INVESTIGATION INTO THE EFFECT OF FABRIC STRUCTURE ON SURFACE TEMPERATURE DISTRIBUTION IN WEFT-KNITTED FABRICS USING THERMAL IMAGING TECHNIQUE

by

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The aim of this paper was to evaluate the surface temperature distribution in several single and double jersey weft-knitted fabrics. Plain knitted fabrics as well as those with, double cross-tuck, cross-tuck, double cross-miss, and cross-miss pattern together with plain rib and interlock structures were under consideration in term of their structural differences. In order to investigate the temperature distribution in produced samples, all the fabrics were placed on a 35 °C adjusted hot plate instrument and thermal images were captured by an infrared thermal camera. The results revealed that the presence of tuck stitches in single jersey weft-knitted fabrics increase the air permeability due to the increasing the fabrics' porosity, which in turn leads to decrease their thermal resistance as compared with plain knitted structure. On the other hand, addition of miss stitches in single jersey knitted structures would decrease the thickness of fabrics and improves their heat transfer ability. The obtained results, from rib and interlock knitted structures, suggested their lower heat conductivity in comparison to the single jersey knitted samples.

Key words*: weft-knitted fabrics, temperature distribution, infrared thermography*

Introduction

Heat transfer is one of the factors affecting the comfort property of fabrics and this property is influenced by fabric structural pattern [1, 2]. Among different fibrous structures, weft-knitted fabrics provide excellent wearing comfort which make them appropriate options to be used in clothing [3]. These fabrics structured by the loop-shaped yarns in form of knit, tuck and miss stitches, could be manufactured by different machines under various conditions [4, 5]. Generally in weft-knitted fabrics, the combination of different stitch types could be resulted in achieving some desired qualities, since they have all individual properties and could make changes in the produced fabrics performance [6]. Kane *et al*. [6] studied the effect of knit structure on some single jersey weft-knitted fabrics properties. Their findings showed that the presence of tuck stitches in the fabrics' patterns changed their air permeability, thermal insulation value, tensile properties and *etc*. Oglakcioglu and Marmarali [7] focused on the thermal comfort properties of plain single jersey, 1×1 rib and interlock knitted structures. Their results showed that various knitting structures represent different thermal comfort properties. Stankovic

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et al. [8] examined the thermal properties of plain single jersey knitted fabrics. They reported that the heat transfer phenomena depends on the volume of entrapped air within the fabrics, thermal conductivity of fibers and surface geometry of yarn. Onofrei *et al.* [9] investigated the effect of fabric structure on heat and moisture management properties of weft-knitted fabrics. Their results revealed that the thermal properties are affected by knitted structure parameters. Bivainyte *et al*. findings [10] on thermal properties of some weft-knitted fabrics revealed that the knitting pattern is a dominant factor on heat transfer properties. Gupta *et al*. [11] studied the effect of fiber type and yarn linear density on thermal comfort properties of weft-knitted fabrics. They declared that fabrics with higher loop length show lower thermal conductivity. Moreover, the aim of Saricam and Erdumlu [12] study was to investigate the effect of some fabric parameters like thickness, porosity and knit structure on thermal comfort properties of weft-knitted fabrics. They found that the knit structure is the most influential parameter on thermal comfort properties in comparison to other parameters.

From the previous studies, it is considered that the effect of different stitch types on physical and mechanical properties of weft-knitted fabrics have been investigated thoroughly [13-16]. But, the effect of different stitch types on heat transfer properties in weft-knitted fabrics has not been well-studied. Therefore, the main aim of this work was to investigate the surface temperature profile in different weft-knitted fabrics. Also, most of the previous studies have been examined static heat transfer in fabrics, while the investigation of dynamic heat transfer in fabrics provides useful information about temperature distribution within the fabrics per a certain time [17]. Therefore, in this study, dynamic heat transfer in each sample was investigated. An infrared thermal camera was used to capture the surface temperature distribution within the fabric samples. Different types of weft-knitted fabric were produced. Using a hot plate apparatus, the map of surface temperature of the fabrics was captured. The effect of knitting structure on temperature distribution was investigated and discussed.

Experimental

Materials

Seven groups of weft-knitted fabrics differed from their structural patterns were knitted on an E5 STOLL computerized flat knitting machine (CMS400) solely using 12/2 Nm acrylic yarn. The produced fabrics stitch densities (course per centimeter × wale per centimeter) were measured after exposing them to dry relaxation at standard atmospheric condition (20±2 °C temperature and 65±2% relative humidity) for 24 hours. Specifications of the weft-knitted fabrics are shown in tab. 1. Mass per unit area, thickness and air permeability of samples were tested according to ASTM D3776-96, ASTM D1777-96 and ASTM D737-96, respectively. The fabrics porosity were determined according:

$$\text{Porosity}[\%] = \frac{\rho_0 - \rho}{\rho_0} \times 100 \tag{1}$$

where ρ_0 and ρ [gcm^{-3}] are the densities of fiber and fabric, respectively. Technical face and technical back of the produced samples are shown in fig. 1.

Methods

The experimental set-up used in this research is shown in fig. 2. During all tests, the samples were placed on a 35 °C adjusted hot plate instrument (ASTM D-1518-85) which has been explained by details in our previous research [18]. The other side of the samples which is called the cold side, was kept at standard condition; temperature of about 20 ±2 °C and rela-

Table 1. Specifications of knitted samples

Fabric structure	Mass per unit area [gm^{-2}]	Thickness [mm]	Stitch density [loops cm^{-2}]	Air permeability [cm^3/sec/cm^2]	Porosity [%]
Plain	338.11(5.12)*	1.50(0.04)	18.56	95.00(2.51)	81.10
Double cross-tuck	432.70(7.89)	2.15(0.02)	11.04	117.08(2.01)	83.20
Cross-tuck	365.37(7.01)	2.02(0.02)	10.40	114.70(3.88)	84.80
Double cross-miss	300.50(8.61)	1.33(0.04)	17.68	87.16(1.65)	81.10
Cross-miss	328.05(7.64)	1.40(0.03)	19.04	80.41(2.22)	80.40
Rib	529.90(9.06)	2.60(0.01)	14.85	47.10(3.45)	82.90
Interlock	792.33(10.10)	3.20(0.05)	18.60	25.50(3.88)	79.20

* The values in the parenthesis are standard deviations.

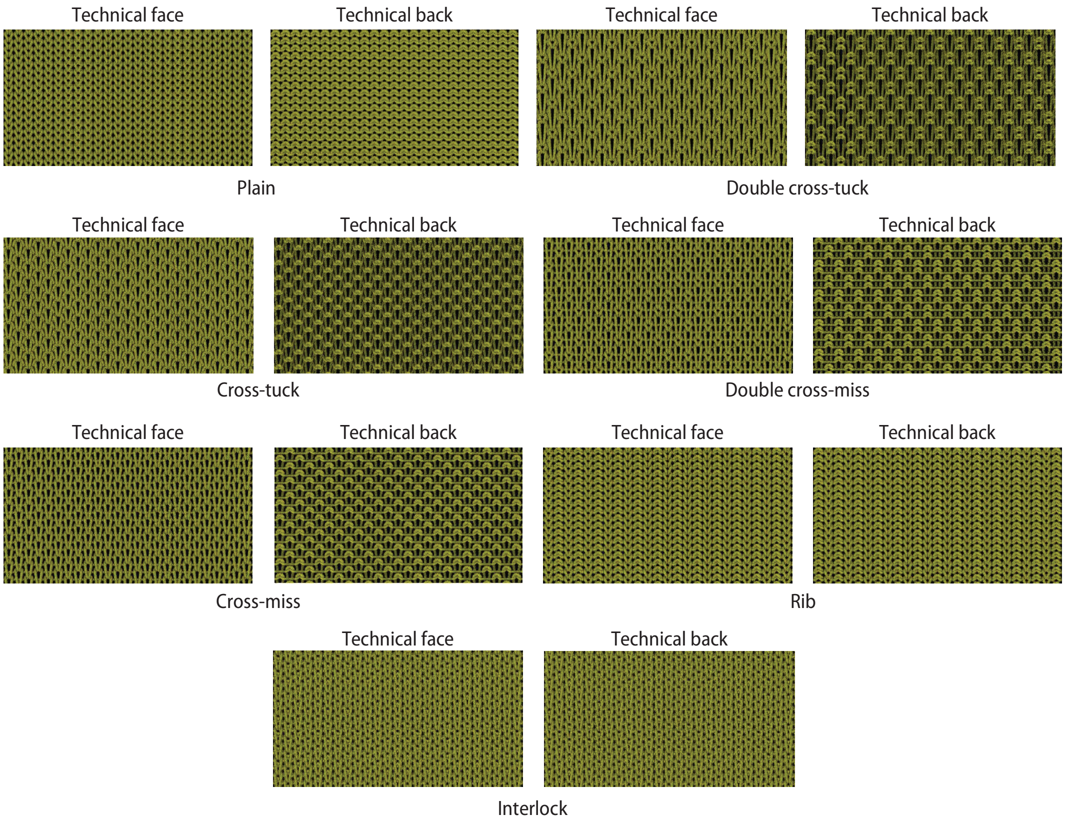


Figure 1. Technical face and technical back of samples

tive humidity at 65 ±2%. Relaxed state of the samples should be essentially considered before performing the tests, otherwise the results would be varied unwillingly. In order to observe the surface temperature profile of the fabrics, an infrared thermal camera was used [19]. Finally, for more accurate analysis, the captured thermal images were transferred to a data acquisition system.

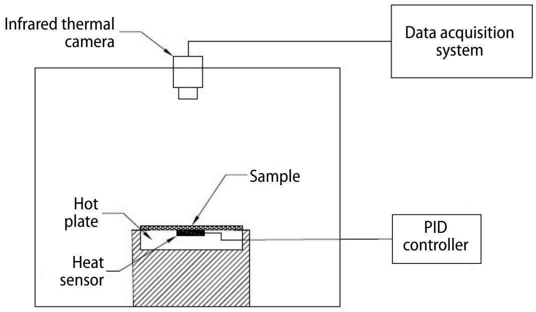


Figure 2. Experimental set-up [18]

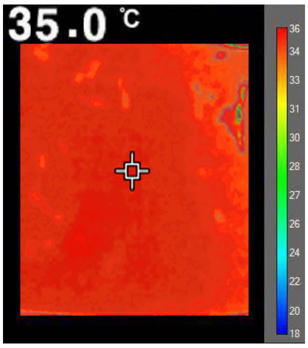


Figure 3. An example of thermal image for the hot plate

Results and discussion

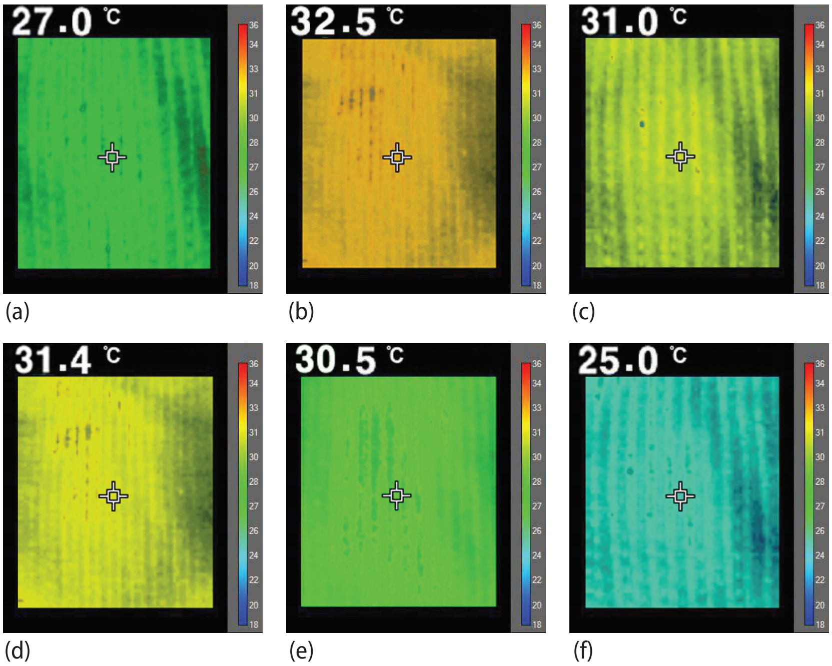
Temperature distribution within the fabric's structures were investigated using an infrared thermal camera (FLIR TG165). An example of thermal image for the hot plate was shown in fig. 3. It should be noted that the temperature shown above the thermal image is the temperature of the point indicated by the cursor of the camera.

As previously mentioned, in order to provide useful information about temperature distribution within the fabrics per a certain time, dynamic heat transfer in each sample was investigated. For all samples, period of heat transfer observation was considered up to 1800 second, during which, the steady-state condition could be achieved for each sample. Results of heat transfer investigation is given in tab. 2. After reaching the steady-state for the fabric samples, corresponding thermal images were captured and then transferred to the data acquisition system. The thermal images of samples are shown in fig. 4.

In order to observe the dependence of heat transfer on the knit structure, it should be referred to the curves of temperature and time as presented in fig. 5. The values of curves are the calculated average from five tests for each sample at each time point [17]. Figures 5(a)-5(c) investigated the effect of tuck stitches, miss stitches, single and double jersey structures on temperature distribution within the fabrics, respectively.

Table 2. Surface temperature [°C] of the fabrics at different times

Time [s]	Plain	Double cross-tuck	Cross-tuck	Double cross-miss	Cross-miss	Rib	Interlock
0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
1	20.1	20.4	20.2	20.3	20.2	20.2	20.0
10	21.1	22.9	22.5	22.0	21.7	20.8	20.1
20	21.6	25.0	24.1	23.9	23.0	21.5	20.7
30	22.0	27.3	25.0	24.7	25.1	22.0	21.3
40	23.2	29.0	26.1	26.0	27.0	22.1	21.6
50	24.0	29.0	26.9	28.5	27.8	22.6	22.0
100	25.3	30.7	27.2	30.0	28.4	23.0	22.2
200	26.0	31.5	29.0	30.0	29.0	23.3	22.5
300	26.5	31.9	30.0	30.7	29.8	23.8	22.7
500	26.5	31.9	30.0	30.9	29.9	24.0	23.0
1000	26.8	32.0	30.5	31.0	30.0	24.5	23.1
1200	26.9	32.1	30.7	31.1	30.0	24.8	23.5
1400	27.0	32.4	30.8	31.3	30.5	25.0	23.6
1600	27.0	32.4	31.0	31.4	30.5	25.0	23.6
1800	27.0	32.5	31.0	31.4	30.5	25.0	23.6



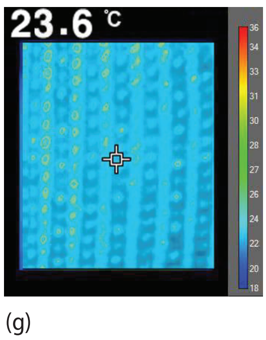
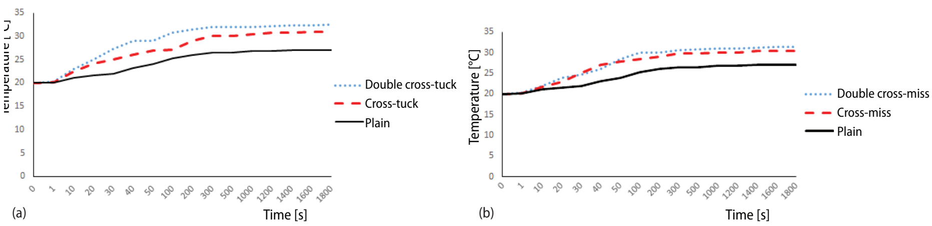


Figure 4. Thermal images of (a) plain, (b) double cross-tuck, (c) cross-tuck, (d) double cross-miss, (e) cross-miss, (f) rib, and (g) interlock knitted structures

As can be seen in tab. 2 and fig. 5, the heat transfer contains two different stages: dynamic or transient stage and the steady-state stage. In the dynamic stage, the temperature is gradually increasing over time. However, after reaching the steady-state stage, the heat transferred from the sample remains constant. The transmitted heat become stable in the range of 1200 to 1400 seconds.

The results revealed that using tuck or miss stitches in single jersey weft-knitted fabrics affected some fabric characteristics including fabric weight, thickness, porosity, air permeability and thermal insulation property [14]. A tuck stitch which consists of a held loop and one or more tuck loops, is created when a needle holding its loop also receives the new loop, fig. 6. Yarn accumulation at tucking places causes to increase the thickness of tuck stitched fabrics compared with the fabrics containing knit stitches. Due to thicker in nature, the tuck stitched fabric is heavier than plain single jersey fabric. Also, tuck stitched structure is more porous and open than the knit stitched fabric [13]. More tuck stitches in successive courses increases the fabric thickness and porosity as well as fabric weight, due to increase the yarns accumulated at



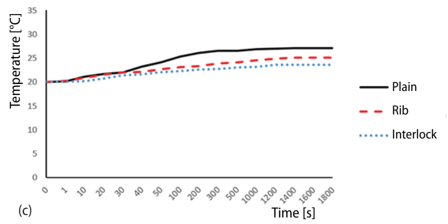


Figure 5. Heat transfer dependence on the knitted structure: (a) effect of tuck stitch, (b) effect of miss stitch, and (c) effect of single and double jersey structures

the tuck places. Therefore, double cross-tuck structure will be thicker, more porous and open and also heavier in comparison to cross-tuck structure [15, 16].

According to obtained results, it can be concluded that the ability of the tuck stitched fabrics for heat transfer varies in the following order: double cross-tuck > cross-tuck > plain single jersey.

It is expected that the heat transfer ability of the thicker fabrics decreases due to higher percent of air pockets entrapped through the structure. But both tuck stitched fabrics which possess higher thickness, demonstrate higher thermal conductivity than plain single jersey fabric. This could be attributed to the neutralizing effect of more porosity of knitted structures containing tuck stitches.

Also, the results show that the ability of the miss stitched fabrics for heat transfer varies in the following order: double cross-miss > cross-miss > plain single jersey.

A miss stitch is composed of a held loop and one or more float loops, fig. 6. It is produced when a needle holding its old loop, does not receive the new yarn which is fed to the needle. At the places in which the miss stitch is created, a freely floating yarn is observed on the reverse side of the held loop. In this structure, wales are drawn closer together by the floats which in turn leads to increase in the stitch density and consequently decrease the fabric porosity. Because there is no yarn accumulation during this process, miss stitches decrease the fabric thickness compared with the tuck stitched and knit stitched fabrics [15, 16]. Accordingly, a greater number of miss stitches in successive courses makes the fabric thinner and tighter.

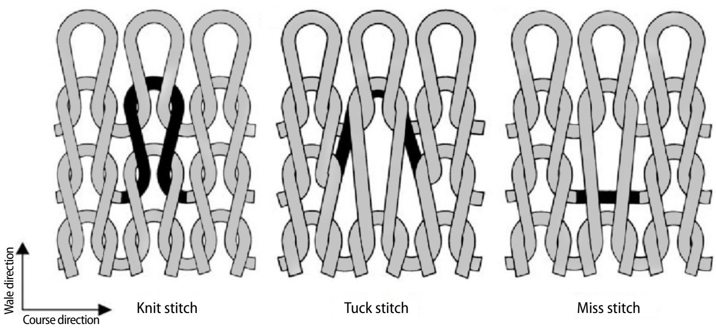


Figure 6. Loop notation of three different stitches [20]

Ucar and Yilmaz [21] reported that as the knitted fabric become tighter, the heat loss lessens, due to reduced air permeability as well as reduced air circulation within the fabric. But the obtained results in this research show that when the fabric structures such as cross-miss and double cross-miss is taken into consideration, the conductive heat loss due to thinner structure becomes more dominant than the heat loss due to air circulation. Therefore, decrease in thermal resistivity due to reduction in thickness is responsible for this behavior.

A rib knitted fabric is composed of two series of knitted loops arranged into two parallel lines in a course. As a result, fabric thickness will be approximately twice than plain single jersey fabric. The thermal conductivity of this structure lessens in comparison to plain single jersey fabric because of higher fabric thickness and consequently higher entrapped air pockets within the fabric structure. Interlock fabrics contain two separate 1 × 1 ribbed structures which are interknitted. Consequently, plain interlock fabric is thicker, heavier and tighter than plain rib fabric. Therefore, it demonstrates less heat conductivity than single jersey and rib knitted fabric.

The ANOVA statistical analysis was performed at the 95% probability level using SPSS software to find out the significant differences between the results. Table 3 shows details obtained by this test in term of investigating the effect of knit pattern. As shown in tab. 3, level of significance (sig.) was under 0.05 for all groups. It means that presence of tuck stitch, miss stitch and also single and double jersey structures have significant effect on heat transfer property in weft-knitted fabrics.

Table 3. The ANOVA data analysis

		Sum of squares	df	Mean square	F	Sig.
Effect of tuck stitch	Between groups	135.375	1	135.375	9.692	0.003
	Within groups	642.537	46	13.968		
	Total	777.912	47			
Effect of miss stitch	Between groups	93.220	1	93.220	7.172	0.01
	Within groups	597.936	46	12.999		
	Total	691.157	47			
Effect of single and double jersey structures	Between groups	38.633	1	38.633	9.531	0.003
	Within groups	186.450	46	4.053		
	Total	225.083	47			

Conclusion

In this paper, studying surface temperature profiles of some single and double jersey weft-knitted fabrics was under consideration using thermal imaging technique. For this aim, effect of stitch type on the quality of temperature distribution within the fabrics was investigated using a hot plate instrument and an infrared thermal camera. The results showed that the presence of tuck stitches within weft-knitted structures helps increasing their thermal conductivity. Substituting knit loops with the tuck stitches would increase the fabrics porosity, from this viewpoint, in the case of double cross-tuck and cross-tuck knitted structures, air permeability increase and accordingly thermal resistance decrease in comparison to plain single jersey knitted fabric. Similarly, the presence of miss stitches within the weft-knitted structures decreases the fabrics thickness which in turn leads to improve their heat conductivity. Moreover, rib and interlock knitted samples due to higher thickness with more air gaps included have lower temperature transmit-ability in comparison to the single jersey knitted samples.

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