INFLUENCE OF YARN STRUCTURE ON COMPRESSION BEHAVIOUR OF PLAIN KNITTED FABRICS

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ABSTRACT: *The compression behaviour of textile fabrics is influenced by their structure, fibre properties, and the compressibility and surface properties of yarn. Due to the limited research on how yarn twist affects the compression properties of textile fabrics, this study examined the influence of yarn twist on the compression behaviour of plain knitted fabrics. Three plain knitted fabrics were produced from cotton yarns differing in twist intensity. The knitted fabrics were subjected to successive compression-release cycles. The compression-release curves of plain knitted fabrics were analysed, allowing for the calculation of specific compression parameters, including recoverable and irrecoverable compression. Using these parameters, the non-elastic deformation components were calculated. The results indicated that varying the yarn twists, which directly influence the packing density and fibre mobility in yarns, as well as the fabric structure, allows for the adequate design of the compression behaviour of plain knitted fabrics.*

Keywords: *compressibility, yarn, twist, knitted fabric, deformation components.*

UTICAJ STRUKTURE PREĐE NA KOMPRESIONO PONAŠANJE GLATKIH PLETENINA

APSTRAKT: *Kompresiono ponašanje tekstilnih materijala uslovljeno je njihovom strukturom, svojstvima vlakana, kao i kompresibilnošću i površinskim svojstvima pređe. Usled ograničenog broja istraživanja uticaja upredenosti pređe na kompresiona svojstva tekstilnih materijala, ovo istraživanje je posvećeno upravo ispitivanju efekata upredenosti pređe na kompresiono ponašanje glatkih DL pletenina. U tu svrhu su od tri različito upredene pamučne pređe proizvedene tri glatke pletenine koje su podvrgnute uzastopnim kompresionim ciklusima. Analizirane su dobijene kompresione krive, i izračunati su specifični parametri koji opisuju kompresiju pletenina. Koristeći ove parametre, izračunate su neelastične komponente deformacije pletenina. Rezultati su pokazali da variranje upredenostsi pređe, koje direktno utiče na gustinu pakovanja i pokretljivost vlakana u* *pređi, kao i na strukturu pletenine, omogućava adekvatno projektovanje kompresionih svojstava glatkih DL pletenina.*

Ključne reči: *kompresibilnost, pređa, upredenost, pletenina, komponente deformacije.*

1. INTRODUCTION

The compression behaviour of textile fabrics has long been recognized as one of the most important properties determining fabric suitability for various end-uses. In addition to the ability of a fabric to compress, the recovery from compression, known as compressional resilience, is also of considerable interest. Generally, resilience can be defined as the capability of a material to return to its original form after the removal of a deforming stress. Textile fibre and fabrics are considered as an imperfectly elastic body, since they exhibit hysteresis upon the removal of stress. This hysteresis loss arises from the friction between fibres and the viscoelastic properties of the yarns in the fabric [1]. Therefore, the deformation resulting from fabric compression may be divided into two components: immediately elastic deformation and other delayed deformation, subdivided into recoverable (viscoelastic) and irrecoverable (plastic) deformations [2].

Conventional textile fabrics experience many repeated stresses and removals during their lifetime. Therefore, they should be capable of absorbing energy imparted to them during loading and releasing it upon removal of the previously applied load. The energy-absorption properties of a fabric exposed to compression cycles are a function of its load-thickness characteristics. The interaction of fibre and yarn parameters with the structural properties of the fabric contributes to energy absorption and return during multi-cycling compression. This study investigated the influence of yarn structure on the compression behaviour of knitted fabrics using the concept of energy. Although investigations have shown that changing yarn parameters such as twist, fineness, bulk, finishing treatments, etc., affect the compressional behaviour of textile fabrics, a limited number of such studies are available. Majumdar and Pol have shown that the compressibility of woven fabrics can increase with increased hairiness and decreased packing density of yarn [3]. In the study conducted by Kim and Kim [4], yarn spinning techniques (ring, compact, and air-vortex) influenced the compression behaviour of single jersey knitted fabrics by influencing surface geometry (hairiness) and packing density of yarns, ranging from the least compressible air-vortex, to the most compressible cotton yarn. Parallel bundles in the core of the air-vortex yarn caused slight rigidity under lateral compression. A more regular structure of the compact yarn, with a less hairy surface, made it less compressible than the ring yarn. Zhang et al. produced Siro false twist yarn (SFTY) by introducing two false twisters into the spinning zone. The knitted fabrics made from SFTY and conventional Siro spun yarns were compared in terms of comfort properties, indicating better compressibility and superior softness of the former knit [5]. Banale and Chattopadhyay modified cotton yarns by the de-twisting method, which caused an 8% increase in 23 tex yarn compression rate and about a 5% increase in 15 tex compression rates [6]. This yarn modification has increased the thickness and compressibility of the single jersey knitted fabrics made therefrom. Stankovic and Bizjak indicated that using two-folded yarn can increase the compressibility of the single jersey knitted fabric [7]. Although yarn twist is a fundamental parameter in textile material design, only two studies have examined its impact on the compressibility of these materials. Atalie et al. investigated the influence of weft yarn twist on woven cotton fabrics' mechanical and sensorial comfort, indicating that an increase in yarn twist led to less compressibility of the fabric [8]. Assefa and Govindan investigated the influence of the twist factor of yarn on the sensorial comfort of single jersey knitted fabrics, showing that fabric produced from low-twisted yarn was more compressible and had higher compressional resiliency compared to the fabric from higher-twisted yarn [9]. This shortage of results prompted us to explore how yarn twist affects the compressibility of plain knitted fabrics.

2. MATERIALS AND METHODS

From three 50 tex yarns, which were produced by rotor (open-end, OE) spinning technique, with the same cotton fibre and different twist levels, three plain weft knitted fabrics were produced on a circular knitting machine under the same knitting conditions to obtain identical structure. The structural properties of the yarns and knits are presented in Tab. 1.

Table 1: Structural properties of the cotton yarns and plain knitted fabrics

Sample	Yarn		Knitted fabric (wet relaxed)		
	Factual linear density, tex	Twist, t/m	Stitch density, cm^{-2}	Thickness, mm	Mass, g/m^2
KCo1	48.94	490	82.8	1.248	446.2
KCo2	48.08	590	85.0	1.256	453.0
KCo3	49.06	690	85.5	1.268	458.8

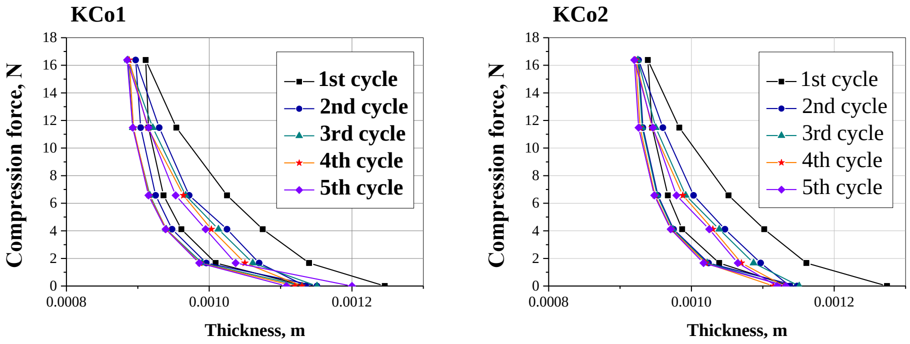
The wet relaxed plain cotton knitted fabrics were subjected to compression-release cycles by using the hand-operating thickness tester (TexTesT-306). The compression test was as follows: a piece of fabric was placed between a specimen table and a circular pressure foot having an area of 64 mm^2. Thickness measurements were made over a pressure range of 0.45-2560 cN/cm^2 with the progressively increased compression force stages: 1.7, 4.1, 6.6, 11.5, and 16.4 N. When the maximum load was reached, the recovery of the sample was conducted at successively decreasing loads. The measurements for every sample were completed in five compression-release cycles without moving the sample. Each knitted fabric was investigated by making three separate tests described on different portions of the knit, so each thickness measurement was the average of these three tests. The sample thickness measured under initial force (0.29 N) was recorded as the original sample thickness without added load. The difference in initial sample thickness (t_0) and its final thickness after the fabric was compressed (t_f) determined the compressibility of the knits for each compression cycle:

$$C(\%) = \frac{t_0 - t_f}{t_0} \times 100 \qquad (1)$$

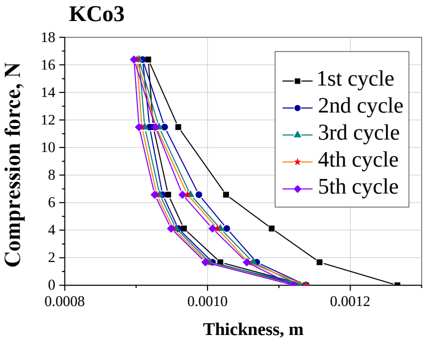
Energy-absorption properties of the knitted fabrics were evaluated from the compression-release curves by calculating the area bellow the compression curve as indication of work done or energy absorbed by the fabric (WC_{tot}), the area bellow the decompression curve indicating the energy released upon removal of the compression load (WC_{el}) and the area occupied by the hysteresis loop as a measure of non-elastic compression work or the energy lost (WC).

3. RESULTS AND DISCUSSION

The registered corresponding changes in thickness with stepwise loading and unloading provided the information necessary for the compression-release curves of the plain cotton knitted fabrics differing in yarn twist. It can be seen from the compression/release curves for five successive cycles, presented in Figure 1, that considerable changes in the fabric thickness are obvious between the first and the second cycle. Furthermore, the second cycle resulted in a hysteresis loop with entirely different characteristics, while the loops approach each other more closely with repeated cycling. What is striking is the fact that the knitted fabrics underwent both elastic and delayed deformation to a great extent during the first compression cycle. As a result of the dynamic inter-fibre friction, the irrecoverable fibre slippage and rearrangement occur to some extent, causing a highly packed fibre assembly to become larger. In a densely packed assembly, only lateral compression of the fibres is possible, resulting in a slight reduction in fabric thickness. With each subsequent compression cycle, the changes in thickness decreased.



a)   b)



c)

Figure 1: Compression-release curves for five successive cycles of KCo1 (a), KCo2 (b) and KCo3 (c) knitted fabrics

The compressibility of the plain cotton knitted fabrics for repeated compression cycles is presented in Table 2. The knitted fabric produced with the highest twisted cotton yarn (Co3) has higher compressibility in relation to KCo1 and KCo2 knits for the first compression cycle. In principle, an increase in yarn twist should lead to a decrease in yarn bulk (increase in packing density) and a consequent reduction in the fabric compressibility, and therefore, the results obtained were unexpected. At least two elements were in opposition here: yarn geometry and fabric structure. Although the plain knitted fabrics were prepared under the same conditions, slight differences were found in the basic structural properties after wet relaxation (Table 1), caused by the different twist levels of the yarns. The increased stitch density of KCo2 and KCo3 knits resulted from the distortion caused by the residual torque in the yarns due to higher twist. An increase in the number of yarn contact points with an increase in stitch density reduces the inter-yarn and inter-fibre mobility, so a reduction of compressibility may be expected. However, the compressibility of KCo3 knit is higher than that of KCo1 knit (Table 2). In our speculation, the explanation is based on an inverse relationship between the yarn flattening (when incorporated into a fabric) and the twist level. The distortion from the circularity of yarn cross-section at interlocking points of knit is smaller for a highly twisted yarn. Therefore, it can be assumed that the lowest- and medium-twisted cotton yarns spent their compression ability by flattening at interlocking points to a higher extent compared to KCo3 knit. The compression forces applied during the compression cycling in this experiment (up to 2560 cN/cm^2) appear sufficient to move fibres in Co3 yarn against their static frictional force, despite their high packing density. The Co2 yarn flattening effect and the structure of KCo2 knit (stitch density) act synergistically, resulting in reduced fibre mobility and knit compressibility compared to the other two knits, during repeated compression cycles (Table 2).

Table 2: Compressibility of the cotton knitted fabrics

Sample no.	C, %				
	1st cycle	2nd cycle	3rd cycle	4th cycle	5th cycle
KCo1	26.9	21.0	23.0	21.4	20.1
KCo2	26.3	18.6	19.4	18.6	17.5
KCo3	27.6	20.3	19.9	20.8	20.5

The shift to the left from the first compression-release curve, as well as the reduction of the hysteresis loop area with repeated cycling (Figure 1), indicate a kind of mechanical conditioning (minimal thickness change). Due to the irrecoverable deformation at the previous compression cycles, the knitted fabrics become less compressible, but the non-elastic deformation also decreases. The energy-absorbing properties of the plain cotton knitted fabrics presented in Table 3 are a quantitative indication of their repeated compression stress performance. Slight differences may be noted in the energy stored up as potential energy (WC_{tot}), as well as the energy restored after recovery part of the cycle (WC_{el}), among the knitted fabrics. Even though KCo2 knit was characterized by the lowest compressibility (Table 2), the highest values of released energy (WC_{el}) in all compression cycles indicated a higher proportion of elastic deformation than other knits (Table 3). A certain amount of variability among knitted fabrics is observed for the energy lost (WC) for repeated cycles, except for the first cycle. With each subsequent cycle, the energy dissipated decreases at varying rates for different samples. As a consequence, after similar dissipated energy (WC) in the first compression cycle, the dissipation of energy in the 4th and 5th cycles was the lowest for KCo2 knit (Table 3).

Table 3: Energy-absorbing properties of the plain cotton knitted fabrics

Property	Sample	1st cycle	2nd cycle	3rd cycle	4th cycle	5th cycle
Energy absorbed $WC_{tot}\times10^{-4}$ J	KCo1	167.08	160.02	158.78	157.73	157.42
	KCo2	171.51	164.46	163.25	162.04	161.40
	KCo3	168.40	161.44	160.09	159.50	158.74
Energy released $WC_{el}\times10^{-4}$ J	KCo1	155.47	153.73	152.14	152.05	151.75
	KCo2	160.05	158.06	157.75	157.19	157.06
	KCo3	156.75	155.52	154.82	154.11	153.57
Energy dissipated $WC\times10^{-4}$ J	KCo1	11.61	6.28	6.64	5.67	5.67
	KCo2	11.46	6.40	5.49	4.85	4.33
	KCo3	11.64	5.93	5.26	5.39	5.17

Since the energy dissipation is governed by delayed deformation (viscoelastic and plastic), the particular procedure, described elsewhere [2, 10], was performed to calculate the percentage of both plastic (D_p) and viscoelastic (D_{ve}) deformation components (Table 4). According to the data given in Table 4, the viscoelastic deformation is higher than the plastic deformation for all knitted fabrics. However, the values of deformation components were almost equal for KCo2 and KCo3 knitted fabrics, whereas the viscoelastic deformation of KCo1 knitted fabric was higher than the other two knits. This can be attributed to the greater fibre mobility in the least twisted cotton yarn and the lowest stitch density of this knit.

Table 4: Compression behaviour of the plain cotton knitted fabrics

Sample no.	WC a), x10^{-4} J (1+2+3+4+5)	WC_p b), x10^{-4} J (1-5)	WC_{ve} c), x10^{-4} J	D_p d), %	D_{ve} e), %
KCo1	35.87	15.33	20.54	42.74	57.26
KCo2	32.53	14.45	18.08	44.42	55.58
KCo3	33.39	14.83	18.56	44.41	55.59

a) The total energy absorbed at repeated cycles, b) the energy lost due to irreversible deformation or the irreversible work of five-cycle compression, c) the energy or the reversible compression work of five-cycle compression, d) the percentage of plastic, and e) the percentage of viscoelastic deformation

The energy-absorbing properties (Table 3) and the calculated percentages of delayed deformation components (Table 4) enabled a determination of the shares of deformation components in the total five-cycle compression. The values presented in Table 5 indicated that the deformation components (elastic, viscoelastic, and plastic) were equally present in all knitted fabrics in the first compression cycle. Starting from the third cycle, the proportion of delayed deformation components (viscoelastic and plastic) in KCo2 and KCo3 knits exhibited a steeper decreasing trend compared to KCo1 knit. With further compression cycling, a reduction in the shares of delayed deformations was most pronounced in KCo2 knit. In addition, the share of the elastic deformation (the compression resilience) was the highest in KCo2 knit after the five-cycle compression. These results indicated better retention ability of KCo2 knit after compression.

Table 5: Shares of deformation components in total compression of the plain cotton knitted fabrics

Cycle no.	KCo1			KCo2			KCo3		
	d_{el} a), (%)	d_{ve} b), (%)	d_p c), (%)	d_{el}, (%)	d_{ve}, (%)	d_p, (%)	d_{el}, (%)	d_{ve}, (%)	d_p, (%)
1st	93.05	3.98	2.97	93.32	3.71	2.97	93.08	3.85	3.07
2nd	96.07	2.25	1.68	96.11	2.16	1.73	96.33	2.04	1.63
3rd	95.82	2.39	1.79	96.63	1.87	1.5	96.71	1.83	1.46
4th	96.4	2.06	1.54	97	1.67	1.33	96.62	1.88	1.5
5th	96.4	2.06	1.54	97.31	1.49	1.2	96.74	1.81	1.45

a) Share of elastic deformation, b) share of viscoelastic deformation, c) share of plastic deformation

3. CONCLUSION

This research presents the compression behaviour of plain knitted fabrics produced from various twisted cotton yarns. Compression of knitted fabrics is the result of a complex interaction of many factors resulting from the geometry of the yarn and the fabric structure. Since both the yarn geometry and fabric structure were designed by twist intensity of yarn, it can be concluded that yarn twist significantly influences the compressibility properties of knitted fabrics. Careful analysis based upon the energy-absorption properties enables the determination of the deformation components at compression of the knitted fabrics. This indicates that, in addition to compressibility, the yarn twist influences the mechanical conditioning of the knitted fabrics during cycled compression.

REFERENCES

[1] Stankovic, S. (2008). Static lateral compression of hemp/filament hybrid yarn knitted fabrics, *Fibers and Polymers*, 9(2), 187-193.

[2] Stankovic, S. (2014). Quantification of deformation response at cyclic compression of polymer fibrous systems, *Materials Letters*, 122, 162-165.

[3] Majumdar, A., Pol, S.B. (2014). Low stress mechanical properties of fabrics woven from bamboo viscose blended yarns, *Fibers and Polymers*, 15(9), 1985-1991.

[4] Kim, H.A., Kim, S.J. (2018). Mechanical properties of micro air vortex yarns and the tactile wear comfort of knitted fabrics, *Fibers and Polymers*, 19(1), 211-218.

[5] Zhang Y., Zheng F., Liu X., et al., (2023). Siro false twist spun yarn structure and the knitted fabric performance, *Textiles Research Journal*, 93(17-18)4096-4104.

[6] Banale, A.K., Chattopadhyay, R., (2015). Effect of yarn twisting and de-twisting on comfort characteristics of fabrics, *Indian Journal of Fibre & Textile Research*, 40, 144-149.

[7] Stankovic, S., Bizjak, M. (2014). Effect of yarn folding on comfort properties of hemp knitted fabrics, *Clothing and Textile Research Journal*, 32 (3), 202-214.

[8] Atalie, D., Ferede, A., Rotich, G.K. (2019). Effect of weft yarn twist level on mechanical and sensorial comfort of 100% woven cotton fabrics, *Fashion and Textiles*, 6(3), 1-12.

[9] Assefa, A., Govindan, N. (2024). Effect of twist factor of yarn on sensorial comfort of single jersey knitted fabrics, *Indian Journal of Fibre & Textile Research*, 49, 63-71.

[10] Stankovic, S., (2008). Compression hysteresis of fibrous systems, *Polymer Engineering and Science*, 48, 676-682.