RESEARCH ARTICLE

Measurement of Thermal Diffusion Coefficient of High Thermal Conductivity Pellets by Laser Scattering Method

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Abstract: UO2-BeO high thermal conductivity pellets have the characteristics of high thermal conductivity, high efficiency, long cycle and low recovery cost compared with traditional nuclear fuel. In this paper, the thermal diffusion coefficient of UO2-BeO pellets is characterized by laser flash method, in which the selection and optimization of test parameters are the main research part.
Keywords: High thermal conductivity pellets; Laser flash method; thermal diffusion coefficient

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1 Introduction

Fuel is the last key link before nuclear fuel enters the reactor. High thermal conductivity pellets made of UO2 and BeO will be used in future fuel components. Compared with traditional nuclear fuel pellets, UO2-BeO pellets with high thermal conductivity are improved in efficiency and safety. The melting point, thermal expansion, thermal conductivity, specific heat and enthalpy, elastic modulus, Poisson's ratio, thermal stability and other properties of high thermal conductivity pellets with different proportions need to be tested separately. This paper mainly studies the detection method of thermal diffusion coefficient of high thermal conductivity pellets.

2 Method Principle

The thermal diffusion coefficient reflects the thermal diffusion ability or heat exchange rate of a substance. Laser flash method, as a common method to measure the thermal conductivity of materials, is based on the principle that at a certain set temperature, a laser pulse is emitted by a laser source, which irradiates the lower surface of the sample, instantly raises the surface temperature of the sample, and conducts the energy to the upper surface of the sample in one dimension. The infrared detector is used to continuously measure the temperature rise process of the upper surface of the sample, and then the relation curve of temperature rise relative time is obtained. By measuring the time (t50) required for the temperature of the upper surface of the sample to rise to half of the maximum value after receiving light pulse irradiation, the thermal diffusion coefficient of the substance is calculated by the following formula:

α= 0.1388 * d2 / t50

Where: α-thermal diffusion coefficient of the substance;

D—— the thickness of the tested sample;

T50—— The time required for the upper surface temperature of the sample to rise to half of the maximum value.

3 Reagents and Materials

Graphite spray

4 Instruments and Equipment

LFA457 Laser Pulse Thermal Conductor

Temperature range:-100 ~ 1100℃ ;

Measuring range: 0.1 ~ 2000 W/MK;

Measurement accuracy: 3% ~ 7%;

Sample diameter: 12.7 mm.

5 Experimental Methods

5.1 Add Liquid Nitrogen

Use a plastic funnel to add enough liquid nitrogen into the small hole above the infrared detector until it overflows, and wait for one to two minutes. After the vaporized liquid nitrogen is sprayed out, add liquid nitrogen again until it overflows, and use a special plug to block the small hole.

5.2 Loading Samples

Turn on the furnace body, turn the infrared detector, remove the SiC sample sleeve, and load the sample (note: align the gap of SiC sample sleeve with the center, make it align with the thermocouple, and ensure that the thermocouple does not touch the sample sleeve), turn the infrared detector to return to its original position, and close the furnace body.

5.3 Vacuumizing

Turn off the air outlet valve, turn on the vacuum pump, loosen the vacuum gauge (black valve) until all the pressure lights are off, and turn off the vacuum pump. Open the charging valve and fill it until the pressure increases to 0, that is, continue filling for (5~10)s after the right boundary light is on, and close the copper valve after a slight positive pressure. Close the vacuum valve. Repeat the above process for 3 times. Open the air outlet valve, adjust the low pressure valve of the gas cylinder to 0.1MPa, and then adjust the mass flowmeter to a flow rate of 50mL/min.

5.4 Set Measurement Parameters

Open the measuring software, select InSb as the detector, Tcal zero as the calibration file, SiC 12.7mm as the sample holder, Cape-Lehman model as the model, linear as the basic type, and click Add to input the material name and density, and set the initial conditions, temperature conditions and ending conditions.

6 Results and discussion

6.1 Selection of Sample Thickness

(1) High thermal conductivity materials: materials with thermal diffusivity greater than 50mm2/s at 500℃ (including metal, graphite, functional high thermal conductivity ceramic materials, etc.): generally, the thickness of sample preparation should be controlled between 3 and 6 mm.

(2) Medium thermal conductivity materials: materials with thermal diffusion coefficient of 0.5 ~ 50 mm2/s at 500 ℃ (including most general ceramics and some alloy materials, etc.): the general sample preparation thickness should be controlled between 2 ~ 3 mm.

(3) Low thermal conductivity materials: materials with thermal diffusion coefficient less than 0.5mm2/s at 500℃ (including plastics, rubber, glass, etc.): generally, the sample preparation thickness should be controlled between 0.1 and 2 mm.

By preliminary measurement, the thermal diffusion coefficients of various proportions at 500℃ are all between 0.5 ~ 50 mm2/s, which shows that the material is a medium thermal conductivity material. In view of the low thermal diffusion coefficient of the core block due to high heat among the medium thermal conductivity materials, the sample thickness is determined to be between 2.0 ~ 2.5 mm..

6.2 Correction Model Selection

There are five correction models of LFA457 laser pulse thermal conductivity meter, which are adiabatic model, Cowan model, CapeLehman model, radiation model and pulse correction model. Through investigation, we have mastered the characteristics and advantages of various models, as follows:

(1) Adiabatic model: no heat loss correction, this model has no correction for the half-temperature rise time value, and it is generally not recommended for use.

(2)Cowan model: It includes heat loss correction, which is close to CapeLehman model when the sample thickness is less than 2mm and the temperature is less than 500℃ , and is suitable for measuring the thermal diffusion coefficient of low thermal conductivity materials.

(3)CapeLehman model: It includes surface heat loss correction and radial radiation heat loss correction, which is accurate in calculation, especially when the temperature is above 800℃ and the sample thickness is between 2 and 4 mm.

(4) Radiation model: it is only used in the case where the sample is partially transparent (such as glass and artificial crystal samples).

(5) Pulse correction: to correct the influence of the irradiation pulse width on the initial temperature rise of the curve (especially when the energy transmission time is short and t50 is close to the pulse width by order of magnitude), XX model plus pulse correction is recommended.

In view of the fact that more attention is paid to the test results of high temperature section in the test of thermal diffusion coefficient of high thermal conductivity pellets, and the sample thickness is between 2 ～ 4mm and 4 mm, CapeLehman correction model is selected.

6.3 Test Parameter Setting (LFA457)

The high thermal conductivity core is an opaque medium thermal conductivity ceramic material. The detection parameters of this kind of material are as follows: amplifier gain is set to 50, signal sampling time is 3000ms, laser voltage is 1826V, filter transmittance is 100%, temperature stability threshold is 0.20K/30s, and temperature difference threshold is 2.0K K.

6.4 Determination of Thermal Diffusion Coefficient of High Heat to Pellets with Different Proportions

Using the above selected test parameters, the thermal diffusion coefficient of high thermal conductivity pellets with different proportions was tested, and the results are shown in the figure below:

6.5 Precision Test

Using the correction model, sample preparation thickness and detection parameters selected by investigation, the repeatability test of thermal diffusion coefficient measurement results at 500℃ was carried out with 3% and 5% high thermal conductivity pellets, respectively. The measurement results are as follows.

The measurement results show that using CapeLehman model, the sample thickness is 2.5mm, and the detection parameters are set according to LFA457 Application Record of Laser Pulse Thermal Conductor. The precision of thermal diffusion coefficient of high thermal conductivity pellets is better than 5%, and the precision of thermal diffusion coefficient test of LFA laser pulse thermal conductor is also 5%, which meets the requirement of thermal expansion coefficient test precision.

Table 1 Measurement results of thermal diffusion coefficient of 3% pellets at 1000℃

Measurement times	one	2	three	four	five	six
Thermal diffusion coefficient (mm2/s)	1.411	1.436	1.516	1.486	1.612	1.528
Specific heat RSD(%)	4.5%					

Table 2 Measurement results of thermal diffusion coefficient of 5% pellets at 1000℃

Sample quantity (mg)	one	2	three	four	five	six
Thermal diffusion coefficient (mm2/s)	1.778	1.968	1.812	1.796	1.958	1.864
Specific heat RSD(%)			4.1%			

7 Conclusion

Through experiments, the optimal test parameters of thermal diffusion coefficient test of high thermal conductivity pellets are determined, that is, the correction model

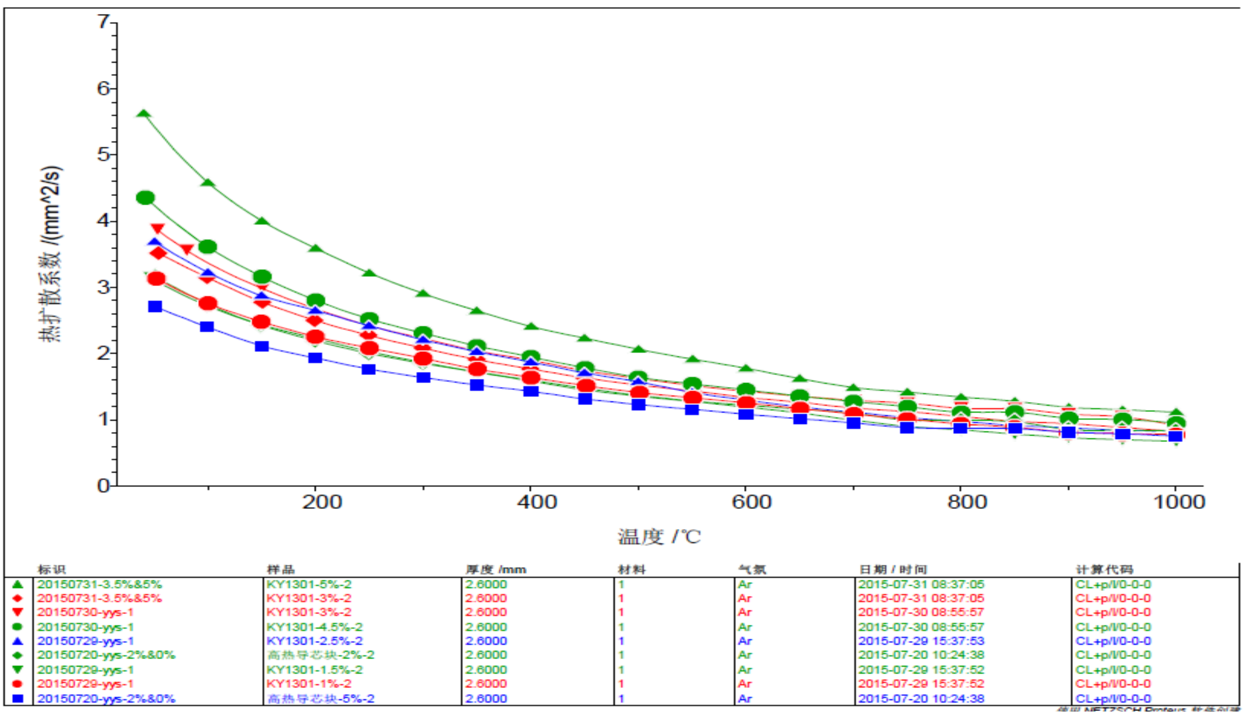

Fig. 1 Test results of thermal diffusion coefficient of high thermal conductivity pellets with different proportions

is CapeLehman, the sample thickness is about 2.5mm, the amplifier gain is set to "50", the signal sampling time is 3000ms, the laser voltage is 1826V, the transmittance of filter is 100%, the temperature stability threshold is 0.20K/30s, and the temperature difference threshold is 2.0K K. According to the above conditions, the test results were repeated, and the precision was 5%, which met the test requirements of thermal diffusion coefficient.

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