(REFEREED RESEARCH)

EFFECTS OF CALENDERING AND MILLING PROCESSES ON CLOTHING COMFORT PROPERTIES OF SUIT FABRICS

KALANDIRLAMA VE DİNKLEME İŞLEMİNİN TAKIM ELBİSELİK KUMAŞLARIN GİYSİ KONFORU ÖZELLİKLERİNE ETKİSİ

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ABSTRACT

The term of clothing comfort can be defined as a pleasant state including physiological, psychological and physical harmony between a human body and its environment. It is commonly classified into four broad categories: thermal, body movement, aesthetic and sensorial (tactile) comfort. One of the important components that affecting clothing comfort is the fabric that provides thermal balance between body and environment and achieves good tactile properties. Clothing comfort properties of fabrics are affected by fabric structure, type and ratio of fiber, yarn structure and finishing treatments. Within this study, the effects of calendering and milling process on thermal comfort and surface properties of suit fabrics were investigated. The results indicate that air permeability, thickness and thermal resistance values were decreased, while thermal absorptivity values were increased after calendering process. However, calendering had no significant effect on surface properties. Besides, milling process increased air permeability, thickness, thermal resistance and surface friction coefficient values and decreased thermal absorptivity values.

Key Words: Suit fabric, Calendering process, Milling process, Thermal comfort, Surface properties.

ÖZET

Giysi konforu, genel olarak çevre ile insan vücudu arasındaki fiziksel, fizyolojik ve psikolojik uyumu içeren memnuniyet durumu olarak tanımlanabilir. Isıl, vücut hareketi, estetik ve duyusal konfor olmak üzere dört temel grup altında incelenmektedir. Giysi konforunu etkileyen en önemli parametrelerden birisi çevre ile insan vücudu arasında ısıl dengeyi ve iyi tutum özelliklerine sağlayan kumaş yapısıdır. Giysilerin üretiminde kullanılan tekstil malzemesinin konstrüksiyonu, kullanılan lif tipi ve oranı, iplik yapısı ve uygulanan terbiye işlemleri giysilerin konfor özelliklerini etkilemektedir. Bu çalışma kapsamında, takım elbiselik kumaşlara uygulanan kalandırlama ve dinkleme işlemlerinin kumaşların ısıl konfor ve yüzey özelliklerine etkileri araştırılmıştır. Sonuçlar, kalandırlama işleminden sonra hava geçirgenliği, kalınlık ve ısıl direnç değerlerinin düştüğünü; ısıl soğurganlık değerinin arttırdığını; yüzey özelliklerinde istatistiksel açıdan önemli bir değişim olmadığını göstermiştir. Bunun yanı sıra, dinkleme işlemi hava geçirgenliği, kalınlık, ısıl direnç ve sürtünme katsayısı değerlerini arttırmış; ısıl soğurganlık değerlerini düşürmüştür.

Anahtar Kelimeler: Takım elbiselik kumaş, Kalandırlama işlemi, Dinkleme işlemi, Isıl konfor, Yüzey özellikleri.

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1. INTRODUCTION

In recent years, people's demands from the garment are psychological and physiological comfort, besides protection from hazards conditions (UV protection, anti-bacterial, flame retardant etc.). Clothing comfort, which includes thermal, body movement, aesthetic and sensorial comfort characteristics, is an important parameter for stabilizing the physiological balance between the body and environment. In different environmental conditions the body needs to transfer heat and moisture to its surrounding environment to provide this balance. In this case, the garment between the body and environment has a significant effect on the heat and moisture transfer and plays an important role to achieve the clothing comfort (1). Therefore, physical and thermal properties of textile materials that used in clothing have a great effect on physiological balance. Besides, tactile properties such as stiffness, bending rigidity, surface friction have also significant effects on entire clothing comfort properties.

The type and content of fiber (2-7), properties of yarn (8), fabric structure (9) and finishing treatments (10) are the significant factors affecting thermal comfort properties of fabrics. In addition, the finishing treatments such as dyeing, printing, calendering and milling, which are applied on textile materials to improve the appearance, handle (softness etc.) or performance properties (flame retardant, water repellent, resistance to creasing etc.) of the fabrics effect thermal comfort properties significantly.

Bajzik and Hes have studied about influence of finishing treatment on thermal properties of wet fabrics. Five different finishing treatments (two types of hydrophobic finishes, softening finish, sanforizing and temporary inflammable finish) were applied on three different cotton fabrics. Thermal conductivity, thermal resistance, thermal absorptivity and water vapour permeability of dry and wet fabrics were measured. They concluded that the highest effect was found for sanforizing, which caused substantial decrease of thermal conductivity of samples in wet state (11). Macsim et al. have studied about the effect of dyeing process conditions and they found that the structural parameters of knitted fabrics were affected by the process conditions (12). Tyagiet. al. have investigated the plain woven fabrics produced using polyester/viscose and polyester/cotton blended yarns in different ratios. They studied about the effects of finishing processes (such as desizing, scouring, rinsing, washing, neutralizing and drying) on thermal properties. The results indicated that the air and the water vapour permeability decreased by finishing treatments, while thermal insulation property increased (13). Akcakocaet. al. have worked on the effects of finishing treatments, such as bleaching, napping, sharing after napping and laundering, on thermo-physiological comfort properties of three-yarn fleece fabrics. They pointed out that thermal comfort properties of fabrics were affected significantly by finishing treatments, so it is needed to determine the comfort properties of fabrics after finishing processes (14).

As seen from the previous researches the effects of wet finishing treatments on thermal comfort properties were proved, however the mechanical processes such as calendering and milling processes have not been studied yet. In this case, this study will be an important step to introducing effects of the most common mechanical finishing processes on thermal comfort and also surface properties of garments.

2. MATERIAL AND METHOD

In this study, with the aim of analysing the effects of calendering and milling processes on thermal comfort and surface properties of woven suit fabrics, 2/2 twill fabrics were produced. Two fabrics with different structure were designed for summer and winter use to determine the differences. The fabrics were woven using 44/1 Nm 40%-40%-20% wool-cashlook-polyester blended warp yarn (caslook is a blend of 50% polyamide 6 and 50% polyamide 6.6 with a special soft finish) and 67/1 Nm 20%-40%-40% wool-cashlook-polyester blended weft yarn for winter use and using 44/1 Nm wool-viscose-polyester blended warp yarn and 57/1 Nm wool-viscose-polyester blended weft yarn for summer use by the same processes. After weaving process, gassing, washing and drying processes were applied to all fabrics and this fabric type is called as “dull”. Afterwards, calendering (shiny and very shiny) or milling processes were applied to these dull fabrics. For shiny effect, reverse side of the fabric calendered at 120ºC and 30 bar pressure; for very shiny effect, front side of the fabric calendered at 155ºC and 90 bar pressure.

All samples were kept under standard atmospheric conditions (20±2ºC and 65±2% moisture) for 24 hours before measurements.

Measured properties and test instruments are given on Table 1. Additionally, the physical properties of fabrics; such as tightness, mass, are shown in Table 2. In order to evaluate the test results, SPSS statistical software was used and to determine the statistical importance of the variations, ANOVA tests were applied by using Duncan multiple comparison procedure. The result of tests is a set of subsets of means (Table 2-8), where in each subset means have been found not to be significantly different from one another. To deduce whether the finishing parameters were significant or not, p values were examined. If “p” value of a parameter is greater than 0.05 ($p > 0.05$), the parameter will not be important and should be ignored.

Table 1. Measured fabric properties and test instruments

Tests	Instruments
Air permeability	SDL Atlas M021A air permeability tester(according to EN ISO 9237)
Water vapour permeability	PERMETEST (Sensora instruments, according to TS EN 31092)
Thickness, thermal resistance and thermal absorptivity	ALAMBETA (Sensora instruments)
Pilling	Martindale and pilling grade instruments (according to ISO 12945-2)
Surface friction coefficient	FRICTORQ II
Circular bending rigidity	SDL Atlas digital pneumatic stiffness tester (according to ASTM D4032)

Table 2. Physical properties of the fabrics

Fabric construction	Finishing treatment	Weft Density (pick/cm)	Warp Density (end/cm)	Weight (g/m^2)
40%-40%-20% Wool-Cashlook-Polyester	Untreated	42	40	170
40%-40%-20% Wool-Cashlook-Polyester	Dull	38	40	166
40%-40%-20% Wool-Cashlook-Polyester	Shiny	37	40	177
40%-40%-20% Wool-Cashlook-Polyester	Very shiny	38	40	176
40%-40%-20% Wool-Cashlook-Polyester	Dull+milled	36	38	183
20%-40%-40% Wool-Viscose-Polyester	Untreated	38	38	154
20%-40%-40% Wool-Viscose-Polyester	Dull	40	39	170
20%-40%-40% Wool-Viscose-Polyester	Shiny	40	39	169
20%-40%-40% Wool-Viscose-Polyester	Very shiny	40	39	169
20%-40%-40% Wool-Viscose-Polyester	Dull+milled	42	39	183

3. RESULTS AND DISCUSSION

3.1 Air Permeability

The amount of air flow that passes through from one side of the fabric to another side of fabric in certain area and under certain pressure is defined as air permeability. Air permeability values are affected by not only properties of fabric, such as porosity, structure, yarn properties, finishing treatments, but also environmental conditions, such as wind or pressure (15).

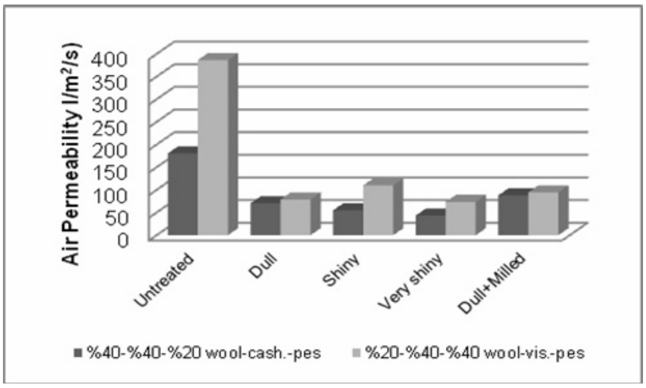

Figure 1. Air permeability values of the fabrics

The test results indicated that air permeability values decreased significantly after finishing processes and the fabrics treated as very shiny effect had the lowest air permeability (Figure 1, Table 2). These results can be explained by the structural changes in the fabric porosity because of the crushing of the yarns within the fabric after high pressure and temperature during calendering. Besides, milling process generates a bulkier fabric structure with a high air permeability characteristic. Furthermore, fabrics designed for summer use had higher air permeability than the winter fabrics, as expected.

3.2 Water Vapour Permeability

Fabric's ability of transfer non-condense water vapour from microclimate to environment is defined as water vapour permeability. If the water vapour cannot be transferred to environment, it condenses on the skin and it gives uncomfortable feeling to wearer (15).

All fabrics within this study provided higher water vapour permeability values that were greater than %50 (Figure 2). The statistical analysis shows that untreated fabrics had higher water vapour permeability values than the treated ones, while the differences between treated fabrics were insignificant (Table 3).

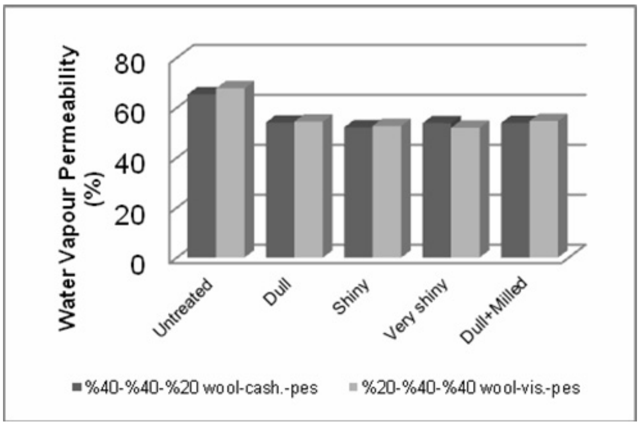

Figure 2. Water vapour permeability of the fabrics

Table 2. Effects of finishing process on air permeability values (W/C/P=wool/cashlook/polyester, W/V/P=wool/viscose/polyester)

Duncan	N	Subset for alpha = 0.05							
		1	2	3	4	5	6	7	8
Very Shiny-W/C/P	3	43.3							
Shiny-W/C/P	3	55.0	55.0						
Dull-W/C/P	3		70.3	70.3					
Very Shiny-W/V/P	3			73.6	73.6				
Dull- W/V/P	3			79.0	79.0	79.0			
Dull+Milled-W/C/P	3				87.9	87.9			
Dull+Milled-W/V/P	3					94.6			
Shiny-W/V/P	3						110.0		
Untreated-W/C/P	3							180.6	
Untreated-W/V/P	3								386.6
Sig.		.129	.051	.279	.080	.058	1.000	1.000	1.000

Table 3. Effects of finishing process on water vapour permeability values

Duncan	N	Subset for alpha = 0.05		
		1	2	3
Very shiny-W/V/P	3	51.9		
Shiny-W/C/P	3	52.2		
Shiny-W/V/P	3	52.7		
Very shiny-W/C/P	3	53.8		
Dull+Milled-W/C/P	3	53.9		
Dull-W-C-P	3	54.1		
Dull-W/V/P	3	54.4		
Dull+Milled-W/V/P	3	54.7		
Untreated-W/C/P	3		65.4	
Untreated-W/V/P	3			67.8
Sig.		.050	1.000	1.000

3.3 Thermal Resistance

Resistance of the fabric against to the heat flux is defined as thermal resistance. Thermal resistance values of the fabric are affected by fabric properties, such as thickness, porosity and amount of trapped air within the fabric and it is related to thickness and thermal conductivity values of material as shown in Eq.1.

$$R = \frac{h}{\lambda} \quad \text{Eq. 1}$$

where; R is thermal resistance (m^2K/W), h is thickness (m) and λ is thermal conductivity (W/mK) (15).

The results indicated that the thermal resistance values of untreated fabrics were higher than treated ones and decreased significantly after the finishing processes. This situation could be explained by change of the fabric thicknesses. In calendering process, the high pressure and temperature caused a decrease in thickness of fabrics (Figure 4), therefore thermal resistance values also decreased (Figure 3). Besides, these parameters had a decreasing trend with the increment of pressure and temperature. In milling process, the fabrics gained more hairy structure during passing through the milling cylinders. Therefore, the fabric had higher thermal resistance due to the high fabric thickness and more trapped air within the structure. In addition, the statistical evaluation indicated that thermal resistance values of fabrics designed for summer and winter uses had similar trends except milled fabrics (Table 4). After milling process, summer fabrics became to provide higher thermal resistance than the winter fabrics.

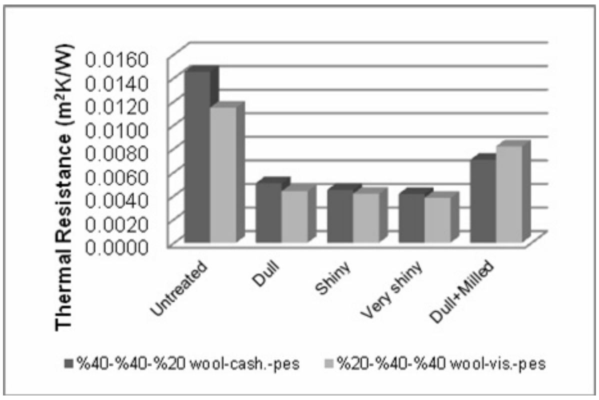

Figure 3. Thermal resistance of the fabrics

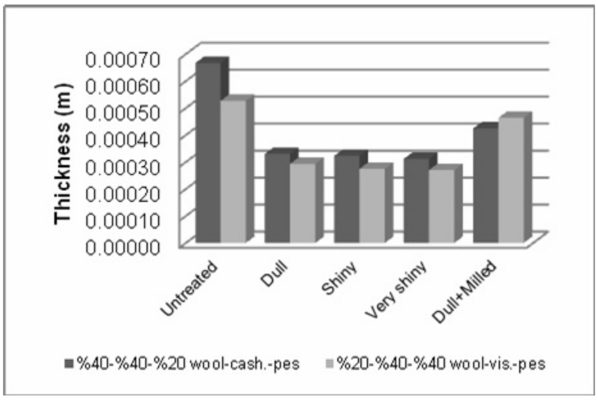

Figure 4. Thickness of the fabrics

Table 4. Effects of finishing process on thermal resistance values

Duncan	N	Subset for alpha = 0.05					
		1	2	3	4	5	6
Very shiny-W/V/P	3	.00380					
Very shiny-W/C/P	3	.00414					
Shiny-W/V/P	3	.00415					
Dull-W/V/P	3	.00436	.00436				
Shiny-W/C/P	3	.00448	.00448				
Dull-W/C/P	3		.00504				
Dull+Milled-W/C/P	3			.00703			
Dull+Milled-W/V/P	3				.00818		
Untreated-W/V/P	3					.01146	
Untreated-W/C/P	3						.01450
Sig.		.075	.062	1.000	1.000	1.000	1.00

3.4 Thermal Absorptivity

When a human skin touches a material, heat exchange occurs between the human skin and material. This first sense is defined as a warm-cool feeling and affected by thermal absorptivity characteristic. The sense of warm-cool feeling depends on temperature differences between human skin and material (15).

The fabrics gave cooler effect after finishing processes. Shiny effects led to cooler feeling at first contact (Figure 5, Table 5) due to their smoother surfaces. Besides, milled fabrics provided lower thermal absorptivity and so warmer feeling than calendered ones due to their hairy surface. Additionally, there was not any significant difference between the thermal absorptivity values of summer and winter fabrics.

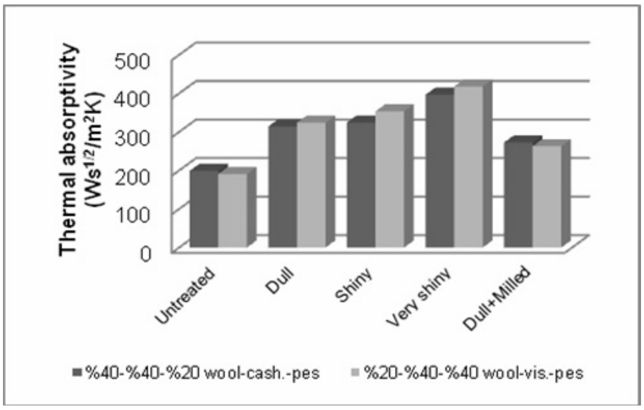

Figure 5. Thermal absorptivity of fabrics

Table 5. Effects of finishing process on thermal absorptivity values

Duncan	N	Subset for alpha = 0.05				
		1	2	3	4	5
Untreated-W/V/P	3	191				
Untreated-W/C/P	3	199				
Dull+Milled-W/V/P	3		263			
Dull+Milled-W/C/P	3		273			
Dull-W/C/P	3			314		
Dull-W/V/P	3			324		
Shiny-W/C/P	3			325		
Shiny-W/V/P	3				354	
Very shiny-W/C/P	3					397
Very shiny-W/V/P	3					418
Sig.		.522	.456	.467	1.000	.117

3.5 Pilling

Pilling is defined as the entangling of fibers on a fabric surface. Although it is a surface characteristic; it affects the structure of the fabric, as well. After pilling a deformation occurs and fabric becomes thinner with this deformation (16). That's why it also affects the thermal balance between human body and environment.

Pilling characteristics of untreated fabrics were not tested, as well as surface friction and bending rigidity, since they are commonly accepted as end product specifications.

The statistical results revealed that the pilling characteristics of all fabrics were close to each other, while the fabrics designed for summer use achieved better pilling values than the winter designs because of the hairy structure of cashlook yarn in winter fabric constructions (Figure 6, Table 6).

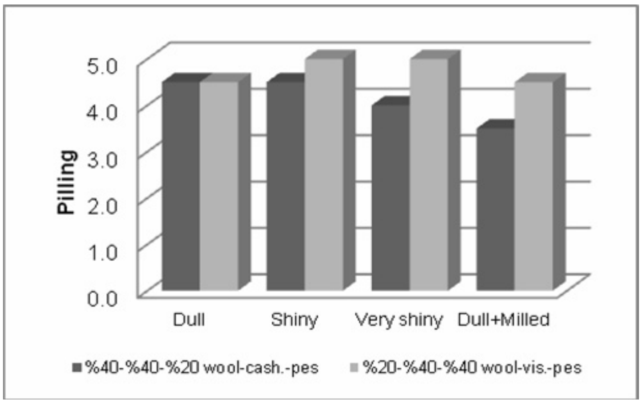

Figure 6. Pilling of the fabrics

Table 6. Effects of finishing process on pilling values

Duncan	N	Subset for alpha = 0.05		
		1	2	3
Dull+Milled-W/C/P	3	3.5		
Very shiny-W/C/P	3	4.0	4.0	
Dull-W/C/P	3		4.5	4.5
Shiny-W/C/P	3		4.5	4.5
Dull-W/V/P	3		4.5	4.5
Dull+Milled-W/V/P	3		4.5	4.5
Shiny-W/V/P	3			5.0
Very shiny-W/V/P	3			5.0
Sig.		.176	.219	.224

3.6 Surface Friction Coefficient

The resistance force of two mating surfaces is defined as frictional force. Friction coefficient, which is a scalar value, is the ratio of the frictional force to the down force that put two surfaces together. Friction coefficient between two textile surfaces is affected by yarn properties, fabric structure and finishing process. This property is commonly related to handle propertiesof fabrics. Therefore, it is very important for the sensorial (tactile) comfort properties of textiles (17).

Fabrics treated with milling process had higher surface friction coefficient due to their hairy structure, whereas calendering process gave low friction coefficient characteristic (Figure 7, Table 7). On the other hand, fabrics designed for hot or cold weathers had similar friction properties.

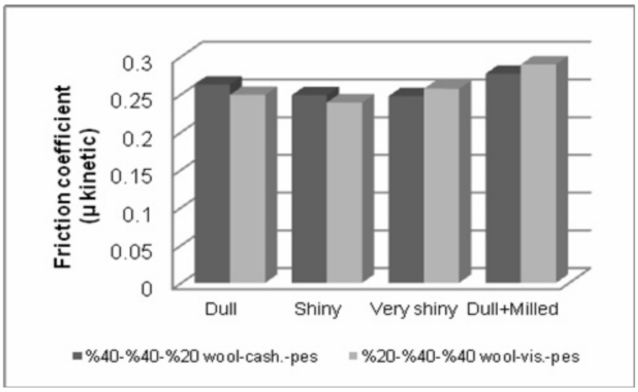

Figure 7. Friction coefficient of the fabrics

Table 7.Effects of finishing process on friction coefficient values

Duncan	N	Subset for alpha = 0.05			
		1	2	3	4
Shiny-W/V/P	3	.2392			
Very shiny-W/C/P	3	.2476	.2476		
Shiny-W/C/P	3	.2487	.2487		
Dull-W/V/P	3	.2491	.2491		
Very shiny-W/V/P	3	.2573	.2573		
Dull-W/C/P	3		.2629	.2629	
Dull+Milled-W/C/P	3			.2772	.2772
Dull+Milled-W/V/P	3				.2895
Sig.		.065	.114	.106	.159

3.7 Bending Rigidity

The resistance of textiles to drape is defined as bending rigidity. This value determines that if a fabric has a stiff or soft handle. Therefore, it is again important for tactile comfort of fabrics (18).

Evaluations showed that in general calendering or milling processes didn't exhibit any significant difference in bending rigidity values. However, the fabrics that designed for winter use had lower bending rigidity than summer designs due to the soft finish of cashlook yarn (Figure 8, Table 8).

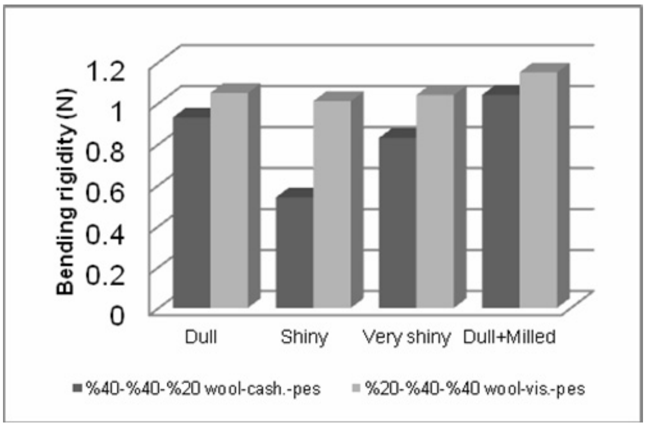

Figure 8. Bending rigidityof fabrics

Table 8. Effects of finishing process on bending rigidity values

Duncan	N	Subset for alpha = 0.05		
		1	2	3
Shiny-W/C/P	5	.54		
Very shiny-W/C/P	5		.83	
Dull-W/C/P	5		.93	.93
Shiny-W/V/P	5		1.01	1.01
Dull+Milled-W/C/P	5		1.04	1.04
Very shiny-W/V/P	5		1.04	1.04
Dull-W/V/P	5		1.05	1.05
Dull+Milled-W/V/P	5			1.15
Sig.		1.000	.067	.067

4. CONCLUSION

In this study, it is aimed to determine the influence of finishing treatments on thermal comfort and tactile properties of suit fabrics. For this aim, the effects of the most common finishing processes for woven suit fabrics, such as calendering and milling processes, on comfort properties of winter (wool/cashlook/polyester) and summer (wool/viscose/polyester) fabrics were investigated.

It was found that fabrics which were treated with calendering process by using cylinder with high temperature and pressure (very shiny effect), had lower air permeability, lower thermal resistance and higher thermal absorptivity values. While a fabric was passing through the cylinders, it became smoother and thinner. Thus, the pores within the fabric structure became smaller and air permeability and thermal resistance decreased, as well. Besides, because of losing its hairy structure, these fabrics became to give cooler feeling at first touch and provided low friction coefficient characteristic.

On the other hand, fabrics treated with milling process had higher air permeability and thermal resistance and ensured lower thermal absorptivity within entire treated fabrics. While a fabric was passing through milling cylinders, its surface became more hairy, pores became wider and so fabric became thicker and bulkier. By this way, air could be easily transferred through the fabric and these fabrics could provide high thermal resistance properties with warmer feeling at first contact. However, this bulky and hairy structure led to high surface friction coefficient.

Besides, it was proved that the fabrics designed for summer use had high air permeability properties and it should be advantageous to treat calendering process to achieve also higher thermal conductivity and cooler feeling at first contact. On the other hand, applying of milling process on winter fabrics leads to obtain higher thermal insulation and warmer touch feeling; however this process has negative effect on surface friction characteristic.

It can be concluded as, while design a suit, it should be considered that thermal and tactile properties of fabrics could be changed by finishing treatments. Therefore, it is important to determine and apply required treatments according to end use to achieve high functional characteristics.

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REFERENCES

1. Milenkovic, L., Skundric, P., Sokolovic, R. and Nikolic, T., 1999, “Comfort properties of defence protective clothing”, *The Scientific Journal FactaUniversitatis*, Vol.: 4, pp:101-106.
2. Jun Y., Kang K. Y., Park C. and Choi C., 2002, “Evaluation of textile performance of soccer wear”, *Textile Asia*, 5(33), pp:43-44.
3. Wang G., Zhang W., Postle R. and Phillips D., 2003, “Evaluating wool shirt comfort with wear trials and the forearm test”, *Textile Research Journal*, 2(73), pp:113-119.
4. Zhou L., Feng X., Du Y. and Li Y., 2007, “Characterization of liquid moisture transport performance of wool knitted fabrics”, *Textile Research Journal*, 12(77), pp:951-956.
5. Marmaralı A., Kadoğlu H., Oğlakcıoğlu N., Çelik P. veÜte T. B., 2008, “A research on properties of natural colored cotton/Angora rabbit fiber blended yarns and their effects on thermal comfort properties of knitted fabrics”, *Tekstil ve Konfeksiyon*, 3(18), pp:191-197.
6. Blaga N., Marmaralı A. and Mihai A., 2009, “High comfort knitted fabrics for linings of orthopaedics footwear”, *The 6th International Conference Management of Technological Changes*.
7. Bilen U. and Kırtay E., 2010, “The thermal properties of alpaca/wool blended fabrics”, *Fiber Society Spring International Conference on Fibrous Materials*, pp:137-138.
8. Nergis B. U., Candan C. and Küçükali M., 2010, “A study on moisture related properties of wool/acrylic blend fabrics”, *Fiber Society Spring International Conference on Fibrous Materials*, pp:147-148.
9. Majumdar A., Mukhopadhyay S. and Yadav R., 2010, “Thermal properties of knitted fabrics made from cotton and regenerated bamboo cellulosic fibres”, *International Journal of Thermal Sciences*, 49 (10), pp:2042-2048.
10. Abdel-Fattah S. H. and El-Katib E. M., 2007, “Improvement of pilling properties of polyester/wool blended fabrics”, *Journal of Applied Sciences Research*, 3(10), pp:1206-1209.
11. Bajzik V. and Hes L.,2012, “The effect of finishing treatment on thermal insulation and thermal contact properties of wet fabrics”, *Tekstil ve Konfeksiyon*, Vol: 1, pp:26-31.
12. Macsim M., Butnaru R. and Penciuc M., 2011, “The influence of dyeing process conditions on structural parameters of cotton knitted fabrics”, *Tekstil ve Konfeksiyon,* Vol: 3, pp:257-264.
13. Tyagi G. K., Krishna G., Bhattacharya S. and Kumar P., 2009, “Comfort aspects of finished polyester-cotton and polyester-viscose ring and MJS yarn fabrics”, *Indian Journal of Fibre& Textile Research*, Vol: 34, pp. 137-143.
14. Akcakoca K. P., Marmarali A. and Oglakcioglu N., “Finishing treatment effects on thermal comfort properties of three-yarn fleece fabrics”, *AATCC Review: the magazine of the textile dyeing, printing, and finishing industry*, Vol. 11, No. 4, 2011, pp. 46-51.
15. Marmaralı A., Kretzschmar D. S., Özdil N. and Oğlakcıoğlu N., 2006, “Parameters that affect thermal comfort of garment”, *Tekstil ve Konfeksiyon*, Vol: 16, No:4, pp. 241-246.
16. Candan C., “Factors affecting the pilling performance of knitted wool fabrics”, 2010, *Engineering Environmental Science*, Vol:24, pp. 35-44.
17. Lima M, Hes L, Vasconcelos R and Martins J, 2005, “Frictorq, accessing fabric friction with novel fabric surface tester”, *Autex Research Journal*, Vol.5, No 4, pp. 194-201.
18. Du Z, Zhou T, Yan N, Hua S and Yu W, 2011, “Measurement and characterization of bending stiffness for fabrics”, *Fibers and Polymers*, Vol.12, No.1, pp. 104-110.