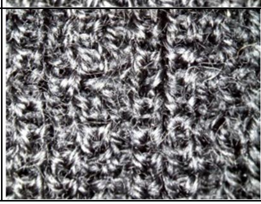
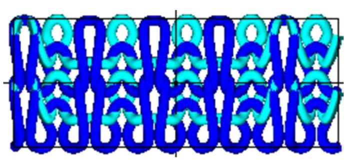
In order to study the effects of the pattern and of the number of tuck loops on the structure and the properties of knitted fabrics two sets of samples were produced. They differ in the repeat of tuck and regular loops alternation as well as in the order of needles work in different systems (Table 1):

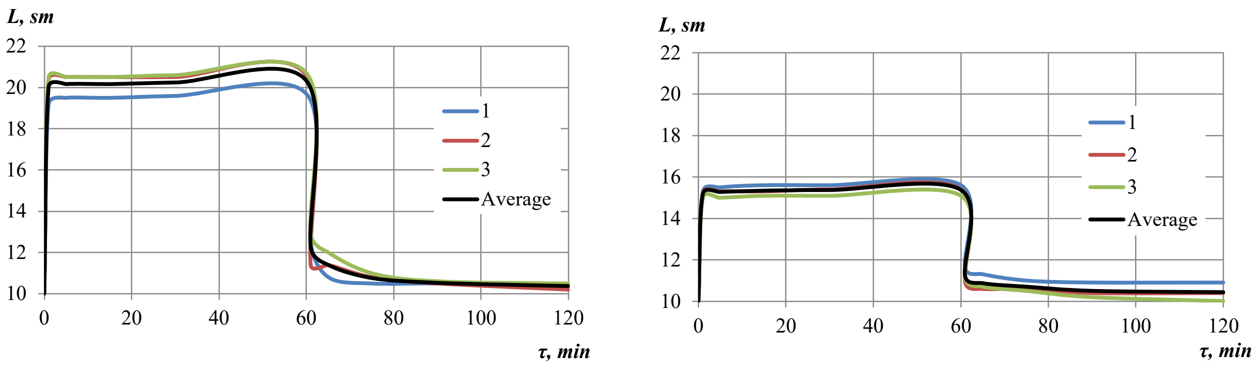
- the first set of samples (1.1 ÷ 1.3) – tuck stitches on the single rib (2/1, 3/1 and 4/1);

– the second set of samples (2.1 ÷ 2.3) - alternation of rib 1+1 course and course with tuck loops formed according to repeat;

– rib 1+1 and a half cardigan as basic structures for comparison.

Table 1 Developed knitted fabrics with tuck stitches

Variant		Grafical	Sample photo front	Sample photo back	Structure
Rib 1+1	R				
Half cardigan	HfC				
tuck stitches on the incomplete rib	1.1				
	1.2				
	1.3				
alternation of rib 1+1 course and course with tuck loops	2.1				
	2.2				
	2.3				



a) coursewise b) walewise

Figure 2 Specimen`s length during the study on the relaxometer for variant 1.1.

For the manufacture of the first set, the needles of the front bed are taken out of action according to repeat. So, there are plain areas on the fabric surface, which changes the properties of the rib structure. This part is the subject to curl with an increase in the number of adjacent plain loops. The tuck loop is formed on the rib of structure. The tuck stitches form straight wales and create relief at the front side of the fabric. On the fabric back side, wales connected with rib on the front side are curved due to uneven redistribution of yarn on both sides of the loop. There are one or more straight wales between curved ones with increases the number of adjacent plain loops. This difference creates a tint effect on the fabric.

For the manufacture of the second set of fabrics, needles work in the following order: all needles form loops at the first feeder; all needles of one bed form loops and certain needles of other bed form tuck loops at the second feeder. The wales on the front side are straight and formed by held loops some of them with tuck loops. There is a slight tint effect due to the different perceptions of tuck stitches and float stitches. The wales on the back side are formed by tightened loops and round or regular loops that reflected in the surface irregularity.

The percentage of needles of the front needle bed which formed tuck loops (TS) was chosen as an input factor of the experiment.

All knitted fabrics after knitting before the study are brought to a conditionally balanced state by washing and ironing according to ISO 6330:2013 [24]. Shrinkage during washing and ironing was determined according to ISO 3759-2007 [25] and ISO 5077-2007 [26].

Studies of the structural parameters of the fabrics were conducted according to standard methods:

- stitch density is according to BS EN 14971: 2006 [23]
- the loop length is according to BS EN 14970: 2006 [24],
- mass per square meter is according to ISO 3801: 1977 [25],
- thickness is according to ISO 5084: 1997 [26].

Ten parallel measurements were carried out for each fabric variant. Taking into account the relief effect of knitted fabrics of the first set, the study of thickness was carried out with a double number of measurements. The average values are used for the analysis.

The deformation of the knitted fabrics was investigated on a relaxometer both coursewise and walewise. The test on the cycle "load-unload-rest" was carried out according to ASTM D2594-20 [31] at 6 N load. The time of loading and rest was 60 minutes each. 3 specimens for each fabric variant were tested; the results show high convergence (Figure 2).

3 RESULTS AND DISCUSSION

3.1 Fabrics shrinkage

As a result of shrinkage investigation (Figure 3), it was found that the width of all studied fabrics variants increases after washing, drying and ironing. In general, the value ranges from 5 to 10% and is primarily related to the production conditions on the knitting machine. The draw-off force is directed walewise and therefore the loops are extended in length and reduced in width. The shape of the loop and its dimensions changes as a result of relaxation processes during wet-heat treatments. The value is more evident for the first set of fabric. An increasing the distance between adjacent plain and rib wales in rib knitted fabric by reducing the telescopic approach between adjacent loops is another reason for the fabric's width increase. The value is more evident for the first set of fabric because of eliminating curl areas of plain in single ribs. Shrinkage coursewise is observed only for the second set of knitted fabric. Length reduction is from -5 to -10% as a result of held loop reshaping.

It should be noted that the size changes of knitted fabrics occur generally during the first wash, and after that they are stable. This fact must be taken into account when developing technological modes of wet-heat treatment of semi-finished products in order to ensure high-quality knitted clothes.

3.2 Structural parameters

The study results of the structural parameters (stitch density, the loop length, the thickness and mass per area unit) of the developed knitted fabrics with tuck stitches are summarized in Table 2.

The loop length is the main structural parameter that determines the density and properties of knitted fabrics. Studies results have shown some difference between the loop length at the first feeder, which forms only loops, and the loop length at the second feeder, which forms both loops and tucks. This difference is not too significant (up to 6%), so the analysis is performed on the average value of the indicator (Table 2). The experimental data shows that neither the interlooping nor its repeat affects the loop length which is on mean equal to 5.85±0.19 mm. All fabrics are produced from the same yarn on the same knitting machine with the same technological parameters (yarn tension, sinking depth, draw-off force). Therefore, the further analysis of experimental data is expedient to think about the influence of the number of tuck stitches (not loop length) on the investigated properties of knitted fabrics.

The study result shows that the tuck stitches significantly affect the stitch density of the knitted fabrics. The height of the tuck stitch is usually two times more than the height of a regular loop (Figure 1). The tuck stitches are positioned at the front side of the studied knitted fabrics that leads to a difference in the number of courses on both sides of the fabric (Table 2). The number of courses per 100 mm of half cardigan is 15% less on the front side and 75% more on the backside compared to the rib 1+1 knitted fabric. It was found (Figure 4) that the number of courses per 100 mm decreases with decreasing number of tuck loops in interlooping repeat in both sets of knitted fabrics.

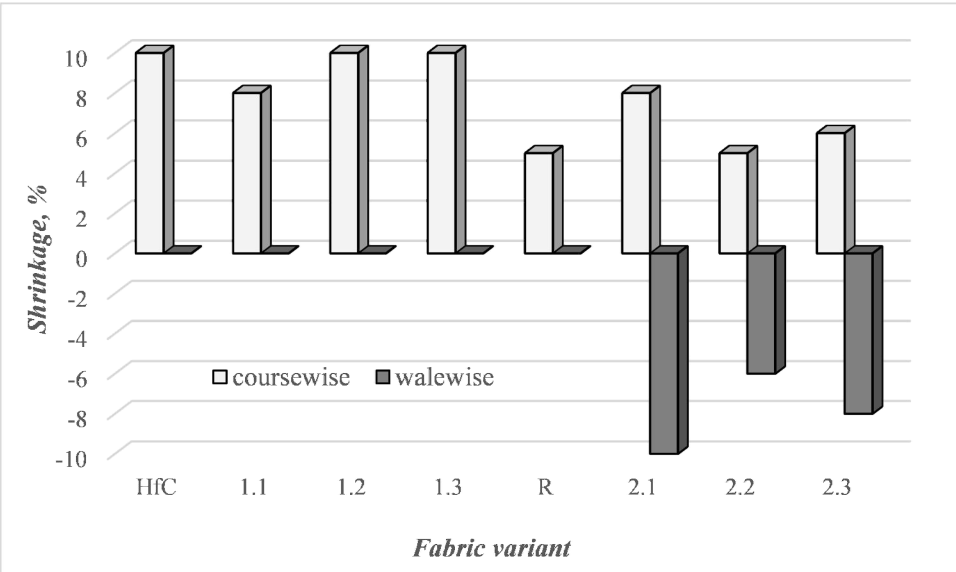
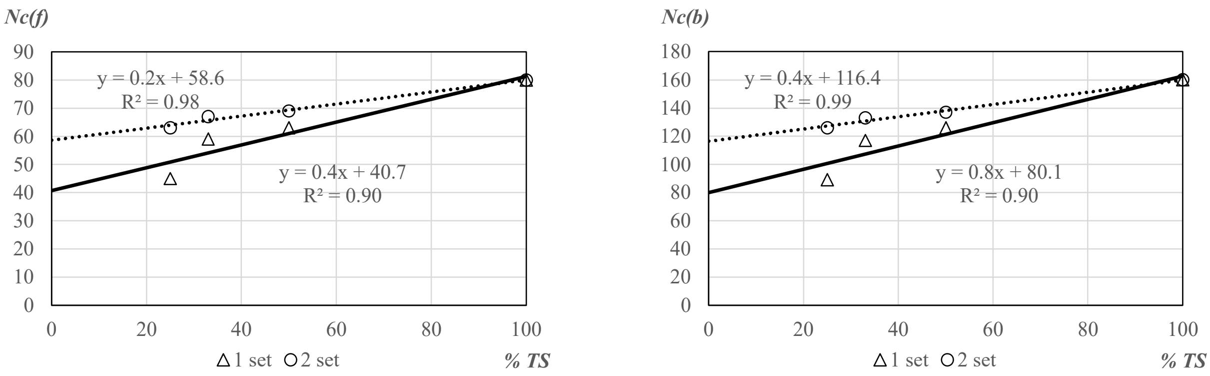


Figure 3 Shrinkage of knitted fabric

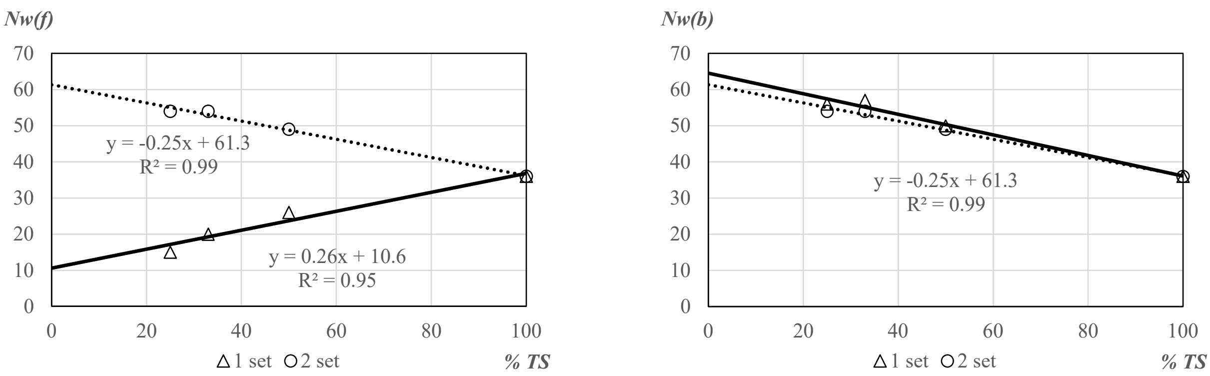
Table 2 Structural parameters of knitted fabrics

Variant	TS [%]	Thickness [mm]	Stitch density				Mass per square meter [gr/m^2]	Loop length [mm]
			Wales per 100 mm		Courses per 100 mm			
			front	back	front	back		
R	0	1.27±0.11	53±2	53±2	92±2	92±2	348.7±12.2	5.82±0.21
HfC	100	1.77±0.18	36±1	36±1	80±2	159±4	473.1±20.8	5.78±0.14
1.1	50	1.23±0.20	26±2	50±2	63±2	126±3	352.4±24.3	5.89±0.12
1.2	33	1.10±0.13	20±0	57±1	59±2	117±3	329.9± 8.4	5.80±0.14
1.3	25	0.94±0.10	15±1	56±1	45±2	89±3	270.8±23.3	6.00±0.16
2.1	50	1.72±0.15	49±1	49±1	69±2	137±3	466.2±22.1	5.84±0.10
2.2	33	1.75±0.07	54±1	54±1	67±2	133±4	481.5± 6.9	5.88±0.08
2.3	25	1.58±0.15	54±1	54±1	63±2	126±5	446.9±16.1	5.90±0.07



a) front side b) back side

Figure 4 Number of courses per 100 mm



a) front side b) back side

Figure 5 Number of wales per 100 mm

It is well known that the tuck stitch is wider than a regular loop due to straightening up the yarn of tuck loop. It leads to a reduction in the number of wales per 100 mm. The conducted research has confirmed this state: the density of half cardigan is third less than rib 1+1 knitted fabric (Table 2). Accordingly, the value is growing with reducing the number of tuck stitches (Figure 5). It is necessary to emphasize that tendency is opposite for the front side of the first set of fabric (Figure 5a): the wales number per 100 mm increases with an increase in the number of tuck stitches in the interlooping repeat. This is due to the fact that fabric produced with complete taking out of action the needles according to repeating in front bed.

The fabric thickness is mostly determined by the disposition of different loops in the structure as well as skeletons and junctures of the same loops. The results of the study (Table 2) showed that the half cardigan is almost 40% thicker than rib 1+1 fabric. It is due to a change in the shape of the backside loop that connected to the tuck loop. This loop has got rounded shape and curved into the fabric thickness. It should be noted that the number of tuck loops in repeat does not affect fabric thickness for the second set (Figure 6).

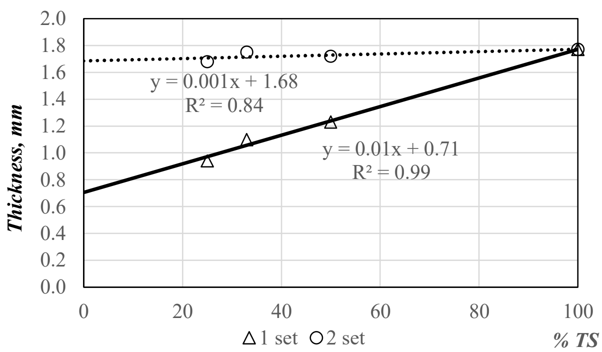


Figure 6 Thickness of knitted fabric

Therefore, it can be stated that tuck stitches in the rib 1+1 knitted structure significantly affect its thickness, regardless of their number in repeat. There is a directly proportional relationship between the number of tuck stitches in the interlooping repeat and fabric thickness for the first set (Figure 6).

But it is the result of different thicknesses of plain and rib structure mostly. Therefore, with a decrease in the number of tuck stitches increases the thinner plain areas which, in turn, reduces the fabric thickness.

The mass of the fabric is an indicator of both raw material consumption and, indirectly, the heat-protective properties of the knitted fabric. The mass per square meter of the half cardigan is almost 25% higher than the mass per square meter of rib 1+1 knitted fabric (Table 2) due to the presence of a tuck loop behind the held loop and greater thickness of the fabric. The influence of the interlooping repeat on the mass value for the first set of fabric is obvious (Figure 7). As for the thickness, it is a consequence of taking out of action the needles according to repeat and the formation of plain surfaces of different widths. The effect of the number of tuck stitches on the mass per square meter is less significant for the second set of fabric. Value is mainly related to the difference between the length of the tuck loop and the float loop behind held loops.

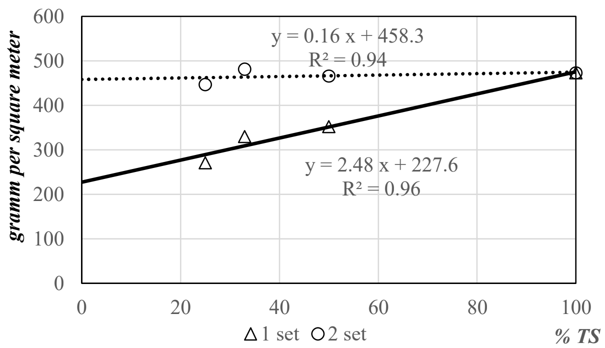


Figure 7 Mass per square meter

3.3 Stretch properties

The widespread use of knitted fabric is due primarily to its high extensibility and elasticity compared to weaving fabric. That is why it is important to test the stretchability of knitted fabric before recommending it for usage in a certain product. Full deformation and its components are preferred single-cycle characteristics [32]. The results of processing the experimental data (Table 3) show that the stretch property of developed knitted fabrics along the courses exceeds its stretch property along the wales. The full deformation of half cardigan along the courses is 40% less, and along the wales is almost 60% higher than the corresponding indicators of the rib 1+1 fabric. This difference is conditioned by the type and the shape of the loops. The stretchability of rib 1+1 fabric coursewise is increased due to the telescopic approach between the front and back loops, and at the same time, the tuck loops limit stretchability in this direction. The rods of loops skeletons oriented along the stretching create the main resistance to stretching in the wales direction. At the same time, the tuck stitch is a complex of loops of different shapes and sizes, which increases the stretchability of fabric.

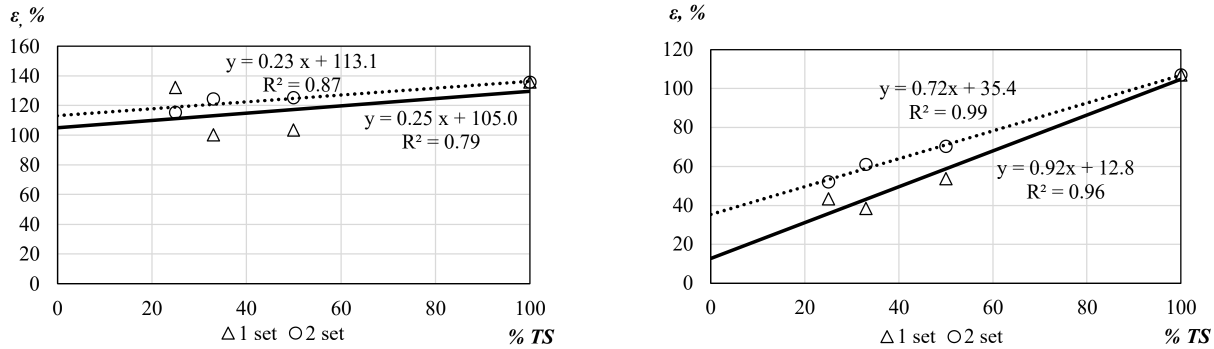
Both the interlooping type and the number of tuck stitches affect the full deformation of knitted fabrics. Thus within the experiment, the full deformation of the fabrics when stretching coursewise (Figure 8a) increases by 15-30% with an increase in the number of tuck loops, while the effect of the basic weave is negligible. The difference in the performance of the fabrics of both sets is in the 10-20% range. At the same time, the full deformation of the fabrics when stretching walewise maintaining the tendency to increase is more significant (Figure 8.b): the full deformation increases by 60%.

The elastic component is the main part of full deformation. All tendencies that revealed for full deformation remain: increase in the number of tuck loops leads to growth of an elastic component both at stretching coursewise and walewise. The tendency is more expressed at stretching walewise; indicators are higher for second set of fabrics (variants 2.1-2.3).

The residual component of the full deformation is an indicator of the stability of the knitwear. It depends primarily on the basic interlooping (Figure 9). Attention should be paid to the high value of residual deformation for the second set of fabric (variants 2.1-2.3). It is primarily due to the irreversible yarns redistribution between the different loops in the structure. The residual deformation for the first set of fabrics (variants 1.1-1.3) is much smaller. It increases with increasing number of tuck stitches.

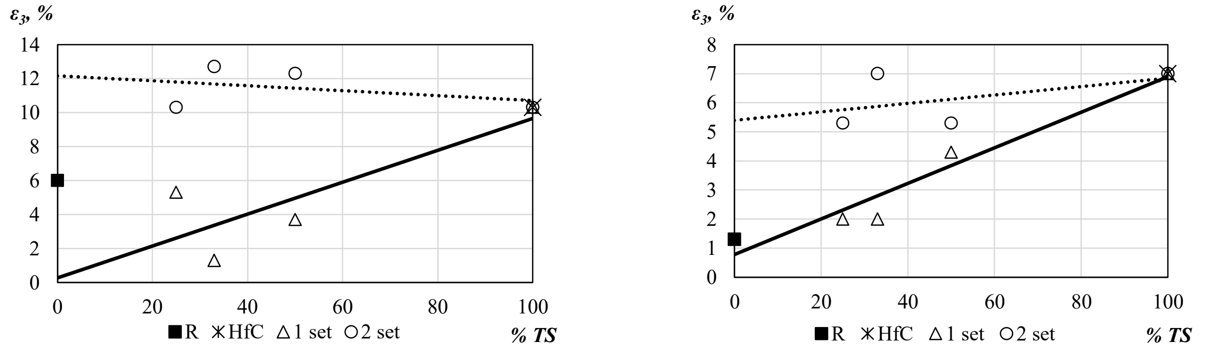
Table 3 Deformation characteristics of knitted fabrics with tuck stitches

Variant	TS [%]	Deformation in direction of courses [%]				Deformation in direction of wales [%]			
		Full, ε	Elastic, $ε_1$	Plastic, $ε_2$	Residual, $ε_3$	Full, ε	Elastic, $ε_1$	Plastic, $ε_2$	Residual, $ε_3$
R	0	176.6	151.6	19.0	6.0	47.0	38.0	7.7	1.3
HfC	100	135.7	100.4	25.0	10.3	107.0	85.7	14.3	7.0
1.1	50	103.4	80.7	19.0	3.7	53.7	41.7	7.7	4.3
1.2	33	100.3	88.3	10.7	1.3	38.4	30.7	5.7	2.0
1.3	25	132.0	107.4	19.3	5.3	43.4	33.7	7.7	2.0
2.1	50	125.3	96.3	16.7	12.3	70.3	56.0	9.0	5.3
2.2	33	124.4	89.7	22.0	12.7	61.0	42.7	11.3	7.0
2.3	25	115.3	93.0	12.0	10.3	52.0	38.4	8.3	5.3



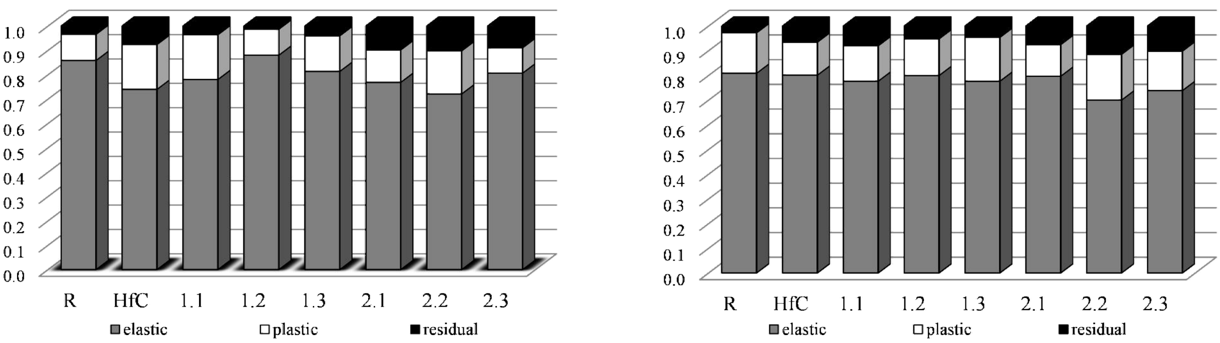
a) coursewise b) walewise

Figure 8 Effect of tuck stitches on full deformation



a) coursewise b) walewise

Figure 9 Effect of tuck stitches on residual deformation



a) coursewise b) walewise

Figure 10 The components contribution in full deformation during stretching

The components' contributions in full deformation are important indicators of the quality of textile materials along with their actual values (Figure 10). It is obvious that the elastic component is a significant part and the residual component is the smallest part of the full deformation.

The study results show that when stretched walewise (Figure 10b), the elastic contribution is 0.8 and does not depend on the knitted fabric variant. The contribution of residual deformation does not exceed 0.1. At the same time, when stretching coursewise (Figure 10a), the effect of the number of tuck stitches on the elastic contribution is observed. The value decreases with an increasing number of tuck stitches. It is 0.86 for the rib 1+1 and 0.74 for the half cardigan fabric. It should be noted that the residual contribution for rib 1+1 and the first set of fabrics (1.1.-1.3) does not exceed 0.04. The residual contribution for the half cardigan and for the second set of fabrics (2.1-2.3) reaches 0.1.

4 CONCLUSION

The investigation of tuck knitted fabric, made on the basis of the single rib of different repeats and on the basis of the rib 1+1 with a different number of tucks in the repeat allowed us to conclude the following:

- The number of tuck stitches in the interlooping repeat is significantly affecting the structural parameters as well as deformation properties of the knitted fabric.
- The number of courses per 100 mm, the thickness and mass per unit areas of the fabric increases, and the number of wales per 100 mm decreases with the increasing number of tuck loops.
- The full tensile deformation walewise is much smaller than coursewise. The increase in the number of tuck stitches in the repeat leads to a value increase. The tendency is greater extent when stretching walewise.
- The elastic component is a significant part of the full deformation. its value is 0.8 when stretching walewise. The value decreases from 0.86 for rib 1+1 to 0.74 for the half-cardigan with increasing the number of tuck stitches in the repeat when stretching coursewise.
- The residual deformation reaches 10-12% for the second set of knitted fabric when stretched coursewise. The residual deformation does not exceed 7% when fabrics stretched walewise. It is 0.1 of full deformation. This must be taken into account when designing clothes from such fabrics.

Developed knitted fabrics are recommended for demi-season outerwear clothing.

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