Short communication

Elastane Addition Impact on Structural and Transfer Properties of Viscose and Polyacrylonitrile Knits

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Abstract

The objective of the research was to compare the porosity/compactness of the knitted structures made from viscose and polyacrylonitrile yarns with incorporated elastane and without elastane, respectively, and to evaluate the elastane addition impact to their moisture management and air permeability properties. The addition of elastane considerably reduces the wettability of the wet relaxed viscose knits, while it moderately increases the wettability of the wet relaxed polyacrylonitrile knits. The polyacrylonitrile knits exhibit distinctively better wickability than comparable viscose knits. When no elastane is added, air permeability is better for viscose knits while with the elastane addition, air permeability is better for polyacrylonitrile knits.

Keywords: Knit, elastane, wicking, wetting, air permeability

1. Introduction

1. 1. Elasticized Materials

Man-made elastane fibres were developed to replace natural rubber filaments. The elastane fibres are characterized by high extension and rapid and substantial recovery associated with rubber-like elasticity. These fibres from segmented polyurethane polymers are stronger than rubber and have greater elastic recovery. They have high resistance to chemicals, sunlight and other degradative influences, and may be washed repeatedly with no ill-effects. They can also be dyed.[1] Apart from the form of bare threads incorporated into various structures through interlacing, elastane fibres can be used in core-spun yarns, where the non-elastic fibre sheath is spun around the core of elastane or other elastomeric yarn. Core-spun elastane yarns are used for making woven and knit goods of many types. They supplement the recovery properties of knitted structures, improving the dimensional stability.[2]

1. 2. Knitted Structures

Knitted structures are created by interlooping the thread. Due to the three-dimensional curved shape of the basic unit – the loop, they are generally more porous and extensible than other textile structures. The appearance and performance properties of various knitted structures differ mainly due to the differences in the material composition and structural parameters. Knitting with yarns with incorporated elastane usually results in a compact to very compact, i.e. supercompact, structure due to the thread extension in the knitting zone, fabric relaxation after the knitting process and consecutive yarn compression within the fabric structure. The structure compactness which is described with loop modules and loop constants directly influences the performance, and the mechanical and comfort properties of knits.[3] The compactness is expected to be closely connected to absorbency and air permeability of the structure.

1. 3. Transfer Properties

Moisture management, i.e. the transport of both moisture vapour and liquid away from the body, is a complex process influenced by a variety of fabric characteristics, e.g. type of fibre (hydrophilic and hydrophobic), porosity and thickness.[4] The liquid moisture flow through textile materials is controlled with two processes, i.e. wetting and wicking. The wetting and wicking behaviour is a critical aspect of the performance of products such as sportswear, hygiene disposable materials and medical items.

Wetting of a fabric in a garment can occur from either the external environment of the wearer or from the garment internal environment when the wearer is perspiring. Wetting is the initial process, involved in fluid spreading; it is controlled by the surface energies of the involved solid and liquid. Wetting is a complex process further complicated by the structure of fibrous assembly. The curvature of fibres, crimps on fibres and orientation and packing of fibres in fibrous materials make the evaluation of wetting phenomena of fibrous assemblies more complicated. The curvature and roughness of contact surfaces are two critical factors for the wetting phenomena in fibrous materials, which are porous media of intricate, tortuous and yet soft, rough structure. A liquid that fully wets a material in the form of a smooth planar surface may not wet the same material when presented as a smooth fibre surface, let alone a real fibrous structure. Wetting of fibrous materials is important in a diverse range of applications in the textile manufacture such as desizing, scouring, bleaching, dyeing, finishing, cleaning and composite manufacture. Clothing comfort also depends on the wetting behaviour of fibrous structure.[5, 6]

Wetting can be described by Young's equation[6]:

$$\gamma_{SV} - \gamma_{SL} - \gamma_{LV} \cos\theta = 0 \quad (1)$$

where γ_{SV}, γ_{SL} and γ_{LV} denotes interfacial tensions between solid/vapour, solid/liquid and liquid/vapour, respectively, and θ is the equilibrium contact angle.

Wicking occurs when a fabric is completely or partially immersed in a liquid or is in contact with a limited amount of liquid, e.g. a drop placed onto the fabric. The capillary penetration of a liquid can therefore occur from an infinite (unlimited) or finite (limited) reservoir. The wicking processes from an infinite reservoir are immersion, transplanar wicking and longitudinal wicking. Wicking from a limited reservoir is exemplified by a drop placed onto the fabric surface.[6] The capillary pressure for a caplillary with a circular cross-section can be described by Young-Laplace equation[6]:

$$\frac{\Delta P = 2g_{LV}}{R} \quad (2)$$

where ΔP is the pressure difference across the fluid interface, R = r/cosθ, r is the capillary radius and γ_{LV} is the capillary tension between liquid/vapour.

The wickability can be defined as the ability to sustain the capillary flow, while the wettability can be defined as an interaction between the liquid and the substrate before the wicking takes place. Hence, it could be said that wetting is a prerequisite of wicking.[7]

It is assumed that water is retained by a fabric in only three places:

1. in the spaces designated by weave intersections (the so-called "fabric water"),
2. in the capillary space between individual fibres within a yarn (the so-called "yarn water"), and
3. within the fibres themselves (the so-called "fibre water").[8]

Air permeability is one of important factors defining comfort properties of textiles, providing ventilation, maintenance of the body temperature and resistance to wind. Air permeability is determined by measuring the rate of air flow through a fabric. The fabric structural parameters have an impact on air permeability by causing a change in the length of airflow paths through a fabric. Density (porosity), e.g. the shape and size of pores, and finishing processes also influence air permeability. However, porosity evaluated with air permeability testing does not necessarily correlate closely with other assessment of porosity, e.g. structural porosity, since the resistance to the passage of air does not depend directly on the percentage of fabric that is porous. Different surface textures on either side may exhibit different air permeability depending upon the direction of airflow.[9, 10]

The objective of the research was to compare the porosity/compactness of knitted structures made from yarns with incorporated elastane and yarns without elastane, respectively, and evaluate the impact of elastane addition to the moisture management and air permeability properties of the elasticized and non-elasticized structures.

2. Experimental

2. 1. Raw Material Selection

For the research, viscose and polyacrylonitrile (acrylic) fibres were selected as the basic material due to their different origin and diverse properties. Viscose is made from a natural polymer – cellulose, while polyacrylonitrile is a man-made fibre made with an additional polymerization of acrylonitrile. The specific gravity of viscose is 1.50–1.52 g cm^{-3}, while the specific gravity of polyacrylonitrile is 1.16–1.18 g cm^{-3}. The reduced crystallinity of cellulose in viscose renders the fibre more responsive to water-penetration. Water molecules can force their way between the loosely organized cellulose molecules in the amorphous regions of the fibre. Viscose has a moisture regain of 13% under standard conditions. The water absorption of polyacrylonitrile is relatively low; however, it is sufficient to reduce the difficulties associated with the development of static charges and enables relatively good dyeability. Despite the low moisture absorption, acrylic fibres readily remove water by wicking. Polyacrylonitrile has a moisture regain of 1–3% under standard conditions.[11, 12]

2. 2. Sample Preparation and Structural Parameters

The samples of single jersey (cf. Table 1) were made from two different kinds of structured yarns produced with the same nominal parameters and linear density (100

Table 1. Samples characteristics and labelling

yarn	material composition	yarn structure	relaxation	knitted structure density compact	open
CV-EL	97.8% CV	core-spun	dry	CV-EL DR C	CV-EL DR O
	2.2% EL		wet	CV-EL WR C	CV-EL WR O
PAN-EL	97.8% PAN		dry	PAN-EL DR C	PAN-EL DR O
	2.2% EL		wet	PAN-EL WR C	PAN-EL WR O
CV	100% CV	conventional ring-spun	dry	CV DR C	CV DR O
			wet	CV WR C	CV WR O
PAN	100% PAN		dry	PAN DR C	PAN DR O
			wet	PAN WR C	PAN W O

tex), and made of the same viscose and polyacrylonitrile fibres, respectively. One kind of yarns included elastane (core-spun), while the other comparative yarns were conventional without the added elastane. From yarns, knitted fabric samples were produced under the same processing and environment conditions, in two density (porosity) levels which were defined as compact and open. After the knitting process, all knitted samples were statically dry relaxed. Then, half portions of samples were also dynamically wet relaxed by laundering and tumble drying, following the Starfish procedure to achieve full consolidation and the reference state.[13, 14]

Combining two yarn structures, two fibre types, two density (porosity) levels and two relaxation conditions, sixteen different knitted samples were prepared in all. Despite the portion of added elastane to the elasticized samples being equal and the samples being produced under the same processing and environment conditions, different relaxation behaviour of viscose and polyacrylonitrile fibres during wet processes and different extension resulted in different porosity/compactness of the investigated knitted structures due to the formation of loops of different shapes and sizes. Consequently, differences in wetting and wicking properties, and air permeability were expected.

In order to evaluate the performance properties of structures with and without elastane addition, the basic structural parameters were determined with laboratory tests. From the measured basic parameters, the following knitted structure parameters describing the porosity/compactness of the structure were calculated: density coefficient C, cover factor K and loop modules – δ (linear), δpl (planar) and δv (volume). The density coefficient C describes the loop shape as it represents the ratio between the loop width and the loop height. The cover factor K indicates the extent to which the area of the knitted fabric is covered with the yarn. It represents the ratio between the square root of the yarn linear density and loop length. A higher cover factor indicates a tighter structure. The linear loop module δ indicates the ratio between the yarn diameter and the portion of the yarn length forming one loop. The planar loop module δpl indicates the ratio between the area filled with yarn within one loop and the area of a rectangle outlining the loop. The volume loop module δv

Table 2. Parameters describing porosity/compactness and structure of investigated knits: density coefficient, loop modules, cover factor, fabric thickness and fabric mass per unit area

sample	C	δ	δpl	δv	K ($tex^{1/2}$ mm^{-1})	t (mm)	M ($g\ m^{-2}$)
CV-EL DR C	0.54	11.00	0.29	0.90	1.29	1,92	488
CV-EL WR C	0.49	6.49	0.10	0.22	1.89	2,13	832
CV-EL DR O	0.56	14.77	0.28	1.09	0.96	2,40	471
CV-EL WR O	0.52	8.92	0.11	0.26	1.37	2,39	780
PAN-EL DR C	0.57	11.62	0.38	1.18	1.20	1,84	364
PAN-EL WR C	0.51	7.10	0.14	0.36	1.72	2,47	622
PAN-EL DR O	0.61	15.43	0.41	1.59	0.91	2,31	333
PAN-EL WR O	0.53	9.52	0.15	0.43	1.32	2,79	566
CV DR C	0.76	13.51	0.67	1.46	1.14	1,10	261
CV WR C	0.55	11.93	0.65	1.52	1.22	1,31	263
CV DR O	0.84	17.81	0.98	1.96	0.87	1,01	171
CV WR O	0.66	15.90	0.89	1.97	0.92	1,24	182
PAN DR C	0.75	14.60	0.68	1.83	1.12	1,26	253
PAN WR C	0.73	13.67	0.61	1.76	1.13	1,43	268
PAN DR O	1.08	19.29	1.09	2.94	0.85	1,25	193
PAN WR O	0.87	17.91	0.82	2.34	0.86	1,42	200

indicates the ratio between the space filled with yarn within one loop and the volume of a rectangular solid outlining the loop. The planar and the volume loop module are expected to predict the transfer properties of the knits (air permeability and moisture transfer). The values of the calculated parameters were compared to the ideal values: $C = 0.856$, $K = 1.4$, $\delta = 16.6$, $\delta pl = 1.0$, $\delta v = 1.0$.[14] The results are shown in Table 2.

2. 3. Testing Methods

Wetting was evaluated with the sinking test method, i.e. by measuring the time required for a piece of fabric to sink completely from the surface layer of water in a beaker. A sample of 3 × 3 cm was cut from the fabric and placed onto the surface layer of water in a 500 ml beaker. The wetting time was estimated with a stop watch as the time interval between the moment of immersion and the moment when the sample sunk under the water level.[7, 15] Each experiment was performed at least five times. The sinking time of about 5 sec is generally considered satisfactory for well prepared cellulosic materials.[16]

The wicking was evaluated with the wicking strip test method.[17, 5] Specimens of size 200 × 25 mm, the length parallel to wale and course direction, respectively, were prepared. Each specimen was suspended vertically with its lower end immersed in a reservoir of distilled water to which a dye for tracking the movement (1% Prussian blue) was added. After 60 sec, the height reached by the water in the fabric above the water level in the reservoir was measured with a clamped scale to 1 mm. Each experiment was performed at least five times in each direction (wale-wise and course-wise).

Air permeability was tested according to the ISO 9237:1999 (E)[18] standard on the apparatus FX 3300 (Textest Switzerland) at 100 Pa. The air flow through a specimen was determined from the pressure drop across the orifice of known area. The rate of airflow was expressed as the quantity of air in litres passing per second through a square meter of fabric.

3. Results and Discussion

The wetting time of the samples measured with the sinking test method is presented in Table 3 and Figure 1.

Table 3. Wetting time (sinking test method)

sample	wetting time (sec)			
	DR C	WR C	DR O	WR O
CV	1.36	1.93	1.53	2.07
CV-EL	0.67	16.55	1.07	51.88
PAN	1.38	6.59	5.29	13.94
PAN-EL	1.09	1.46	1.41	2.49

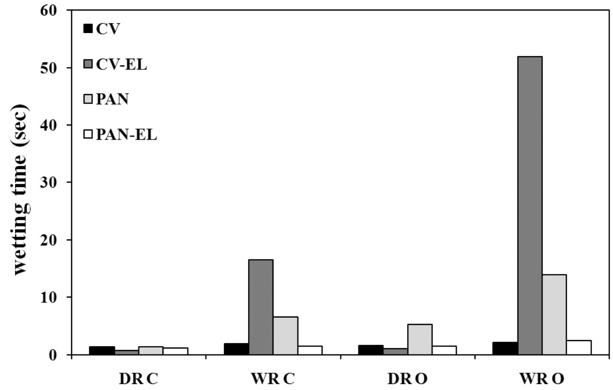

Figure 1. Wetting time (sinking test method)

From Table 3 and Figure 1, it can be seen that the wet relaxed (consolidated) elasticized viscose knits in both density (porosity) levels exhibit much longer wetting time, i.e. much lower wettability than other knits. The latter can be assigned to the packing of fibres within a yarn due to wet relaxation (shrinking), which leads to extreme compactness of the structure (expressed in structural parameters, cf. Table 2). The only other samples that exceed the level of 6 sec[16] are the wet relaxed polyacrylonitrile knits in both density (porosity) levels. Their reduced wettability after wet relaxation could be explained through the changes of surface roughness during the dynamic relaxation procedure.[13] The addition of elastane considerably reduces the wettability of the wet relaxed structure from hydrophilic viscose fibres, while it moderately increases the wettability of the wet relaxed structure from hydrophobic polyacrylonitrile fibres. All dry relaxed samples meet the satisfactory values of wetting time ≤ 5 sec.

Table 4. Wicking height (strip test method)

sample	wicking height (mm)							
	DR C		WR C		DR O		WR O	
	w	c	w	c	w	c	w	c
CV	30	29	30	28	32	29	34	25
CV-EL	38	39	21	28	43	42	34	32
PAN	53	38	59	46	55	37	53	41
PAN-EL	57	56	57	58	57	57	58	58

w = wales, c = courses

Table 4 and Figure 2 demonstrate that for the structures with no added elastane, the wickability (wicking height) is better in the direction of wales than in the direction of courses, which can be attributed to the "V" shape of the loop and yarn orientation within the loop. For the structures with added elastane, the wickability in the direction of courses is generally better than in the direction of wales, or almost equal due to the changed loop shape, which is contracted in the vertical direction (expressed in

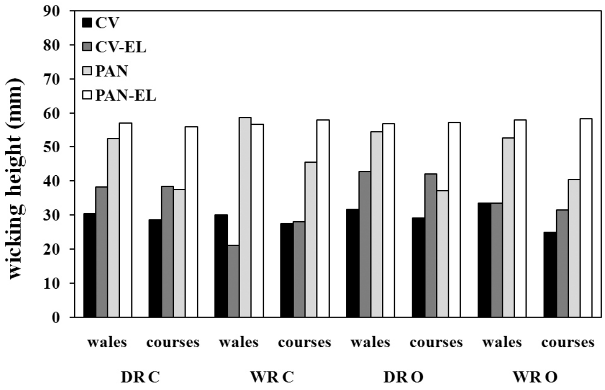

Figure 2. Wicking height (strip test method)

low density coefficient C, cf. Table 2). All polyacrylonitrile samples exhibit distinctively better wickability than comparable viscose samples, which can be attributed to good wicking characteristics of polyacrylonitrile fibres. In all cases, except for the wet relaxed compact (less porous) structures tested wale-wise, the elastane addition led to the improvement of wickability. The wet relaxed compact structures are very dense, the loops are contracted in the vertical direction and the yarn inclination in loop limbs is increased, which influences the wickability.

Table 5. Air permeability

sample	Air permeability ($lm^{-2} s^{-1}$)							
	DR C		WRC		DR O		WR O	
	f	b	f	b	f	b	f	b
CV	2635	2461	2344	2233	4510	4245	3827	3791
CV-EL	178	176	27	27	296	292	47	45
PAN	792	733	723	671	2158	1867	1700	1601
PAN-EL	229	227	77	76	379	377	115	112

f = front, b = back

From Table 5 and Figure 3, it can be seen that air permeability is much better for the samples with no elastane than for the samples with incorporated elastane due to their porosity. When no elastane is added, air permeability is better for the viscose samples, while with the elastane addition, air permeability is better with polyacrylonitrile samples. The latter can be explained with the much more compact fabric structure in the case of elastane addition to the viscose yarn (expressed in lower values of loop modules δ, δpl and δv). In all cases, air permeability is lower if measured on the back side of the samples, which can be explained with the difference in the roughness of the surface texture. Air permeability is the lowest for the wet relaxed compact (less porous) structures with added elastane.

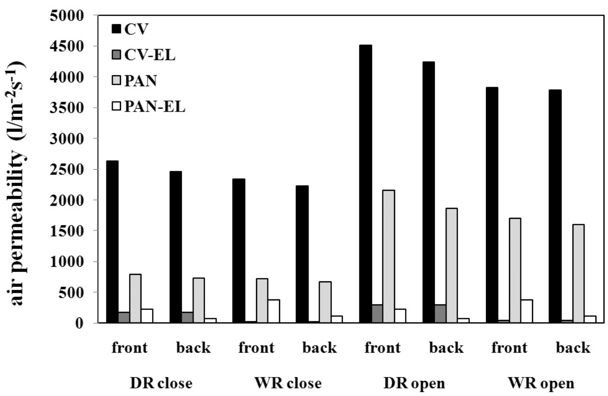

Figure 3. Air permeability

There is no explicit correlation between the structure compactness expressed by the loop modules and the cover factor and the examined transfer properties, presumably due to the complexity of the transfer process through fibrous materials.

4. Conclusions

The addition of elastane considerably reduces the wettability of the wet relaxed knits from hydrophilic viscose fibres, while it moderately increases the wettability of the wet relaxed knits from hydrophobic polyacrylonitrile fibres.

The polyacrylonitrile knits exhibit distinctively better wickability than comparable viscose knits, which can be attributed to good wicking characteristics of polyacrylonitrile fibres. The addition of elastane improves the wickability, apart from the case of very compact wet relaxed knitted structures, where the wale-wise wickability is reduced.

Air permeability is much better for the knits with no elastane than for the knits with incorporated elastane due to their porosity. When no elastane added, air permeability is better for the viscose knits, while with the elastane addition, air permeability is better for polyacrylonitrile knits.

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Povzetek

Cilj raziskave je bil primerjati poroznost/zbitost pletiv iz viskoznih in poliakrilonitrilnih prej z vgrajenim elastanom oz. brez elastana, in oceniti vpliv dodatka elastana na njihovo vpojnost in zračno prepustnost. Dodatek elastana znatno zmanjša omakanje mokro relaksiranih viskoznih pletiv, medtem ko poveča omakanje mokro relaksiranih poliakrilonitrilnih pletiv. Poliakrilonitrilna pletiva so bolj vpojna od primerljivih viskoznih pletiv. Pri pletivih brez elastana je večja prepustnost viskoznih pletiv, medtem ko je pri pletivih z dodanim elastanom večja prepustnost poliakrilonitrilnih pletiv.