STUDY ON THE RELATIONSHIP BETWEEN MOISTURE CONTENT AND THERMAL CONDUCTIVITY OF SiO₂ FIBER MEMBRANE

Liulei¹, Liu Wei–jun², Ding Xiu–peng³

¹College of Mechanical Engineering, Shanghai University of Engineering Science
²College of Mechanical Engineering, Shanghai University of Engineering Science
³College of Mechanical Engineering, Shanghai University of Engineering Science

Abstract

On the basis of testing the SiO₂ fiber membrane material, the relationship between the moisture content of the SiO₂ fiber membrane and the thermal conductivity is obtained. The results show that the thermal conductivity of SiO₂ fiber membrane increases slowly with the increase of moisture content first and then increases rapidly, and then tends to be stable and slow. The thermal conductivity of SiO₂ fiber membrane is minimum in the case of almost no water. When the moisture content of SiO₂ fiber membrane is higher than 20%, the thermal conductivity increases rapidly with the increase of moisture content, the maximum thermal conductivity occurs when the moisture content of SiO₂ fiber membrane is about 46.67%, the thermal conductivity of SiO₂ fiber membrane tends to be stable between 46.67% and 100% of its moisture content.

Keywords: SiO₂ Fiber Membrane; Moisture Content; Thermal Conductivity.

1. INTRODUCTION

SiO₂ fiber membrane has been frequently applied to thermal insulation materials because of its many advantages[1], such as good thermal stability, low heat transfer coefficient, electrical insulation and excellent optical performance. The heat transfer of the SiO₂ fiber membrane during the moisture absorption is a compound heat transfer process, the internal heat transfer mechanism of SiO₂ fiber membrane varies with the moisture content of the fiber membrane, when the water content is high, the diffusion and heat transfer of water molecules occurs[2], and there is also the diffusion and heat transfer of the gas. In this paper, the changing rule of thermal conductivity of SiO₂ fiber membrane under different conditions is studied through experiments, which provides some basis for the research of SiO₂ fiber membrane thermal insulation filling materials.

2. TEST METHODS AND INSTRUMENTS

2.1 Test Methods

A standard parameter to measure the strength of thermal conductivity is the coefficient of thermal conductivity[3]. According to the relationship between temperature and time, the method of measuring the thermal conductivity of material can be divided into two categories: steady state method and non - steady state method[4]. The thermal conductivity of the test instrument DRE-III transient heat conduction coefficient is provided by Hunan Xiangtan Xiangyi Apparatus Co. Ltd., the thickness of the sample is 20mm, the temperature of laboratory is 15°C, and the relative humidity is 75%. In the experiment, Firstly, SiO₂ fiber membrane is dried and weighed and then we measure its thermal conductivity, SiO₂ fiber membrane is continuously humidified with humidifier and its thermal conductivity is measured many times. The specific test method of thermal conductivity is as follows:

1. Put the probe into two sample planes that need to measure thermal performance and firmly fix the probe and sample on the test bench.

2. The bridge is balanced before the experiment, if the resistance of one sensor is 1 to 50 Ohm, the current should not exceed 1mA.

3. The output power and measurement time are set, and the lower power is preferred to heat the probe and to record the voltage increment and temperature rise during the measurement.

4. At least 100 time points should be collected during the measurement time.

5. According to figure 1, the following formula is used to calculate the temperature rise ΔT(t) of the probe and the read out voltage ΔU(t) after recording the time and voltage data, the temperature rise of the probe is calculated by formula (1):
Fig 1: A schematic diagram of electric bridge with increase in the resistance value of the probe

| 1 | Potentiometer; 2 | Probe; 3 | Probe lead line; R_s | Series resistance (Ω); R_L | Total resistance of the probe lead (Ω); R_0 | Resistance of the probe before the transient heating (Ω); ΔR | Increase of the probe resistance (Ω); ΔU | Voltage imbalance caused by the increase of the probe resistance (V); |

\[ \Delta T(t) = \frac{(R_s+R_L+R_0)\Delta U(t)}{[J_0\cdot R_s\cdot \Delta U(t)]\cdot (\alpha\cdot R_0)} \]  

(1)

\[ \Delta T(t) \] - The average temperature rise of the probe (K);

\[ \Delta U(t) \] - Unbalanced output of bridge road caused by change of probe resistance (V);

\[ \alpha \] - The temperature coefficient of the resistance of the probe (1/K);

\[ J_0 \] - Initial current of sensor during transient process (A);

6. Change the test temperature to cover the temperature required by the sample in order to ensure the temperature balance at each temperature[5].

7. After the test is completed at the highest temperature, it is cooled to one or more lower temperatures to repeat the measurements[6].

8. The thermal conductivity measured under different temperatures and pressures is recorded.

9. Thermal performance calculation:

For a slight rise in the temperature of the probe, there are the following equations:

\[ R(T) = R_0\cdot (1+\alpha\cdot \Delta T(t)) \]  

\[ \Delta T(t) = T(t) - T_0 \]  

\[ \Delta T(t) = \Delta T_i(t) + \Delta T_s(t) \]  

(3)

\[ \Delta T_i(t) \] - Temperature rise of the insulating layer of the probe (K);

\[ \Delta T_s(t) \] - Sample surface temperature rise (K);

It is assumed that a double line probe is approximated made up of a number of concentric equidistance circles, and the heat conductivity equation is as follows:

\[ \Delta T_s(t) = P_0\left(\frac{\sigma^2}{4\pi\lambda r}\right)^{1/2} \]  

(4)

\[ P_0 \] - The output power of the probe;

\[ r \] - The radius of the outer ring of the probe;

\[ \lambda \] - The thermal conductivity of the sample;

\[ \tau \] - Characteristic time ratio;

\[ \tau = (t/\theta)^{1/2} \]  

(5)

\[ \theta \] - Characteristic measurement time, \( \theta = r^2/\kappa \)

\[ \kappa \] - Thermal diffusivity of materials;

\[ D(t) \] - The dimensionless time function;

\[ D(t) = \left[ m(m+1)\right]^{\chi/2} \sum_{l=1}^{m} \frac{I_0\left(\frac{\lambda k^2}{4\pi^2 r^2}\right)^{1/2}}{2^{l^2-1}2m^2\pi^2} d\sigma \]  

(6)

\[ m \] - Concentric ring source number;

\[ I_0 \] - Modified Bessel function;

\[ t_c \] - Time correction;

\[ \tau_c = \left((t-t_c)/\theta\right)^{1/2} \]  

(7)

2.2 Test Instruments

The main technical parameters of the DRE-III thermal conductivity tester are detailed in Table 1.

Table 1: The main technical parameters of the DRE-III thermal conductivity tester

<table>
<thead>
<tr>
<th>Technical indicators</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measuring object</td>
<td>Metals, alloys, ceramics, silicon, polymers, adhesives, etc.</td>
</tr>
<tr>
<td>Sample size</td>
<td>A lump or cylinder, requiring only a relatively smooth surface</td>
</tr>
<tr>
<td>Temperature range</td>
<td>Room temperature to 120°C</td>
</tr>
<tr>
<td>Precision of temperature</td>
<td>≤0.001°C</td>
</tr>
<tr>
<td>Relative error of measurement</td>
<td>≤3%</td>
</tr>
<tr>
<td>Repeatability error</td>
<td>≤3%</td>
</tr>
<tr>
<td>Power</td>
<td>30V DC</td>
</tr>
<tr>
<td>Range of thermal conductivity</td>
<td>0.005 to 100 W/(m·K)</td>
</tr>
<tr>
<td>Thermal diffusivity</td>
<td>0.1 to 100 mm²/s</td>
</tr>
</tbody>
</table>
The measurement time is 10 ~ 160 s.

External power supply: AC 220V±10% ; 50/60 Hz

Entire Power: <500W

Equipment reference standard: ISO22007.2-2008

The thermal conductivity test site is shown in Figure 2:

Fig 2: Thermal conductivity test site

### Measurement time
10 ~ 160 s

### External power supply
AC 220V±10% ; 50/60 Hz

### Entire Power
<500W

### Equipment reference standard
ISO22007.2-2008

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### RESULTS AND ANALYSIS

As shown in Figure 3, the SiO₂ fiber membrane has a great influence on its thermal conductivity of the film after it is dampened, the thermal conductivity of SiO₂ fiber membrane increases slowly with the increase of moisture content first and then increases rapidly, and then tends to be stable and slow. Under the condition of almost no water, the thermal conductivity of SiO₂ fiber membrane is the minimum 0.049 W/(m•K). When the moisture content of SiO₂ fiber membrane is higher than 20%, the thermal conductivity increases rapidly with the increase of moisture content, the maximum thermal conductivity of SiO₂ fiber membrane is between 0.049-0.229 W/(m•K).

When the moisture content of SiO₂ fiber membrane is between 46.67% and 100%, the thermal conductivity of SiO₂ fiber membrane tends to be stable.

The thermal conductivity of SiO₂ fiber membrane material under different water content is tested. The conclusions are as follows:

1. The thermal conductivity of SiO₂ fiber membrane increases slowly with the increase of moisture content first and then increases rapidly, and then tends to be stable and slow. The thermal conductivity of SiO₂ fiber membrane is between 0.049-0.229 W/(m•K).
2. When the moisture content of SiO₂ fiber membrane is higher than 20%, the thermal conductivity increases rapidly with the increase of moisture content, the thermal conductivity of SiO₂ fiber membrane tends to be stable when its moisture content is between 46.67% and 100%.
3. The water content should not exceed 20% when the SiO₂ fiber membrane is used as a thermal insulation material, and it is better to take waterproof measures in the application.

### REFERENCES