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INVESTIGATION OF THE THERMAL COMFORT AND SURFACE PROPERTIES OF 3/1 Z TWILL WOVEN DENIM FABRICS

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ABSTRACT

Denim fabrics are very preferred in recent years because it is easy to use and does not require ironing. But there is a limited study about the thermal and sensorial comfort of denim fabrics in the literature. The aim of this paper is to investigate the effect of the denim fabric composition on thermal comfort and sensorial comfort properties of denim fabrics. For this purpose, air permeability, thermal comfort, and water vapour permeability properties of 3/1 Z twill woven denim fabrics have been examined. Also, the Kawabata KES-FB4 system was used for the evaluation of the surface properties of fabric samples. It was found that the fabric with high surface roughness (F2) had a low thermal absorptivity value, and the fabric with low surface roughness (F3) had a high thermal absorptivity value. On the other hand, the lowest friction coefficient (MIU) was found in the lowest thickness value F4 coded fabric.

Keywords: *Denim, Thermal comfort, Water vapour permeability, Kawabata KESFB, Surface roughness*

3/1 Z DİMİ DOKUMA DENİM KUMAŞLARIN ISIL KONFOR VE YÜZEY ÖZELLİKLERİNİN İNCELENMESİ

ÖZET

Denim kumaşlar, jean olarak tanımlanan pantolonların üretiminde kullanılan, çok tercih edilen bir üründür. Çünkü özellikle günlük giyimde ütüye gerek duyulmadan kolay kullanım özellikleri sağlar. Ancak literatürde denim kumaşların termal ve dokunsal konforu ile ilgili sınırlı sayıda çalışma bulunmaktadır. Bu makalenin amacı, denim kumaşların termal konfor ve dokunsal konfor özelliklerine denim kumaş kompozisyonunun etkisini araştırmaktır. Bu amaçla 3/1 Z dimi dokumalı denim kumaşların hava geçirgenliği, ısıl konfor ve su buharı geçirgenlik özellikleri incelenmiştir. Ayrıca test edilen kumaş numunelerinin yüzey özelliklerinin değerlendirilmesi için Kawabata KES-FB4 sistemi kullanılmıştır. Yüzey pürüzlülüğü yüksek olan kumaşın (F2) düşük ısıl soğurma değerine sahip olduğu, düşük yüzey pürüzlülüğüne (F3) sahip olan kumaşın ise yüksek ısıl soğurma değerine sahip olduğu bulunmuştur. En düşük sürtünme katsayısı (MIU) ise en düşük kalınlık değerine sahip olan F4 kodlu kumaşta bulunmuştur.

Anahtar Kelimeler: *Denim, Termal konfor, Su buharı geçirgenliği, Kawabata KESFB, Yüzey pürüzlülüğü*

1. Introduction

Denim fabrics are preferred because they are easy to use, need no ironing, and provide wear comfort to users. Denim is produced with 3/1 and 2/1 twill structures with indigo dyed warp and white weft yarns, having weights of 14.5 ounces per square yard [1]. Denim fabrics are used especially in the manufacture of overalls and trousers which has good durability and comfort properties for this reason

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denim jeans are extremely popular for leisurewear. Denim fabrics are the name given to the fabrics that are mostly dyed with warp indigo dye and weft are produced in white colour. For this reason, one side of the material is seen with the blue warp threads and the other side is seen with white weft threads. Denim jeans are produced using the yarn called elastic core-spun yarn in order to provide comfort and freedom of movement to the wearer. This yarn consists of a hard, textured or elastic filament in the center covered with cut natural, man-made or synthetic fibers [2]. Nowadays, a double core yarn, defined as dual-core, has been developed in order to improve the recovery properties of elastic yarns. These yarns are especially preferred in denim fabric production, as they cause improvement in elasticity and growth properties. These yarns consist of a combination of a softcore such as elastane at the center with a hardcore such as polyester or PBT [3].

Denim fabrics are subjected to processes such as dyeing, finishing, and coating to satisfy the expectancy of people from fashion, but this duration influences some comfort characteristics like permeability. Thermophysiological comfort is correlated with the heat and moisture transmission characteristics of the clothes, as well as the interaction of the fabric with the skin. The most preferred method of producing denim clothes with better thermal comfort is the production of denim with different fiber compositions [4]. Although denim fabrics are popular, there are not many studies on comfort properties and especially tactile comfort properties.

Tactile comfort is the feeling that results from the touch of the fabric on the skin and is expressed in terms such as softness, smoothness, wetness, and itching. These descriptors may relate to the quantity of surface fibers and contact points, evaluate fabric, mechanical and surface properties, containing wet adhesion to the surface. Tactile comfort is influenced by fiber properties, yarn construction, fabric construction, and finishing applied to the fabric. The KES-FB measurement system developed by Kawabata and Niwan was used to estimate human tactile sensations by using mechanical measurements of fabrics [5]. Previous studies have revealed that surface properties are parameters that contribute strongly to the perceived touch of the fabric compared to other properties [6]. Kawabata KES-FB4 system was used for the measurements of geometrical surface roughness (SMD) and coefficient of friction (MIU) values of fabrics. SMD was identified as the average deviation of surface roughness of the fabric which unit is micrometer (μm). MIU represents the smoothness, roughness, and crispness of the fabric as well as the friction coefficient of the fabric surface. SMD value measures the geometric roughness value of the fabric and the lower the SMD value, the smoother the fabric surface [7].

In a study investigating the properties affecting the warm-cool feeling in cotton denim fabrics, it was observed that fabrics produced with a finer yarn count were measured cooler than the others. In addition, the washing process creates a feeling of coolness, but the washing process has a negative effect on the thickness, bulk density, and coating factor [8]. The effects of visual and tactile factors on consumers' purchasing process of denim bottom garments showed that dark denim prices are perceived as high and consumers evaluate the thermophysiological and tactile comfort properties of denim trousers by using their fingers. In addition, it has been shown that social, psychological, and sensory pleasures are also taken into account when determining the comfort characteristics of a denim product [9]. In a study investigating the thermal comfort of denim fabrics under dynamic humid conditions, a model was developed for the development of garments with higher thermal resistance under wet conditions. They explained that denim manufacturers will be able to produce garments that provide great benefits to users by making use of the findings obtained from this model [10]. The impact of fabric structural properties on thermal and air permeability features of denim fabrics were investigated in a study. It was concluded that properties such as fiber type, yarn structure and fabric thickness affect thermal comfort [11]. Jamshaid et al. [12] compared areal density, fabric thickness, air permeability, thermal insulation, and liquid moisture management features of a group of woven and knitted denim fabrics. The results showed that moisture management, thermal resistance, and air permeability results of knitted denim fabrics are higher than woven denim fabrics. The thermal comfort features of cotton and cotton/elastane denim fabrics were investigated and less thermal conductivity, absorptivity, and resistance results were observed in elastane composition fabric samples. Adding elastane to denim fabrics increases the thermal resistance of samples and gives a warm feeling and increases the water vapor resistance of fabric specimens [13]. Hosen et al. [14] investigated the effect of different softeners on the thermal and comfort features of stretch denim fabrics. Different types of enzymes and softeners were applied to %98 cotton and %2 elastane including denim fabric. The results demonstrated that the water vapor permeability values are higher when non-ionic softeners are used than in both enzyme washing and stone enzyme washing, while the thermal conductivity is lower when non-ionic and anionic softeners are used.

Güneşoğlu [15] investigated the effects of hydrophilic polyurethane coating on denim fabric's physical and comfort properties. It was concluded that the coating process affects the abrasion resistance, tensile strength, air permeability, water vapor permeability, and contact angle values of denim fabrics. The performance and comfort characteristics of laminated and raised denim woven fabrics were researched and some tests were applied to fabric samples such as; fabric thickness, air permeability, and water vapor permeability. It was concluded that the raising operation increases the air permeability properties of the fabric sample. It was declared that because of sealing operation the air permeability results of laminated fabrics measured zero [16]. In another study, the tactile comfort of denim fabrics from the perspective of mechanical properties and sensory properties was investigated. Softness, roughness, and tactile comfort properties were assessed by experts and consumers using subjective evaluation scales. The results emphasized that low-tensile mechanical properties were highly correlated with perceived tactile comfort and stone washing was the most efficient way of developing tactile comfort compared to enzyme washing [17]. Tactile comfort properties of different types of denim fabrics were measured with the FTT (Fabric Touch Tester) test device and sensory evaluations with a questionnaire. Cotton was used on the front side of the fabric and composition fibers were used with contact to the skin side. The result showed that the fibre type, weaving type and weft yarn count affect the tactile comfort properties of denim fabrics [18].

There are some studies about the physical features of denim fabrics in the literature but there is limited work on the thermal and tactile comfort features of denim fabrics with different compositions. This paper deals with air permeability, thermal comfort, water vapour permeability, and surface properties of 3/1 Z twill weaved denim fabrics. Contribution to previous studies, denim fabric's surface properties were carried out by using Kawabata FB4 measuring device.

2. Material and Method

Table 1 shows the properties of 3/1 Z twill weaved denim fabric samples. In this study, four fabrics were used, one without elastane and the other three with elastane. One of the fabrics containing elastane is dual-core and the other two are core-spun yarns. Core-spun yarns got this name because elastane is in the centre of the yarn. The yarn specified as dual-core consists of Elastomultiester (EME) and elastane and it is produced by feeding EME and Elastane together into the centre of the yarn. The tested fabrics were conditioned under the standard atmospheric conditions which are 20±2°C temperature and 65±2 % relative humidity for 24h. The thickness values of the fabrics were measured according to ASTM D1777 using a James Heal R&B cloth thickness tester. Depending on the thickness values of the fabrics, the volume of 1 m^2 fabric was calculated in cm^3. The fabric density in gr/cm^3 was found by dividing the calculated fabric weight by the volume value. By using the SDL Atlas air permeability measuring device, the air permeability tests were carried out under 100 Pa pressure in a 20 mm2 test area according to the ASTMD737-04 (2012) standard. The Alambeta tester is designed for the measurement of static and dynamic thermal properties of textile structures. The Alambeta tester generally consists of a measuring head and a base on which the sample is placed. Properties of fabrics such as thermal conductivity, thermal resistance, and thermal absorbency were measured using the Alambeta test device [19]. Permetest device is a new device that is used to quickly measure the water vapour, thermal resistance, and relative water vapour permeability properties of smooth fabric structures (fabric, non-woven surface, and paper) without damaging the sample [20]. The relative water vapour permeability results of fabrics were tested with the Permetest test device according to ISO 9920 testing standard. The measuring head is covered with the semi- permeable foil, while the test sample is placed on the curved moistened porous surface and exposed to the parallel airflow of adjustable velocity [21]. The coefficient of friction (MIU), mean deviation of MIU (MMD), and surface roughness (SMD) values of fabrics were measured with the Kawabata KES-FB4 measurement system. Measurements were made using the ISO 4287:1997 "Geometric Product Properties- Surface Texture: Profile Method Terms, Definitions and Surface Texture Parameters" standard. This system allows measuring the friction force as the fabric passes under the metallic friction head. With the help of this device, hand movements in the form of slipping from the fabric surface made by experts while evaluating the fabric texture can be simulated and objective measurement results can be obtained. ANOVA (single factor variance) analyses were used to determine the statistical significance of the fabric types and to deduce whether the parameters were significant or not, the p values were examined. If the p-value of a parameter was greater than 0.05 ($p>0.05$), the parameter was not investigated further.

Table 1. Fabrics used in the experiments

Fabric Code	Warp Yarn Count (Ne)	Weft Yarn Count (Ne)	Composition	Warp Ends (cm)	Picks (cm)	Weight (gr/m^2)	Thickness (mm)	Density (g/cm^3)
F1	7.6 /1 Cotton	6/1 Cotton	%100 Cotton 	24	19	396	0.69	0.57
F2	9.4/1 Cotton	12/1 DualCore	%95 Cotton, %3.5 EME, %1.5 Elastane 	32	17	295	0.62	0.47
F3	10/1 Cotton	13.1 /1 Corespun	%97 Cotton %3 Elastane 	34	20	326	0.56	0.58
F4	10/1 Cotton	13 /1 Corespun	%98 Cotton, %2 Elastane 	31	22	311	0.52	0.59

3.Results and Discussion

3.1.*Air Permeability*

The structural properties of the woven fabric and the finishing process exerted on the fabric affect the air permeability properties. To be detailed, fabric structure, fabric density, yarn twist amount, yarn count, yarn type especially the fabric porosity and thickness type affect the air permeability of woven fabrics. The air permeability of textile fabric structures is determined by the airflow rate passing through a material with the effect of the pressure difference between the two fabric surfaces [22]. Figure 1 shows the air permeability values of tested fabrics. When we compare the same yarn count of F3 and F4 fabrics, F3 fabric showed a higher air permeability value because of lower picks number per cm and lower density value. It supports previous work, when the number of filling yarns per centimeter decreases, the air permeability of the woven increases [23]. When the fabric that does not contain elastane is compared with the fabrics containing core-spun and dual-core, the lowest air permeability value was seen in the fabric without elastane (F1). Additionally, there was no significant relationship between elastane content and air permeability between fabrics produced from dual-core and core-spun. For this reason, it can be said that the parameters affecting air permeability are structural parameters rather than composition in this study. The highest weight F1 coded fabric showed the lowest air permeability value. This supports previous studies that air permeability decreases as weight increases [24]. The ANOVA test results supported that fabric type had an important effect on the air permeability of denim fabrics (Table 2).

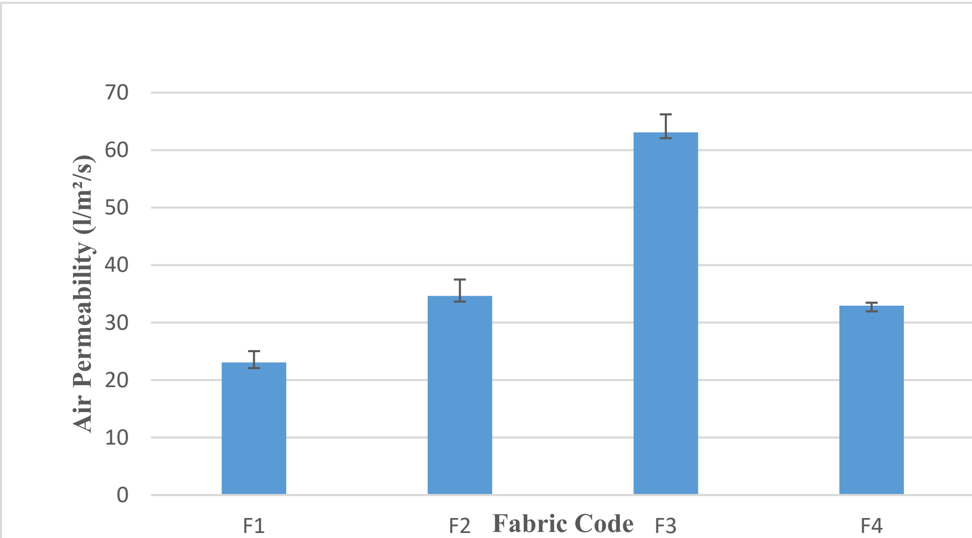

Figure 1. Air permeability values of the fabrics

Table 2. Anova table for air permeability results

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4438.746	3	1479.582	267.133	.000
Within Groups	88.620	16	5.539		
Total	4527.366	19			

3.2. *Thermal Conductivity*

The thermal conductivity of a material depends on its ability to conduct heat. The thermal conductivity values of fabrics are calculated according to the equation (1):

$$\lambda = Q/(F.\tau.\Delta T/\sigma)\ W.m^{-1}K^{-1} \quad (1)$$

Where; Q conducted heat amount, F area of which the heat conducted, τ time of heat was conducted, ΔT drop of temperature, and σ fabric thickness [25]. The thermal conductivity values of tested fabrics were given in Figure 2.

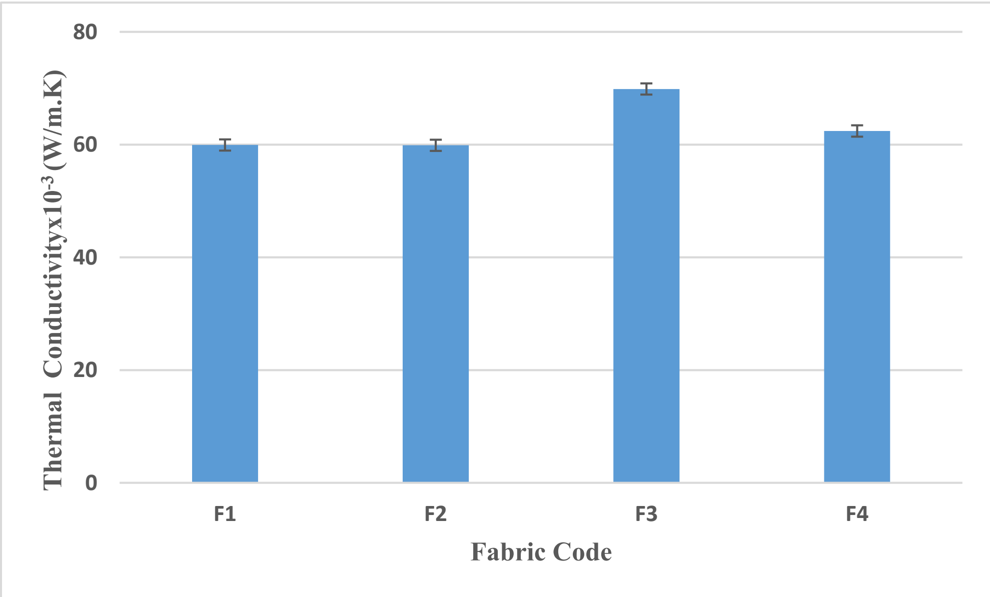

Figure 2. Thermal conductivity values of the fabrics

The thermal conductivity results of fabrics were close to each other because all fabrics were produced with cotton warp yarn. The thermal conductivity value of the fabric produced with F2 coded dual-core yarn was found to be equal to the F1 coded fabric made of 100% cotton. The fabric with the highest thermal conductivity test result was 97% Cotton, and 3% Elastane added fabric (F3), which also had the highest air permeability test result. When we compare F3 and F4 cotton and elastane included fabrics, the higher elastane composition F3 coded fabric showed a higher thermal conductivity value. The relationship between thermal conductivity and air permeability were given in Figure 3. The correlation coefficient is 0.90 here which means there is a good relationship between thermal conductivity and air permeability. As in previous studies, it has been shown that the increase in air permeability also increases the thermal conductivity value [26]. Because fibrous materials are composed of entrapped air and fibers. Stagnant air is defined as the amount of air held in the fabric's internal structure. Since the thermal conductivity value of stagnant air is less than the fibres, the amount of stagnant air is one of the important factors affecting the thermal conductivity value of textile structures ($\lambda air = 0.025$) [27]. The ANOVA test results supported that fabric type had an important effect on the thermal conductivity of denim fabrics (Table 3).

Table 3. Anova table for thermal conductivity test results

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	332.457	3	110.819	5.756	.007
Within Groups	308.020	16	19.251		
Total	640.477	19			

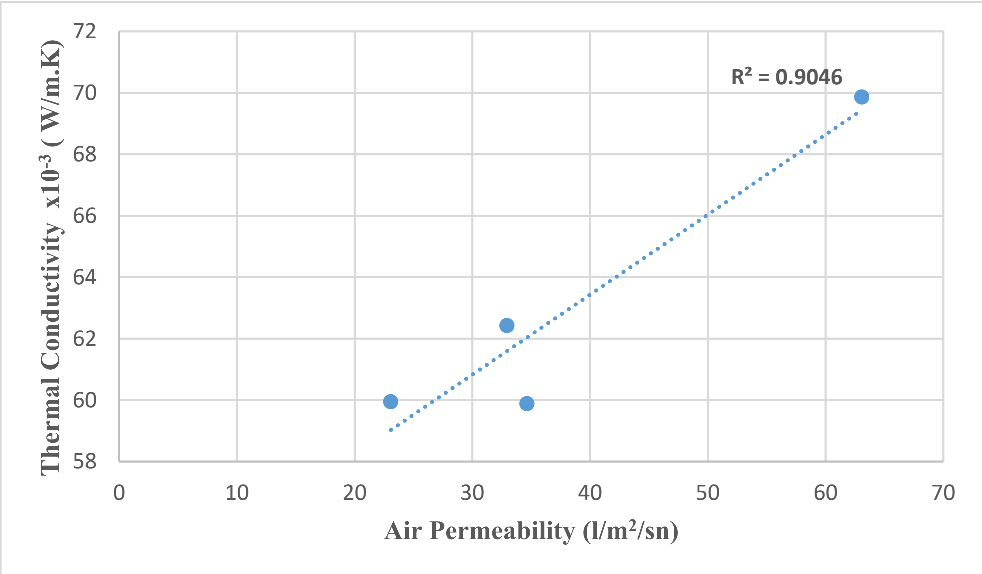

Figure 3. Relationship of AP and thermal conductivity of fabrics

3.3. Thermal Absorptivity

Based on the study of Yoneda and Kawabata, the temperature of the external environmental conditions was ignored and the thermal absorptivity definition was revealed based on the thermal and non-thermal properties of the fabric [19]. The thermal absorptivity results of samples were given in Figure 4. Fabrics with a higher thermal absorption value felt cooler on first contact with the skin than fabrics with a lower thermal absorption value. The most important factor affecting this is the fabric surface character and thermal absorption can be calculated according to the following:

$$b = \sqrt{(\lambda.\rho.c\ )}\ W.\ s^{1/2}.\ m^{-2}\ K^{-1} \tag{2}$$

Where: λ thermal conductivity, ρ fabric density, and c the specific heat of fabric [28]. The highest thermal absorption results were evaluated in the highest thermal conductivity and density values of cotton and elastane woven fabrics (F3 and F4). This is most likely due to fabrics that contain less entrapped air having higher thermal absorptivity values. The yarn count of F3 and F4 coded fabrics was almost the same because elastane composition was higher, F3 coded fabric showed a higher thermal absorptivity value. Elastomultiester fiber is a multi-component fiber and its chemical structure includes

40% polyester (3-GT type) and 60% polyester (2-GT type). For this reason, when these two different polyesters are exposed to heat, they shrink at different degrees and show elasticity. The lowest thermal absorptivity value was seen in %95 Cotton, %3.5 EME, %1.5 Elastane including dual-core weft yarn weaved fabric (F2). This means these fabrics feel warmer than the other fabrics according to Alambeta test results. Although all fabrics were produced with cotton as raw material, the thermal absorptivity value of this fabric was lower due to the presence of EME fiber, that is, a polyester-containing fiber in the fabric [29]. The ANOVA test results supported that fabric type had an important effect on the thermal absorptivity of denim fabrics (Table 4).

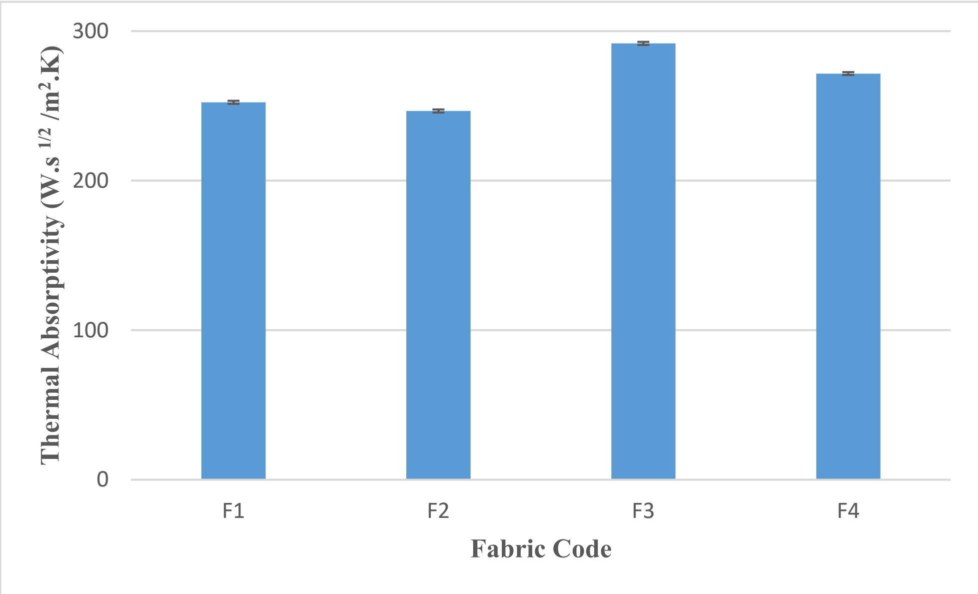

Figure 4. Thermal absorptivity values of fabrics

Table 4. Anova table for thermal absorptivity test results

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6288.400	3	2096.133	3.556	.038
Within Groups	9430.400	16	589.400		
Total	15718.800	19			

3.3.***Thermal Resistance***

Thermal resistance is the most important feature that determines the heat flow from the body in different climatic conditions. In cold climate conditions, it is desirable to reduce the heat flow from the body by using fabrics with high thermal resistance. In a given climatic condition, if the thermal resistance of the garment is small, the heat energy will gradually decrease with a feeling of coolness [30]. The thickness and thermal conductivity ratio of the fabric are effective in the measurement of thermal resistance, and this value is calculated according to the equation below [31]:

$$R = h/\lambda \quad m^2K.W^{-1} \tag{3}$$

The thermal resistance test results of samples were shown in Figure 5. The thermal resistance value changes directly proportional to the thickness of the fabric and inversely proportional to the thermal conductivity value. In addition, the primary determinant of thermal resistance is fabric thickness [32]. The highest thermal resistance values were seen in the highest thickness F1 cotton and F2 Cotton and dual-core weft yarn weaved fabrics. The highest air permeability, thermal conductivity and thermal absorptivity value, F3 coded fabric showed the lowest thermal resistance value. This can be explained with the higher density of this fabric. As a result of the increase in fabric density, the thermal resistance value of the fabric will decrease. The greater amount of entrapped air in fabrics acts as a barrier to thermal transmittance. When we compare F3 and F4 fabrics, F4 coded fabric showed a higher thermal resistance value because of the lower thermal conductivity value. The ANOVA test results supported that fabric type had an important effect on the thermal resistance value of denim fabrics (Table 5).

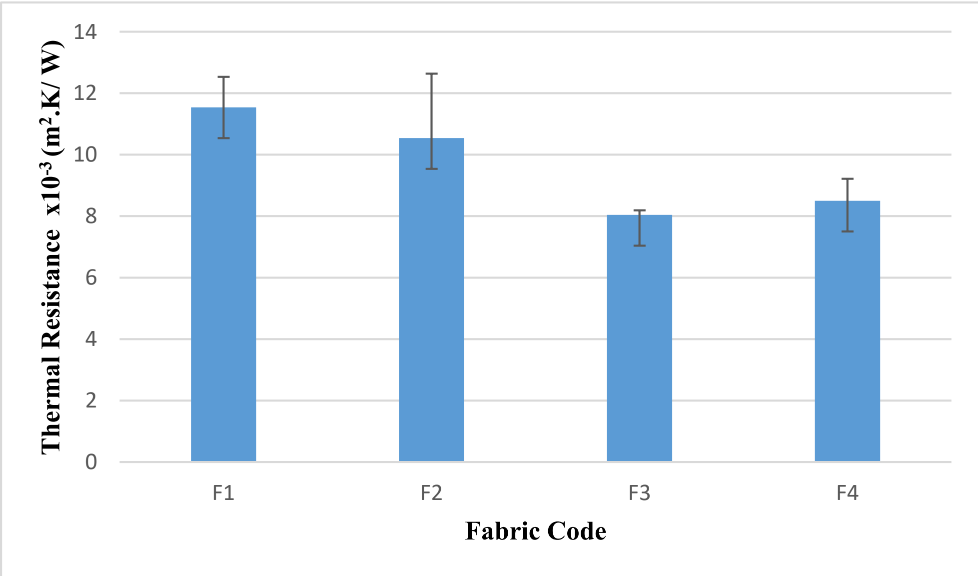

Figure 5. Thermal resistance values of fabrics

Table 5. Anova table for thermal resistance test results

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	41.393	3	13.798	9.332	.001
Within Groups	23.656	16	1.479		
Total	65.049	19			

3.5. Relative Water Vapour Permeability

Water vapour permeability is the capability to transmit vapour from the body to the outer surface. The relative water vapour permeability (RWVP) has been calculated according to the below equation:

$$RWVP = 100.\ Us/U0 \tag{4}$$

Where: Us the ratio of heat loss from the measuring head with a fabric sample, Uo the ratio of heat loss from the measuring head without a fabric sample [33]. The water vapour permeability values of fabrics were given in Fig. 6. The highest relative water vapour permeability value was seen in the lowest density value F2 coded dual-core weft yarn including fabric. This may be attributed to lower mass per square meter and thickness which causes the water vapour to pass easily through the fabric. The same warp yarn count F3 and F4 coded fabrics showed a close relative water vapour permeability value but F4 coded lower weight and thickness fabric showed a higher relative water vapour permeability value. Fabric thickness is one of the important parameters affecting the water vapour permeability value and as the material thickness increases, the water vapour permeability decreases. The highest thickness and weight value F1 coded fabric showed the lowest water vapour permeability value. As the water vapour permeability value of the fabrics increases, sweat evaporates and it becomes easier to be discharged from the human body to the outside. This means the highest water vapour permeability fabrics felt more comfortable and sweat in vapour form can be transferred to the outer surface of the fabric more easily. The ANOVA test results supported that fabric type had an important effect on the relative water vapour permeability value of denim fabrics (Table 6).

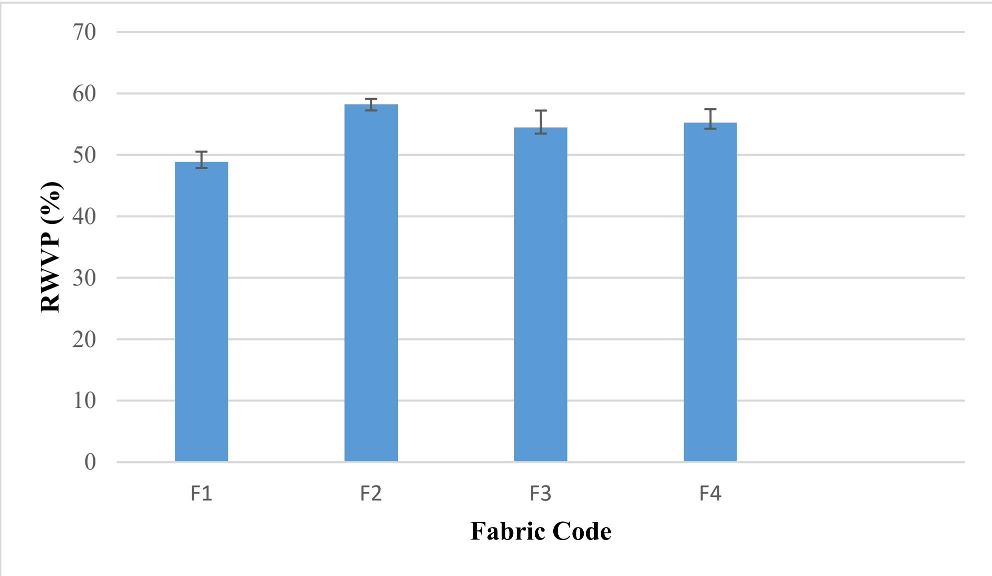

Figure 6. Relative water vapor permeability values of fabrics

Table 6. Anova table for relative water vapour permeability test results

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	137.553	3	45.851	11.482	.003
Within Groups	31.947	8	3.993		
Total	169.500	11			

3.6. Surface Properties

Kawabata has formed some terms for determining the tactile comfort of fabrics from mechanical measurements of fabrics. For the measurement of these mechanical properties, four devices were produced in cooperation with Kato Ironworks. With the help of these devices tensile, shear, bending, compression, and surface characteristics of fabrics can be measured. In this study, the fabric surface properties were emphasized and the surface properties of fabrics were measured with the Kawabata KES-FB measurement system. KES-FB measures geometrical roughness successfully and the KES-FB4 system is used for SMD (mean deviation of surface roughness) measurements. Also, MIU (coefficient of friction) and MMD (mean deviation of MIU) parameters were taken from the KES-F4 measurement system. Fabrics with lower MIU and SMD values often show better surface features [7]. MIU is associated with the slipperiness sensed when touching the surfaces of objects, and a higher MIU result indicates lower slipperiness [34]. The highest coefficient of friction value (MIU) was shown in F3 the highest warp and weft setting value fabric, this means that fabric warp and weft setting value increases, and MIU value also increases. The lowest coefficient of friction value (MIU) was seen as the lowest thickness value fabric (F4) which means this fabric is more slippery than others. The ANOVA test suggested that there wasn't a significant difference between the coefficient of friction value (MIU) of fabrics ($F = 0.414$, $p = 0.748 > 0.05$).

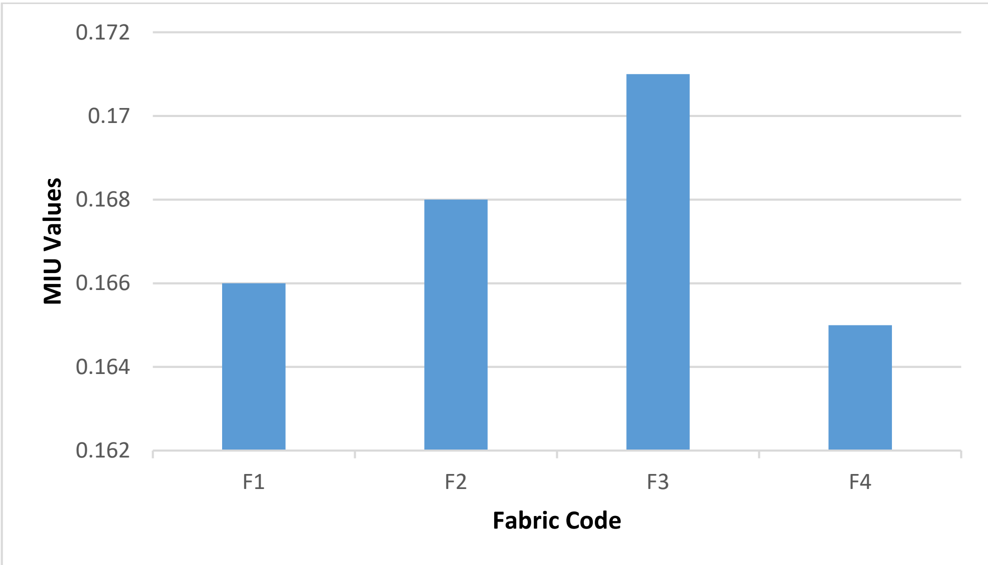

Figure 7. MIU values of fabrics

The surface roughness (SMD) values of fabrics were given in Figure 8. The highest surface roughness value was shown in F2 the lowest weight and density value fabric. Kim et al. (2005) declared that there was an inverse relationship between geometrical roughness, perceived softness, and warmth of touch. They find SMD= -0,683. perceived softness and SMD= -0,725. warmth of touch [5]. This means that a rougher surface provides a cooler and rougher touch. F2 coded fabric was woven with dual-core weft yarn. The results showed that the surface roughness value of F2 coded fabric was higher than the other fabrics. In other words, this fabric has a cooler and rougher handle than others. On the contrary, this fabric was measured with the lowest thermal absorptivity value according to Alambeta test results. The lowest SMD value was shown in F3 coded the highest thermal absorptivity value fabric. This means that this fabric has a low geometric roughness value and can be said to feel softer. In this study, the SMD value of the fabric with a high thermal absorptivity value was found to be low, while the SMD value of the fabric with a low thermal absorptivity value was found to be high. The screenshot of the Kawabata test system was given in Figure 9. The ANOVA test results supported that fabric type had an important effect on the surface roughness value of denim fabrics (Table 7).

Table 7. Anova table for surface roughness test results

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.507	3	1.502	18.546	.001
Within Groups	.648	8	.081		
Total	5.155	11			

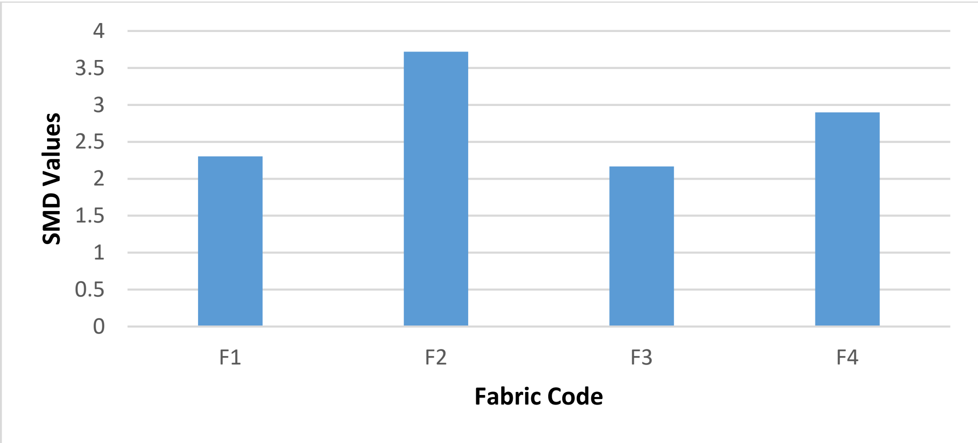

Figure 8. SMD values of fabrics

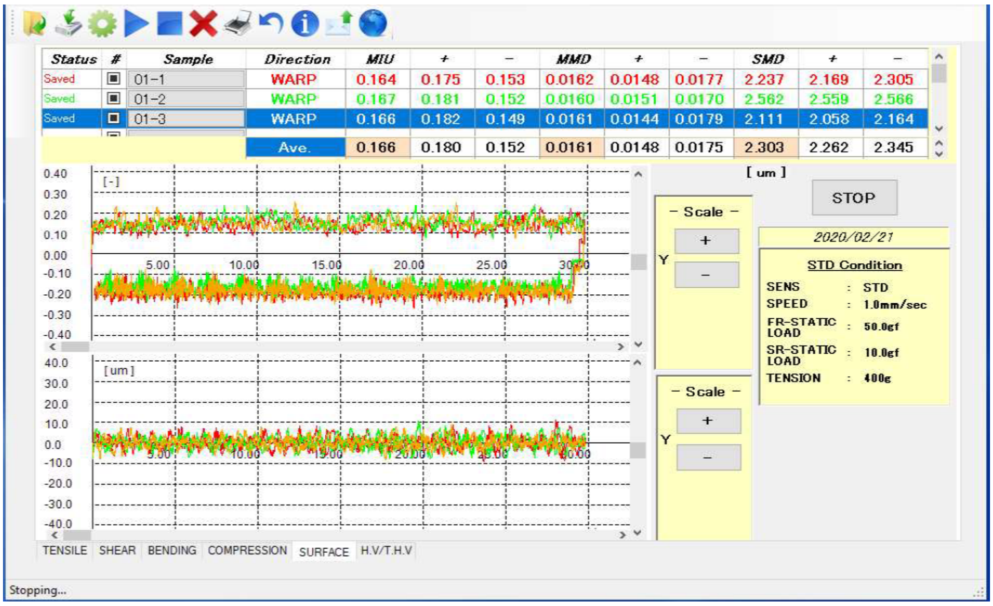

Figure 9. Screenshot of Kawabata test system

3. Conclusion

In this study, the air permeability, thermal properties, water vapour permeability, and surface roughness properties of a group of denim fabrics were investigated. The results showed that the highest thermal resistance values were seen in the highest thickness F1 cotton and F2 coded cotton dual-core composition weft yarn weaved fabrics. % 97 Cotton, %3 Elastane included fabric showed the highest air permeability, thermal conductivity, and thermal absorptivity values (F3). There is a strong relationship between thermal conductivity and air permeability (R2 = 0.90). The reason for this is that the amount of stagnant air in the fabric structure is one of the most important parameters affecting the thermal conductivity value and the conductivity value decreases as the amount of stagnant air increases. The highest thermal absorptivity values were seen in the highest density value elastane included fabrics (F3 and F4). This is most probably due to fabrics that contain less entrapped air having higher thermal absorptivity values. Also, EME included fabric showed the lowest thermal absorptivity value because this fiber consists of polyester fibers and the thermal absorptivity value of polyester is lower than that of cotton. It was found that the fabric with a high surface roughness had a low thermal absorptivity value, and the fabric with low surface roughness had a high thermal absorptivity value in this study. On the other hand, the lowest friction coefficient (MIU) was found in the lowest thickness value F4 coded fabric.

Acknowledgment

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Conflict Of Interest

The authors declare that they have no conflict of interest.

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