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Influence of the Rigid Element Area on the Compression Properties of Knitted Orthopaedic Supports

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Abstract
This study attempts to investigate the influence of the area of a rigid element integrated into a knitted orthopaedic support on its elasticity. Usually researches analyse compression and other properties of compressive stockings and do not investigate the influence of non-textile parts used in knitted orthopaedic supports. The main goal of this paper was to investigate the influence of the surface area of the rigid element on the elasticity of a knitted orthopaedic support. It was found that the compression of the support increases depending on the area of the rigid element in the knitted support. The rate of influence of the rigid area on compression properties rises with an increase in the elongation value.

Key words: *knitted orthopaedic support, rigid element, elongation, tensile force.*

Introduction

Knitted knee braces generally provide mild compression and support for the knee, and can be a good alternative for individuals with negative reactions and allergies to neoprene knee braces. Most knitted knee braces have a knee sleeve design, making them easy to slip on and off. Many knitted knee braces can be used for everyday wear, and are lightweight, cool and comfortable [1].

The correct care of knee injuries is an important part of any sports medicine. Injuries to the ligamentous structures of the knee in young athletes are becoming more common. The medial collateral and anterior cruciate ligaments are the prime stabilisers of the knee and can be injured when direct or indirect forces are applied to the knee. The ideal knee support would produce a synergism with the inherent knee stabilisers, both muscular and ligamentous, throughout the normal range of motion. [2].

Depending on their construction and field of indication, medical supports of this kind essentially exert a fixing, guiding, supporting or compressing action on the corresponding body part, for example the limbs.

Compression supports are available in different degrees of compression. The physician prescribes the compression class corresponding to the pathology of the patient. According to the German Standard RAL–GZ–387/1:2008 light compression class 1 (24 ÷ 28 hPa) or 2 (31 ÷ 43 hPa), strong compression is class 3 (45 ÷ 61 mmHg) or 4 (> 65 mmHg) depending on the norm used. The compression class depends on the trauma character and intensity.

Elastic compression supports are available in many forms. Commonly such supports are composed of soft, elastic material so that when worn, they provide a certain amount of support for an injured joint [3]. In [4] were found significant differences in material properties for compressive fabrics with different pressure levels. Fabrics with a higher pressure level are rougher, stiffer, and less extensible.

The supports are produced by cutting out suitable blanks from planar material, such asmore or less elastic woven fabrics or knits, foam materials, e.g. neoprene, etc. The shape of the blanks and their subsequent joining takes on an anatomically adapted shape. Normally joining is made by sewing or gluing. The main disadvantage of this is that an exact anatomical fit of the bandages can only be achieved with difficulty, and a large number of connecting points, such as seams, are created. These connecting points partially alter the properties of the material used, e.g. its elastic properties and adaptability, and this pose in particular the risk of pressure points or chafing points of the skin.

Another possible way of producing medical supports is shaped knitting on flat or circular knitting machines [5]. The benefits of flat knitted supports are as follows a) the anatomical shapes guarantee perfect fitting; b) the supporting and compressing effect due to the stretch construction; c) the integration of viscous–elastic profiles or pads for stabilisation, support and massage effects improve blood circulation and absorption of haematoms and oedemas [6].

The main characteristics of yarns used for compression orthopaedic products determine the characteristics thereof . Therefore the yarn chosen must ensure sufficient longitudinal (wales) and transverse (courses) tensile properties of the product, as well as minimum residual

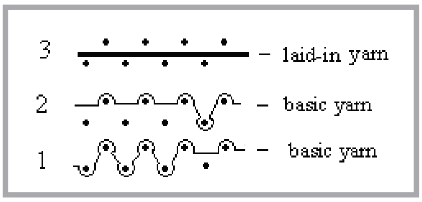

Figure 1. Pattern of knitted fabric investigated.

Table 1. Characteristics of yarns.

Yarn type	Fibre	Linear density of yarn, tex
Basic	polyamide 6.6 (PA)	7.6
Basic	polyurethane (PU)	31
	covered with	
	PA 6.6	4.4 × 2
Laid-in	PU	22.7
	covered with	
	PA	11
	and viscose	14.3

deformation, durability of functional and physic-mechanical properties during wear, and hygienic properties, such as good air permeability. The main yarns used for this type of product are polyamide 6.6 (PA) yarns (filament and textured), polyurethane (PU) (core spun) yarns, elastic (made of rubber) yarns, and cotton yarns. Elastomeric yarns (natural or synthetic), distinguished for their more than 100% stretch break and ability to regain a state close to the initial one (after removing the tensile force), are used to make compressive products. Mostly, a combined knitting pattern is used for the manufacture of orthopaedic products. Alternating the compression in the length of the product can be achieved by changing the knitting density and tension of the core spun elastomeric yarn (e.g. from 0.7 cN in the non-tensed area up to 7.5 cN in the pressing area) [7]. Compression of the support depends on the support area, shape and characteristics of knitting. The relation between the compression pressure and circumference force in a knitted support is determined by the Laplace formula:

$$P = \frac{2 \cdot \pi \cdot F}{S}, \qquad (1)$$

where P is a pressure in Pa, F the force in the knitted support in N, and S is the area in m^2 calculated as a product of the circumference of a limb and height of the knitted support.

As the Laplace formula (1) shows, the value of support pressure depends in direct proportion on the quotient of the circumference force and circumference of the knitted support [8].

The elastic properties of elastic knitted fabrics have been analysed in many researches [9 - 12]. Ozbayrak et al. [9] noted that when the number of inlay yarns in the knit structure increases, there is significant increase in wale extensibility values, but a significant decrease in course extensibility values. Abdessalem et al. [10] investigated the relation between Lycra® consumption and fabric dimensional and elastic behaviour. The results obtained showed that the Lycra® proportion inside fabric has an effect on the fabric width, weight and elasticity.

The mechanical properties of weft-knitted fabrics are strongly related to the fabric structure, yarn properties and fabric direction [13]. The ways how textile materials deform under applied stresses play an important role in their processing and end–use. [14]. Many studies have been made on the deformability on knitted fabrics [13 - 16].

Knitted orthopaedic supports are often made from an anatomically knitted fabric with some additional inserts. Such a support without a knitted frame often has silicone or other parts added. Orthopaedic supports may also comprise other components, such as at least one strap and one fastener, including a disengageable two part fastener system, such as Velcro (i.e. the brand name of the first commercially marketed fabric hook – and – loop fastener) or similar hook and loop type fasteners for engaging the support with the body. Other types of disengageable fastener that may be used are buckles, buttons, snaps and the like [17]. All parts included in the support reduce its total elasticity.

Usually researches analyze compression and other properties of stockings and do not analyze the influence of non-textile parts used in the knitted orthopaedic support. The main goal of this paper was to investigate influence of rigid element surface area on knitted orthopaedic support elasticity.

Materials and methods

Experimental samples were manufactured on a flat double needle–bed knitting machine CMS 340TC-L (f. STOLL, Germany) in a combined jacquard-laid-in pattern with elastomeric weft threads (***Figure 1***). The main characteristics of the yarns used are given in ***Table 1***. The dimensions of the knitted samples were 20.5×20.5 cm, and the surface area of each sample was equal to 0.042 m^2.

Table 2. Elongation value of rigid fabric

Tensile force, N	30	45	60
Elongation, %	2.45	3.12	3.57
Coefficient of variation, %	6.93	5.14	4.39

All experiments were carried out in a standard atmosphere for testing according to ISO Standard 139:2002. Structure parameters of the knitted samples were analysed according to British Standard BS 5441:1998.

The tensile behavior of the knitted fabrics tested was evaluated using a universal testing machine - Zwick/Z005. We performed one cycle tensile test and measured the tensile force at a fixed value of extension: 10, 20, 30, 40 & 50%. Such extension percentages are chosen because knitted supports are often stressed perpendicularly to their surface and undergo such stresses extended in various directions. Simple body movements such as bending knees or elbows stretch the knitted garment by up to 50%.

In the middle of the knitted sample surface a square rigid element was sewn to investigate the influence of the rigid element area on knit elasticity. Samples were tested in four groups: 1) A0 – without the rigid element; 2) A1 – when the rigid element occupies 1.9 % of the total area of the support area; 3) A2 – when the rigid element occupies 4.3 % of the total area of the support area; 4) A3 – when the rigid element occupies 7.6 % of the total area of the support area.

The rigidity of the rigid element is very high. For instance, at 45 N the tensile force the rigid element extents just at 3.12%, while the complete knitted orthopaedic support at such a tensile force extents approximately 50% (see the ***Table 2***).

Tensile properties were measured in transverse (courses) and longitudinal (wales) directions of the knit.

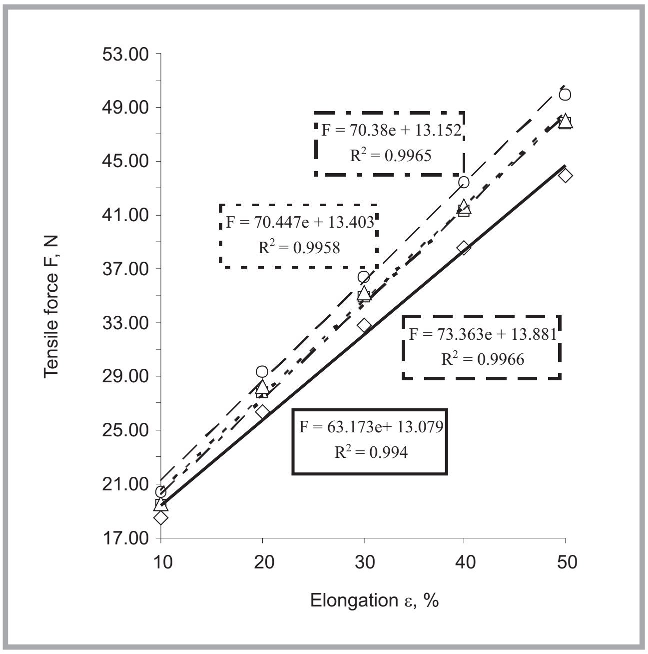

Figure 2. Dependence of tensile force value on elongation during stretching in the course direction (◆ - A0, ■ - A1;▲ - A2; ● - A3).

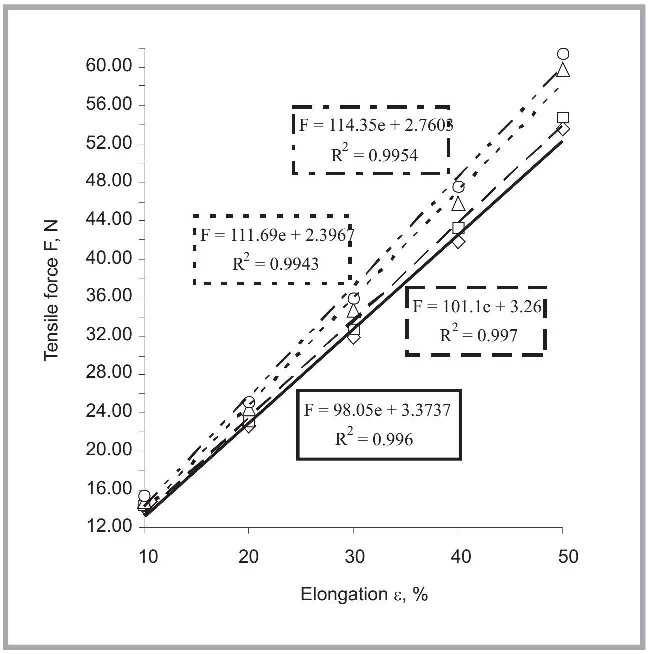

Figure 3. Dependence of tensile force value on elongation during stretching in the wale direction (◆ - A0 sample, ■ - A1;▲ - A2; ● - A3).

Results and discussions

Tensile properties were measured in the transverse (course) and longitudinal (wale) directions of the knits. The results obtained are presented in ***Figure 2*** and ***Figure 3***.

The results presented in ***Figure 2*** demonstrate that regardless of the elongation value selected, the lowest values of tensile force (from 18.47 till 43.95 N) are obtained by the stretching of A0 samples. This is because of the knitted orthopaedic sample was stretched without the rigid element, which may affect the elasticity of the whole sample. The maximum values of tensile force (from 20.38 till 49.99 N) were obtained by stretching the A3 samples, which can be explained by the fact that this sample has a rigid area composed of 7.6% of the general elastic knitted area (i.e. the largest area of the rigid element sewn into the knit). The rigid part of the fabric changed the deformation of the total knitted sample, i.e. reduced the elasticity of the total product; therefore a higher tensile force is needed.

There is a tendency that increasing the area of the rigid element also increases the tensile force that is necessary to achieve the elongation value desired. When samples were stretched at a small level of extension (at an elongation of 10 or 20%), they needed less tensile force to stretch; data scatter is also smaller. By increasing the extension level, the force required to stretch the sample increases at the same time, with the data scatter also rising. This is due to the fact that a small tensile force is needed at a small extension value, hence the points are not very distant from each other and vice versa.

We found that tensile force values increased depending on the area of the rigid element (from 4.93 till 8.85% for sample A1, from 5.85 till 9.35% for sample A2, and from 10.34 till 13.74% for sample A3). Results show that there are higher differences between tensile force values of samples A0 and A3 (in 10.34 ÷ 13.74 %). However, very little difference is seen between samples A1 and A2 at all elongation points. Results differ only by a few percent (0.46 ÷ 1.33%). Relative error values of the tensile force results were calculated and range from 0.21 till 2.88%.

In ***Figure 3***, we can see the results of knitted samples stretched in the wale (longitudinal) direction. The results obtained show that the lowest values of tensile force (from 14.16 till 53.53 N) were obtained by stretching samples A0, and maximum values (from 15.37 till 61.36 N) were obtained by stretching samples A3. The same tendency was observed for samples stretched in the course (transverse) direction. As in the previous ***Figure 2***, we found that tensile force values increased depending on the area of the rigid element (from 0.85 till 3.2% for sample A1, from 4.24 till 11.84% for sample A2, and from 8.55 till 14.63% for sample A3). Relative error values of the tensile force results were calculated and range from 0.02 till 3.52%.

Comparing the force value for the knitted samples stretched in the course and wale directions, we can see that the results are similar; however a slightly higher tensile force is required for samples stretched in the wale direction. This can be explained by the fact that when tensile loading is applied to the knitted fabric, the yarn within the structure moves until it jams and then the yarn elongates until it breaks. Under an applied load, plain knitted fabric has less elongation in the wale direction than in course direction due to longitudinal jamming occuring sooner than transverse jamming [15]. It also may be affected by the fact that PU yarn is inserted in the course (transverse) direction and consequently knitted fabric is naturally more elastic in this direction. It can be concluded that the fabric tensile force value increases with an increasing level of extension in both directions (the same tendency was found by other researchers [12]).

There is strong relation between the elongation value and tensile force (all coeficient values determined were not lower than 0.99, being approximately 0.994 ÷ 0.997). The results show that a linear correlation exits at such elongation points.

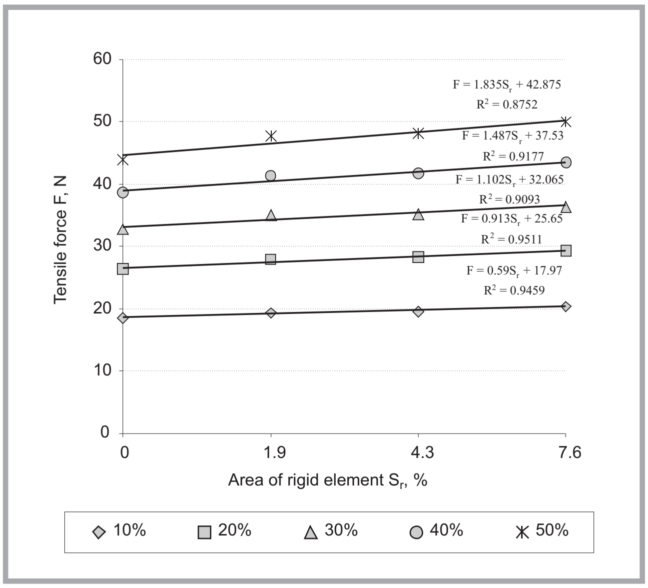

Figure 4. *Dependence of force value on the area of the rigid element in course direction.*

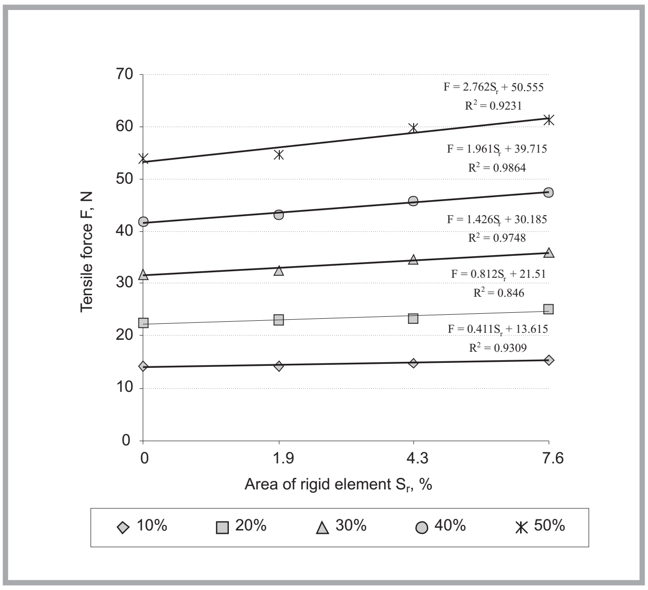

Figure 5. *Dependence of force value on the area of the rigid element in in wale directions.*

In ***Figure 4*** the dependence of the tensile force (in course direction) on the area of the rigid element is presented, and in ***Figure 5*** that of the tensile force (in wale direction) on the area of the rigid element is presented.

Analysis of ***Figures 4*** and ***5*** shows that the influence of the rigid area in the knitted support on its tensile properties increases with an increase in the elongation value. By stretching in the wale direction, the difference between tensile force values of the sample with the maximum rigid area (A3 – 7.6%) and those of the sample without a rigid element (A0) is 8.5% in the case of the lowest elongation (10 %), and 13.9% in the case of the highest elongation (50%). Consequently, by stretching in the course direction, these values are 10.3% and 13.7%. If the tensile force linear influences the compression of the knitted orthopaedic support, the results presented enable us to design a support with rigid elements according to the necessary compression. The influence of the area of the rigid element on the compression of the support by increasing the elongation is even more clearly demonstrated in ***Figure 6***. The dependence of coefficient a_1 (of equations presented in ***Figures 4*** and ***5***) on elongation is presented in ***Figure 6***.

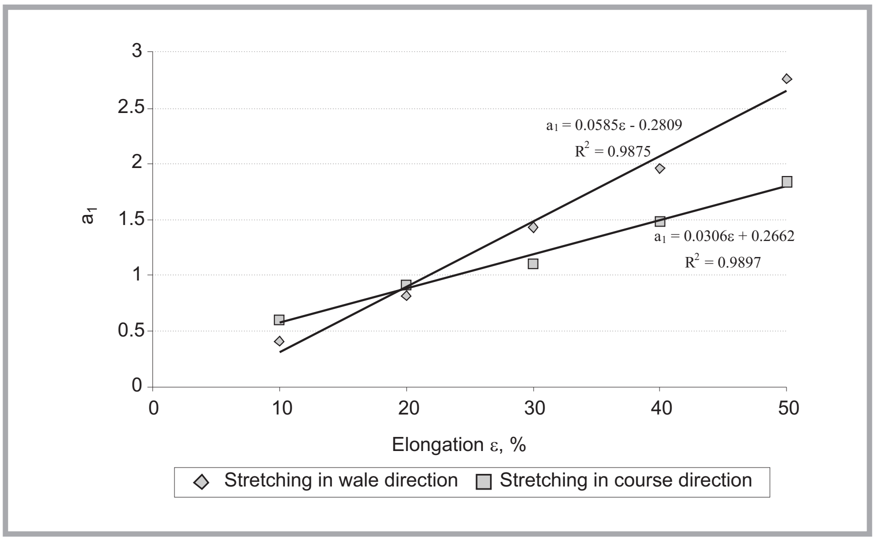

Figure 6. *Dependence of coefficient a_1 on elongation.*

Table 3. *Dependence of support pressure P (in hPa) on the area of the rigid element S_r and fixed value of extension ε*

	Relative area of rigid element S_r	Elongation ε				
		10%	20%	30%	40%	50%
In course direction	0%	27.62	39.42	49.03	57.67	65.72
	1.9%	29.02	41.66	52.21	61.80	71.54
	4.3%	29.23	42.21	52.63	62.27	71.86
	7.6%	30.47	43.78	54.38	64.94	74.75
In wale direction	0%	21.17	33.75	47.56	62.62	80.04
	1.9%	21.35	34.48	48.80	64.62	81.83
	4.3%	22.07	36.41	51.90	68.52	89.52
	7.6%	22.98	37.65	53.62	71.10	91.74

In the linear equations ($y = a_0 + a_1x$) coefficient a_1 characterizes the rate of influence of parameter x (in our case, x is the area of the rigid element in the knitted support). As is seen from ***Figure 6***, the rate of influence of the rigid element area on elongation increases linearly in both cases by stretching in the wale and course directions.

The influence of the area of the rigid element and elongation of the knitted support on the pressure value is presented in ***Table 3***. The pressure values are calculated according to formula (1). The results presented in ***Figures 7*** and ***8*** demonstrate that pressure generated linearly depends on the area of the rigid element when the difference between the circumferences of

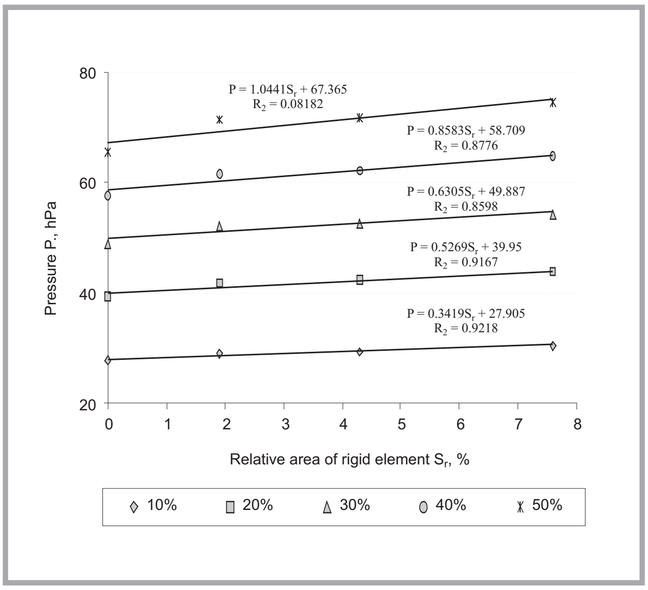

Figure 7. *Dependence of pressure on the area of the rigid element and value of extension in wale direction.*

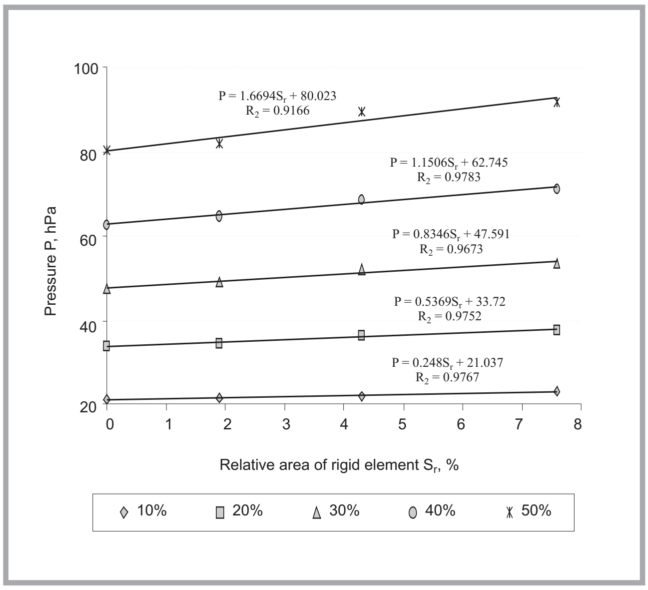

Figure 8. *Dependence of pressure on the area of the rigid element and value of extension in wale directions.*

the limb and knitted support has a fixed value. The values of coefficient a_1 of equations presented in ***Figures 7*** and ***8*** demonstrate that for a higher difference between the circumferences of the limb and knitted support, the value of the rigid element area has a higher influence on the pressure of the knitted support generated. Therefore when the area of the rigid element in the knitted support is small (e.g. element of fasteners) or the support will be used with low deformation, it is not necessary to assess the influence of the rigid area on the compression of the knitted support. However, when the area of the rigid element is high (e.g. fixers of knees or elbows) or the support will be used with high deformation, the influences presented must be taken into account at the time of designing the support properties.

Conclusion

- The influence of knitted support elongation on the tensile force, which characterises the compression of the support, depends on the area of the rigid element in the support.
- The rigid element in a knitted support increases the pressure thereof. The rate of influence of the rigid area on compression properties increases with an increase in the elongation value.
- When the area of the rigid element is high or the support will be used with high deformation, the influences of the rigid element area must be evaluated at the time of designing the support properties.

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Received 30.03.2011 Reviewed 22.11.2011