Xiaoming Zhao[1,2], Yuanjun Liu[1,2*], Tenglong Liang[1]

[1] **Tianjin Polytechnic University, School of Textiles,** Tianjin 300387, China

[2] **Key Laboratory of Advanced Textile Composites of Ministry of Education,** Tianjin, 300387, China
* E-mail: yankansd@163.com

Influence of the Needle Number on the Heat Insulation Performance of Pre-oxidized Fibre Felts

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Abstract
Many factors were needed to be considered to prepare pre-oxidised fibre felts with excellent heat insulation performance, and different production processes showed differences in the heat insulation performance of pre-oxidised fibre felts. In order to probe into the influence of the production process on the heat insulation performance of materials, a large number of experiments were needed to be carried out. For needle-punched nonwoven pre-oxidised fibre felts, web features, needle characteristics and the needle process will all affect the structure of pre-oxidised fibre felts, thus bringing a major influence on the heat insulation performance of pre-oxidised fibre felts. In this paper, the influence of the needle number on the heat insulation performance of pre-oxidised fibre felts was mainly studied. Results showed that an increase in the needle number will cause a decrease in the thickness and gram weight of pre-oxidised fibre felts, and a weakening trend in the heat insulation performance of pre-oxidiaed fibre felts with an increasing needle number at room temperature and at 100-200 °C was shown. Moreover when the needle number was 1 and 2, the pre-oxidised fibre needled felts had good heat insulation performance, and for pre-oxidized fibre felts at different needle numbers with increasing temperature, the temperature difference in a steady state increased linearly.

Key words: *needle number, pre-oxidized fibre felt, heat insulation performance, thermal conductivity coefficient, back temperature.*

Introduction

Pre-oxidised fibre fibre felt has properties such as excellent heat insulation, sound-absorption, noise reduction, waterproofness and oil-repellency, and it is also a type of non-combustible product. Due to characteristics of poor electrical conductivity, low crimp and brittle fibres of PAN pre-oxidized fibres, it is difficult for the fibre to come together [1 - 4]. Hence at present most pre-oxidized fibre products are mostly produced through nonwoven technology, of which needle nonwoven technology is common [5 - 7]. The main technology for preparing pre-oxidized fibre felt is nonwoven needle processing technology. The pre-oxidized fibre needle felt is prepared by loosening, combing, meshing and needling [8 - 14]. Current studies mostly focus on pre-oxidised fibre felts produced from PAN pre-oxidized fibres using the needle method, while carbon fibre felt and carbon-carbon composite materials are produced by carbonisation [15 - 19]. In this paper, the influence of the needle number on the heat insulation performance of pre-oxidised fibre felts was mainly studied.

Experimental

Experimental materials

PAN pre-oxidized fibres were provided by Tianjin Multidimensional Technology Co., LTD., specifications of which are shown in ***Table 1***. T-8112 antistatic agent was provided by Tianjin Technical University Textile Auxiliaries Co., LTD

Equipment

The equipment used in the study is shown in ***Table 2***.

Experiment scheme

fibre Opening, combing into nets, cross netting, pre-needling and master needle (multichannel) technologies are used on PAN pre-oxidised fibres to prepare pre-oxidized fibre felt.

Quantitative pre-oxidised fibres are weighed and opened two times using an XFH opening machine. The pre-oxidized fibres are fully released, and tangled large fibres are released in small pieces of fibres or bunches through tearing; even the single fibre state is shown. Given the poor electrical conductivity of PAN pre-oxidised fibres, which easily produce static in the process of friction with the parts, and in order to carry out the subsequent processing smoothly, pre-oxidised fibres after the opening are required to be evenly sprayed with an antistatic agent, then they are packaged for 24 hours in a plastic bag [20-24].

Pre-oxidised fibres applied with the antistatic agent need to be combed into a network by a combing machine, and fabrics outputed by a carding machine are of a single-layer network, where both the quantity and width cannot meet the requirements, and which need to be folded into thick wires through ta web machine, and then the subsequent processing is carried out. In this article, the method of webbing used was cross webbing, where the layer number of webbing was 30.

Fabrics after webbing are transferred to a pre-needle machine, where the pre-needle process mainly reinforces fabrics which are highly fluffy and with small force between fibre nets. The fibre assemblies after experiencing the pre-needle process are transferred to the main needle-punching machine. The research emphasis in this paper was to explore the influence of the needle number on the heat insulation performance of PAN pre-oxidised fibre felts. What needs to be specially noted is that in the process of practical experiments, the strength of pre-oxidised fibre is low, and a too large needle frequency will cause the damage and fracture of fibres. Hence in this paper, the design value of the needle frequency is lower than the conventional value of the needle frequency of the fibre. The concrete implementation plan is shown in ***Table 3***.

Testing and characterisation

Thickness test

In accordance with GB/T24218.2-2009 (Textile Test Method of Nonwoven Clothes Part 2: Determination of the Thickness), the thickness of samples was, where the compression pressure was 100 cN, the pressurized time 10 s, and the presser foot area was 2000 mm^2, taking an average of ten measurements.

Gram weight test

In accordance with GB/T24218.1-2009 (Textile Test Method of Nonwoven Clothes Part 1: Determination of Mass per Unit Area), the gram weight of samples was measured. Three samples of 250 mm × 250 mm were taken, and according to the provisions of GB/T 6529 they were wetted. Then the gram weights of the three samples were respectively obtained and the average calculated.

Test of the coefficient of thermal conductivity

A test of the coefficient of thermal conductivity of the sample was carried out using a TPS 2500S thermal constant analyser in a laboratory at a constant temperature and humidity of 20±1 °C and 65±5%, respectively.

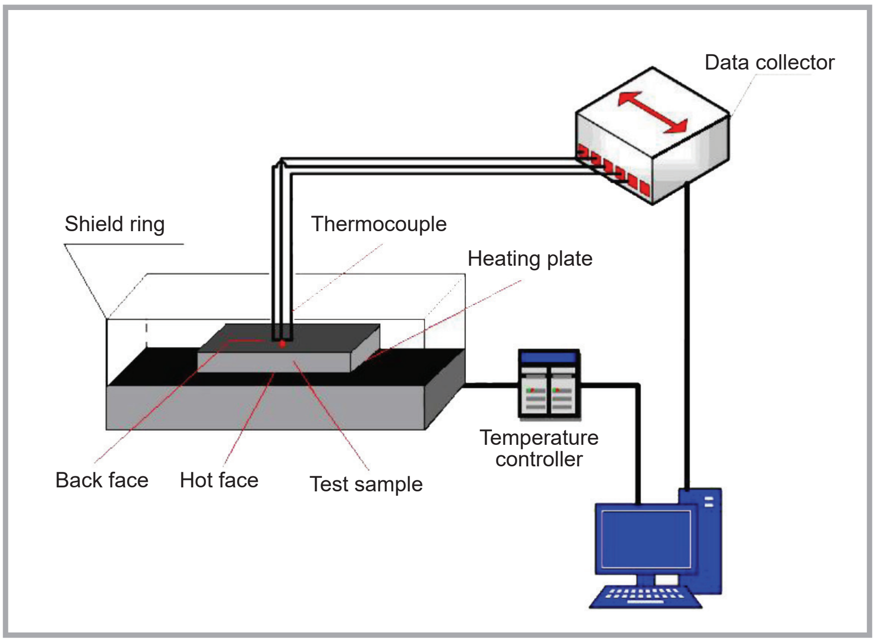


Figure 1. *Schematic diagram of the test device for the insulation.*

Back temperature experiment

The test device for the back temperature is shown in ***Figure 1***, where the size of the test sample is 50*50 mm, which makes the sample cover the heating plate. One sample of each group of experiments was respectively tested when the heating plate was at a temperature of 100, 150 and 200 °C. Each sample was tested for 1800 s at the corresponding constant temperature, with 3 samples of each group of experiments tested in total.

Results and discussion

Test results of structure parameters of pre-oxidized fibre felts

The result of the increase in the needle number was an increase in needle density, while an increase in the needle density will cause a decrease in the thickness and gram weight of non-woven materials [25-27]. As shown in ***Table 4***, with the increasing needle number, the thickness and gram weight of pre-oxi-

Table 1. *Specifications of pre-oxidised fibres.*

Average length, mm	Linear density, dtex	Average diameter, µm	Fracture strength, cN/dtex	Elongation at break, %	Crimp number, crimp number/cm
51.00±0.02	1.66±0.03	12.40±0.02	1.53±0.02	18.29±0.02	4.40±0.05

Table 2. *Equipment.*

Device name	Type	The manufacturer
Opening machine	XFH type	Qingdao Jiaonan Knitting Machinery Factory
Carding machine	WL-GS-A-500	Taicang City Shuangfeng Non-woven Equipment Co., LTD
Needle-punching machine (pre)	WL-ZGSZ-Y-400	Taicang City Shuangfeng Non-woven Equipment Co., LTD
Needle-punching machine (main)	WL-ZGSZ-Z-400	Taicang City Shuangfeng Non-woven Equipment Co., LTD
Counter balance	HCTP11B	Beijing Medical Balance Factory
Fabric thickness gauge	YG 141LA	Laizhou City Electronic Instrument Co., LTD
Thermal constant analyser	TPS 2500S	Swedish Hot Disk Company
Intelligent constant temperature heating units	JF-976S	Dongguan City changan Jinfeng Electronic Tools Factory
Temperature recorder	DM6801A	Shenzhen Yisheng Shengli Technology Co., LTD

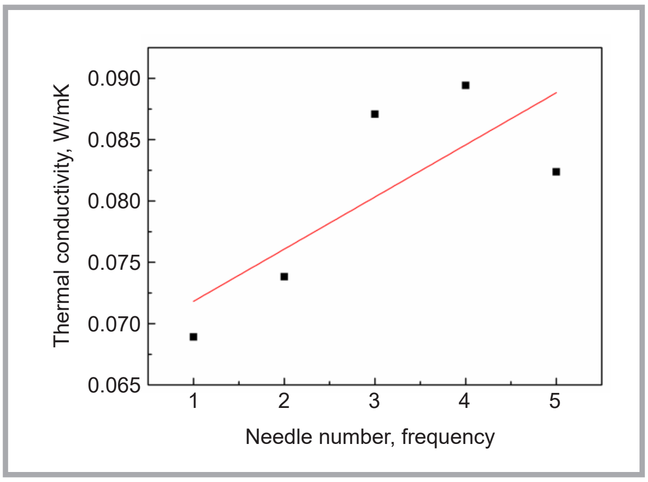


Figure 2. Influence of the needle number on the coefficient of thermal conductivity of pre-oxidized fibre felts.

dized fibre felts both showed a decreasing trend. This was mainly because with the increasing needle number, the density increased accordingly. Moreover the fabrics experienced a higher needle effect, the strengthened entanglement between fibres caused the fabrics to be closer, and the ability of fibres to retain a fluffy state decreased due to the springback of the stress, leading to a decrease in the thickness of the pre-oxidised fibre felts. An increase in the needle number will cause an increase in the needle density, and under the the constant effect of the needle, fibres locked with each other. The needle pressure and draft action made fabrics deformed, thus diffusing, and causing a decrease in fabric thickness. The gram weight was caused to decrease in the case of a given weight of fabrics [27-29].

Test results of thermal conductivity

PAN pre-oxidized fibre felts were prepared using the needle-punched nonwoven process with different needle numbers (1, 2, 3, 4, 5) of PAN preoxidation fibre felt. First of all, a test of the coefficient of thermal conductivity was carried out at room temperature. The experimental results are shown in ***Figure 2***, where with an increase in the needle number, the coefficient of thermal conductivity showed a linearly increasing trend. In the main needle-punching process, the needle number increased, with the pre-oxidized fibre felts prepared becoming tighter and the density increasing. The fibre content per unit of the volume increased, pores between fibres became smaller, and the porosity decreased, leading to a decrease in the still air contained, and causing an increase in heat conduction, thus causing an increase in thermal conductivity.

In addition, under the lead of the barbed hook of the needle, fibre bundles on the surface and sub-surface were almost in a vertical status contained in the fabric with the vertical movement of needles, and with an increase in the needle number, fibre bundles of this state became more and more numerous. Generally the axial coefficient of thermal conductivity of fibres was larger than the radial coefficient of thermal conductivity, so that an increase in the needle number caused an increase in the distribution of fibre bundles parallel to the direction of heat flow in the pre-oxidised fibre felts, thus causing an increased coefficient of thermal conductivity.

Experiment results of back temperature

For pre-oxidized fibre felts of different needle number, the heating plate temperatures were set at 100 °C, 150 °C and 200 °C, respectively. In the back temperature experiment, the rising process of the back temperature was recorded for samples 1#~5# at different temperatures, results of which are shown in ***Figures 3.a, 3.b, 3.c, 3.d*** and ***3.e.*** In order to discuss the heat transfer characteristics and heat insulation effect of samples 1#~5# under different working temperatures, the rising curve of the back temperature of samples 1#~5# was analysed under the same working temperature.

Figure 4 shows the back temperature and time curve of samples 1#~5# under the condition of the temperature of the heating plate being 100 °C. We can see from before the rising process of the transient state of 150 s, the rising processes of the back temperature of samples 1#, 2#, 3#, 4# and 5# overlapped with each other, after which the heating rate of 1# and 2# were markedly lower than that of 3#, 4# and 5#, which showed that the performance of the hysteresis heat transfer of needle numbers of 1 and 2 was superior to that of needle numbers of 3, 4 and 5 of pre-oxidised fibre felts. From the temperature curve of the steady state, the curves of the back temperature of samples 3#, 4# and 5# overlapped with each other, where the steady-state average temperature was 78.2, 77.3 and 77.3 °C, respectively. The average temperature of the steady state of samples 1# and 2# was significantly less than that of samples 3#, 4# and 5#, which showed that the insulation ability of pre-oxidized fibre felts was better when the needle numbers were 1 and 2 in the steady state phase. We can further observe from ***Figure 5*** that with the increasing needle numbers, the temperature difference of the steady state of pre-oxidized fibre felts showed linearly decreasing trends, which showed that the

Table 3. *Experimental scheme.*

Sample number	Needle number, number	Needle depth, mm	Needle frequency, sting/min
1#	1	8	110
2#	2	8	110
3#	3	8	110
4#	4	8	110
5#	5	8	110

Table 4. *Influence of needle number on structural parameters of oxidized fibre felts.*

Number of samples	Thickness, mm	Gram weight, g/m²
1#	4.76±0.02	371.26±0.03
2#	4.84±0.02	450.51±0.03
3#	4.15±0.02	370.24±0.03
4#	3.77±0.02	376.38±0.03
5#	3.94±0.02	379.03±0.03

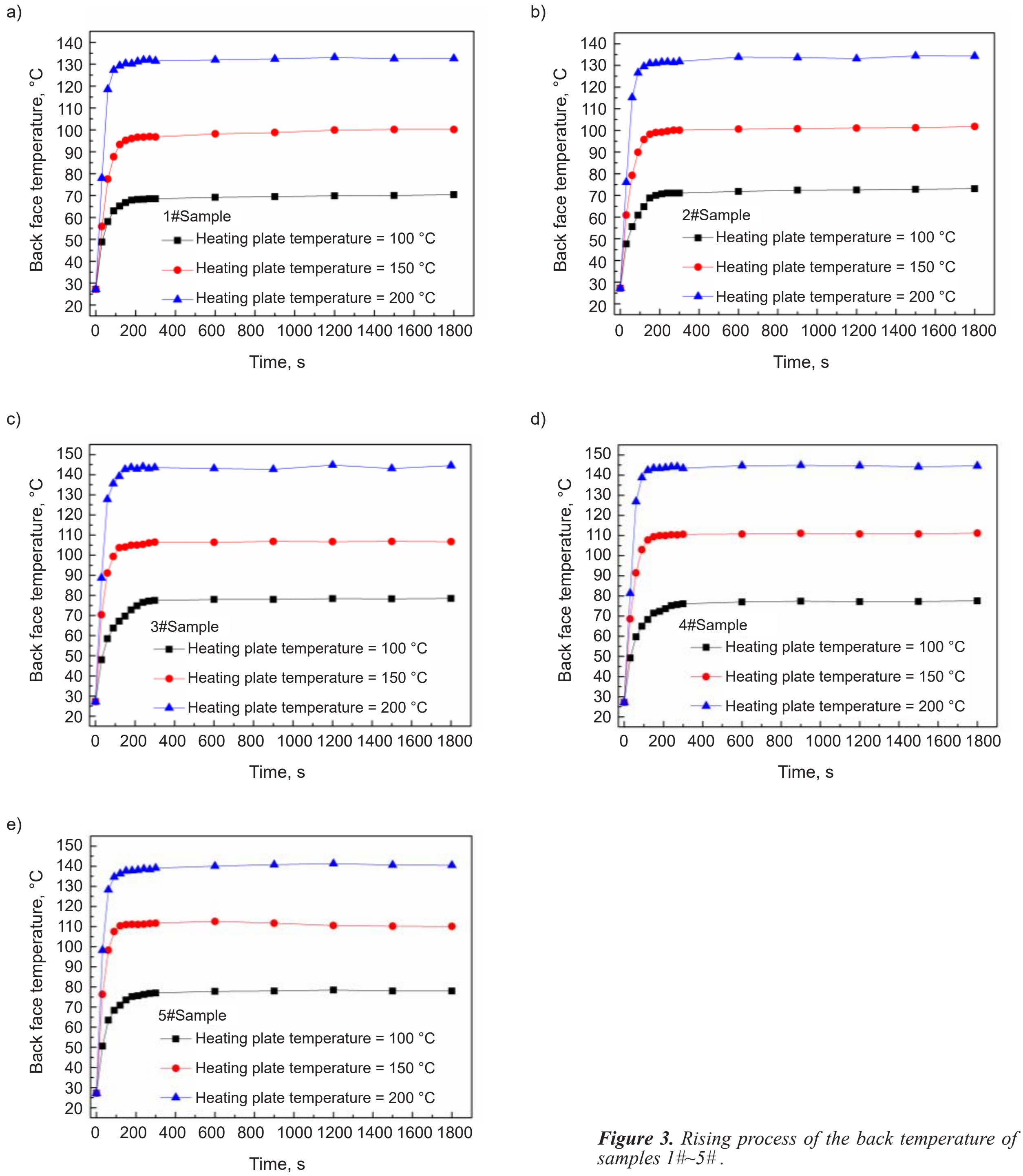


Figure 3. Rising process of the back temperature of samples 1#~5#.

insulation capacity decreased with the increasing needle numbers.

Characteristics of the thermal transmission of the transient and steady states of samples 1#~5# at a working temperature of 100 °C were comprehensively analysed, where the thermal insulation performance of pre-oxidized fibre felts showed a weakening trend with the increasing needle numbers, including acupuncture, and pre-oxidized fibre felts with a needle number of 1 and 2 had better thermal insulation performance.

Figure 6 shows a curve of the back temperature and time of samples 1#~5# when the temperature of the heating plate was 150 °C. We can observe from the 60 s front of the transient state, intertwined and overlapped rising curves of the back temperature of samples 1#, 2#, 3#, 4# and 5#, and in the period of a transient state of 60 to 300 s, the rise rate of the back temperature of 1# and 2# was significantly lower than that of samples 3#, 4# and 5#, which showed that the performance of the blocking ability of thermal transmission of pre-oxidized fibre felts with needle numbers of 1 and 2 was superior to that with needle numbers of 3, 4 and 5. From the temperature curve in a steady state, curves of the steady temperature of samples 1# and 2# were close to each other, those of the steady-state temperature of samples 4# and 5# over-

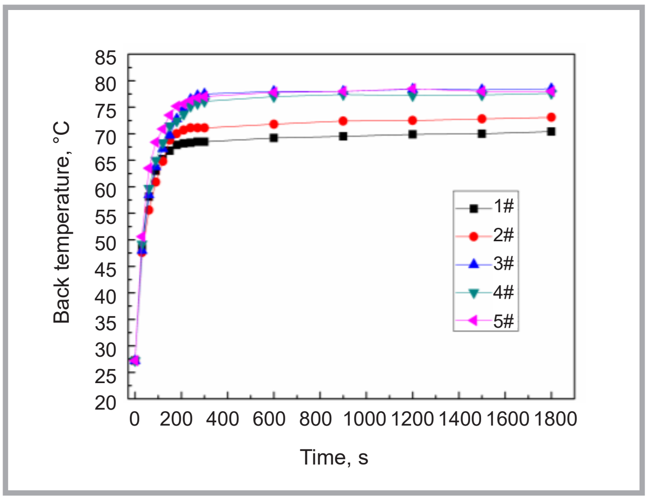


Figure 4. *Influence of the needle number on the back temperature when the hot surface temperature was 100 °C.*

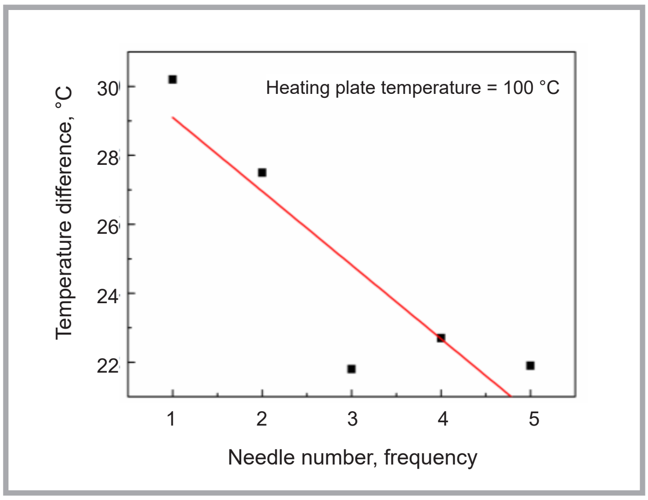


Figure 5. *Influence of the needle number on the temperature difference in a steady state of pre-oxidized fibre felts.*

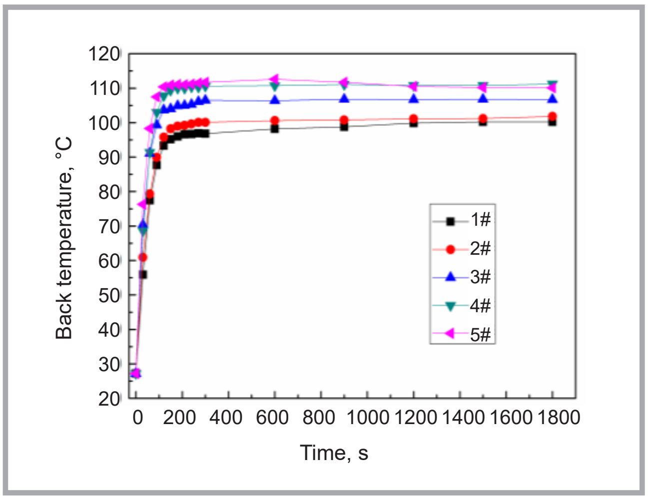


Figure 6. *Influence of the needle number on the back temperature when the hot surface temperature was 150 °C.*

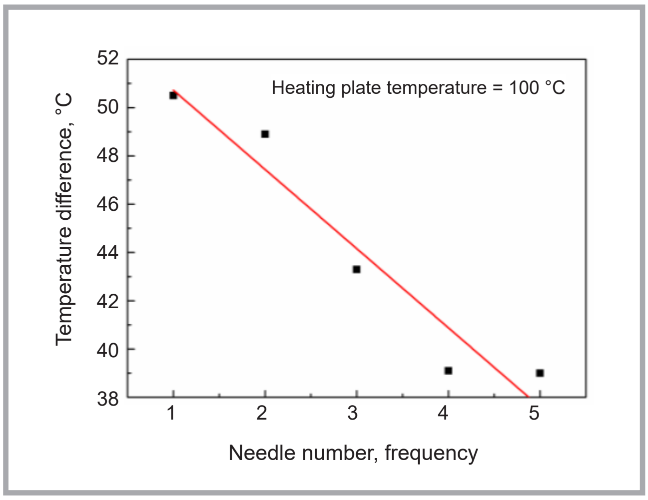


Figure 7. *Influence of the needle number on the temperature difference of the steady state.*

lapped, and the steady-state temperature of samples 1# and 2# was significantly less than that of samples 3#, 4# and 5#. The average temperature of samples 1#, 2#, 3#, 4# and 5# in a steady state were 99.5, 101.1, 106.7, 110.9 and 110.0 °C, respectively. We can learn from ***Figure 7***, which can be further analyzed, that with the increasing needle numbers, the temperature difference of the steady state of pre-oxidized fibre felts decreased linearly, which illustrated that the steady-state heat insulation effect was on the wane. Furthermore pre-oxidized fibre felts with needle numbers of 1 and 2 had a better steady-state heat insulation effect.

Characteristics of the thermal transmission of the transient and steady states of samples 1#~5# at a working temperature of 150 °C were comprehensively analysed, where the thermal insulation performance of pre-oxidized fibre felts showed a weakening trend with the increasing needle numbers, including acupuncture, and pre-oxidized fibre felts with a needle number of 1 and 2 had better thermal insulation performance.

Figure 8 shows a curve of the back temperature and time of samples 1#~5# when the temperature of the heating plate was 200 °C. We can derive from the rising process of the transient state that before 60 s the rising process of each sample overlapped with each other, and in the period of 60 s to 300 s, rising processes of 1# and 2# also overlapped with each other, and the rising processes of samples 3#, 4# and 5# intertwined with each other; however, the rise rate of the temperature of 1# and 2# was significantly lower than that of samples 3#, 4# and 5#, which showed that the performance of the blocking ability of the heat flow of pre-oxidised fibre felts with needle numbers of 1 and 2 was superior to that of needle numbers of 3, 4 and 5. From the temperature in a steady state, we can observe that curves of the steady temperature of samples 1# and 2# intertwined and overlapped with each other, as with those of the steady temperature of samples 3#, 4# and 5#. The steady-state temperature of samples 1# and 2# were significantly less than that of samples 3#, 4# and 5#. We can learn from ***Figure 9***, which can be further analysed, that with increasing needle numbers, the temperature difference of the steady state of pre-oxidized fibre felts decreased linearly, which illustrated that the steady-state heat insulation effect was on the wane. Moreover pre-oxidized fibre felts of needle numbers of 1 and 2 had a better steady-state heat insulation effect.

Characteristics of the thermal transmission of the transient and steady states of

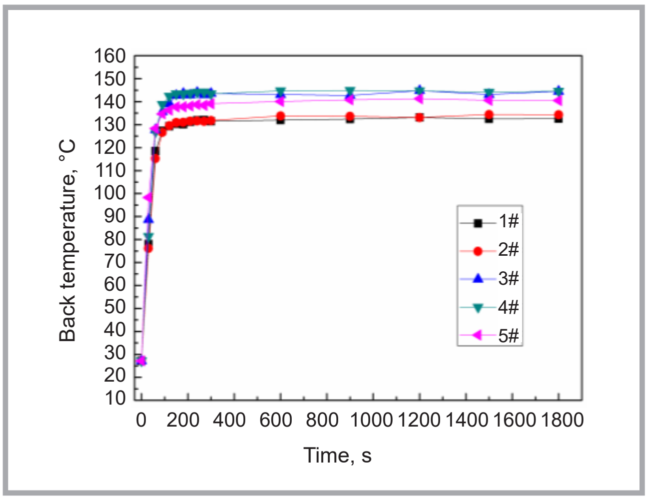


Figure 8. Influence of the needle number on the back temperature when the hot surface temperature was 200 °C.

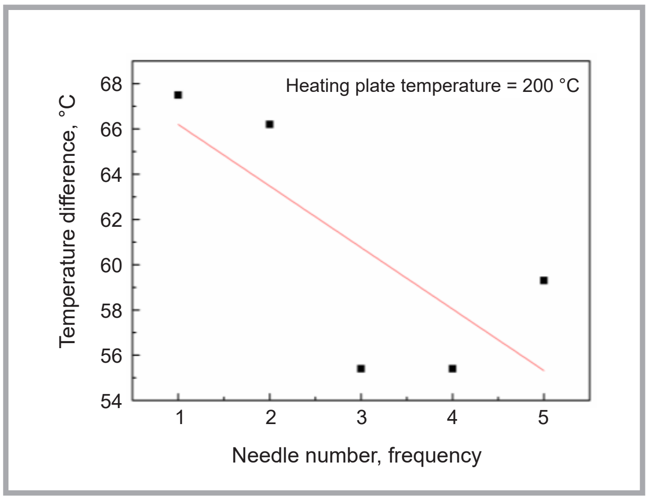
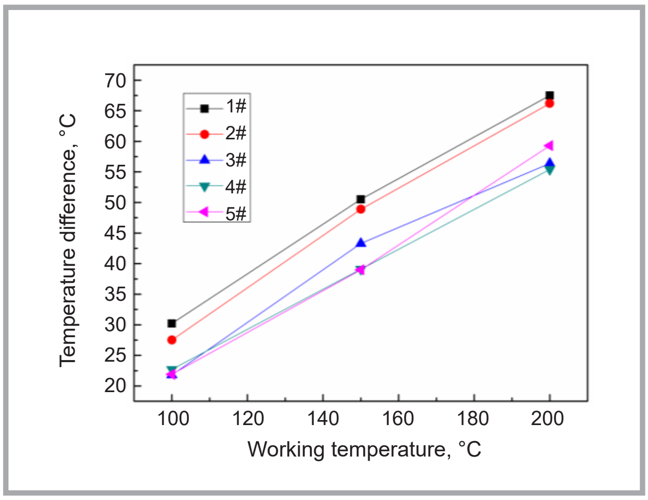


Figure 9. Influence of the needle number on the temperature difference of the steady state.

samples 1#~5# in the working temperature of 200 °C were comprehensively analysed, where the thermal insulation performance of pre-oxidized fibre felts showed a weakening trend with the increasing needle numbers, including acupuncture, and pre-oxidized fibre felts of a needle number of 1 and 2 had better thermal insulation performance.

Compared with the heating rate of the transient state, the steady-state temperature difference can characterise the thermal insulation performance at a temperature close to the actual service temperature more accurately in this area for the insulation materials studied. ***Figure 10*** shows that with the increasing heat surface temperature, namely with an increase in the actual working temperature of pre-oxidized fibre felts of 1#~5#, the steady-state temperature difference also increased linearly. The steady-state temperature differences of needle numbers of 1 and 2 of pre-oxidized fibre felts became constantly closer with rising temperature, and the steady-state temperatures were much higher than those of the remaining needle numbers of pre-oxidized fibre felts.

Figure 10. Influence of the working temperature on the steady-state temperature difference.



Conslusions

An increase in needle numbers led to an increase in needle density, a decrease in the thickness and gram weight, and increase in the content of pre-oxidized fibres per unit volume of pre-oxidized fibre felt, and leading to aggravation of the thermal transmission of the solid phase at the corresponding working temperature. In addition, due to the increase of the number of acupuncture channels, the puncture of the needle drives more fibres on the surface of the fibre net to stay vertically in the fibre assembly, leading to an increase in fibre bundles parallel to the direction of the heat flow, which exacerbated the thermal transmission of the solid phase. Hence with an increase in the needle number, the thermal insulation performance of pre-oxidized fibre felts at room temperature and 100 ~200 °C was on the wane.

With the actual ring working temperature of pre-oxidized fibre felts, the steady-state temperature difference also increases linearly. The steady-state temperature differences of needle numbers of 1 and 2 of pre-oxidized fibre felts with a rising working temperature became constantly closer, and the steady-state temperatures were much higher than those of the remaining needle numbers of pre-oxidised fibre felts.

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