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FABRICATION OF THREE-LAYER HEATING WOVEN FABRIC AND ANALYSIS OF THE EFFECT OF FABRIC STRUCTURAL PARAMETERS AND ELEMENT TYPE ON HEATING BEHAVIOUR

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Abstract: *Electrical heating garments are getting more and more attention in the last decades because of their wide range of application such as medical textiles, military textiles and domestic uses. These textiles are produced by integration of the heating elements in fabrics. There are some common ways to produce these textiles, for instance weaving, knitting and embroidery. In this research 12 groups of three-layer woven fabrics were produced using different weave pattern on the front and back layers, two heating element ratio and three kinds of heating elements namely the Nickel-Chrome, Tungsten, Aluminium-Chrome. The mentioned three layer fabrics were warp stitched woven fabrics in which the heating elements were embedded in the middle layer as wadded weft. After measurement of physical characteristics of the produced fabrics such as the areal weight, thickness, bending and air permeability, the heating ability of the fabrics under two different voltages was evaluated. In order to report the heating performance of fabrics thermal parameters such as the "maximum temperature" at different sides of the fabric and the "rate of temperature increment" were measured. According to the results the fabrics with similar weave structures on both sides of the fabric, have similar physical and heating behavior on both front and back layers. Moreover, among various heating elements which were embedded in the central layer of the fabrics, Tungsten presented the best heating performance from the view point of "maximum temperature" and the "rate of temperature increment", followed by Aluminium-Chrome with a considerable difference.*

Key words: *Heating Element, Thermal Behaviour, Weave Structure, Air Permeability, Bending*

1. INTRODUCTION

The Thermal comfort temperature range for the human body is between 15 to 28 °C. However, physiological comfort has narrower range about 22.2 to 25.5 °C [1]. Smart textile has the ability to receive environment condition data, process them and then adapt itself to it. Therefore, smart textiles can create a suitable condition for users. Because of this application, heating textiles have largely been expanded and getting more attention in the recent years. They are divided into four main categories; namely, electrical heating garment, phase change material (PCM), chemical heating clothing and heating clothing with fluid. The aim of using electrical heating textiles is to produce heat for the wearer. These textiles usually contain sensors, activator, data processor, and energy source and user interface [2, 3]. Kyacan et al. (2009) put forward heated fabric panels to investigate metallic textile structures. In this research, different kinds of fabrics were produced by incorporating steel yarns and their heating behavior was analyzed [4]. Hao et al. (2012) utilized conductive filaments for producing flexible heating fabrics and tried to develop a method to adjust conductive filament density in order to control the rate of power according to user's requirements [5]. Yen et al. (2013) studied the thermal conductivity of heating electric fabrics numerically to analyze heat transfer and thermal conductivity [6]. Roh et al. (2016), developed intelligent temperature regulation system for smart clothing applications in order to reach the best thermal comfort for the users [7].

2. EXPERIMENTAL

2.1 Sample Preparation

twelve kinds of three layer warp stitched woven fabrics were designed and produced on a handloom machine with 8 shafts, in the way that the front layer and back layer fabrics consisted of two kinds of weave patterns (Twill 2/2 and Plain) and the heating elements were embedded in the middle layer as wadded weft. Moreover, the presence of heating elements in the fabric structure had two conditions of 6 and 12 (for example after 6 weft yarn insertion, 1 heating element was embedded). Besides, three types of heating elements namely the Nickel-Chrome, Tungsten, Aluminium-Chrome was utilized in order to evaluate the heating performance of various elements. The specifications of the three layer woven fabrics are shown in Table 1.

Table 1: *fabrics specification*

Sample No.	Weight (g/m^2)	Thickness (mm)	Weave pattern "Front Layer"	Weave pattern "Back layer"	Heating element and (element ratio to weft)
1	572	3.08	Twill 2/2	Twill 2/2	Ni-cr (6)[1]
2	578	3.02	Twill 2/2	Twill 2/2	W (6)[2]
3	506	3.01	Twill 2/2	Twill 2/2	Al-Cr (6)[3]
4	493	2.64	Twill 2/2	Plain	Ni-Cr (6)
5	446	2.48	Twill 2/2	Plain	W (6)
6	453	2.51	Twill 2/2	Plain	Al-Cr (6)
7	538	3.15	Twill 2/2	Twill 2/2	Ni-Cr (12)
8	542	3.16	Twill 2/2	Twill 2/2	W (12)
9	573	3.18	Twill 2/2	Twill 2/2	Al-Cr (12)
10	485	2.88	Twill 2/2	Plain	Ni-Cr (12)
11	513	3.03	Twill 2/2	Plain	W (12)
12	559	3.08	Twill 2/2	Plain	Al-Cr (12)

As an example the weave pattern, drafting plan and the peg plan for weaving of the sample No. 4 is shown in Figure 1. It is necessary to mention that the heating element insert after 6 or 12 weft.

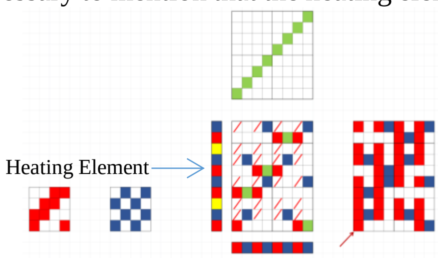


Fig. 1*: The weave pattern, drafting plan and the peg plan of sample No. 4*

[1] Nickel-Chrome
[2] Tungsten
[3] Aluminium-Chrome

As it was mentioned above, three kinds of heating elements were utilized to produce the fabrics. Heating element diameter was similar and it was chosen to be equal to 0.1 mm. All the samples were woven using 24/2 Nm Acrylic yarns for both weft and warp yarns of the front and back layers. It is obvious that bending of the heating element has a significant role on fabrics' flexibility and with regards to the wearer comfort; it is one of the most important parameters which needs to be considered in electrical heating fabrics. To measure the bending properties of heating element, the two ends of the elements were fixed between two stands and by the use of "Two Supports Beam System" proposed by Ghane et al. (2008) [8], the bending rigidity of the heating elements were calculated with the aid of MATLAB image processing toolbox. The measurement of the bending rigidity of heating elements was carried out at three different stand distances of 4, 6 and 5 cm (Table 2). The deflection gradient of the elements in each situation was reported as a measure of element bending rigidity. Furthermore, other properties, such as air permeability and thermal behaviour of different woven fabrics with various weave structures and element types were measured and analysed and the results are shown in Table 3 and 4.

3. Result and discussion

3.1. Fabric Physical Properties

Since the constituent yarns of the fabrics in the back and front layer are the same, the bending performance and the flexibility of the studied fabrics with similar weave patterns are directly influenced by the bending rigidity of the heating elements. Thus, the results obtained for the deflection gradient of elements can be used as guidance for prediction of fabrics' flexibility in each weave structure. The results of bending properties of heating elements (Table 2) show that the highest bending rigidity among the samples belongs to Al-Cr and the maximum flexibility was recorded for Ni-Cr element and Tungsten stands between the two mentioned elements.

Table 2: *Bending of heating elements*

Deflection Gradient			Element Type
6 cm	5 cm	4 cm	
0.2425	0.1460	0.0750	Al-cr
0.3879	0.2180	0.1934	Ni-cr
0.1256	0.1958	0.1343	W

Figure 2 also shows the ability of heating elements to bend. According to the Figure 2, similar trends were achieved at various distances of measurement stands. The lowest the value of the deflection gradient, the highest the bending rigidity of the heating element is. According to the results it can be predicted that for each weave structure, fabrics consisted of Ni-cr has the highest flexibility which results in higher movement comfort of the wearer.

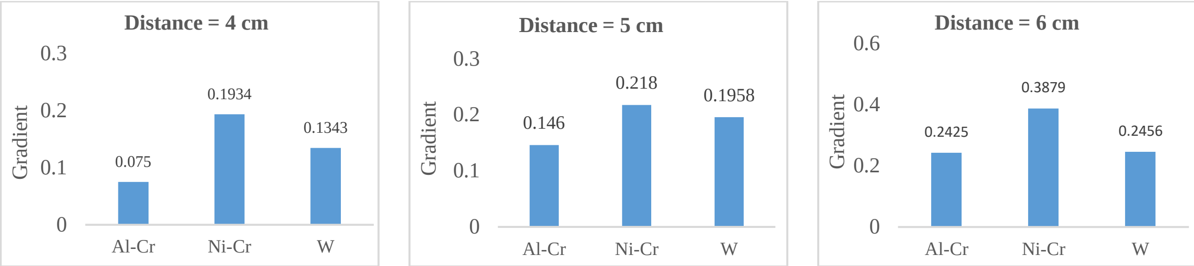


***Fig. 2**: Bending ability of heating elements*

As it is mentioned in Table 1, other physical properties of samples were also measured. According to the results gathered in Table 1, since the diameter of the heating elements was equal, this parameter did not affect the areal weight (g/m^2) and the thickness (mm) of the samples. The mentioned characteristics were mainly affected by the weave structure of the front and back layers. It can be concluded that fabrics with twill 2/2 weave structures on both layers had higher areal weight and consequently higher thickness compared to twill2/2-plain structures.

Besides the air-permeability of the fabrics from both side of the fabrics due to the change of weave structure at front and back layers were measured and the results are gathered in Table 3.

***Table 3:** Air permeability of samples (ml/s.cm^2)*

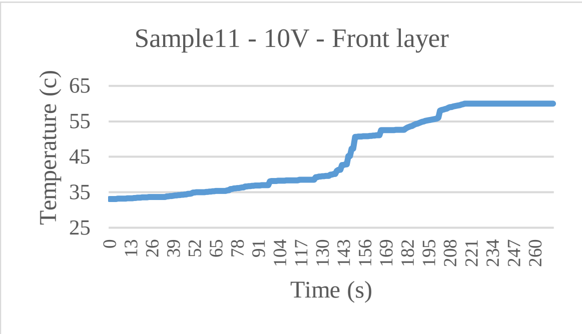
Sample No.	Air permeability “Front Layer”	Air permeability “Back Layer”	Sample No.	Air permeability “Front Layer”	Air permeability “Back Layer”
1	21.50	19.75	7	22.75	22.50
2	19.00	18.00	8	19.75	20.00
3	27.00	28.75	9	22.45	22.50
4	20.25	25.25	10	19.00	20.25
5	26.75	27.75	11	17.50	18.25
6	24.50	24.75	12	14.00	15.25

From the results it is clear that the samples with the same weave structures on their front and back layer have equal air permeability on both sides of the fabric. For the samples with different weave structures on the front and back layer, the layer with opener structure, and higher amount of air passing spaces, have higher air permeability. Analysis of results show that higher quantity of air can pass through the plain side of the fabric compared to the twill side. It should be noted that the thickness of twill 2/2 is more than plain, which results in more resistance against air passage from this side of the fabric. Besides, increasing the ratio and presence of heating elements embedded in the fabric structure, reduces the air permeability in fabrics. According to the results, type of element has no significant effect on air permeability of the fabrics.

3.2. Heat production ability of the fabrics

Heat producing and heat transfer are the most important features of the electrical heating textiles. In this regard, the heat produced in all of the fabrics was measured under two different voltages of 10V and 12V. The heating performance of sample 11 (twill2/2-plain with

Tungsten heating element) is shown in Figure 3.



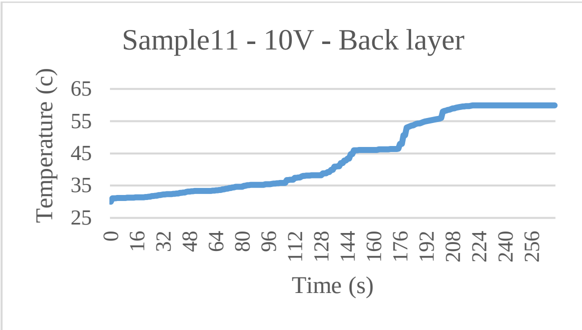


Fig. 3*: Maximum temperature and rate of temperature rise in sample 11*

From Figure 3 it is clear that the heating procedure of the fabrics commences with a gradual growing trend followed by a sharp rise, then it increases slightly and in the end it remains constant.

In order to report the heating performance of various samples, the “maximum temperature” obtained for the front and back layer and also the “rate of temperature increment” of fabrics in different conditions of testing was calculated and recorded. As it is obvious in Table 4, the results show that the heated samples subjected to 12V voltage has higher temperature and higher rate of heat production, compared to the heated samples exposed to the voltage of 10V.

Considering the results shown in Table 4, it is clear the “maximum temperature” and the “the rate of temperature increment” are much higher for the Tungsten heating element compared to the other incorporated elements. Thus, it can be concluded that the best heating performance can be achieved by utilizing tungsten. On the other hand, the weakest heating ability belongs to Ni-cr element.

Table 4: *Maximum temperature (°C) and rate of temperature increment (°C/S)*

Sample No.	Maximum Temperature (10V) “Front layer”	Maximum Temperature (10V) “Back layer”	Rate of Temperature Increment (10V)	Maximum Temperature (12V) “Front layer”	Maximum Temperature (12) “Back layer”	Rate of Temperature Increment (12V)
1	36.4	35.6	0.016	38.9	38.9	0.018
2	68.9	68.6	0.698	73.5	72.5	0.728
3	34.3	34.7	0.014	36.8	36.5	0.016
4	34.7	34.7	0.014	35.9	35.0	0.015
5	68.9	67.8	0.712	74.9	72.8	0.744
6	34.3	34.0	0.015	36.0	35.8	0.017
7	34.4	34.2	0.014	38.6	38.6	0.018
8	60.1	60.1	0.652	68.6	68.6	0.723
9	32.3	32.9	0.013	36.0	35.6	0.210
10	34.6	34.2	0.014	38.1	36.6	0.221
11	60.1	59.9	0.066	68.3	68.0	0.752
12	33.5	34.6	0.014	36.9	35.3	0.200

While analyzing the effect of fabrics structural parameters on the heating performance of fabrics, it was recognized that the fabrics with same weave structures on front and back layer have the equal maximum temperature on both sides. In comparison of the twill 2/2 and plain weave structures located on different sides of the fabrics (front and back layer) it was noticed that the samples with twill 2/2 weave structure on both sides, due to their higher thickness can save the heated air and have the higher temperature compared to plain weave structure.

4. CONCLUSIONS

In this study twelve groups of three layer warp stitched woven fabrics with three type of heating elements, two kind of weave pattern and two kind of heating element density were designed and produced and the effect of fabric structural parameters, element type and the voltage of the heating system was investigated on the fabric physical properties and the heating performance of the structure. According to the results, the highest temperature in equal voltage belongs to samples with Tungsten element used as the weft wadding. These samples have the most rate of increasing temperature, too. Moreover, the samples with equal weave structure on both sides of the fabric have the same physical properties and heating behavior. According to the results the fabrics with the weave structure of twill 2/2 on both front and back layer had better heating performance considering the maximum resultant temperature on both sides of the fabric.

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