Development and Application of Radiation Heating Facility

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Abstract This paper reports the development and application of radiation heating facility in China Academy of Aerospace Aerodynamics (CAAA). The facility includes 0 to 150 kW quartz lamps heater, test chamber, vacuum system and control system. The performances of low density thermal insulation materials in deferent low pressures have been studied on the radiation heating facility. The model cross size is 100 mm × 100 mm. The maximum running time is 2 000 s. The surface temperature of low density thermal insulation materials is up to 1 000 K. The minimum pressure in the test chamber is 10 Pa.

Key words Radiation heating facility, Low density thermal insulation materials, Low pressures

辐射加热设备的开发及运用

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文 摘 介绍了中国航天空气动力技术研究院辐射加热设备的开发及运用情况。设备包括0-150 kW 的石英灯加热器,试验舱,真空系统以及控制系统。在辐射加热设备上对低密度隔热材料在不同低压下的隔热性能进行了研究,所用模型横截面积为100 mm×100 mm,最长运行时间2 000 s,低密度隔热材料的表面温度高达1 000 K,试验舱最低压力为10 Pa.

关键词 辐射加热设备, 低密度隔热材料, 低压

0 Introduce

As we all know, for TPS of non-ablating reusable vehicles, the thermal insulation performance is very important. Many studies have been developed on low density thermal insulation materials[1-4], especially for pressure range from 1 Pa to 100 kPa, the surface temperature above 1 000 K, which represents the typical thermal conditions of TPS and must be endured in the course of reentry to the earth atmosphere[5-10].

Radiation, gas conduction and solid conduction are three main heat transfers in low density TPS materials (such as high-porosity fiber and silica aerogel composites), so the environmental temperature, pressure and the density of materials will influence the thermal insulation performances.

A radiation heating facility was developed to study the thermal insulation performances of low density materials at different pressures. Some tests have been conducted.

1 Description of facility

The radiation heating facility includes the 0 to 150 kW quartz lamps heater, the test chamber, vacuum system and control system. The following sections describe these items and their interaction.

1.1 Quartz lamps heater

The quartz lamps heater is the core part of the radiation heating facility, which are made of 75 quartz lamps (three groups, 25 quartz lamps in every group), two reflection plates (the model window located in the bellow reflection plate), anode and cathode and thyristor supply.

Every quartz lamp is 220 mm long and with the diameter of 8.0 mm. The maximum power of every quartz lamp is 2.0 kW, so the maximum power of the quartz lamps heater is 150 kW.

The thyristor supply can provide the maximum direct current 1 000 ampere and the maximum direct voltage up to 500 volts.

The size of the model window is 100 mm×100 mm×50 mm. The reflection plates are made of stainless steel with the size of 300 mm×300 mm×50 mm. The anode and cathode are made of aluminum and connect the quartz lamps with the thyristor supply.

The reflection plates, the anode and cathode are all cooled by cooling water in tests.

Fig. 1 is the sketch of quartz lamps heater.

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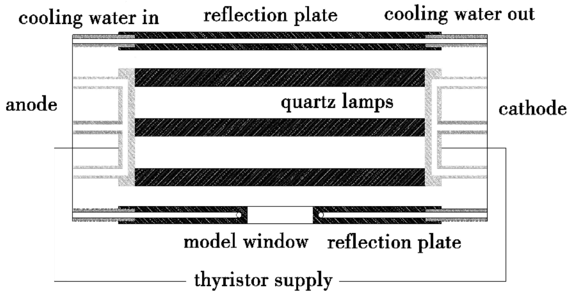


Fig. 1 Sketch of quartz lamps heater

1.2 Test chamber and vacuum system

The over dimension size of test chamber is 800 mm ×800 mm×800 mm. There is an observation window in the door of test chamber to inspect the quartz lamps heater and model during test. The vacuum manometeris used to measure the pressure inside the test chamber. The thermocouples in test model are brought through the chamber and connected to the computer data acquisition system. The test chamber and the quartz lamps heater are both cooled by cooling water. The vacuum valve and pump are used to provide different pressure in test chamber. The vacuum pumping rate is 30 L/s. The limit pressure of the vacuum pump is 6×10^{-2} Pa. The test chamber pressure range is from 10 Pa to 100 kPa.

The Fig. 2 shows the image of test chamber and vacuum system.

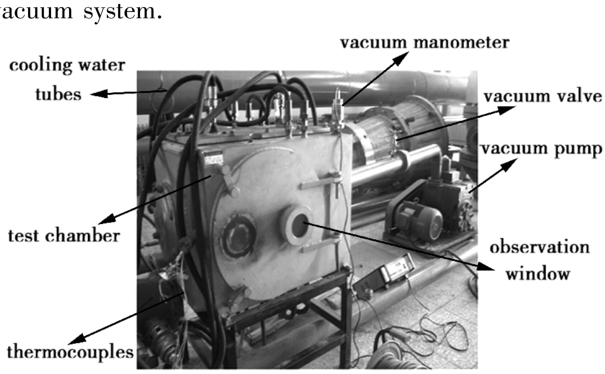


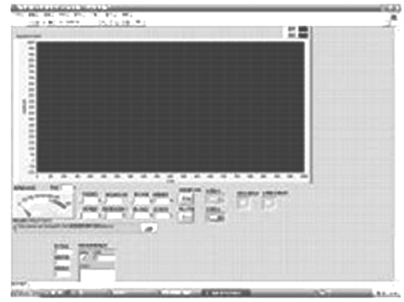
Fig. 2 Photograph of test chamber and vacuum system

1.3 Control system

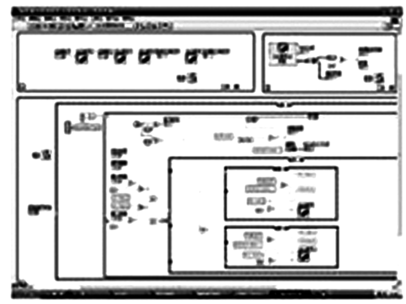
Comparative analysis of the material performance based on data from different tests is greatly simplified if the test conditions are repeatable. In order to study the performance of low density thermal insulation materials in different low pressure, the prime consideration is to keep the surface temperature constant.

The role of the control system is to compare the measured surface temperature of thermal insulation materials with the temperature value needed, control the output of thyristor supply and make the surface temperature steady and keep the temperature in the desired value. The control system was developed in 2009. Before the control system was used, the output of thyristor supply was controlled manually. It is very difficult to keep the surface temperature constant and repeatable.

Fig. 3 is the sketch of control system.



(a) Control window



(b) Control procedure

Fig. 3 Sketch of control system

2 Application of the radiation heating facility

Although the start-up tests of heat pipe[11], the spectral emittance measurement of carbon/carbon composite[12] have also been carried out with the facility, the radiation heating facility is mainly used to study the performance of low density thermal insulation materials in different low pressures. The following sections describe the tests of low density thermal insulation materials. In order to state the importance to develop the control system, one application example without using the control system is given firstly. The other tests have been conducted with control system.

2.1 Test without control system

2.1.1 Model

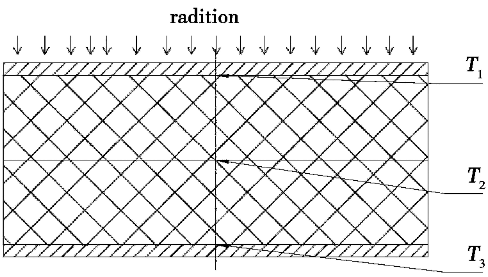
The test model was mounted in the model window of quartz lamps heater, which was made of two pieces of low density thermal insulation materials, two pieces of copper plate and three pairs of thermocouples. The model size is with a width of 100 mm, a length of 100 mm and a thick of 36.0 mm. Three pairs of K type thermocouples were used to measure the temperature response of model. The upper copper plate was near the quartz lamps and with the thickeness of 3.0 mm. Two pieces of low density thermal insulation materials (density 0.45 g/cm^3) have the same thickness (15.0 mm) and the same components. All thermocouples were brought from the 3.0 mm thick bottom copper plate.

The Fig. 4 shows the image of the model. The T_1, T_2 and T_3 represent three pairs of thermocouples.

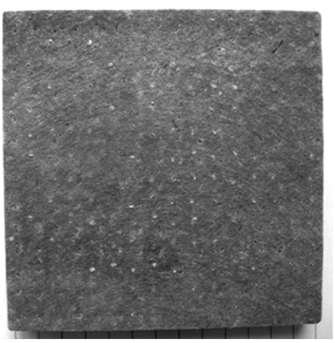
2.1.2 Test results

Three tests were conducted. The pressure in the test chamber were 10.0 kPa, 5.0 kPa and 0.25 kPa. The Fig. 5 shows the temperature responses during tests. Because the control system did not exist, the surface temperatures were difficult to control. Tab. 1 gives the temperature responses at the end of test (2 000 s).

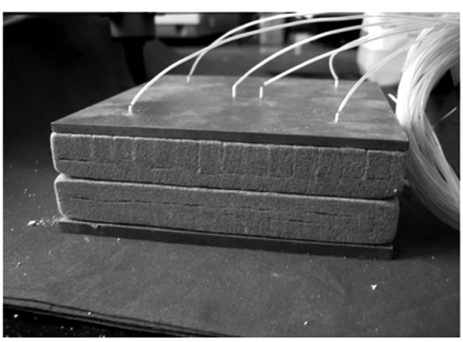
From Fig. 5 and Tab. 1, we can find that in three tests the surface equilibrium temperature (T_1) varies from 526.0℃ to 570.8℃, the middle temperature (T_2) and the bottom temperature (T_3) decrease with the pressure decreasing. The results accord well with the insulation mechanism of low density thermal insulation materials.



(a) Sketch of model



(b) Photo of material



(c) Photo of model

Fig. 4 Test model without control system

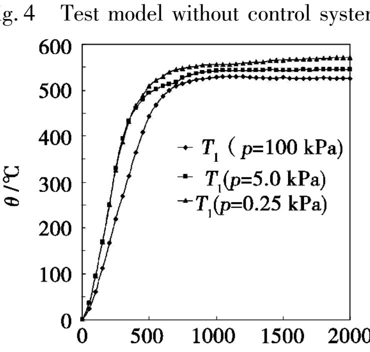


Fig. 5 Temperature response without control system

Tab. 1 Temperature response of 2 000 s

pressure/kPa	T_1/℃	T_2/℃	T_3/℃
100.0	526.0	293.1	35.5
5.0	545.0	292.0	31.0
0.25	570.8	289.9	27.2

2.2 Test with control system

2.2.1 Model

The models' structure size was almost the same as that for the tests without control system. The deference was only one piece of low density thermal insulation materials (30 mm) and two pairs of thermocouples in the models. Control system was used to keep a constant surface temperature (T_1) in all tests. The low density thermal insulation materials have the same components but include three kinds of density (0.8 g/cm^3, 0.6 g/cm^3 and 0.4 g/cm^3). The surface temperature controlled was 730℃. The running time was 1 000 s. Fig. 6 shows the image of the model. The T_1 and T_2 represent two pairs of thermocouples.

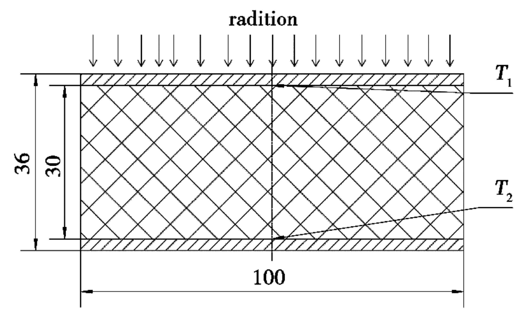
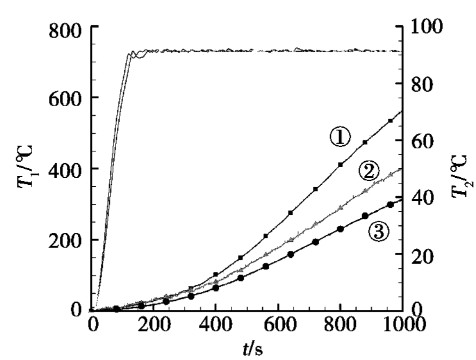


Fig. 6 Test model with control system

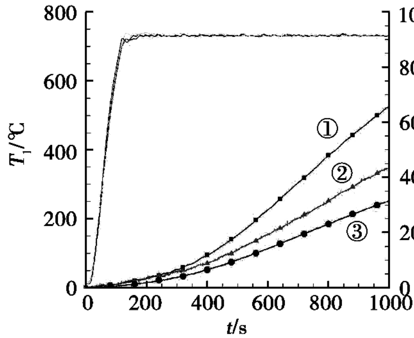
2.2.2 Test results

The test results include the temperature responses of three kinds of density thermal insulation materials. The surface temperature controlled was 730℃ and the tests were carried out in three deferent pressures (100 kPa, 5 kPa and 10 Pa).

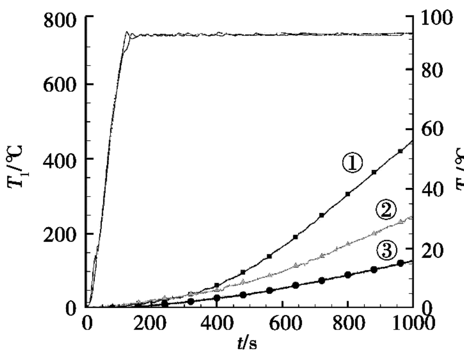
Fig. 7 gives the temperature responses during the tests. The surface temperature (T_1) was well controlled and the measured surface temperatures were between 727℃ to 733℃. Tab. 2 shows the temperature responses at the end of test (1 000 s).



(a) Pressure: 100.0 kPa



(b) Pressure: 5.0 kPa



(c) Pressure: 10.0 Pa

Fig. 7 Temperature responses with control system

①D=0.8 g/cm^3; ②D=0.6 g/cm^3; ③D=0.4 g/cm^3.

The objective of the tests was to study the performance of low density thermal insulation over a wide range of pressures where solid conduction, gas conduction and radiation are the three modes of heat transfer. The results show that, at the same surface temperature and the same components, the density and pressure will affect the thermal insulation performance of materials. Decreasing the pressure or decreasing density will be favor of improving the thermal insulation performance.

Tab. 2 Temperature responses of 1 000 s

density/g·cm^{-3}	pressure/kPa	T_2/℃
0.8	100.0	70.6
	5.0	65.9
	0.01	56.4
0.6	100.0	50.3
	5.0	43.6
	0.01	30.6
0.4	100.0	39.4
	5.0	31.5
	0.01	16.0

3 Conclusion

The radiation heating facility is developed for long duration non-ablating reusable thermal materials testing. The power of the quartz lamps heater is 0 to 150 kW. The minimum pressure in the test chamber is 10 Pa. The maximum running time is 2 000 s at the surface temperature about 600℃.

The control system has been developed to control the output of thyristor supply and keep the surface temperature of the tested materials constant.

The low density thermal insulation materials have been tested on the radiation heating facility at the surface temperature of 730℃ and pressures of 10.0 Pa, 5.0 kPa and 100.0 kPa. The results show that, at the same test condition, the density and pressure will affect the thermal insulation performance of the materials. Decreasing the pressure or decreasing the density will improve the thermal insulation performance.

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