ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 18, No. 4. 2012

Investigation on Alteration of Compression of Knitted Orthopaedic Supports during Exploitation

Diana ALIŠAUSKIENĖ, Daiva MIKUČIONIENĖ *

Department of Textile Technology, Kaunas University of Technology, Studentų 56, LT-51424 Kaunas, Lithuania

crossref http://dx.doi.org/10.5755/j01.ms.18.4.3097

Received 29 May 2011; accepted 01 December 2011

One of the areas of medical textile is the spacer knitted orthopaedic products. The concept of compression therapy of orthopaedic supports lies on a simple and efficient mechanical principle – it consists of applying elastic garment around the limb. Spacer orthopaedic supports are knitted on flat knitting machines equipped with especial elastomeric thread feeder. Compression made by the support depends on the support area, shape and characteristics of knitting. Because of orthopaedic supports are intended for durable wearing and need to vouchsafe compression of fixed value, it is very important to known how processes acting during exploitation influence alteration of compression values.

The aim of this study was to establish the alteration of compression of knitted support during exploitation, i. e. after multifold extension, washing and drying. The samples were knitted on a flat double needle bed knitting machine in combined jacquard-laid-in pattern with elastomeric weft threads. It was established that compressive properties of knits after cyclic tensile load changed slightly, i. e. range between margins of error. It was measured that knitted orthopaedic supports dimensions and density after washing and drying cycles changes significant, i. e. knitted supports shrinks and thickens and their compression decreases.

Keywords: knitted spacer orthopaedic supports, shrinkage, laundering and drying, compression force.

1. INTRODUCTION

Knitted orthopaedic supports are one type of medical textile product widely used after various knee, elbow and ankle joints traumas. The concept of compression therapy of orthopaedic supports lies on a simple and efficient mechanical principle – it consists of applying elastic garment around the limb.

Knitted orthopaedic supports are divided in three groups: preventive supports, functional supports, and post-operative/rehabilitative supports [1]. Compression supports are available in different degrees of compression. The physician prescribes the compression class corresponding to the pathology of the patient. Light compression class 1 (15 ÷ 21 mmHg) or 2 (23 ÷ 32 mmHg), strong compression is class 3 (34 ÷ 46 mmHg) or 4 (> 49 mmHg) depending on the used norm. Compression class depends on the trauma character and intensity [2].

Medical compressive orthopaedic supports must satisfy the following requirements:

- Correspond with the dimensions of he individual limb;
- To evaluate the biomechanical condition of muscle;
- Ensure a fixed compression (compression force);
- To preserve the geometric shape and compression characteristics during long – term wear;
- To maintain the size and compression characteristics after washing [2].

Many of compression supports are made from knitted stretch fabrics. The elasticity and power provided by these fabrics allow the support to be kept in place [1].

The physical properties of weft knitted fabrics for compressive functional behavior are influenced by different factors – the materials: type of yarn, yarn linear density, type of elastane thread; and the production process: machine and specific parameters of production. Elastic properties of weft knitted fabric are directly related to the type of yarn used and its mechanical properties [3].

J. Cruz and other [3] investigated behavior of weft knitted fabrics produced with different elastomeric materials to be applied in medical and well-being products. Different knitted fabrics produced using seamless knitting machines have been tested for cyclic tensile behavior. The elastic deformation and the permanent deformation of each one has been measured and analyzed. The researchers found that fabrics with polyamide with higher linear density and trilobal cross section, presents the better mechanical behavior but the lowest elasticity. For the same yarn linear density the cross section does not influence the mechanical properties and the elasticity [3].

Laundering is the most usual process for care of textile. The complex of combination of thermal, mechanical, and physical factors influences fabrics during the laundering process. It is known that textile garments change their dimensions during laundering by expanding or shrinkage. The stability properties are very important which depend on fabric structure and final treatment. Fabric shrinkage capacity during laundering also depends on laundering conditions such as water solidity, washing powder, temperature, and mechanical action [4].

Many researchers investigated dimensional properties, dimensional stability of cotton/spandex knitted fabrics under relaxation processes (washing) [5 – 7]. Marmarali [5] found that dimensional and physical properties of cotton and cotton/spandex single jersey fabrics are affected by the amount of spandex in the fabric and the loop length.

Some authors investigated influence of fiber composition on structural properties of knits manufactured

*Corresponding author.Tel.:+370-37-300219, fax: +370-37-353989, E-mail adress: *daiva.mikucioniene@ktu.lt* (D.Mikučionienė)

from cotton, bamboo, soybean yarns and its combination with textured polyamide and elastane threads. They noticed that higher course and wale densities have knits plated with elastane thread under the same machine set stitch lengths (due to yarn relaxation) than knits from pure yarns [8].

Y. Beceren and other investigated dimensional and selected physical properties of a series of plain jersey fabrics made from viscose/spandex siro–spun and carded ring yarns. The researchers found that stitch density increased after the laundering process, irrespective of stitch length, yarn type, etc [9].

Because of orthopaedic supports are intended for durable wearing and need to vouchsafe compression of fixed value, it is very important to know how processes acting during exploitation influence alteration of compression values. De Araujo and other authors have investigated mechanical behavior of weft knitted fabrics for technical applications. It has been established that knitted fabrics with longer floats were distinguished for improved extensibility. Thus, combining the stitches and floats of different length can be obtained the rigid or flexible structure [10].

The aim of this study was to establish the alteration of compression of knitted support during exploitation, i. e. after multifold extension, washing and drying.

2. EXPERIMENTAL

The investigations were carried out with two-layered samples, which were knitted on the flat double needle bed knitting machine "CMS 340TC-L" (f. STOLL, Germany) in combined jacquard-laid-in pattern with elastomeric weft threads. All samples were knitted from polyamide 6.6 (PA) yarns with linear density of 7.6 tex – basic yarn; polyurethane (PU) yarns with linear density of 31 tex covered with PA yarns with linear density of 4.4 tex × 2 – coating yarn; PU threads with linear density of 22.7 tex covered with PA yarns with linear density of 11 tex and viscose spun yarns with linear density of 14.3 tex – laid-in yarn. The initial wale density of knit was 7.5 cm^{-1} and initial course density 6.5 cm^{-1}.

Knitted fabrics were conditioned in standard atmosphere according to the standard ISO 139:2002: relative humidity (65 ±2) % and temperature (20 ±2) °C.

The course and wale density of samples were counted according standard in longitudinal and transverse direction at 10 cm distance and evaluated per cm [11].

Tensile properties of the knits were determined using universal testing machine "Zwick/Z005". Cyclic tensile tests with 10 % fixed extension were executed and the testing parameters used were as follows: distance between clamps – 100 mm; speed – 100 mm/min; initial load – 2 N; number of cycles – 4 tests for 30 cycles.

Washing procedure of knits was carried out in an automatic washing machine. The specimen dimensions were 200 mm × 200 mm. Specimens were washed in four different modes to investigate washing regime duration and intensity influence on compression and shrinkage changes: 1) Quick: washing time – 15 min, water temperature – 30 °C, drilling mode – 400 rpm; 2) Sport: washing time – 39 min, water temperature – 30 °C, drilling mode – 400 rpm; 3) Cottons: washing time – 1 hour, water temperature – 30 °C, drilling mode – 400 rpm; 4) Intensive: washing time – 1 hour 44 min, water temperature – 30 °C, drilling mode – 400 rpm. The samples were dried on a smooth surface for 24 hours. After drying till tensile testing samples were conditioned in standard condition for 24 hours.

Specimens were washed in Quick regime and dried for 5 cycles to investigate the influence of washing cycles on compression and shrinkage changes.

Properties of the knitted fabric such as shrinkage, length, width, course and wale densities were investigated after washing processes. The shrinkage value was defined by equation (ISO26330:1993) [12]:

$$\lambda = \frac{L - L_0}{L_0} \cdot 100\ \%, \qquad (1)$$

where: L_0 is dimension of the sample before washing and drying in mm; L is dimension of the sample after washing and drying in mm.

Compression of a product P can be calculated according to the equation [13]:

$$P = \frac{2 \cdot \pi \cdot F}{S}, \qquad (2)$$

where: F is the limb pressure force in N; S is the product area in m^2.

The product area S depends on the specific product shape and construction. Limb pressure force F depends on the ratio between limb size in the fixation point and the support size. This ratio must be chosen with respect of the desired compression size [13].

Compression made by the support depends on the support area, shape and characteristics of knitting. Measurement of area of spacer knitted support is complicated. In this work authors suggest knitted orthopaedic support area calculate as a function of loop length, wale spacing and course spacing [13]:

$$S_{sk} = N_S \cdot N_E \cdot A \cdot B, \qquad (3)$$

where: N_S is columns number of knitted product; N_E is rows number of knitted product; A is the wale spacing of knitted sample in mm; B is the course spacing of knitted sample in mm.

3. RESULTS AND DISCUSSIONS

3.1. The dependence of shrinkage value on number of washing and drying cycles

Fabrics, which change their dimensions during the finishing process significantly, have more stable dimensions during wearing and washing. Knitted fabrics with instable dimensions have tendency to shrink during washing and drying. Full relaxation and shrinkage is not always attained during first washing cycle, and often several cycles are required before dimensional stability is reached [4]. The specimens were washed in Quick regime for 5 cycles to investigate the influence of number of washing and drying cycles on shrinkage value. The dependencies of investigated fabrics shrinkage on number of washing and drying cycles in longitudinal and transverse directions are presented in Fig. 1 and Fig. 2.

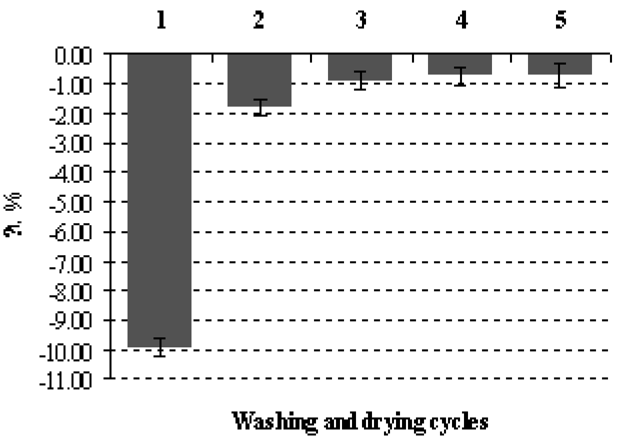

Fig. 1. The dependence of shrinkage λ values in longitudinal direction of knitted fabrics upon the number of washing and drying cycles

The results presented in Fig. 1 demonstrate that after 1st cycle of washing and drying the investigated samples shrunk in longitudinal (wale) direction significant, i. e. shrinkage value in longitudinal direction was approximatelly 10 %. The knitted samples still shrunk slightly after 2nd and 3rd washing and drying cycles (respectively 1.81 % and 0.92 %). After last two cycles shrinkage values in longitudinal direction keep fixed (approximately 0.74 %).

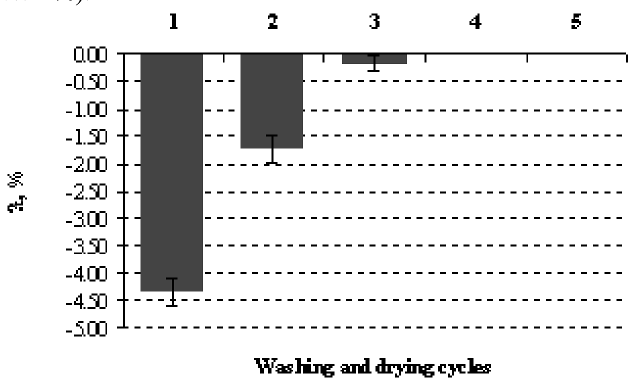

Fig. 2. The dependence of shrinkage λ value in transverse direction of knitted fabrics upon the number of washing and drying cycles

The dependencies of investigated samples shrinkage in transverse direction upon the number of washing and drying cycles are presented in Fig. 2. Figure shows that the greatest changes in transverse direction (as well as in longitudinal direction) are after 1st washing and drying cycle (approximately 4.4 %). The knitted samples still shrunk slightly after 2nd and 3rd washing and drying cycles (shrinkage values were respectively 1.73 % and 0.18 %). Shrinkage values stabilized in transverse direction after last two cycles.

It can be concluded that the greatest changes of dimensions in longitudinal and transverse directions are after 1st washing and drying cycle. The same tendency was found by other researchers [4, 14]. Shrinkage values decreases taper off after repeated washing and drying until dimensional stability is reached.

Stitch densities characteristics of investigated samples before and after 5 washing and drying cycles are presented in Table 1.

Table 1. Stitch densities characteristics of investigated samples before and after 5 washing and drying cycles

Washing and drying cycles	Density of stitches	
	Wale density P_v, cm^{-1}	Course density P_h, cm^{-1}
0	7.5	6.5
1	8.2	6.8
2	8.3	6.8
3	8.4	6.8
4	8.4	6.8
5	8.4	6.8

Note: the relative error of all measurements is less than 5 %.

It was inestigated that after 1st washing and drying cycle wale densities values increased approximately 9.3 % and course densities values – 4.6 %. As was expected, the stitch density increased after washing process (as w ell as in [9]). After 2nd cycle wale densities values increased approximately 1.2 % and course densities remain unchanged. After last three cycles both densities values remain unchanged. It was measured that after first two cycles knit stitches densities values stabilized. The calculated absolute error values of densities didn‘t exceed 1 %.

Compressive orthopaedic supports must be necessary washed after knitting at least one cycle to obtain constant knit dimensions of knitted fabrics.

3.2. The dependence of shrinkage value on washing duration and intensity (washing regime)

The samples were washed in four different regimes to investigate the influence of duration and intensity of washing regime on shrinkage values. The results of investigation are presented in Table 2 and Fig. 3.

Table 2. Shrinkage characteristics of knits after four different washing regimes

Washing regime	Alteration of densities after washing, %		Shrinkage, %	
	Wale density P_v	Course density P_h	In longitudinal direction	In transverse direction
Quick	9.33	4.62	–9.97	–3.36
Sport	13.89	6.25	–11.48	–4.04
Cottons	13.89	6.25	–11.96	–4.04
Intensive	13.98	6.55	–12.98	–4.55

Note: the relative error of all measurements is less than 5 %.

As the cyclic washing showed, significant changes show up after the first washing cycle, therefore investigation of washing duration and intensity influence on shrinkage changes was carried out in one washing cycle.

From the data presented in Table 2 it could be seen that regardless of the selected washing regime, knitted compressive orthopaedics supports after a washing cycle thickens more vertically (almost double), i. e. wale density values increased (approximately in 9.33 % ÷ 13.89 %) by more than a course density values (approximately in

4.62 % ÷ 6.55 %). Also, the product shrunk more in longitudinal direction (approximately 9.97 % ÷ 12.98 %) than in transverse direction (approximately 3.36 % ÷ 4.55 %) as well [6]. The greatest shrinkage value is of the knitted fabric washed in intensive regime (–12.98 % in longitudinal direction and –4.55 % in transverse direction). The lower shrinkage value has the knitted fabric washed in Quick regime. The same tendency is observed in terms of alteration of course and wale densities after washing (greatest value was obtained after Intensive regime and lowest value after Quick regime).

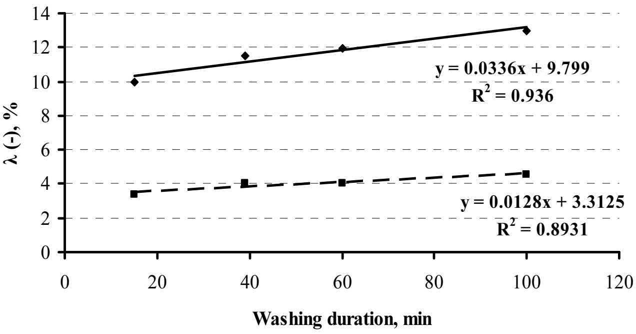

Fig. 3. Dependence of shrinkage λ value in longitudinal ——— and transverse – – · directions upon the washing duration

With reference to Fig. 3, it may be concluded that regardless of the selected washing regime intensity and duration of washing, knitted orthopaedic supports changes their dimensions and density significant, i. e. knitted supports shrinks and thickens, and the shrinkage value depends on the washing duration. Longer washing duration causes higher shrinkage value.

3.3. Compression force alteration after washing and drying procedure

After each washing cycle in Quick regime it was investigated washed and dried knits average tensile strength changes and its influence on compression force of compressive support.

Tensile test was carried out (the size of deformation $\varepsilon = 10$ %) after 1st washing and drying cycle and was received average tensile strength of 19.89 N. The product compression was evaluated according to formula (2) and received compression pressure of 6398.12 Pa. All other data are presented in Table 3.

The results presented in Table 3 demonstrate that when area of knitted support decreases (after each cycle, it shrinks and thickens), the average tensile strength remains almost the same. The greatest change was observed when knit was washed 1st time. The area of sample decreased in 11 % and compression of support increased in 3.6 %. Also, original knit needs less tensile force (18.52 N) than once washed (19.89 N), i. e. tensile force increases in 7.4 %. Knitted support area changes not much (approximately 1.1 % ÷ 1.6 %) after each next washing and drying cycle, also compression changes approximately 0.06 % ÷ 3.6 %. This is because shrinkage value after each washing and drying cycle is small and this influence is not high for threads so the compression of the support changed slightly.

Table 3. Compression values

Number of washing and drying cycle	Force F, N	Area S, m^2	Compression pressure P, Pa
0	18.52 ±0.67	0.0207 ±0.0020	5631.52
1	19.89 ±0.85	0.0184 ±0.0003	6398.12
2	19.56 ±0.81	0.0181 ±0.0003	6394.12
3	20.12 ±0.40	0.0179 ±0.0003	6626.10
4	19.87 ±1.49	0.0179 ±0.0003	6546.11
5	19.41 ±1.23	0.0179 ±0.0004	6406.12

Thus, the compressive strength is calculated according to formula (2), it can be assumed that when the support area is decreasing the higher compression force it to work, and vice versa. In this case, the product area decreased about 13.5 %, when compressive force increased by about 7.7 % (after 5 washing and drying cycles).

3.4. Compression force alteration after cyclic tests

By wearing of orthopaedic supports, it is important that the product will retain a geometric shape and compression properties during long-term wear. Orthopaedic supports are worn every day for several hours, so they must not only retain a geometric shape but also to maintain the size and compression characteristics. Investigation of the influence of cyclic test on compression changes were carried out and results are presented in Fig. 4. It was important to know not even the final results, but also the intermediate results. Changes of knitted support area after cyclic loading are presented in Fig. 4.

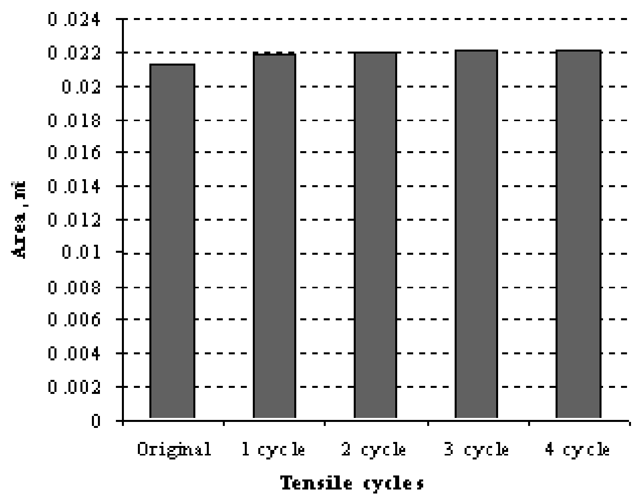

Fig. 4. Changes of knitted support area after cyclic loading

The results presented in Fig. 4 demonstrate that most area of knitted sample changes after 1st (approximately 2.6 %) fatigue cycle. After each next fatigue cycles knit area remain almost unchanged.

From section 3.3 results it can be concluded that under the little change in the product area (from the initial product area after cyclic loading area has changed approximately 2.6 % ÷ 3.49 %) compressive force will increase by only a few percents.

It was established that compressive properties of investigated knits after cyclic tensile load changed slightly, i. e. range between margins of error.

4. CONCLUSIONS

After investigation of influence of washing cycles on shrinkage changes it was found that the values of knitted fabric wale and course densities most increased after first washing and drying cycles. Shrinkage values decreased after repeated washing and drying until dimensional stability is reached.

Investigation of washing duration and intensity influence on compression and shrinkage changes shows that regardless of the selected washing regime and duration of washing knitted orthopaedic supports dimensions and density after washing and drying cycle changes significant. Knitted supports shrink and thicken, and the shrinkage value depends on the washing duration. Longer washing duration causes higher shrinkage value.

Alteration of compression force after washing and drying procedure showed that the highest change is observed when knit was washed 1st time, then the product area decreased by 11 % and compression of support increased by 3.6 %. After each next washing and drying cycle knitted support area and compression force changes not much. This is because shrinkage value after each next washing and drying cycle is small and this influence is not offering high for threads so the compression of the support changed slightly.

The analysis of cyclic test results shows that knit area after cyclic tensile load changed slightly (approximately 0.3 % ÷ 2.6 %). It is possible to assume that most changes of knit area and compressive force happen after 1st fatigue cycle.

REFERENCES

1. **Pereira, S., Anand, S. C., Rajendran, S., Wood, C.** A Study of the Stucture and Properties of Novel Fabribs for Knee Braces *Journal of Industrial Textiles* 36 (4) 2007: pp. 279 – 300.
2. SIGVARIS Compression Bulletin 4, 02/2003.
3. **Cruz, J., Fangueiro, R., Soutinho, F., Fereira, C., Andrade, P.** Study of Compressive Behavior of Funcional Knitted Fabrics Using Elastomeric Materials *Proceedings of AUTEX World Textile Conference* Vilnius, Lithuania, 21 – 23 June, 2010: p. 33.
4. **Mikučionienė, D., Laureckienė, G.** The Influence of Drying Conditions on Dimensional Stability of Cotton Weft Knitted Fabrics *Materials Science* (*Medžiagotyra*) 15 (1) 2009: pp. 64 – 68.
5. **Marmarali Bayazit, A.** Dimensional and Physical Properties of Cotton/Spandex Single Jersey Fabric *Textile Research Journal* 73 (1) 2003: pp. 11 – 14. http://dx.doi.org/10.1177/004051750307300102
6. **Tezel, S., Kavusturan, Y.** The Influence of Relaxation Process on Dimensional Properties of Cotton/Spandex Knitted Fabrics *4th International Textile, Clothing & Design Conference – Magic World of Textiles* Croatia, Dubrovnik, October 5 – 8, 2008: pp. 281 – 286.
7. **Herath, C. N., Kang Choon, B., Jeon Yong, H.** Dimensional Stability of Cotton – Spandex Interlock Structures under Relaxation *Fibers and Polymers* 8 (1) 2007: pp. 105 – 110.
8. **Abromavičiūtė, J., Mikučionienė, D., Čiukas, R.** Structure Properties of Knits from Natural Yarns and Combination with Elastane and Polyamide Threads *Materials Science* (*Medžiagotyra*) 17 (1) 2011: pp. 43 – 46.
9. **Beceren, Y., Candan, C., Cimilli, S., Ulger, K.** Properties of Plain Knits from Siro–Spun Viscose/Spandex Yarns *Fibres & Textiles in Eastern Europe* 18 (1) 2010: pp. 41 – 46.
10. **Mikučionienė, D., Čiukas, R., Mickevičienė, A.** The Influence of Knitting Structure on Mechanical Properties of Weft Knitted Fabrics *Materials Science* (*Medžiagotyra*) 16 (3) 2010: pp. 221 – 225.
11. Textiles–Knitted Fabrics–Determination of Number of Stitches per Unit Length and Unit Area. LST EN14971:2006.
12. Textiles – Domestic Washing and Drying Procedures for Textile Testing: ISO 26330:1993. UDC 677.017.855:648.23 ÷ 648.33. – 1993. – November.
13. **Ališauskienė, D., Mikučionienė, D.** Establishing the Compression of Knitted Spacer Orthopedic Supports *AUTEX 2010 World Textile Conference* Vilnius, Lithuania, 21 – 23 June, 2010: p. 149.
14. **Van Amber, R. R, Niven, E. B., Wilson, A. C.** Effects of Laundering and Water Temperature on the Properties of Silk and Silk – blend Knitted Fabrics *Textile Research Journal* 80 (15) 2010: pp. 1557 – 1568. http://dx.doi.org/10.1177/0040517510366019

Presented at the 20th International Baltic Conference "Materials Engineering 2011" (Kaunas, Lithuania, October 27–28, 2011)