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Method of Structure Design and Heat Treatment of an Integrated Consolidation Sensor and Embedded Temperature Sensing Fabric

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Abstract
In order to solve the problem of temperature sensors easily slipping and improve the precision of temperature measurement in temperature sensing fabric, a specially designed fabric was developed. In this paper, the fabric comprised plain and multi-layered fabric. Sensors were embedded into the multi-layered fabric. The multi-layered fabric was treated by partial heat treatment to make the temperature sensors be fixed to the fabric. The temperature sensing fabrics were measured before and after the partial heat treatment. The results showed that during the heat treatment, the number of fabric layers and fabric organization had an effect on temperature measurement, and the values measured after partial heat treatment were closer to the true value than without treatment. In addition, with an increase in the number of fabric layesr, the values measured were closer to the real value. And the measurement results were closer to the true value when the multi-layered fabric's organizational structure was plain.

Key words: *temperature sensing fabric, structure design, partial heat treatment, fabric testing, temperature value.*

Introduction

Body surface temperature is one of the body's basic physiological indicators. If you wear smart clothes which can sense the temperature of the body's surface, this will be interesting and valuable. The garment is defined as a smart temperature sensing fabric. Moreover in health care and monitoring [1] as well as in military areas [2], temperature sensing fabric can be applied widely. For example, in health care and monitoring, the body surface temperature of patients who must stay in bed for a period of time can be monitored anytime as long as you wear this temperature sensing fabric in hospital. This can ensure the safety of patients and be convenient for doctors' treatment, especially when examining some diseases that require accurate body surface temperature.

At present many researchers focus on the weave research of temperature sensing fabric to precisely test body surface temperature [3 - 5]. The research mainly involves what ways can better resolve the problem of sensor location in fabric. Traditionally weave methods where a temperature sensor was implanted into the fabric included a sensor sewn into the substrate of the fabric, and a sensor implanted into fabric through designing complex fabric organization [6 - 10]. For example, in the fabric weave process, big and small tubes in different configurations to each other were designed in over to place a temperature sensors, in the fabric [11, 12]. Whereas it might be better to hide the temperature sensor in the fabric, the weave processes were complex and the sensor was not packed tightly. In addition, the measurement position was likely to change when the sensor moved in the fabric. Hence temperature measurement values were not accurate enough. In another example, a seamless underwear knitting weave machine was used to weave temperature sensing fabric [13]. The temperature sensor was implanted into fabric as the form of a wide float by weaving [14 - 16].Although the method could weave the sensor into the fabric and improve the comfort thereof, the fabric and temperature sensor did not come into close contact, which was not beneficial to measure temperature accurately. In addition, the weave way was rather difficult and had a low reproducibility. For example, the method of coating was used in temperature sensing fabric weave and treatment [17 - 20] where polyurethane was coated in parts of fabric. Although it could implant a sensor into fabric, the temperature sensor in the fabric still slipped easily and the comfort of the fabric was affected greatly. However, studies on methods which could pack a sensor tightly and improve measurement accuracy have not been reported. In order to solve the problem of temperature sensors easily slipping and improve the precision of temperature sensing fabric measurement, this paper firstly focused on the design of one specific fabric to acquire a temperature physiological signal. The specific fabric was divided into two basic unit blocks in the weave processes. One unit was plain and the other unit was a combination of plain and multi-layered fabric. In the process of multi-layered fabric weaving, temperature sensors were implanted into the multi-layered fabric, and some high-shrinkage polyester filament yarns were used as weft yarns in the multi-layered fabric. A self-designed partial heat treatment apparatus was applied in the fabric heat treatment which could make polyester filaments in the fabric shrink. All of these ways would make the temperature sensor be wrapped tightly in the fabric, and the precision of temperature measurement could be improved significantly. This study explored the effects of partial heat treatment and the fabric layer number and organisation on measurement values of temperature sensing fabric, the results of which will be presented in this paper. Finally the measurement value of temperature sensing fabric will be used to evaluate the weave effect of this fabric.

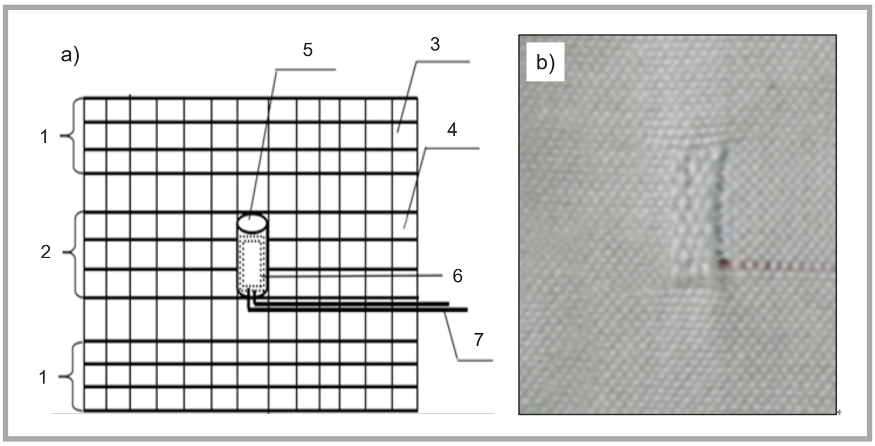

Figure 1. Physical structure distribution diagram of fabric temperature and photo of embedded temperature sensing fabric. 1) the first basic unit block, 2) the second basic unit block, 3) plain fabric in the first basic unit block, 4) plain fabric in the second basic unit block, 5) multi-layered fabric in the second basic unit block, 6) temperature sensor), 7) lead wire. a) physical structure distribution diagram of fabric temperature; b) photo of embedded temperature sensing fabric.

Experimental

Materials

High-shrinkage polyester filaments (specifications: 300 dtex yarn linear density, 96 yarn numbers) were used as weft yarns in the multi-layered fabric. Ordinary cotton yarns (Thread linear density: 38, 36, 30, 20, 16 tex) were used as warp yarns. MF51-9.971K-3950-200L thermal resistors (Dongguan City Star Electronic Technology Co. Ltd, China) were used as sensors, the diameter of which is 1.33 mm and the temperature measurement range and sensivity of the sensor is -10 ~ 60 °C and ± 0.1 °C, respectively Fine copper wire was used as the lead wire of the temperature sensor, and the copper wire was coated by polyurethane. The diameter of the copper wire is less than 0.11 mm and the length of lead wire could be adjusted according to the requirement of fabric production. This was convenient to connect the testing electronic devices, which can be placed freely in any place of the fabric, beneficial to the appearance design of fabric.

Apparatus

An SGA598 semi-automatic proofer sample loom (Jiangyin Tong Yuan Textile Machinery Co. Ltd., China) was applied for fabric weaving. Self-designed heat treatment equipment was applied for the partial heat treatment of fabric. A self-designed peripheral circuit was used to measure the change in voltage when the temperature varied. A USB7360-D data acquisition card (Beijing Sino-Thai Research and Innovation Technology Co. Ltd., China) could be used to collect the signal value acquired. The computer's self-compiled programming system displayed and stored measurement data.

Characterisation

Physical structure design of the temperature sensing fabric

The physical structure design of the temperature sensing fabric is shown in ***Figure 1***. The fabric was divided into two basic unit blocks in the weave process. The first unit block was plain and the second was a combination of plain and multi-layered fabric. The multi-layered fabric was located in the middle position of the second unit block [21]. Firstly the first and second unit blocks of fabric were woven. After the second basic unit block was woven, a special small tube fabric could be woven into the second basic unit block weave. Then a sensor was implanted into the small tube fabric. In the end, the third basic unit block was woven to seal the sensor in the fabric. Lead wires of the temperature sensor were pulled out and woven into the third basic block of fabric together with some weft yarns. The length and width of multi-layered fabric in the second block were designed according to the actual size of the temperature sensor and weave process of the fabric.

Design of temperature sensing fabric organisation

Firstly the organisation of temperature sensing fabric was designed according to its requirements and actual size of the temperature sensor. In the weave processes, warp yarns of the fabric were cotton yarns of different thread density, weft yarns of the first basic unit block - ordinary cotton yarns, and the weft yarns of the second basic unit block were high-shrinkage polyester filaments. A fabric was chosen as an example to explain the design process of the organisation of temperature sensing fabric. This multi-layered fabric had two layers and the foundation organization of the multi-layered fabric was 3/1 twill. The warp yarns were 30 tex cotton yarns, and the weft - 300 D high-shrinkage polyester filaments in a multi-layered fabric weave. The looming drafting of the temperature sensing fabric is shown in ***Figure 2***. Performance parameters

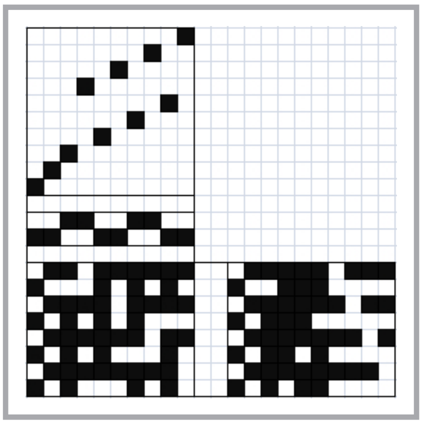

Figure 2. Looming drafting of temperature sensing fabric weave.

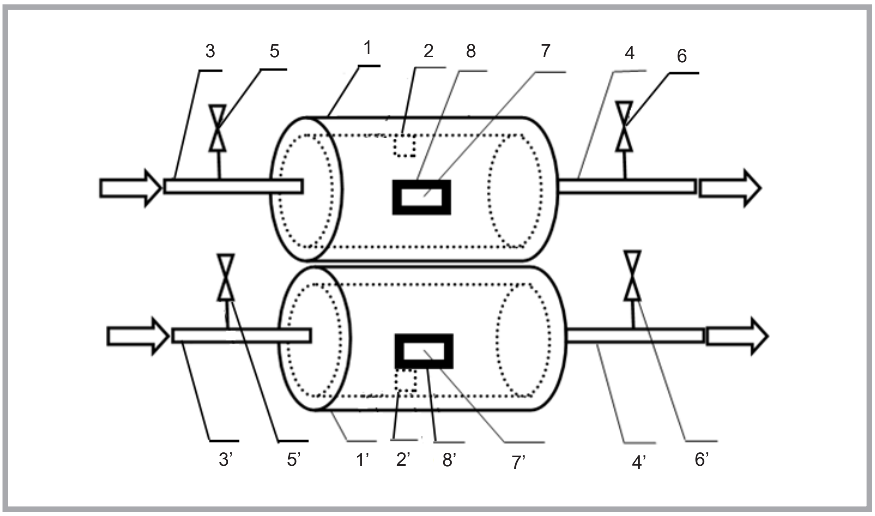

Figure 3. Structure diagram of fabric partial heat treatment equipment. 1, 1' - heated cylinder; 2, 2' - temperature sensor; 3, 3' - intake pipe; 4, 4' - outlet pipe; 5, 5' - intake valve; 6, 6' - outlet valve; 7, 7' - slot; 8, 8' - high temperature resistant elastic block.

of the woven fabric are shown in ***Table 1***. The fabric was treated by a partial heat treatment device and measured by a self-designed temperature measurement system.

Design of partial heat treatment device for temperature sensing fabric

The temperature sensing fabric was treated using a partial heat treatment device so that the temperature sensor embedded in the fabric could be packed tightly, which can improve measurement precision greatly. ***Figure 3*** shows a structure diagram of the partial heat treatment device, which included a heat and control system. The heat system was made of a pair of heated cylinders, whose thermostat heat source was hot air supplied by an intake pipe and a pair of opened slots on the heating cylinder surface, whose slot size was the same as the parts of fabric with an embedded sensor. The control system comprised of an intake valve, outlet valve, a high temperature resistant elastic block around the open slots. The high temperature resistant elastic block was heat insulation material. And the other parts of the heated cylinder surface, except the slot, also had heat insulation material.

The parts containing a temperature sensor in the fabric only interacted with the slot of the heated cylinder surface when the fabric was treated by the partial heat treatment device. The heat treatment temperature was controlled between 110 - 120 °C according to the shrinkage of polyester filaments. The heat flux was 3000 - 3500 m^3/h and the rotation speed of the cylinder 22 - 25 r.p.m. The fabric was heated three times, with the duration of each being 5 seconds. The slot location of the partial device must ensure that it only heated the multi-layered fabric [22].

Table 1. Properties of woven temperature sensing fabrics. ***Note:*** *The three layers of multi-layered fabric comprise an upper sensor of two layers and lower sensor of one layer, and the four layers of multi-layered fabric have an upper sensor of three layers and lower sensor of one layer. The upper sensor is the layer whose location is near the measuring hot copper plate.*

Sample number	Thread density of cotton, tex	Multi-layered fabric organization and its layers	Thickness, mm	P-type covering coefficient, 100%	Weight/ square meter, g/m^2	Partial heat treatment or not
No. 1	38	plain (two)	1.82	26.54	210.42	NO
No. 2			1.84	26.55	212.72	YES
No. 3	36		1.63	27.59	189.66	NO
No. 4			1.65	27.52	190.77	YES
No. 5	30		1.36	28.33	157.24	NO
No. 6			1.00	28.32	161.87	YES
No. 7	20		1.33	28.78	153.78	NO
No. 8			1.37	28.79	158.41	YES
No. 9	16		1.26	29.32	145.68	NO
No. 10			1.31	29.31	152.45	YES
No. 11	30	3/1t will (two)	1.25	20.65	145.56	NO
No. 12			1.28	20.61	147.99	YES
No. 13		2/2 twill (two)	1.33	22.87	153.78	NO
No. 14			1.39	22.89	160.71	YES
No. 15		pain(three)	2.12	29.93	245.11	
No. 16		3/1 twill(three)	1.92	29.01	221.98	
No. 17		2/2 twill(three)	1.99	29.33	230.08	
No. 18		plain(four)	3.01	30.31	298.33	
No. 19		3/1 twill(four)	2.87	29.91	278.59	
No. 20		2/2 twill(four)	2.93	30.01	281.55	

Table 2. Difference values between the average temperature and standard value (33.0 °C).

Sample No.	1	2	3	4	5	6	7	8	9	10
Mean Value of Difference, °C	2.26	1.64	2.34	1.48	2.18	1.38	2.28	0.86	1.78	0.74
Sample No.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Mean Value of Difference, °C	2.64	1.96	2.66	1.76	0.74	0.82	0.74	0.38	0.56	0.54

Results and discussion

Measurement difference between fabric and pure sensor

According to the measurement processes, the twenty samples above were measured with a same pure sensor (The measurement value of the pure sensor was regarded as a standard value). Every sample was measured five times, and the duration of each was three minutes. The ambient temperature was from 10 ± 0.1 to 40 ± 0.1 °C and the relative humidity was 50 ± 0.2%. The measurements were only effective when the mean value of the pure sensor was 33.0 °C and the fluctuations were less than 0.1 °C. The acquisition frequency of data was 10 times per second. Difference values between the average fabric temperature and standard value are shown in ***Table 2***.

Effect of partial heat treatment on the measurement values of the temperature sensing fabric

Figure 4 shows a photo of embedded temperature sensing fabric before and

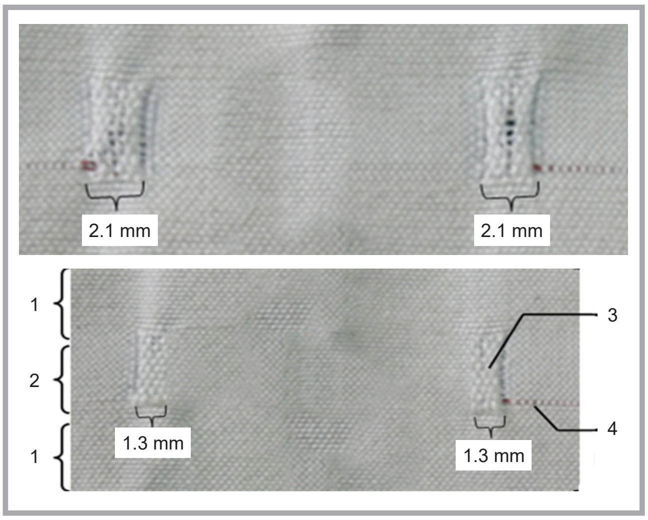

Figure 4. Photo of fabric before and after partial heat treatment.

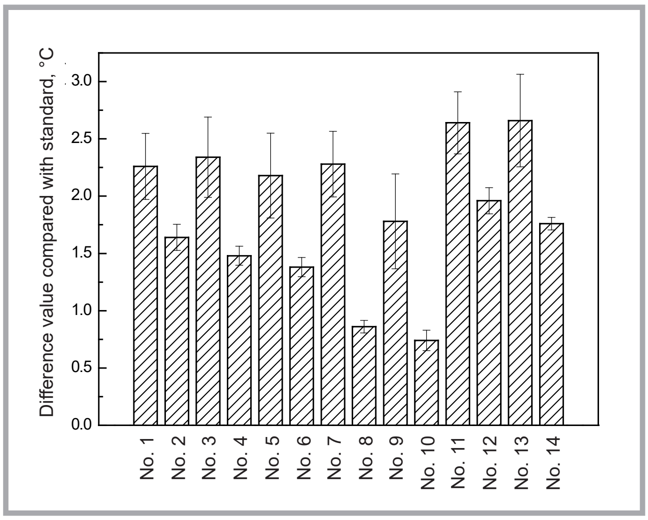

Figure 5. Precise test result comparison before and after partial heat treatment.

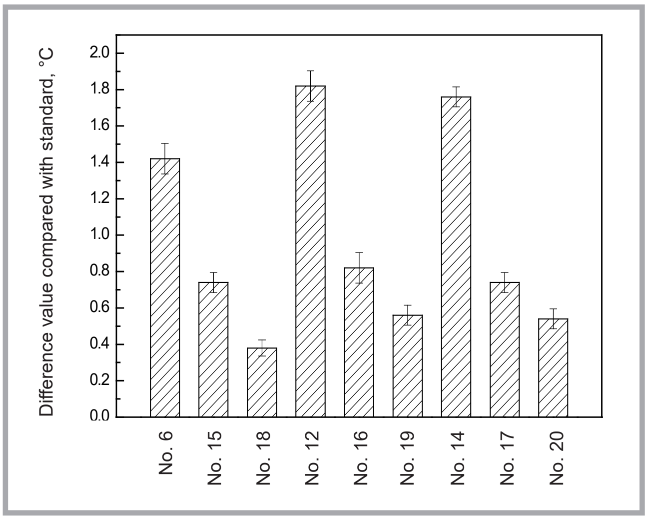

Figure 6. Effect of fabric layer number on measurement values.

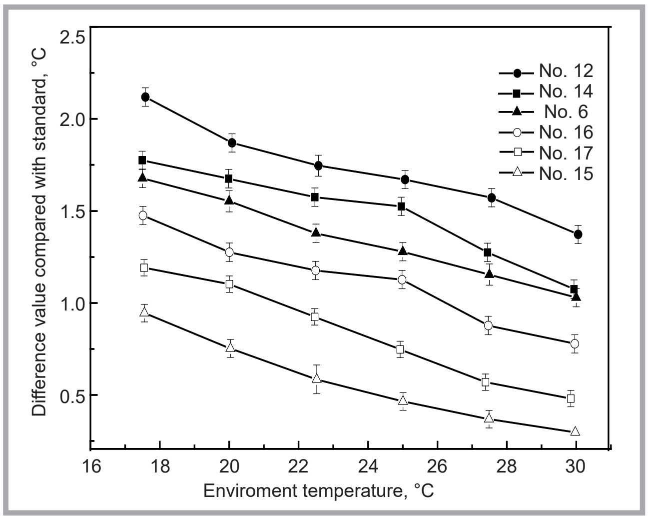

Figure 7. Effect of organization of fabric on measurement values.

after the partial heat treatment. It can be seen clearly that the temperature sensor was wrapped more tightly after partial heat treatment of the multi-layered fabric, and part of the appearance of the embedded temperature sensing fabric was more even after the partial heat treatment. ***Figure 5*** gives a comparison of temperature test results among different samples. The effect of partial heat treatment on the precision of temperature measurement was researched by comparing these samples. As shown in ***Figure 5***, the measurement values of No. 2, No. 4, No. 6, No. 8 No. 10, No. 12 and No. 14, respectively, are more accurate than No. 1, No. 3, No. 5, No. 7 No. 9, No. 11 and No. 13. It also shows that the measurement results are closer to the true value after heat treatment by comparing the width of the multi-layered fabric, the main reasons for which could be attributed to the following: the temperature sensor in the fabric was fixed after partial heat treatment, which could reduce the slippage of the temperature sensor in the fabric greatly. At the same time, when the temperature sensing fabric was treated by the partial heat treatment device, the relative distance between the sensor in the fabric and the hot copper plate became smaller, which allowed the sensor sense temperature more accurately to reflect the temperature value of the body surface in three measurement times. To some degree, it led to the improved precision of the temperature sensing fabric.

Effect of fabric layer number on measurement values of temperature sensing fabric

Figure 6 shows the effects of fabric layer number on the precision of temperature measurement. It can be seen that the measurement values of No. 15, No. 16 and No. 17, respectively, are more accurate than for No. 6, No. 12 and No. 14, and the measurement values of No. 18, No. 19 and No. 20, respectively, are more accurate than those of No. 15, No. 16 and No. 17. It also shows that the measurement results are closer to the true value with an number increasing of fabric layers. The three layers of multi-layered fabric means that the upper sensor has two layers and the lower has one layer, and the four layers of multi-layered fabric means that the upper sensor has three layers and the lower one layer. The main reasons for the results can be attributed to the following: The thermal resistance increased with an increase in the fabric layer number, which decreased the thermal loss of the fabric. There was more hot air between the multi-layered fabrics in a short time, which could make the value of measurement closer to the true value with an increase in the fabric layer number. The rate of heat transfer to the sensor was the same in the lower layer of the sensor. But when the upper sensor had more layers, it could resist the efficiency of heat transmission. On the whole, it can improve the measurement accuracy of temperature sensing fabric.

Effect of fabric organization on measurement values of temperature sensing fabric

The effect of multi-layered fabric organization on the precision of temperature measurement was investigated by comparing No. 6, No. 12 and No. 14; No. 15, No. 16 and No. 17. As can be seen from ***Figure 7*** (see page 71), the measurement values of No. 6 and No. 15, respectively, are more accurate than for No. 14 & No. 17; and those of No. 14 & No. 17, respectively, are more accurate than for No. 12 & No. 16. It shows that the measurement results of plain fabric are closer to the true value than for twill fabric in the fabric organization of multi-layered fabric, and the measurement results of 2/2 twill fabric organization are closer to the true value than 3/1 twill fabric. The main reasons can be attributed to the following: The covering coefficient of plain fabric was more than for twill fabric, and the covering coefficient of 2/2 twill fabric was more than for 3/1 twill fabric. The more the covering coefficient was, the less the air permeability of the fabric. Because the thermal conductivity of air was much less than for the fabric, the thermal resistance increased with an increase in the covering coefficient, which led to the weakening of the heat transmission performance, making multi-layered fabric have more static hot air. Secondly because the plain fabric had a shortened float, the interaction point in fabric was higher. The temperature sensor could be embedded securely in the fabric as far as possible, which also shortened the time to reach a stable temperature value. Hence the value of measurement was closer to the true value when the organisation of the multi-layered fabric was plain.

Conclusion

This paper outlines the design of the physical structure distribution of temperature sensing fabric, and produced fabric in order to solve the problem of temperature sensors easily slipping and improve the precision of temperature measurement in temperature sensing fabric. Moreover the temperature sensing fabric was treated by a self-designed heat treatment device that could make the polyester filaments shrink so that sensors could be packed tightly into the fabric. At the same time, a measurement temperature system for the temperature sensing fabric was specially designed in order to improve measurement accuracy. In the end, the results before and after partial heat treatment of the temperature sensing fabric were measured, and it was found that the fabric layer numbers and organization had affected the temperature measurement value. The results showed that the values measured after the partial heat treatment were closer to the true value than without the partial heat treatment. In addition, with an increase in the fabric layer numberthe values measured were closer to the real one. Furthermore the measurement results were closer to the true value when the organization of the multi-layered fabric was plain.

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