(REFEREED RESEARCH)

FUNCTIONAL KNITTED FABRICS FOR FOOTWEAR LININGS

AYAKKABI ASTARLARI İÇİN FONKSİYONEL ÖRME KUMAŞLAR

Mirega BLAGA
Gheorghe Asachi Technical University
Faculty of Textiles
e-mail: mblaga@tex.tuiasi.ro

Arzu MARMARALI
Ege University
Textile Engineering Department

Aura MIHAI
Gheorghe Asachi Technical
University Faculty of Textiles

ABSTRACT

The research aims to discover new materials adequate for footwear linings, considering the main functions which should be assured, such as: improving its appearance, increasing the comfort and durability of the footwear. Knitted fabrics represent a category of textiles which proof availability for such destinations, due to the wide product range given by various combinations of: geometry, shape, yarns and finishing. Several single jersey fabrics were produced using functional yarns like Coolpass, Coolmax, Outlast and Dri-Release in different stitch densities. This paper reports the study on the influence of yarn type, fabric tightness and finishing on the the behaviour of the knitted fabrics for footwear linings, throughout the properties: fabric extensibility, pilling, friction properties, initial elastic modulus. A comparative analysis between yarn type emphasizes the suitability of the designed fabrics for footwear linings.

Key Words: Functional yarns, Knitted fabrics, Mechanical properties, Footwear linings.

ÖZET

Bu araştırma, ayakkabı astarları için görünümün iyileştirilmesi, ayakkabı konforunun ve dayanıklılığının arttırılması gibi temel işlevleri sağlayan yeni malzemelerin bulunmasını amaçlamaktadır. Örme kumaşlar, geometri, şekil, iplik ve bitim işlemlerinin çeşitli kombinasyonları sayesinde geniş bir ürün yelpazesine ve çok farklı kullanım yerlerine uygun tekstil ürünleridir. Coolpass, Coolmax, Outlast ve Dri-Release gibi fonksiyonel iplikler kullanılarak farklı sıklıklarda süprem kumaşlar üretilmiştir. Bu yazıda, iplik tipi, kumaş sıklığının ve yıkama işleminin ayakkabı astarı olarak kullanılabilecek örme kumaşların, elastikiyet, boncuklanma, sürtünme ve elastik modülü gibi özelliklerine etkisi araştırılmıştır. İplik türleri arasında karşılaştırmalı analiz, ayakkabı astarları için tasarlanan kumaşların uygunluğunu ortaya koymaktadır.

Anahtar Kelimeler: Fonksiyonel iplikler, Örme kumaşlar, Mekaniksel özellikler, Ayakkabı astarı.

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1. INTRODUCTION

Knitted fabrics can find their end use as footwear linings, considering that footwear uppers are partly or completely lined. The main linings of the footwear protect the dorsal surface of the foot against the stressed action of seams, and of some rigid pieces of the middle group, like stiffener and toe puff (1).

Testing standards for knitted fabrics used for footwear are more rigorous than those for garments, considering that the conditions where the footwear is going to be used are quite extreme (2).

Footwear linings can be analysed from different points of view. During the production, linings must contribute to the reduction of the uppers breaks during the lasting process by taking over a part of the tension which the entire upper is subjected to. Thus, the lining parts are subjected to the same stress as the uppers, e.g. the tension during the lasting process and repeated bending in the area over the metatarsal-phalangeal joint when using the product. During wearing, linings must protect the foot skin against the direct contact of the foot with the semi-rigid footwear components such as a stiffener and a toe cap. A lining must prevent an upper from distortion and ensure the stability of the spatial form and, hence, maintain the product aesthetical look over time. To assure feet comfort, the lining footwear material should have basic characteristics such as: good hygienic properties (good absorption capacity, good air and water vapour permeability, capacity to remove static electricity, etc.), good resistance to wet and dry friction, good resistance to stress and strain, good resistance to perspiration, high thermal resistance as regards footwear designed for the cold season, good dyeing resistance.

Jeon Y.H. et.al (2) examined mechanical properties and abrasion behavior of warp knitted fabrics for footwear. Mechanical properties illustrated notable differences in different directions. The weight and thickness of the fabric, the frictional coefficient, and also the surface roughness, are influenced by the abrasion conditions. Heide M. et.al

(3) reported research results showing the possibilities of using permanently effective antimicrobial yarns in fabrics used for medical footwear insoles. The antimicrobial knitted fabrics could be a very useful application for footwear lining, a large demand for such commercial products being reported recently. Neves M. et.al (4) developed linings for comfortable sport footwear, due to special conditions this type of footwear is subject to. Blaga M. et.al. (5) reported the influence of fibers blend ratio between Cotton and Soybean/ SeaCell on the wear behaviour of the knitted fabrics for footwear linings, throughout the properties: fabric extensibility, initial elastic modulus and dyeing behaviour. In this study Blaga M. et.al. (6) and Marmarali A. et.al. (7) analysed the physical and comfort properties of the single jersey fabrics made of functional yarns, like Coolpass, Coolmax, Outlast and Dri-Release, for footwear linings. They have demonstrated the utility of these yarns for linings of orthopaedics footwear, where comfort properties are mostly required.

2. MATERIALS AND METHODS

In case of footwear, considering that the interaction between foot and footwear is made by linings, it is important to select suitable materials, both for linings and for uppers in order to assure the required comfort. Both the raw materials and the fabric structure will influence the overall performance of the lining. The functional yarns used in this research and the corresponding functionality are given in Table 1.

Single jersey samples were knitted using Coolmax, Coolpass, Dri-Release and Outlast yarns. The knitting process was carried out on the experimental circular knitting machine, “Lab Knitter” 294E (Mesdan-Lab) which has 3¾ inches diameter, one knitting system, 240 working needles, negative feed, and cylinder rotation speed from 0 to 450 rpm. For this research, the knitting conditions were established by adjusting the stitch depth at three levels, while the yarn feeding tension, take-down tension and cylinder rotation speed were kept constant. The variation of stitch depth was done by modifying the vertical position of the cylinder at three levels, by means of an accurate mechanical regulator, and thus the difference between consecutive levels was constant. The minimum and maximum values of stitch depth were chosen according to the knitting performance and the samples were defined as loose (1), medium (2) and tight fabrics (3). After the knitting, the fabrics were relaxed in dry state and then finished by washing without detergent, according to the TS EN ISO 6330 standard. The values of the fabric structural parameters that refer to the vertical density cpc, horizontal density wpc, loop length l (cm), tightness factor K, thickness (mm) and mass per unit area (g/m^2) were measured on both raw and finished fabrics. Tables 2 and 3 show the mean values of the characteristics of the knitted fabrics produced.

Fabrics extensibility was tested in both wale and course direction, using a Frima Fabric Extensometer, SDL Atlas, under a 30 N tensile force which is considered to be in the range of the regular strain (8). Tensile tests of the samples were performed on a Testile Tester Satra and the fabrics force-elongation curves were recorded by computer in order to analyse their behaviour under stress, course and wale direction, for one of the fabrics. The ICI Pilling Tester was used to determine the pill formation of the knits, and its test method was applied in accordance to the BS EN ISO 12945-1 standard (9). For all samples, standard 18000 revolutions were used and the fabrics were assessed for their grades. The pilling results were evaluated the grades from 1 (severely pilling) to 5 (no pilling) (10).

Table 1. The yarns used for fabrics and their functionality

Fibre	Commercial name	Yarn count	Functionality	End uses
Polyester	Coolpass	150den	Moisture management and body temperature regulation	Sportswear, casual wear, lingerie, swimwear, hosiery
Polyester	Coolmax	150den	Excellent moisture management and body thermoregulation	Sportswear, fashion cloths, underwear, socks, sports accessories and medical wraps, braces and pads
Polyester/Cotton	Dri-release	Ne30/1	Moisture management and quick drying	Sportswear, underwear
Viscose	Outlast	Ne30/1	Softer hand, increased stretch, thermal regulation	Sportswear, underwear

Table 2. Raw knitted fabric specifications

Fabric type	Tightness	cpc	wpc	l (cm)	K	Thickness (mm)	Mass (g/m^2)
Coolpass	Loose	54	58	0.38	10.80	0.66	88
	Medium	67	63	0.37	11.47	0.63	101
	Tight	90	72	0.29	14.23	0.60	128
Coolmax	Loose	57	58	0.39	10.49	0.73	94
	Medium	73	64	0.35	11.63	0.67	109
	Tight	93	70	0.29	14.18	0.65	104
Dri release	Loose	49	53	0.42	10.64	0.51	83
	Medium	62	58	0.35	12.66	0.51	99
	Tight	82	71	0.30	14.95	0.56	134
Outlast	Loose	52	53	0.43	12.49	0.57	130
	Medium	63	57	0.39	14.02	0.62	148
	Tight	84	65	0.31	17.14	0.66	191

Table 3. Finished knitted fabrics specifications

Yarn type	Tightness	cpc	wpc	L (mm)	K	Thickness (mm)	Mass (g/m²)
Coolpass	Loose	65	59	0.39	10.41	0.73	102
	Medium	80	65	0.34	11.84	0.67	114
	Tight	102	72	0.30	13.52	0.65	134
Coolmax	Loose	63	58	0.40	10.21	0.66	102
	Medium	74	63	0.34	11.84	0.63	121
	Tight	94	74	0.29	14.13	0.60	146
Dri release	Loose	54	54	0.42	10.56	0.51	94
	Medium	64	56	0.37	12.14	0.53	102
	Tight	82	67	0.30	14.66	0.56	130
Outlast	Loose	56	54	0.43	12.43	0.57	142
	Medium	67	55	0.36	14.99	0.62	169
	Tight	88	64	0.32	16.82	0.66	223

3. RESULTS AND DISCUSSION

3.1. Fabric extensibility

Knitted fabrics are surfaces with a high elasticity exhibited mainly in row direction due to their specific loop arrangement. Fabric extensibility is defined as the capacity to reach the maximum value of elongation when subjected to forces below breaking point. In the case of footwear linings, this property is required for upper part formability and 3D shaping. The results are plotted in Figures 1 and 2, for both fabric states.

The test results revealed that, the factors with greater influence are the testing direction, e.g. rows or wales ($p=0.000$). Weft knitted fabric behaviour differs in horizontal and vertical direction, due to the particular way of forming the loops by needles knitting the yarn across the width of the fabric.

When straining the fabrics in row direction, the yarn from the loop is redistributed and the loop shape is modified by reducing its height and increasing its pitch. From all structural parameters, stitch density has the most significant influence on the fabric extensibility. By increasing the fabric compactness, the yarn amount to be redistributed in this way decreases, so its extensibility becomes lower. This relationship is clearly confirmed for all yarn type and for both fabric states.

When applying the force along the wale, the yarn redistribution is considerably smaller and it comes mainly from the length of the sinker loops. For this reason, the fabric extensibility is reduced for all variants. But no relationship between the stitch density and the fabric extensibility in the wale direction may be established. This can be explained by the yarn elongation, which can be limited to the elastic domain or can reach the plastic deformations. Thus, the value of the wale extensibility is directly influenced by the characteristics of the yarn used for knitting.

The finishing stage has certain influence on the fabric extensibility ($p=0.000$). For all yarn types, the stitch density has greater influence in the case of the finished fabrics; the differences between the fabrics with different stitch density are higher compared to the raw state. The effect is more significant for Dri Release samples where the different behaviour of the synthetic and natural fibres from the yarn structure influences more the fabric extensibility for the three fabric densities. It is also known that after knitting and finishing process, the yarns change their physical-mechanical properties and this affects the end use behaviour.

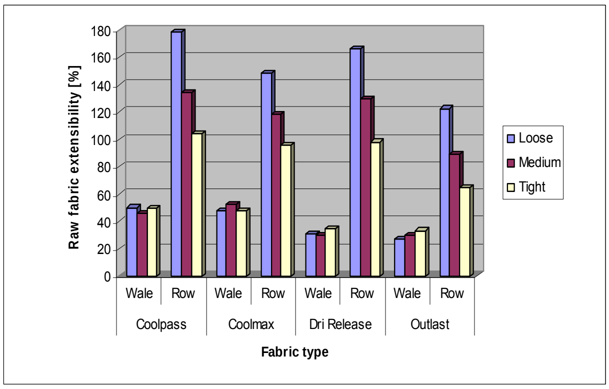

Figure 1. Extensibility of raw fabric

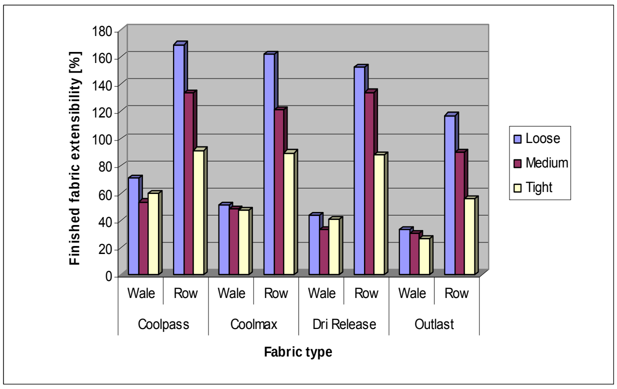

Figure 2. Extensibility of finished fabric

3.2. Fabric initial modulus

Force elongation curves for row and wale directions are presented in Figure 3 and Figure 4 respectively. During the application of a tensile load, the loops change their shape in order to accommodate the applied load. In this part of the deformation, small loads lead to large displacements, which is the typical behaviour of a low stiffness material. The fabric deformation takes place in two stages: initial, the deformation of the knitted fabric is due mainly to the straightening of the curved yarns. The yarns slip with friction in the interlacing regions, while the diameter of the yarn continuously decreases because of local compression effects. This process continues up to the 'critical stretch state', which is a hypothetical state of deformation.

From the mechanical point of view, in this initial stage of deformation, the fabric behaves like a structure rather than a continuous material. As the deformation is non-linear, Hook's law cannot be verified, and so it is not possible to consider Young's modulus. The second step is characterised by the yarn deformation within the structure as the load is transferred directly to the yarn. When the load increases, the cross-section of the fabric becomes more compact (11). Initial modulus indicates the level of fabric stiffness, meaning its resistance to extension. The higher is the modulus of a material, the less it extends for a known force (12).

The main points of deformation process were established on the diagrams. The initial elastic modulus was determined as a measure of the fabric stiffness, as the slope of force-elongation curve for each variant of knitted fabric, e.g. in both testing direction, coursewise and walewise, and in raw and finished state. The results were plotted against the fabric tightness and yarn type, and can be visualised in Figures 5 and 6.

Analysing the diagrams, it is possible to conclude that coursewise, the low values of the initial modulus demonstrate low stiffness and good extensibility. From this point of view, Coolpass, Coolmax and Dri Release show a similar behaviour, while Outlast fabric proves higher stiffness and higher influence of the stitch density on the fabric extensibility than in the case of the other yarns. For all samples, the tightness factor has a direct relathionship with fabric stiffness in course direction (p=0.000). Walewise, a certain rule concerning the elasticity behaviour in relation to fabric tightness cannot be established.

3.3. Fabric pilling

Pilling is the formation of little pills or entangled fibre balls clinging on fabric surface. Pills are formed by a rubbing action on loose fibres which exist on the fabric surface. Due to their flexible structure, knitted fabrics have a higher tendency of forming pills compared to woven fabrics. The tangled fibres that appear on fabric surface during wear or laundering will form the pill (13). Pilling is not only affecting the appearance of the fabric, but also has an accelerating effect on the rate of fiber removal from the yarn structure, and hence reduces the service life (14). The factors which influence the pills formation are related to the physical properties of the fibers, yarn characteristics and fabric properties (15).

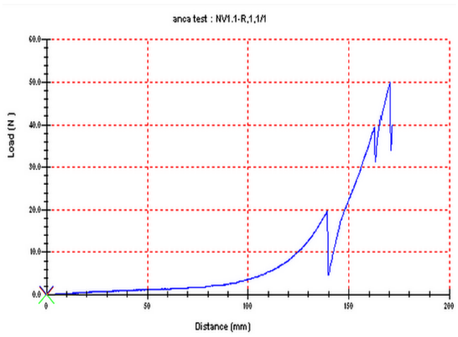

Figure 3. Force elongation curve–row direction

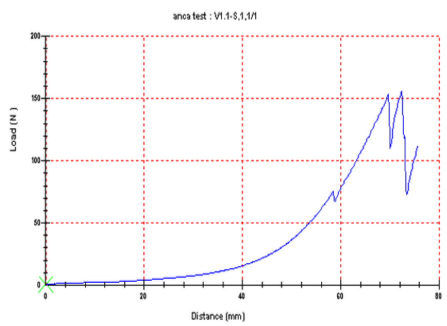

Figure 4. Force elongation curve–wale direction

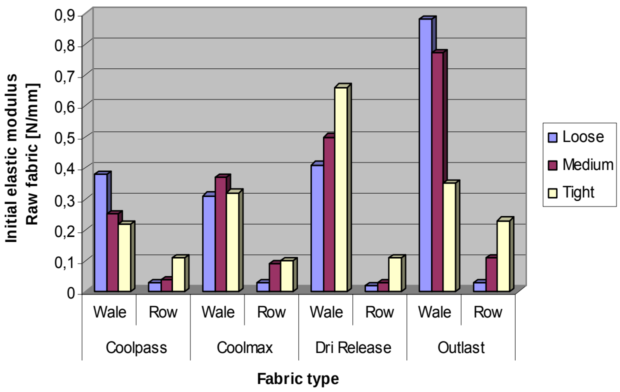

Figure 5. Initial elastic modulus – raw fabric

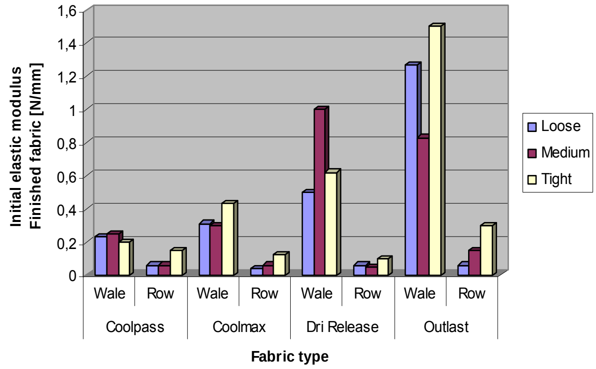

Figure 6. Initial elastic modulus – finished fabric

The pilling rate grade was measured for finished fabrics, considered as being the wearer state and it is assumed that the full relaxation and finishing process reduce the strength of the fabric and consequently increased the pill rate. The results for pilling grades and are displayed in Figure 7.

The fabrics different behavior response to the pilling action can be attributed to the yarn count and nature. Coolpass and Coolmax fabrics made of PES filaments yarn with the same count (150den) exhibit similar pilling grades whereas the other two, made of Dri release and Outlast (Ne30/1) which contain short fibers proved a lower resistance to the pilling. The experimental results for the pilling rate show that fabrics made of Coolpass and Coolmax perform the best pilling properties, and this can be attributed to the tightly structure of the yarns produced from filaments. All samples show that the pilling grades of tight structures are better than those of the loose samples, because tight fabric may hold the fibers/filaments more firmly. The pilling resistance of the knitted fabrics has been noticed to be higher in case of lower stitch length. The looser fabrics due to their higher fibers content may give higher probability to form pills on the surface. This conclusion is sustained by other researchers as well (15).

3.4. Fabric friction resistance

The frictional properties of textile fabrics are of considerable importance in technical applications and in the subjective assessment by consumers. The frictional behavior of textile fabrics has been known to affect comfort in wearing.

Friction coefficient is one of the factors contributing to the fabric hand. Fabric friction is affected by many factors, such as: type of fiber, type of blend, blend ratio, yarn structure, fabric structure and compressibility (18).

The measured coefficient of friction is specific for the two materials in contact. For the present research the inclined plane method was used, applied with the Shirley Fabric Friction Tester M264, developed to comply to British Standard test method BS 3424 (17). Both, the tested samples and the standard fabric from the testing block were conditioned in the standard atmosphere and the tests were carried out in a similar atmosphere. The device is arranged in such a way that the angle of the plane can be continuously adjusted until the fabric just begins to slide. The results given by this method of determining fabric friction (method B of BS 3424, part 10, 1987) are not expressed in absolute coefficients of friction but in degrees of inclination of the inclined plane, which were determined for all fabric types. The testing platform is innitially placed in the horizontal postion. When the inclination of the friction table is high enough to cause the test specimen to slide over the table, the microswitch actuating lever is released, stopping the motor. At this point the angle of inclination of the friction table can be read on the scale, with a 0.5º precision.

For certain applications it is more useful to define static friction in terms of the maximum angle before which one of the items will begin sliding. This is called the *angle of friction* or *friction angle*. It is defined as:

$$\tan\varphi = \mu$$

where φ is the angle from horizontal and μ is the static coefficient of friction between the objects. This formula can also be used to calculate μ from empirical measurements of the friction angle.

Figures 8 and 9 display the effect of fabric tightness on the friction coefficient. It can be observed that, as the fabric tightness increases, the surface friction coefficient increases as well.

This behavior can be explained by the higher number of contact areas as it was explained by Bowden E.P. and Tabor D. (18). The size of contact area directly affects the coefficient of friction. A tighter structure offers an increased contact surface area and this will increase the number of contact points, thus contributing to a higher friction coefficient.

Each variant exhibits a higher coefficient of friction on row direction compared to wale direction. This situation can be attributed to the specific weft loop geometry and to the higher number of contact points along the row compared to the ones disposed walewise.

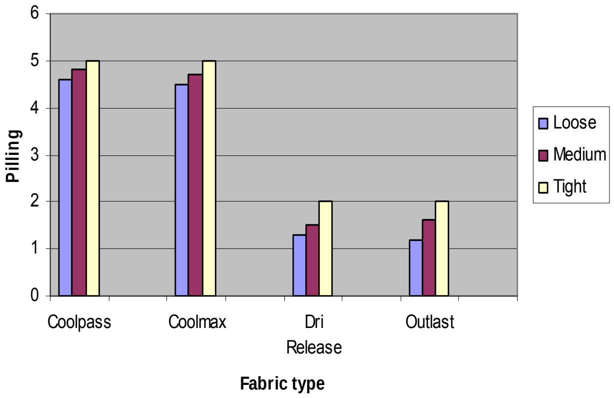

Figure 7. Pilling properties of fabrics

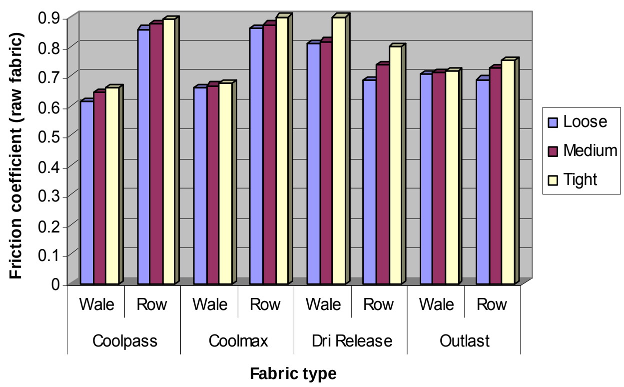

Figure 8. Friction coefficient of raw fabrics

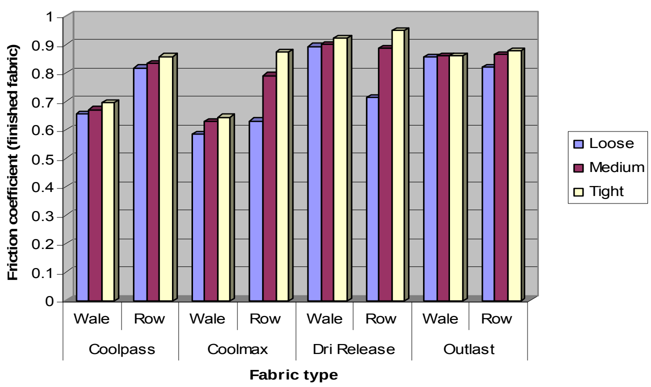

Figure 9. Friction coefficient of finished fabrics

From the fabric specifications in both state (Tables 2 and 3) it can be observed that with the relaxation and finishing process, the fabric becomes more dense, creating more contact points between surfaces and consequently a higher coefficient of friction in the finished state.

4. CONCLUSION

The rational choice of fabrics used for footwear linings must consider the main functions which should be assured, such as: improving its appearance, increasing the comfort and maintaining the durability of footwear.

This research is an initial step in developing knitted fabrics for footwear linings, by trials of new type of yarns, in order to engineer fabric properties. The paper reports the study on the influence of yarn type, fabric tightness and finishing process on the behaviour of the knitted fabrics for footwear linings, throughout the properties: fabric extensibility, pilling, initial elastic modulus and friction properties.

Coolpass and Coolmax fabrics generally present similar results concerning the analyzed properties. This is due to the fact that these yarns are both polyester based and were engineered with a specially designed cross section, based on the larger surface area. Dri-release yarns are blended of natural and synthetic fibres, and this mixture influences the fabric properties. Outlast yarns are generally designed for thermal regulation purposes, for a good hand and an increased stretch. This study proved that knitted fabrics made of the other raw materials have better elastic properties, compared to Outlast ones.

From the extensibility results, one can conclude that fabrics are reacting differently according the testing direction. Course wise, by increasing the fabric compactness, the yarn amount to be redistributed decreases, so fabric extensibility becomes lower. Wale wise, the fabric extensibility is lower compared to the other direction, due to the specific loop geometry. But no relationship between the stitch density and the fabric extensibility in the wale direction has been established.

Analysing the initial elastic modulus, it can be emphasized that coursewise, the low values of the initial modulus demonstrate low stiffness and good extensibility. From this point of view, Coolpass, Coolmax and Dri Release exhibit a similar behaviour, while Outlast fabric proves higher stiffness and higher influence of the stitch density on fabric extensibility then the other yarns.

The fabrics different behavior to the pilling action can be attributed to the yarn count and nature. Coolpass and Coolmax fabrics made of PES filaments yarn with the same count (150den) demonstrate similar pilling grades whereas the other two, made of Dri release and Outlast (Ne30/1) which contain short fibers prove a lower resistance to pilling. The pilling resistance of the knitted fabrics has been noticed to be higher in the case of lower stitch length.

Regarding the friction coefficient, this is influenced by the fabric tightness. As the fabric tightness increases, the surface friction coefficient increases as well. This is due to the amount of contact area of different tightness variants.

A general conclusion can be drawn after testing the knitted fabrics, that they proved their suitability for footwear linings from physical and mechanical point of view but the right choice should take into consideration the exact end use of the footwear and the specific functions that must be met.

Future research on functionalizing the knitted fabrics for footwear must be performed, in order to find new combinations of fibers, yarns, structures and finishing.

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