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Strength and Comfort Characteristics of Cotton/Elastane Knitted Fabrics

Pamuk/Elastan Örme Kumaşların Mukavemet ve Isıl Konfor Özellikleri

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STRENGTH AND COMFORT CHARACTERISTICS OF COTTON/ELASTANE KNITTED FABRICS

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ABSTRACT: This study aims to investigate the elastic knitted fabrics produced by using different elastane yarn counts and elastane rates in terms of physical, strength and thermal comfort characteristics. The physical test results indicated that the fabrics knitted with coarser elastane yarn or higher rate of elastane had higher weight, thickness, bursting strength and puncture resistance. The thermal comfort properties pointed out that the fabrics including coarser elastane yarn or full plating elastane had higher thermal conductivity and thermal absorptivity values, while lower air and relative water vapour permeability.

Keywords: Cotton/elastane fabric, elastane yarn count, elastane rate, bursting strength, puncture resistance, thermal comfort

PAMUK/ELASTAN ÖRME KUMAŞLARIN MUKAVEMET VE ISIL KONFOR ÖZELLİKLERİ

ÖZET: Bu çalışma, farklı elastan iplik numarası ve elastan besleme oranıyla üretilmiş örme kumaşların fiziksel, mukavemet ve ısıl konfor özelliklerinin incelenmesini amaçlamaktadır. Fiziksel test sonuçları, daha kalın elastan numarası ya da yüksek elastan oranıyla örülen kumaşların yüksek gramaj, kalınlık, patlama mukavemeti ve delinme direncine sahip olduğunu göstermiştir. Isıl konfor özellikleri ise kalın elastan iplik numarası ile tam elastanlı yapıda örülmüş kumaşların daha yüksek ısıl iletkenlik ve ısıl soğurganlık değerlerine sahipken, daha düşük hava ve su buharı geçirgenliği sağladığını ortaya koymuştur.

***Anahtar Kelimeler*:** Pamuk/elastan kumaş, elastan iplik numarası, elastan oranı, patlama mukavemeti, delinme direnci, ısıl konfor

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1. INTRODUCTION

Fabrics have varying degrees of flexibility based on structural parameters. As it is known, knitted fabrics have inherently higher stretchability because of the loop form and it can be improved by using special yarn type such as elastane. The use of elastane in knitted fabrics has been increasingly preferred due to the higher movement comfort characteristics, which allows the wearer to adapt the body movements [1]. The fabrics including elastane yarns achieve better fit and higher stretchability with good shape retention throughout the life of wear, beside compact fabric structure, which will provide better strength characteristics [2].

The outstanding property of elastane is its high elasticity that can be more than 500%, while the elastic recovery reaches more than 95% [3]. Bare elastane is commonly used in circular knitting technology and plated with a ground yarn such as cotton, polyester, viscose etc. As it is shown in Figure 1, the elastic knitted fabrics may contain elastane in every course or alternating courses, classified as full plating and half plating, respectively. In order to achieve the desired fabric properties and uniformity, yarn count, feeding rate and feeding tension of elastane should be precisely set [4].

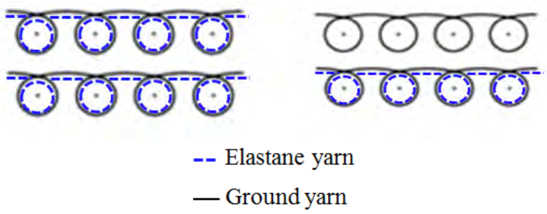


Figure 1. Needle diagram of the elastic single jersey fabrics: (a) in every courses (full plating), (b) in alternating courses (half plating) [4]

Various studies have been carried out about the effects of elastane feeding rate, feeding tension and fabric tightness on physical, dimensional and thermal comfort properties of knitted fabrics. Herath and Choon Kang [5, 6] have examined the effect of laundering on dimensional characteristic of core spun cotton-spandex 1×1 rib knitted fabrics. They have found that cotton-spandex rib structures had more stable than cotton fabrics after 10^{th} laundering cycle. In another study, they have determined that fabrics containing spandex yarn had higher dimensional constants. Geršak et al. [2] have studied the relaxation of the fabrics containing elastane yarns and the longest relaxation time was observed in the fabric having the highest content of elastane. Bayazıt Marmaralı [4] has investigated the characteristics of single jersey fabrics produced by cotton/spandex yarns. The results have indicated that the physical and dimensional properties, except loop length, were significantly affected from the tightness and amount of spandex in the structure. As the amount of spandex have increased, the air permeability, pilling degree and spirality values decreased as well. Tasmacı [7] has investigated the dimensional properties of single jersey fabrics knitted by cotton, viscose and polyester yarns with or without spandex. It has been revealed that the variations of weight were higher and the fabric surfaces were smoother for spandex-containing fabrics. Eryuruk et al. [8] have studied the elasticity, shrinkage, physical and mechanical properties of fabrics with different elastane yarn counts and elastane ratios. It has been found that the elastic recovery in widthwise direction and bursting strength increased, whereas air permeability, drape coefficient and spirality values decreased with an increase of elastane content. Fatkić et al. [9] have investigated the impact of yarn feeding load on knitted fabric properties. They have found that the optimal feeding load of yarns resulted to minimum dimensional changes by ensuring the stability and proper mechanical properties. The samples knitted with the lowest yarn feeding load have reported to enhance the optimum results for structural parameters and dimensional changes in the course of relaxation. Sadek et al. [10] have studied on the effect of lycra extension percent on the fabric properties, such as air permeability, bursting strength, breaking load, initial elasticity modulus and abrasion resistance, in single jersey knitted structures. They have compared half and full plating fabrics and have pointed out an optimal lycra percentage to improve the fabric quality. Senthilkumar et al. [11] have analysed the dynamic elastic recovery characteristics of spandex-plated and core-spandex cotton fabrics. It has been found that the spandex-plated fabric was preferable than core cotton spun fabric due to its elastic recovery characteristic.

Nowadays, an improved consumer demand has been occurred in technical textiles including clothing comfort as well as style and functionality. Comfort can be determined as satisfactory of physical and psychological harmony between body and environment. The thermo-physiological, sensorial and psychological comfort are the main parameters influence clothing comfort and the thermo-physiological comfort is the most important one especially for the garments designed for physical activities. It is closely related to the thermal balance of the body, which is provided by heat, moisture and air transfer [12-16].

In recent years, extensive research has been performed to determine effective parameters on clothing comfort. The type and content of fibre, the yarn properties, the fabric structure and the finishing treatments are found to be the significant factors affecting thermal comfort properties of fabrics [17-25].

Due to their lightweight, permeable and stretch characteristics, knitted structures can be preferable for comfortable clothing. As these fabrics have been used in technical applications, strength properties of these structures are considerably important besides their comfort properties. Within this study, it is aimed to investigate physical, thermal comfort and strength characteristics of knitted fabrics containing different yarn counts and different elastane rates. Apart from the previous studies, this research presents a comprehensive evaluation of the effects of elastane on both puncture resistance and overall thermal comfort properties.

2. MATERIALS AND METHODS

2.1. Production of Fabrics

The interlock knitted structures were produced on Fouquet branded circular knitting machine (gauge 18 and diameter 30”) with constant setting values by using ring spun cotton yarn (30/1

Ne, αe=3.7) and elastane yarns (20, 40, 60 den). In order to determine the effect of elastane rate on the fabric characteristics, the fabrics were knitted without elastane, with elastane in every courses (full plating) and with elastane in alternating courses (half plating). The effect of elastane yarn count was investigated only for the full plating structures. The stitch diagrams and yarn arrangements of samples are given in Table 1.

2.2. Testing

All samples were conditioned for at least 24 h in an atmosphere with a temperature of 20±2ºC and a relative humidity of 65±5%. The physical (course and wale density, mass per unit area, thickness and fabric density), the strength (bursting strength and puncture resistance) and the thermal comfort (air permeability, thermal conductivity, thermal absorptivity and relative water vapor permeability) properties were tested according to the related standards listed in Table 2.

The fabric density of the samples were determined using Equation 1:

$$\rho = \frac{M}{t} \quad (1)$$

where: ρ–fabric density (kg/m^3), M–mass per unit area of the fabrics (kg/m^2), t–fabric thickness (m).

2.3. Statistical Evaluation

Evaluation of the test results were assessed by one-way analysis of variance using SPSS software (Table 4). To deduce whether the group means are significantly different, the significance level (p-value) was determined. A significant difference occurred when $p \leq 0.05$.

The results were discussed in two groups:

- The effect of elastane yarn count
- The effect of elastane rate

Moreover, for the determination of the relation between the tested properties and for the interpretation of the results, correlation analysis was also performed (Table 5 and 6).

3. RESULTS AND DISCUSSION

The results and their statistical evaluations were given in Table 3 and 4, respectively.

Table 1. The stitch diagram and yarn arrangements of samples

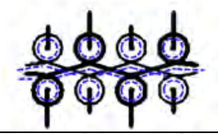
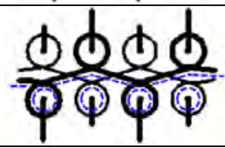
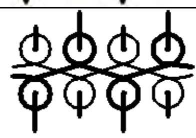
No.	Ground yarn	Elastane yarn count (denier)	Elastane rate	Stitch diagram
1	Ring cotton spun yarn (30/1 Ne, αe=3.7)	20	Full plating	
2		40		
3		60		
4	Ring cotton spun yarn (30/1 Ne, αe=3.7)	40	Half plating	
5	Ring cotton spun yarn (30/1 Ne, αe=3.7)	40	Without elastane	

Table 2. The tested parameters and test methods

Parameter		Related standard	Test devices
Physical properties	Course and wale density	CSN EN 14971:2006	-
	Mass per unit area	TS EN 12127	
	Thickness	-	Alambeta (Sensora instruments)
Strength properties	Bursting strength	TS 393 EN ISO 13938-1	Truburst
	Puncture resistance	EN 388	Zwick R10
Thermal comfort	Air permeability	TS 391 EN ISO 9237	Textest FX 3300 (pressure of 100 Pa and sample area of 20 cm^2)
	Thermal conductivity Thermal absorptivity	-	Alambeta (Sensora instruments)
	Relative water vapour permeability	TS EN ISO 11092	Permetest

Table 3. Test results

Fabric characteristics	Elastane Yarn Count (den)			Elastane Rate		
	20	40	60	Without Elastane	Half Plating	Full Plating
Courses per cm (cpc)	18	18	20	16	16	18
Wales per cm (wpc)	24	24	24	22	22	24
Stitch density (stitch/cm^2)	432	432	480	352	352	432
Weight (g/m^2)	278.57	279.13	363.73	206.6	259.87	279.13
Thickness (mm)	1.280	1.323	1.365	1.161	1.239	1.323
Fabric density (kg/m^3)	217.66	211.05	266.39	177.89	209.71	211.05
Bursting strength (kPa)	1576.16	1669.76	1686.14	1599.86	1633.14	1669.76
Puncture resistance (N)	49.10	50.10	57.57	32.30	40.90	50.10
Air permeability (l/m^{2}s)	1024	1318	782.2	2210	1446	1318
Thermal conductivity (W/mK)	0.0528	0.0533	0.0555	0.0498	0.0507	0.0533
Thermal absorptivity (Ws$^{1/2}$/m^{2}K)	134.78	171.58	171.50	112.28	152.72	171.58
Relative water vapour permeability (%)	48.03	49.18	44.10	50.23	48.88	49.18

Table 4. Statistical evaluation (p values) of the fabrics' characteristics

Fabric characteristics	Elastane Yarn Count (20-40-60 den)	Elastane Rate (without-half plating-full plating)
Weight	.000*	.000*
Thickness	.000*	.000*
Bursting strength	.012*	.000*
Puncture resistance	.008*	.012*
Air permeability	.000*	.000*
Thermal conductivity	.001*	.001*
Thermal absorptivity	.000*	.000*
Relative water vapour permeability	.003*	.504

The values of p are significant at the 0.05 level.

Table 5. Correlation coefficients of the mechanical and physical parameters

	Stitch density	Weight	Thickness	Fabric density	Bursting strength	Puncture resistance
Stitch density	1	.885*	.916*	.844	.502	.949*
Weight	.885*	1	.932*	.993*	.665	.946*
Thickness	.916*	.932*	1	.887*	.692	.986*
Fabric density	.844	.993*	.887*	1	.624	.911*
Bursting strength	.502	.665	.692	.624	1	.585
Puncture resistance	.949*	.946*	.986*	.911*	.585	1

*Correlation is significant at the 0.05 level (two-tailed)

Table 6. Correlation coefficients of the mechanical and comfort parameters

	Stitch density	Weight	Thickness	Fabric density	Air permeability	Thermal conductivity	Thermal absorptivity	Relative water vapour permeability
Stitch density	1	.885*	.916*	.844	-.846	.981*	.644	-.805
Weight	.885*	1	.932*	.993*	-.913*	.951*	.784	-.951*
Thickness	.916*	.932*	1	.887*	-.913*	.965*	.888*	-.780
Fabric density	.844	.993*	.887*	1	-.902*	.915*	.734	-.974*
Air permeability	-.846	-.913*	-.913*	-.902*	1	-.885*	-. 727	.813*
Thermal conductivity	.981*	.951*	.965*	.915*	-.885*	1	.760	-.862
Thermal absorptivity	.644	.784	.888*	.734	-. 727	.760	1	-.583
Relative water vapour permeability	-.805	-.951*	-. 780	-.974*	.813*	-.862	-.583	1

*Correlation is significant at the 0.05 level (two-tailed)

3.1. Weight and Thickness

Figure 2 and Table 4 illustrated that the elastane yarn count and the elastane rate had a significant effect on weight and thickness values. The highest weight and thickness values were obtained from the full plating fabrics with coarser elastane yarn. This situation can be explained by higher stitch density of these fabrics (Table 3).

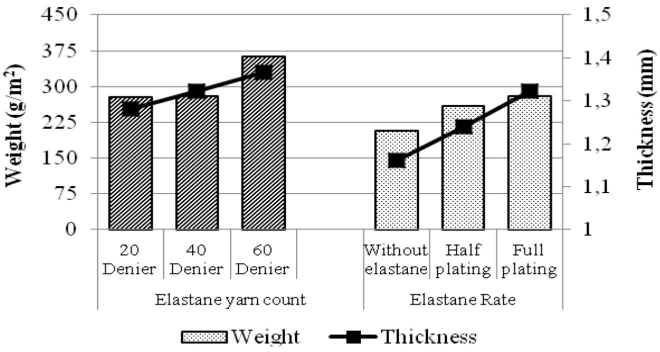


Figure 2. Weight and thickness results

3.2. Bursting Strength

Bursting strength is the force that must be exerted perpendicularly on the fabric surface to break off fabric. The bursting strength, which is the strength against multi directional forces, has become important especially for knitted fabrics [26]. The results indicated that the elastane yarn count and the elastane rate had a significant effect on bursting strength behaviour of the samples (Table 4). As the elastane yarn became thicker and the elastane rate increased, the bursting strength values of the samples increased as well (Figure 3). According to Table 5, the coefficient of correlation revealed that the parameters investigated had a mutual effect on bursting strength which is a complex phenomenon affected by the yarn strength, yarn elongation and fabric construction (structure, weight, thickness, density etc.) [8, 10].

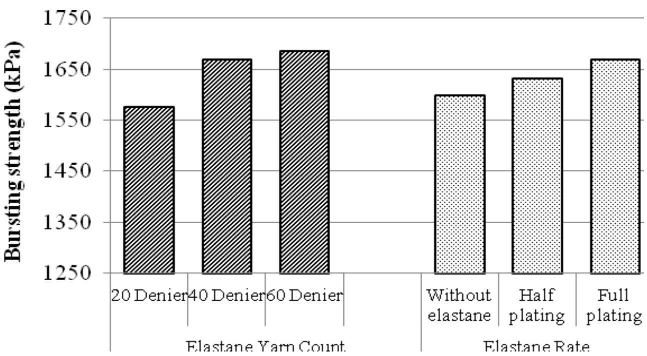


Figure 3. Bursting strength results

3.3. Puncture Resistance

Puncture resistance is the force required to penetrate the sample with a defined stylus using tensile test machine [27-30]. According to EN 388 standard, the puncture resistance level of all samples were at "level 1" in the range of 20-60 N.

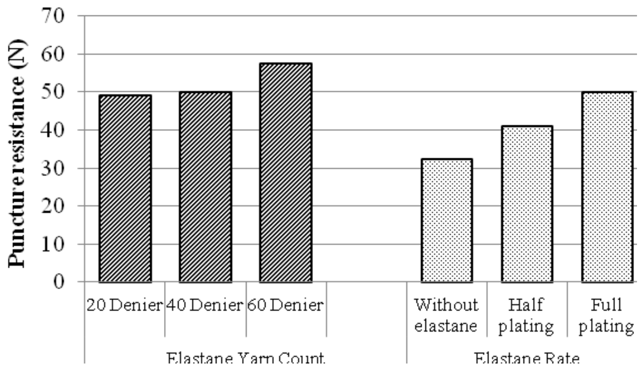


Figure 4. Puncture resistance results

When the results of puncture test were evaluated individually, the highest puncture resistance values were obtained in the samples knitted with the thickest elastane yarn and the highest elastane rate (Figure 4). This situation might be explained by the stitch and fabric densities that have high correlation with puncture resistance (Table 5).

3.4. Air Permeability

Air permeability is the rate of airflow through the fabric when subjected to a pressure difference on either surface of the fabric and it is mostly affected by the fabric porosity in addition to the thickness [31]. It was observed that the elastane yarn count and elastane rate had statistically significant effect on the air permeability. Due to the higher thickness and lower weight (Table 3) resulting in higher fabric density, the fabric knitted with 40 denier elastane yarn exhibited higher air permeability attributes than the fabrics knitted by 20 and 60 denier elastane yarns (Figure 5).

When the effect of elastane rate was compared, an increase in the amount of elastane yarn led to decrease in the air permeability. This situation might be explained by the fabric density, which has high correlation coefficient (R^2=-0.90) (Table 6). Within the samples, the knitted structure having the highest fabric density (the full plating sample knitted by coarser elastane) had the lowest air permeability. The dense character of this sample resulted in less space for air transfer (Figure 6).

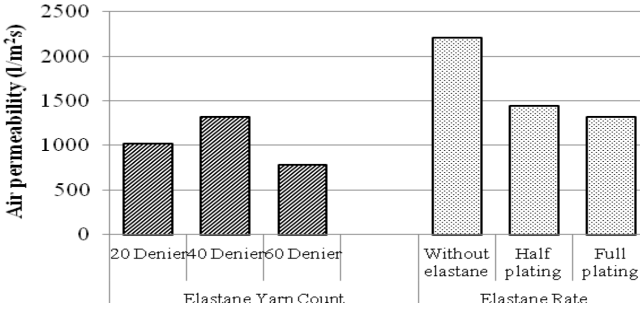
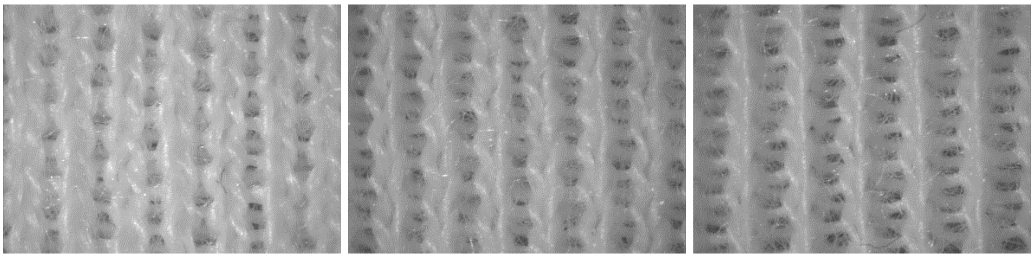


Figure 5. Air permeability results



(a) (b) (c)

Figure 6. Photos of the samples (a) full plating, (b) half plating, (c) without elastane

3.5. Relative Water Vapour Permeability

Water vapour permeability is the ability to transmit vapour from the body. Relative water vapour permeability is given by the relationship (Equation 2):

$$q(\%) = 100x\frac{q_s}{q_o} \qquad (2)$$

where: q_s-heat flow value with a sample (W/m^2), q_o-heat flow value without sample (W/m^2)

As stated in Table 6, the results of water vapour permeability showed similar tendency with air permeability (R^2=0.81). Higher fabric density led to a significant decrease in water vapour permeability (Figure 7).

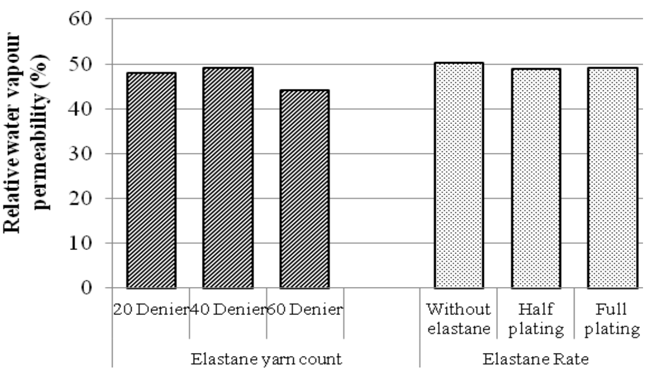


Figure 7. Relative water vapour permeability results

3.6. Thermal Conductivity

Thermal conductivity coefficient (λ) presents the amount of heat, which passes from $1m^2$ area of material through the distance 1m within 1s and the temperature difference 1K [32]. For textile materials, the still air in the fabric structure is the most important factor for conductivity value, since it has the lowest thermal conductivity value compared to all fibres (λ_{air}=0.026). The statistical analysis (Table 4) showed that the elastane rate and elastane yarn count had significant effect on thermal conductivity. The highest value was obtained from the sample including 60 denier elastane yarn. There wasn't any significant difference between the thermal conductivity values of fabrics knitted by 40 and 20 denier elastane yarns. When the results were compared according to the elastane rate, the fabrics knitted without elastane and with half plating elastane had lower and similar thermal conductivity values, whereas the full plating fabrics had higher values (Figure 8).

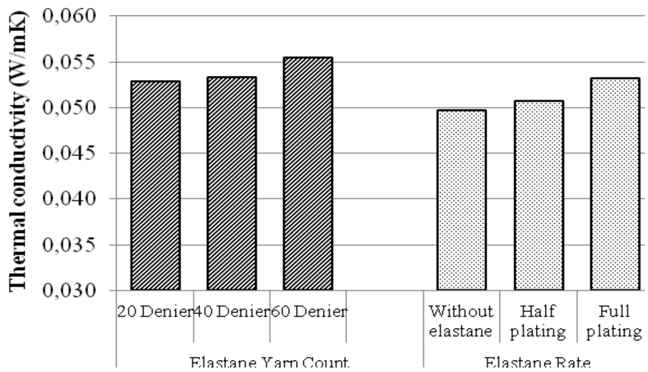


Figure 8. Thermal conductivity results

The differences can be attributed to the material thickness and the amount of entrapped air within the fabric structure. The structures having lower fabric density contain more still air, which has the lowest thermal conductivity value as compared to all textile fibres [33].

3.7. Thermal Absorptivity

Thermal absorptivity is the objective measurement of warm-cool feeling and determines the contact temperature of two materials. Fabrics with lower thermal absorptivity give warmer feeling. It can be expressed as:

$$b = ((\rho c)^{\uparrow}(1/2)\ (Ws^{\uparrow}(1/2)/m^{\uparrow}2\ K) \qquad (3)$$

where: λ-thermal conductivity (W/m K), ρ-fabric density (kg/m^3), c-specific heat of fabric (J/kgK)

It was revealed that the fabrics knitted by coarser elastane yarn had higher thermal absorptivity values and these fabrics gave cooler feeling at initial touch (Figure 9). This may be due to the higher conductivity values of the fabrics knitted by coarser elastane yarn (Equation 3). This situation can be also related to the structure of fabric surface. The existence of elastane yarn within the structure leads to an increase in the fabric density, which will create a smooth surface resulting cool feeling [34].

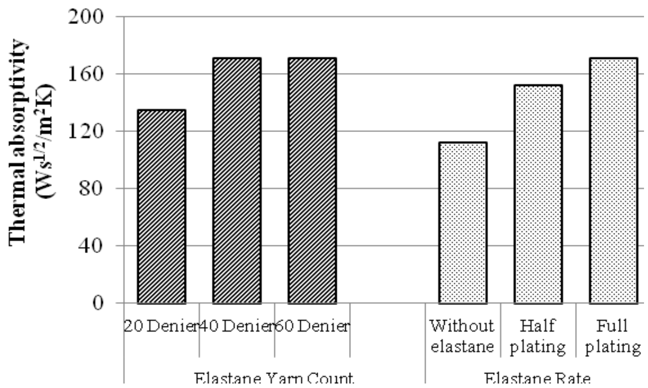


Figure 9. Thermal absorptivity results

4. CONCLUSION

This study aimed to investigate the physical, strength and thermal comfort characteristics of the fabrics knitted by cotton and elastane yarns. The physical properties such as weight, thickness, and stitch density, the strength properties such as bursting strength and puncture resistance and thermal comfort characteristics such as air permeability, thermal conductivity, thermal absorptivity and relative water vapour permeability were measured according to the related standards and statistically evaluated. The results indicated that:

The elastane yarn count had a significant effect on all measured parameters. The fabrics knitted by coarser elastane yarn had higher weight, thickness, bursting strength and puncture resistance. In terms of thermal comfort, the fabrics including coarser elastane yarn provided higher thermal conductivity and thermal absorptivity, lower air and relative water vapour permeability.

The elastane rate affected all parameters except relative water vapour permeability. The fabrics having higher rates of elastane ensured higher weight, thickness, bursting strength and puncture resistance. Additionally, as the rate of elastane yarn in the structure increased, the air permeability decreased and thermal absorptivity increased as well. The fabrics knitted using elastane yarns presented higher thermal conductivity.

According to these results, adding elastane yarn, especially in higher ratios, can be suggested for higher levels of strength performance. Besides altering of these characteristics, elastane would also affect thermal comfort properties. Thus, the structures should be considered in view of the application area.

For the foreseeable future, other than casual wear, the usage of the elastane fibres will become important also for technical products such as sportswear, medical and protective garments due to its higher stretchability. Future researches can focus on using elastane with different spinning methods (i.e. core spun, covered elastane etc.) for various technical purposes (compression effects, cut resistance, elastic recovery etc.).

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