THERMO-PHYSIOLOGICAL COMFORT OF BRUSHED WOVEN FABRICS

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Abstract: *Satisfaction of wearing of clothing is generally affected by clothing comfort properties and specifically by psychological perceptions of the wearer. A woven fabric mostly contains protruding fibers on the surface, which should be removed by burning, clipping, or brushing for appropriate processing. This paper deals with the effect of brushing on thermo-physiological comfort properties of woven fabrics. Three basic woven structures (plain, twill and sateen) were selected for this study. Thermal conductivity, thermal resistance and thermal absorptivity of these fabrics were measured by the Alambeta tester. Moreover, also water vapor permeability and air permeability were experimentally determined. The brushing treatment was applied manually by 1% and 3% of weight loss. A sample without brushing was considered as reference. Consequently, brushing affected the thickness, thermal properties, air permeability and water vapor permeability. With the increase in brushing application water vapor transmission decreased but thermal resistance increased.*

Keywords: *brushing, woven fabrics, thermal comfort properties, water vapor permeability*

1 INTRODUCTION

From last decade, the innovative textile technology and versatile living standards has changed the fabric demands. Nowadays, clothing is not only a belonging of aesthetic reasons but also comfort parameters, so textile fibre manufacturing industry is being flourished by new special fibres which have influential thermal and physiological comfort properties [1]. Generally, comfort is defined as “the absence of displeasure or discomfort” or “a neutral state compared to the more active state of pleasure” [2]. Comfort may be defined as a pleasant state of psychological, physiological and physical harmony between a human being and environment [3].

Many researchers have focused on the analysis of thermal comfort of woven fabrics [4, 5]. The fibre and fabric composition are influencing parameters to thermal properties of clothing. For the hot season, natural fibre is preferred to wear. Human thermal comfort is closely associated to a combination of climate, clothing and physical activity [4].

Thermophysiology is basically not a textile property but a mind condition which expresses satisfaction with thermal environment. Factors having to do with heat, moisture and air transport are associated with thermal comfort. Thermo-physiological properties are closely linked to this research area. So ultimately fibre type, yarn properties, fabric structure, finishing treatments and clothing conditions are the main factors affecting thermos-physiological comfort [6, 7]. The thermal comfort is involving into fabric ability to sustain the temperature of the skin through transfer of heat and sweat produced from human body [8].

A woven fabric usually shows pronounced hairiness and fibers on its surface, which, before digitization, must be removed by burning, clipping, or brushing for a suitable image. Brushing is the procedure used on fabrics to produce a nap, a novelty textured effect and hairy surface. Fabric brushing or surface rinsing is a mechanical finishing process. It is an effective way to increase the ability of the fabric to retain heat or provide a thermal barrier. This process makes fabrics fluffy and warm, with a soft handle. Brushed fabrics are commonly used to make pants or trousers, jackets (sports), shirts, brushed denim and even for sleeping garments and bed sheets. Practically, warp and weft yarns are not distributed in straight lines and at right angles, so before capturing the image, they have to be adjusted in parallel and perpendicular directions [9]. For underwear applications, the fabric must be hydrophilic to move away moisture for the skin interface and spread the limit on the largest possible area to favor evaporation. Often to help this phenomenon, a "brushed" fabric is used causing a considerable increase in surface area thus enhancing the comfort level.

Thus, in this study, different types of woven fabrics were manually brushed and the effect of brushing on thermo-physiological comfort properties was studied.

2 MATERIALS AND METHODS

2.1 Materials

Woven fabric samples which dimension is 50 mm^2 with three basic weave structures (plain, twill and sateen) were woven using a flexible rapier weaving machine; GamMax (Picanol) under the same technological conditions. PC (Polyester/Cotton) yarn with ratio 50:50 was used as warp and weft yarn for all samples. Table 1 presented detailed yarns composition.

Table 1 Yarn specifications for fabrics

Woven fabric type	Composition	Ends/cm	Picks/cm
Plain	50/50 Polyester/Cotton	24	24
Twill 3/1			
Turkish sateen			

2.2 Methods

After pretreatments, woven fabric samples were analyzed for thermal properties as well as air and water vapor permeability. For each sample, three measurements were considered.

2.2.1 Brushing

All samples were manually brushed by using very fine brushing paper. To ensure comparability of brushing results, three samples were brushed for each woven fabric type. It was achieved the reduction of the sample weight by 1 and 3%. It was measured the weight of fabric sample before Alambeta evaluation and brushed it manually till it lost 1% weight. After experimentation of all thermal properties the samples were brushed again till the loss of 3% weight. So this mechanism was manually done on the specimens to produce the desired nap and uniform aspect ratio. This is the novelty of work which was not done before that's why no literature of work is reported on this research.

2.2.2 Principle of ALAMBETA instrument - tester and thermal properties of fabrics

This apparatus used in this study enables the measurement of the following thermal parameters: thermal conductivity, thermal absorptivity, thermal resistance and sample thickness. The Alambeta simulates the dry human skin and its principle depends in mathematical processing of time course of heat flow passing through the tested fabric due to different temperatures of bottom measuring plate (22°C) and measuring head (32°C) under the contact pressure 200 kPa. When the specimen is inserted, the measuring head drops down, touches the fabrics and the heat flow levels are processed in the computer and thermo-physical properties of the measured specimen are evaluated [10]. The measurement lasts for several minutes only. Thus, reliable measurements on wet fabrics are possible, since the sample moisture during the measurement keeps almost constant.

Table 2 Thermal properties specifications

Parameter	Symbol	Unit
Thermal conductivity (coefficient)	λ	$W.m^{-1}.K^{-1}$
Thermal absorptivity, Thermal activity coefficient	b	$W.s^{1/2}.m^{-2}.K^{-1}$
Thermal resistance	R	$K.m^2.W^{-1}$

Thermal conductivity coefficient λ presents the amount of heat, which passes from 1 m^2 area of material through the distance 1 m within 1 s and create the temperature difference 1 K. Thermal conductivity of textile structures generally extends from 0.033 to 0.01 W/m/K. Thermal conductivity of steady air by 20°C is 0.026 W/m/K while thermal conductivity of water is 0.6 W/m/K, which is 25 times more. That is why the water presence in textile materials is undesirable [11].

Thermal absorptivity b of fabrics was introduced by Hes [11] to characterise thermal feeling (heat flow level) during short contact of human skin with the fabric surface. Providing that the time of heat contact (τ) between the human skin and the textile is shorter then several seconds, the measured fabric can be simplified into semi-infinite homogenous mass with certain thermal capacity ρc [J/m^3] and initial temperature t_2. Unsteady temperature field between the human skin (with constant temperature t_1) and fabric with respect to boundary conditions offers a relationship, which enables to determine the heat flow q [W/m^2] course passing through the fabric:

$$q = \frac{b(t_1 - t_2)}{(\pi\tau)^{1/2}} \quad , \quad b = (\lambda\rho c)^{1/2} \tag{1}$$

where ρc [J/m^3] is thermal capacity of the fabric and the term b presents thermal absorptivity of fabrics.

The higher is thermal absorptivity of the fabric, the cooler is its feeling.

Thermal resistance expresses the thermal insulation of fabrics and is inversely proportional to thermal conductivity. In a dry fabric or containing very small amounts of water it depends essentially on fabric thickness and, to a lesser extent, on fabric construction and fiber conductivity [12]. Thermal resistance R [m^2K/W] depends on fabric thickness h and thermal conductivity λ:

$$R = \frac{h}{\lambda} \tag{2}$$

2.2.3 Relative water vapor permeability

Relative water vapor permeability was measured on a Permetest instrument by a similar procedure to that given by Standard ISO 11092 [13] *RWVP* (%) of the textile clothing samples in the isothermal steady state is measured by the given equation:

$$RWVP(\%) = \frac{\text{Heat loss measured with sample}}{\text{Heat loss measured without sample}} \times 100 \tag{3}$$

2.2.4 Air permeability

Air permeability is described as the rate of air flow passing perpendicularly through a known area, under a prescribed air pressure differential between the two surfaces of a material. TEXTEST Air Permeability Tester (FX3300) is used to measure the air permeability according to standard ISO 9237. The air pressure differential between the two surfaces of the textile material was 100 Pa.

3 RESULTS AND DISCUSSION

3.1 Air permeability

The twill and sateen weaving structure have the highest air permeability value as compared to plain weave. These results can be explained by fabric porosity. However, brushing treatment showed non-significant change in the case of plain structure as shown in Figure 1.

In the case of the sateen and the twill fabrics the air permeability increased significantly (reaching 296.2 l/m^2/s for the weight loss of 1% after brushing compared to 175 l/m^2/s without brushing for the twill structure). In fact, the brushing effect is more important due to the floats at the fabric surface. In addition, brushed fibres are more apparent in the surface. This will make yarns more porous. The allied fibres will be more mobile and the velocity of the air through the surface will be more important. However, in the case of 3% fabric weight loss (accentuated brushing), the allied fibres will be oriented in the fabric parallel direction and not out of the surface, so fibres will obstruct the inter-yarn pores and the air permeability will slightly decrease as illustrated in the Figure 1. It can be seen from the results in Table 4 that the independent variables (weave type) have a statistically significant (s) results regarding air permeability.

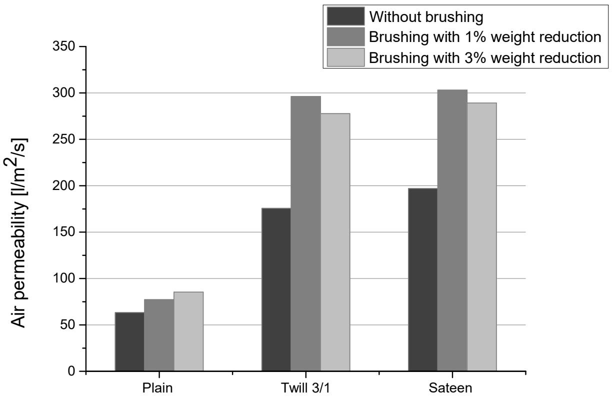

Figure 1 Air permeability of plain, twill and Turkish sateen without and after brushing

3.2 Relative water vapor permeability

The relative water vapor permeability is the percentage of water vapor transmitted through the fabric sample compared with the percentage of water vapor transmitted through an equivalent thickness of air. It can be seen from Figure 2 that, before brushing, all structures have almost the same value of relative water vapor permeability.

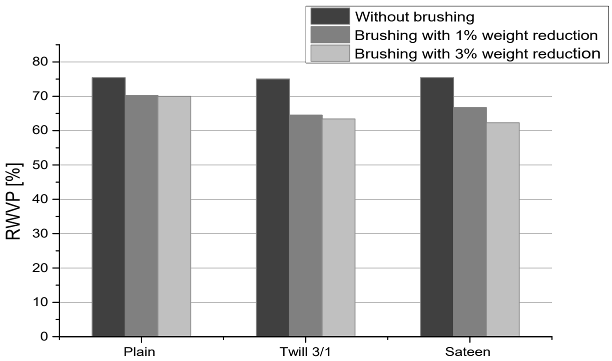

Figure 2 Relative water vapor permeability of plain, twill 3/1 and Turkish sateen without and after brushing

Table 3 Mean values of air and water vapor permeability parameters of different fabrics

Weaving structure	Brushing treatment	Thickness [mm]	Air permeability [l/m^2/s]	Relative water vapor permeability [%]
Plain	without brushing	0.45	63.3	75.4
	brushing with 1% weight reduction	0.72	77.2	70.2
	brushing with 3% weight reduction	0.84	85.4	70
Twill 3/1	without brushing	0.63	175	75
	brushing with 1% weight reduction	1.07	296.2	64.5
	brushing with 3% weight reduction	1.08	277.7	63.4
Turkish sateen	without brushing	0.56	197	75.4
	brushing with 1% weight reduction	1.08	303	66.7
	brushing with 3% weight reduction	1.16	289.2	62.3

After brushing, plain weaving structure has higher relative water vapor values than twill and sateen fabrics. It could be explained by the fact that plain weaving structure is compact (with high warp density) so brushing showed no effect. ANOVA results presented in Table 4 show statistical significance of weave type contingent upon the relative water vapor permeability of the fabric.

Table 4 ANOVA results for woven fabrics

Weave type	Brushing treatment	Air permeability [$l/m^2/s$]	RWVP [%]
Plain	without brushing	s	s
	brushing with 1% weight reduction	s	s
	brushing with 3% weight reduction	s	s
Twill 3/1	without brushing	s	s
	brushing with 1% weight reduction	s	s
	brushing with 3% weight reduction	s	s
Turkish sateen	without brushing	s	s
	brushing with 1% weight reduction	s	s
	brushing with 3% weight reduction	s	s

ns= non-significant; s= significant

3.3 Thermal conductivity

Thermal conductivity is an intensive and specific property of materials that indicates its ability to conduct heat. According to Figure 3 and without brushing, sateen structure has the highest thermal conductivity. Significance of the parameters is given in Table 6.

3.4 Thermal resistance

According to Figure 4, for each structure, the brushing treatment enhanced the insulation of fabrics as the thickness increased. After brushing, the sateen and twill structure exhibited the highest thermal resistance and this could be explained by the fact that these structures were loose and easily to brush compared to plain weave structure. In Table 6, ANOVA results of fabric for thermal resistance are presented.

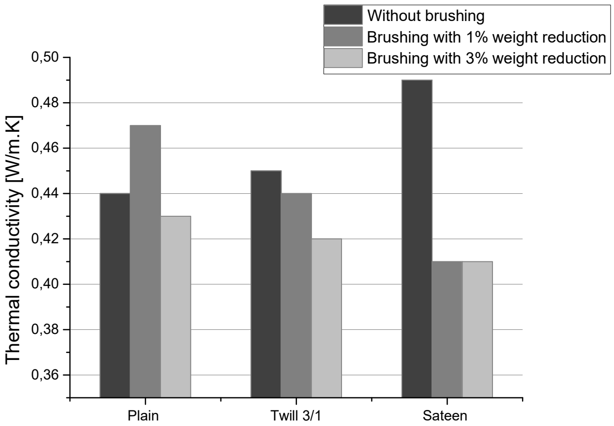

Figure 3 Thermal conductivity of pain, twill 3/1 and Turkish sateen without and after brushing

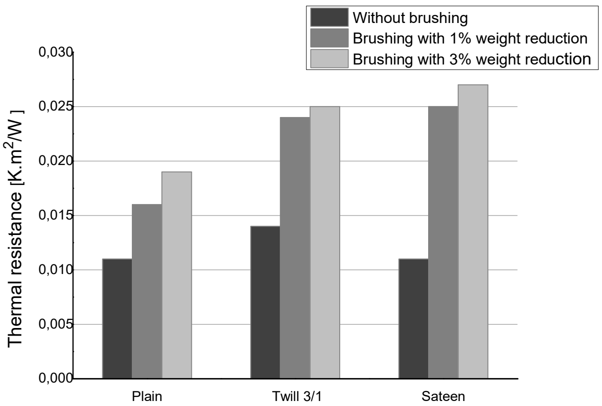

Figure 4 Thermal resistance of plain, twill 3/1 and Turkish sateen without and after brushing

Table 5 Mean values of thermal properties of different fabrics

Weave structure	Brushing treatment	Thermal conductivity [W/m.K]	Thermal resistance [$K.m^2/W$]	Thermal absorptivity [$Ws^{1/2}/(m^2.K)$]
Plain	without brushing	0.044	0.010	148
	brushing with 1% weight reduction	0.047	0.016	90
	brushing with 3% weight reduction	0.043	0.019	70.1
Twill 3/1	without brushing	0.045	0.014	128
	brushing with 1% weight reduction	0.044	0.024	65.2
	brushing with 3% weight reduction	0.042	0.025	64.4
Turkish sateen	without brushing	0.049	0.011	154
	brushing with 1% weight reduction	0.041	0.025	66.6
	brushing with 3% weight reduction	0.041	0.027	62.4

Table 6 ANOVA results of fabric for thermal properties

Weave type	Brushing treatment	Thermal conductivity [W/m.K]	Thermal resistance [K.m^2/W]	Thermal absorptivity [$Ws^{1/2}/(m^2.K)$]
Plain	without brushing	s	s	s
	brushing with 1% weight reduction	s	s	s
	brushing with 3% weight reduction	s	s	s
Twill 3/1	without brushing	s	s	s
	brushing with 1% weight reduction	s	s	s
	brushing with 3% weight reduction	s	s	s
Turkish sateen	without brushing	s	s	s
	brushing with 1% weight reduction	s	s	s
	brushing with 3% weight reduction	s	s	s

ns= non-significant; s= significant

3.5 Thermal Absorptivity

After brushing, thermal absorptivity decreases and we obtain warmer fabrics. The plain weaving structure has the highest thermal absorptivity and, at the same time, the coolest feeling at the moment of contact of the fabric with human skin. Likewise, the thermal conductivity, resistivity and absorptivity have also the statistically significant effect by the weave type.

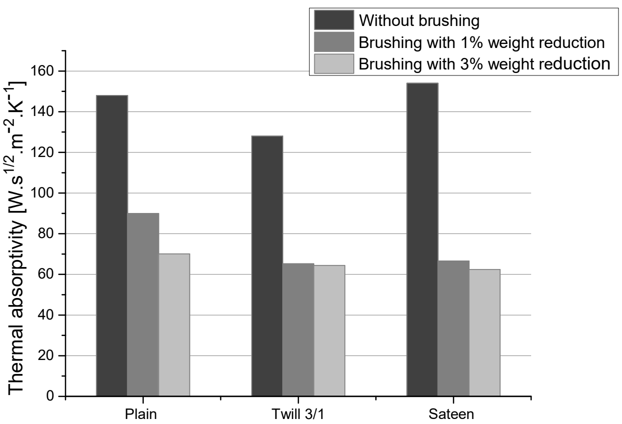

Figure 2 Thermal absorptivity of plain, twill 3/1 and Turkish sateen without and after brushing

4 CONCLUSIONS

It is concluded from the above results that the weaving structure and the brushing treatment are directly related to each other. Twill and sateen weave structure showed the highest air permeability value as compared to plain weave because of its compact weave design. Thermal properties of thrice samples were analysed differently because of brushing effect. Thermal conductivity of sateen fabric without brushing presented higher value than treated samples but the brushing treatment values were lower than the plain and twill samples. Similar values were perceived in case of thermal absorptivity. Thermal resistance values were found significantly different from the thermal conductivity and thermal absorptivity. Plain weave unveiled the less resistance with respect to twill and sateen.

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