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Investigation of the Effects of Blend Ratio on Permeability Properties of Cashmere/Cotton Knitted Fabrics

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Keywords
Cashmere,
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air permeability,
water vapor permeability,
porosity,
vortex spinning.

Abstract: In the context of this study, it is intended to investigate the effects of cashmere/cotton ratio in yarn and fabric density on permeability properties of knitted fabrics. The yarn samples were produced with three different ratios as; 95-5% cotton-cashmere, 90-10% cotton-cashmere and 85-15% cotton-cashmere via vortex spinning system. Then, the yarn samples were knitted with three different loop length values for producing the fabrics as loose, medium and tight structures. In doing so, nine fabric samples were produced. Air permeability and water vapour permeability of these samples were tested as comfort related properties. As a result of the study, it is observed that higher air permeability and lower water vapour permeability values can be obtained by using higher cashmere ratio in yarn structure.

Karışım Oranının Kaşmir/Pamuk Örgü Kumaşlarda Geçirgenlik Üzerindeki Etkilerinin İncelenmesi

Anahtar Kelimeler
Kaşmir,
pamuk,
hava geçirgenliği,
su buharı geçirgenliği,
gözeneklilik,
vortex eğirme.

Özet: Bu çalışma kapsamında, iplikteki kaşmir/pamuk karışım oranının ve kumaş sıklığının örgü kumaşlarda geçirgenlik özelliklerine etkilerinin araştırılması hedeflenmiştir. İplik numuneleri 95-5% pamuk-kaşmir, 90-10% pamuk-kaşmir ve 85-15% pamuk-kaşmir olmak üzere vortex iplik üretim sisteminde üretilmiştir. Daha sonra iplik numuneleri, gevşek, orta ve sıkı yapıda örgü kumaş üretmek amacıyla üç farklı ilmek uzunluğunda örülmüştür. Böylelikle, dokuz farklı kumaş numunesi elde edilmiştir. Konfor özellikleri olarak hava geçirgenliği ve su buharı geçirgenliği özellikleri test edilmiştir. Çalışma sonucunda, iplikte kaşmir oranının artmasıyla daha yüksek hava geçirgenliği ve daha düşük su buharı geçirgenliği değerlerinin elde edildiği gözlemlenmiştir.

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1. Introduction

There are many types of natural and synthetic textile fibers. Each fiber has its own specific mechanical and chemical attributes. With the development in technology and human life standards, the consumer demands from a textile product increases day by day. In order to satisfy the requirements, the fiber blends are used with different ratios to benefit from the attributes of the fibers. In this study, cotton-cashmere blended yarns are used to produce knitted fabric samples. Cotton is the most popular fiber in use and has advantages of excellent comfort properties in terms of absorbency and wickability. Cashmere is mostly produced in Northern China, Mongolia, Tibet and Afghanistan. Each goat produces between 100 and 160 g of usable down per year. This makes the cashmere fiber expensive. The cashmere down has fineness between 12.5–19μm[1]. Very soft handle and good warmness can be obtained owing to its very fine structure.

In the literature, some studies were done on the performance properties of blends made from cashmere and some other animal fiber types. McGregor and Postle [2] presented a study on investigation of the effects of cashmere in blends with superfine wools on the mechanical properties of single jersey knitted fabrics. It was stated that adding cashmere fiber to superfine merino wool provides softness, smoothness, flexibility, and suppleness to the knitted fabric. Oğlakcıoğlu et al. [3] conducted a study on effect of Angora rabbit fiber blend ratio with cotton on thermal performance property of knitted fabric. By means of statistical analysis, it was observed that fabrics including 25 % of rabbit fiber generated a significant difference on thermal performance properties. Naebe and McGregor [4] conducted a study on wool and wool-cashmere blends and their comfort properties. It was stated that both the cashmere blend ratio and fiber crimp of wool affected the comfort properties. McGregor and Naebe [5] produced 81 fabric samples composed of different cashmere blends with superfine wools of different fiber crimp. It was concluded that blending cashmere with wool progressively increased comfort assessment. Li and Zhou [6] presented a study on effect of cashmere yarn twist, knitted fabric density and cashmere fiber properties on fabric pilling performance. It was concluded that yarn twist and fabric density have minor effect on pilling rate whereas, the short fiber content of cashmere has significant effect on pilling rate.

In the literature, there is a lack of information on comfort performance of knitted fabrics composed of cashmere-cotton blend yarns. In this study, cashmere-cotton blended yarns were used regarding combining the advanced comfort properties cotton and cashmere fiber types. Vortex spinning system was preferred as a novel spinning technology owing to expanding usage of this technology for producing knitting yarns. On the other hand, it is intended to apply different knitted fabric densities to observe the effects of blend ratios for different fabric tightness.

2. MATERIAL AND METHOD

2.1.Material

In order to investigate effect of cashmere-cotton blend ratio on fabric comfort properties, three yarn samples via Murata vortex spinning method with three cashmere blend ratios; 5%, 10%, 15% were produced. The properties of fibers are given in Table 1.

Table 1. Fiber properties

	Cashmere	Cotton
Fiber Fineness	17 μm	4.2 Mic.
Length, mm	34	30.14
Strength, cN/tex	14	35

The yarn samples with 5%, 10% and 15% cashmere ratios are coded as Cash5%-Co95%, Cash10%-Co90% and Cash15%-Co85% respectively. The yarn evenness (uniformity, mass variation), imperfection (thin places, thick places, neps) and hairiness characteristics were measured by using USTER Tester 4. The yarn tenacity and elongation properties were determined in accordance with BS EN ISO 2062 [7] via USTER Tensojet4. Yarn properties are given in Table 2.

The yarn samples were knitted in single jersey structure by means of a sample circular knitting machine with 3.5" gauge, 22 fein and one feeder. Each yarn samples were knitted with three different loop length values. The fabric samples were used as raw state. Since the fabric samples were produced with a sample knitting machine with small dimension of fabric width (app. 20 cm), wet treatment process was not applied to fabric samples. The samples were applied to domestic home laundering. They were relaxed under standard atmosphere conditions according to TS EN ISO 139 [8] for 24 hours prior to sampling and testing.

The fabric structural properties are given in Table 3. The course and wale densities were measured according to TS EN 14971:2006 [9]. The fabric thickness and fabric mass were determined in accordance with the standards TS 7128 EN ISO 5048:1998 [10], TS EN 12127:1999 [11], respectively. The yarn loop lengths were measured according to the standard TS EN 14970:2006 [12].

In order to understand the statistical importance of cashmere ratio and fabric density on knitted fabric performance properties, two-way ANOVA was performed. For this aim the statistical software package SPSS 21.0 was used to interpret the experimental data. All test results were assessed at 95% confidence interval.

Table 2. Yarn properties

	Cash5%-Co95%	Cash10%-Co90%	Cash15%-Co85%
Yarn number, Ne	30/1	30/1	30/1
Uniformity, U%	12.8	14.6	12.8
Mass variation, CVm%	16.2	18.5	16.3
Number of thin places, -50%/Km	78	229	64
Number of thick places, +50%/Km	184	368	188
Number of neps, +200%/Km	116	304	160
Hairiness, H	5.0	5.6	5.2
Tenacity, cN/tex	13.6	12.0	12.6
Elongation, %	4.4	4.3	4.2

Table 3. Fabric structural parameters

Sample	Fabric Density	Thickness, mm	Fabric mass, g/m^2	Stitches Density, Stitches/cm		Loop length, mm
				Wale	Course	
Cash5%-Co95%	Loose	0.59	99	11	10	4.96
Cash5%-Co95%	Medium	0.61	111	12	12	4.50
Cash5%-Co95%	Tight	0.63	112	13	13	4.10
Cash10%-Co90%	Loose	0.61	92	10	10	4.96
Cash10%-Co90%	Medium	0.65	108	11	12	4.50
Cash10%-Co90%	Tight	0.67	112	12	13	4.10
Cash15%-Co85%	Loose	0.61	99	11	11	4.96
Cash15%-Co85%	Medium	0.62	111	12	12	4.50
Cash15%-Co85%	Tight	0.67	112	13	13	4.10

2.2.Method

Porosity, air permeability and water vapor permeability of the fabric samples were measured. All the fabric samples were conditioned in standard atmosphere according to TS EN ISO 139 [8] (65±4% relative humidity and 20±2 ^{0}C temperature) for 24 h before the tests.

Fabric porosity:

The porosity of the samples was determined by using image processing algorithm. The method is based on the conversation of the image into binary form to distinguish the pores between yarn intersection and yarn comprising the fabric structure. The pixel values of the image frame are assigned according to the light transmission level so that pore regions are seen bright while the regions covered by yarns are seen dark. The image analysis system consists of image acquisition and image processing parts. Five color image frames in JPG format and 2448 × 3264 pixels in size were acquired from different parts of each fabric sample by means of a camera with 60X magnification lens. The image acquisition process is achieved by using a Logitech HD Pro Webcam C920. The algorithm given in Figure 1 is applied to every sample images. First of all, the image is converted into 256 gray levels in order to apply 2D linear filters and binarization. The gray image is then applied Wiener low pass filter [13] to eliminate the noises caused from lightening condition and electrical reasons. The de-noised image is converted into binary form by applying a suitable threshold value. All pixels of the filtered gray image are replaced with the value 1 (white) when the luminance greater than threshold level, otherwise it is replaced with the value 0 (black). The white pixels

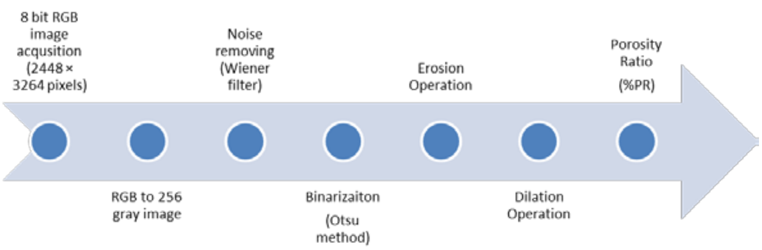

Figure 1. Porosity ratio calculation algorithm

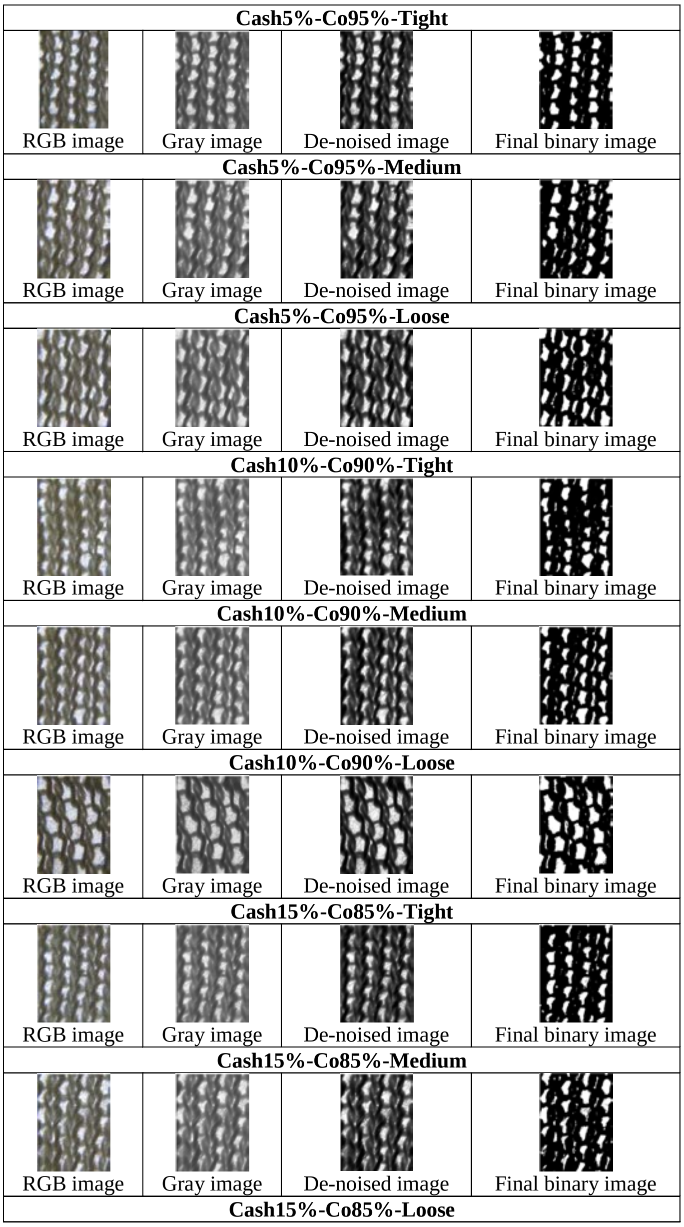

Figure 2. Porosity algorithm applied to fabric samples

correspond to pores and the dark pixels correspond to the yarn. The threshold value is determined by using Otsu method [14]. Since the yarn samples have hairiness, the fiber ends protruding from the yarn structure divides the pores and makes them smaller. In order to eliminate the hairiness effect and pore ratio calculation error, the binary image is applied dilation and erosion morphological operations with different structuring elements. The morphological operations apply a structuring element into the input image. The dilation operation means that if any of the neighbor pixel is set to *1,* the center pixel of the structuring element is set to *1*. In the erosion operation, if any of the pixel's neighbors is *0*, the center pixel of the structuring element is set to *0.* Finally, binary images with clear pores are obtained. The porosity ratio (PR) of each fabric sample is calculated as the percentage of white pixels to the whole pixels of the binary image. The images of the fabric samples applied the porosity algorithm are presented in Figure 2.

The Air permeability:

Air permeability was measured in accordance with the standard TS 391 EN ISO 9237:1999 [15] using SDL ATLAS digital air permeability test device at 100 Pa pressure drop and 20 cm^2 test area. The air flow is applied to the fabric surface to determine the air flow speed between two surfaces of sample. The measurements were repeated ten times for each fabric sample.

Water vapor permeability:

Water vapor permeability is determined according to BS7209-1990 [16] with SDL ATLAS water vapor permeability test device. Three circular specimens from each fabric sample and one reference fabric specimen were prepared and sealed over the open mouth of a dish. Approximately, 46 cm^3 distilled water at 20±2 ^{0}C temperature was transferred to each open dish before it is covered by the fabric specimen. In order to determine the water vapor permeability, successive weighings of the dishes are made at predetermined time periods. The assembled test dishes were placed on a turntable and rotated one hour to establish equilibrium of water vapor gradient. The weights of each assembled dishes were measured after an hour rotation. The assembled dishes were then rotated for five hours within the controlled atmosphere. The assembled dishes were reweighed at the end of this rotation period to determine the difference between the initial weighs.

The water vapor permeability (WVP) is calculated in $g/m^2/day$ by using following equation;

$$WVP = \frac{24M}{At} \quad (1)$$

Where,
M is the loss in mass of the dish over the time period in grams
t is the time between successive weighings of the assembled dishes in hours
A is the area of the sample that is $5.41x10^{-3}$ m^2

Also, the water vapor permeability index (I) is given by means of the following equation (2):

$$I = \frac{(WVP)_f}{(WVP)_r} \quad (2)$$

Where,
$(WVP)_f$ is the mean water vapor permeability of the fabric under test
$(WVP)_r$ is the water vapor permeability of the reference fabric

3.RESULT ANDDISCUSSION

Fabric Porosity

The porosity ratio of the fabric samples in accordance with the fabric density are given in Figure 3. The stitch density of the fabric decreases as the fabric sample gets looser, and so the area of the pores between the stitches comprising the fabric structure increases. The porosity of the fabric samples increases as the fabric density decreased in accordance with the expectation (Figure 3). The loose fabric of each yarn sample has the highest porosity ratio and the tight one has the lowest. In order to investigate the effect of the cashmere ratio on the fabric porosity, the results are given in accordance with the fabric densities (Figure 3). For all three fabric densities (tight, medium and loose), the porosity of sample is decreased as cashmere ratio is increased. This situation can be explained by the difference in yarn diameter owing to increased cashmere ratio.

The yarn diameter, yarn porosity and yarn volume are directly affected by the packing density of the yarn [17]. The packing density is inversely related to the diameters of ring, rotor and air-jet spun yarns [18].The yarn diameter can be calculated theoretically with the following equation [19].

$$\boldsymbol{d} = \frac{\sqrt{\boldsymbol{T}}}{\boldsymbol{280.2}\sqrt{\boldsymbol{\varphi\rho_f}}} \quad (3)$$

Where d= yarn diameter (cm), T= yarn linear density, $\boldsymbol{\rho_f}$= fiber density (g/cm^3) and $\boldsymbol{\varphi}$ = yarn packing factor. The yarn packing factor is mainly depends on the spinning method. Each spinning method has different packing factor coefficient [19]. Since all the yarn samples are produced via vortex spinning method and they have the same yarn number of 19.7 tex (Ne 30/1), the main factor that determines the yarn diameter is the fiber density. In accordance with Equation 3, the yarn diameter increases, as the fiber density decreases. For the blended yarns, average fiber density is given by the following equation [19].

$$\frac{1}{\bar{\rho}} = \sum_1^n \frac{p_i}{p_{ft}} \quad (4)$$

Where $\boldsymbol{\bar{\rho}}$ is the average fiber density, $\boldsymbol{p_i}$ weight fraction of the ith component, $\boldsymbol{p_{ft}}$ is the fiber density of the ith component and *n*is the number of components of the blend. Since wool fiber has lower density than cotton [20], the increase of the cashmere fiber ratio causes lower average fiber density. It can be stated that the cashmere fiber increases the specific volume and the diameter of the yarn structure. Thus, the area covered by the yarn increases as the cashmere ratio of the sample increase. This makes the yarns with higher cashmere ratio covering greater area than lower ones.

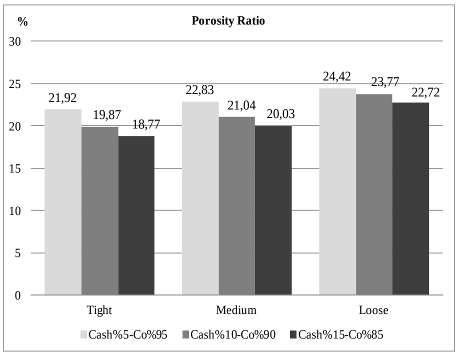

Figure 3. Porosity ratio of samples

Air Permeability Results

The air permeability test results are given in Figure 4. As the fabric tightness (stitch density) increases, the fabric thickness also increases and the pore size between the yarns decreases. So, the air permeability of the all samples increases from the tight density to loose density. The air permeability values of the samples are compared in terms of cashmere content (Figure 4). It can be observed that the air permeability of tight fabrics increase, as the cashmere ratio of the sample increases. Similar trend is also obtained for loose fabrics. Although the air permeability decreases between Cash5%-Co95% and Cash10%-Co90%, the highest air permeability is obtained for the highest cashmere ratio (Cash15%-Co85%). For the medium density, the highest air permeability is obtained with Cash5%-Co95%. The air permeability of Cash10%-Co90% and Cash15%-Co85% are close to each other and lower than that of Cash5%-Co95%.

The knitted fabrics have a porous structure. The air passes through pores between yarns and fiber comprising the yarn structure. The test results indicated that fiber blend ratio and porosity influenced the air permeability. Higher fabric pore size leads to higher air permeability and lower pore size of fabric have lower permeability. Although the higher cashmere ratio conduces to lower pore size between the yarn stitches (Figure 3), the higher air permeability is also obtained with the higher cashmere ratio than lower ones (Figure 4). It can be concluded that the higher cashmere ratio leads to higher open spaces between fibers within the yarn structure and allows air passage through the fabric more easily than lower ones. It can also be said that the more open spaces between the fibers compensates the lower pore sizes of fabric samples with higher cashmere ratios.

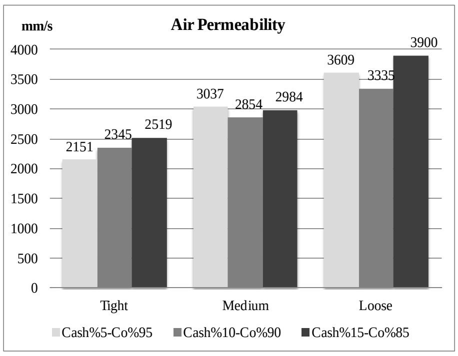

Figure 4. Air permeability of samples

Table 4 represents the results of two-way ANOVA for air permeability of the samples.

Table 4. Two-way ANOVA for air permeability

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	24804321.492[a]	8	3100540.186	189.300	0.000	0.952
Intercept	738452269.701	1	738452269.701	45085.337	0.000	0.998
Cashratio	1254838.928	2	627419.464	38.306	0.000	0.502
Looplength	22870005.251	2	11435002.625	698.151	0.000	0.948
Cashratio * Fabricdensity	1007747.496	4	251936.874	15.382	0.000	0.447
Error	1244803.214	76	16378.990			
Total	790569200.000	85				
Corrected Total	26049124.706	84				

a. R Squared = 0.952 (Adjusted R Squared = 0.947)

According to ANOVA, loop length and cashmere ratio have statistically significant effects on air permeability in 95% confidence interval. In addition, the interactions between loop length and cashmere ratio are found to be statistically significant ($p=0.000<0.05$). This means that the effects of loop length on air permeability differentiate for every cashmere ratio and vice versa. The air has flowing tendency through open spaces. So, it can be commented that since the spaces between the loop stitches are very low for the tight fabrics, the space between the fibers is more effective for air permeability. With the same logic, it can be concluded that since the loose fabrics has larger pores, the spaces between the loop stitches is more important than the spaces between the fibers for air permeability [21]. According to multiple comparison test results for cashmere ratio, it is seen that each ratio (5%, 10% and 15%) have statistically different effects on air permeability. In addition, each loop length value has statistically different effects on air permeability.

Water Vapor Permeability

Figure 5 gives the water vapor permeability (WVP) of the samples. It is observed that WVP index of the fabric samples decrease as the fabric stitch density decrease and get looser.

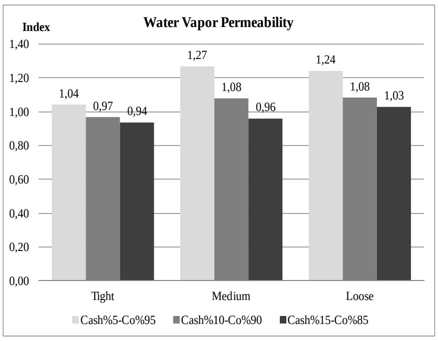

Figure 5. Water vapor permeability index of samples

It can be attributed to the fact that as the fabric stitch density increases, the pores between the yarn stitches decreases and the open area allowing the water vapor transmission also diminishes. On the other hand, the cashmere ratio has considerable effect on WVP index of fabric samples. As presented in Figure 5, the WVP index of each fabric density (tight, medium, loose) decreases with the increase of cashmere content in yarn structure. This situation can be ascribed to the fact that as the cashmere ratio in the yarn structure increases, the moisture absorption capacity of the fabric increases which diminishes the fabric diffusivity. Since cashmere wool has higher moisture absorption capacity (approximately 13-19%) than that of cotton (approximately 7-8.5%) [22,23], more water vapor is retained within the fabric structure.

Table 5 represents the results of two-way ANOVA for water vapour permeability of the samples.

According to ANOVA, loop length and cashmere ratio have statistically significant effects on water vapour permeability in 95% confidence interval. In addition, the interactions between loop length and yarn type are found to be statistically significant ($p=0.000<0.05$). This means the effects of cashmere ratio on water vapour permeability differentiate for every loop length and vice versa. According to multiple comparison test results for cashmere ratio, it is seen that each ratio (5%, 10% and 15%) have statistically different effects on water vapour permeability. With respect to loop length, 4.1 mm and 4.5mm loop length values have statistically similar effects on water vapour permeability whereas 5.0mm has statistically different effect than these values.

Table 5. Two-way ANOVA results for water vapour permeability

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	0.339[a]	8	0.042	109.978	0.000	0.980
Intercept	30.737	1	30.737	79667.934	0.000	1.000
Loop length	0.099	2	0.049	128.139	0.000	0.934
Cashratio	0.210	2	0.105	271.556	0.000	0.968
Loop length * Cashratio	0.031	4	0.008	20.108	0.000	0.817
Error	0.007	18	0.000			
Total	31.083	27				
Corrected Total	0.346	26				

a. R Squared = 0.980 (Adjusted R Squared = 0.971)

4.CONCLUSION

In this study, the effect of cashmere fiber ratio of cotton-cashmere blend yarns on fabric permeability (air permeability and water vapor permeability) and porosity was studied. It was observed that higher cashmere ratio provides higher yarn diameter and lower pore sizes between the yarns in fabric structure. For tight and loose fabric densities, the air permeability of the fabric samples increases with higher cashmere ratio in the yarn. This result was attributed to the fact that the cashmere fiber submits lower yarn packing density, higher yarn diameter and so more open spaces between the fibers in yarn structure. It was observed that the higher open spaces between the fibers compensate lower pore sizes in the fabric structure. So it can be concluded that by using higher cashmere ratio in yarn structure, a tighter and more solid fabric appearance can be obtained and also higher air permeability can be obtained. Since the moisture absorption capacity of the cashmere fiber is much more than that of cotton fiber, WVP performance of fabrics with less cashmere ratio is higher than that of fabrics with higher cashmere ratios.

Consequently, it is seen that the ratio of cashmere fiber content is an important factor that affects the thermal properties of the end product. This study is a preliminary work for the comfort properties of blended cotton knitted fabrics with expensive luxury fiber types such as cashmere. In further studies, the magnitude of the cashmere ratio should be studied in a more detailed manner with higher number of samples. Since, the cashmere fiber is an expensive fiber type. By this way, it would be possible to optimize the ratio of cashmere fiber in yarn structure with respect to cost and thermal comfort properties.

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