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Application Sheet SSH-001

Steady-state thermal conductivity measurement system: SS-H40 measurement principle and equipment

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1. Introduction

Thermal conductivity is important for effective use of heat. For example, power devices are used in inverters for electric vehicles, but heat dissipation is essential for stable operation. Components in miniaturized products such as smartphones and densely mounted, so the thermal conductivity of the materials used for heat dissipation is extremely important. One of the key indicators of the performance of these heat-dissipating materials is thermal conductivity.

In recent years, diverse designs have been conducted using computers, and thermal design is often first conducted by computer simulation as well. Again, thermal conductivity is an important input value.

The appropriate thermal conductivity measurement method differs depending on the thermal conductivity, shape, and form of the material. For example, the thermal conductivity of thermal interface materials used for heat dissipation of electronic components such as power devices is lower than that of metals, and many of them are soft, so a measurement method called the steady-state method is often used. The steady-state method is widely used as a thermal conductivity measurement method because it is characterized by the direct measurement of thermal conductivity by contact.

2. Principle of the steady-state method

2.1 Guarded Hot Plate Method

Thermal conductivity is defined by Fourier's equation. The steady-state method measures the thermal conductivity of a sample based on Fourier's equation. Thermal conductivity can be determined by measuring the heat flow using an electrical calorific value or a heat flow sensor, measuring the temperature gradient in the sample using a thermocouple, and determining the thickness of the sample. [1,2]

The guarded hot plate method or GHP is a widely used and established standard method for measuring thermal conductivity of insulation materials. The amount of heat generated by the heater is used as the amount of heat that passes through the sample. A guarded hot plate is placed around the heater to prevent heat generated by the heater from leaking into the surrounding area, which would result in an error in the heat value. This method is also used to determine the thermal conductivity of reference materials used in various thermal conductivity measurement methods. This method is also called the flat plate absolute method or the flat plate direct method. JIS A 1412 1 and other standards have been established for this method.

Figure 1 shows a diagram of the measurement principle of the protective hot plate method (one-piece method). The main heating plate is surrounded by a guarded hot plate, and the guarded hot plate is controlled to the same temperature as the main heating plate. By suppressing the flow of heat from the main heat plate to the lateral direction, the heat quantity Q generated in the main heat plate flows one-dimensionally from the sample to the lower cooling plate. The elevated temperature side temperature T_h, low temperature side temperature T_c, heat quantity Q (heater power) of the main heating plate, heat flow area S, and sample thickness D are measured while the temperature is maintained at a steady state, and the thermal conductivity λ is obtained using (1) below.

$$Q = \lambda \frac{T_h - T_c}{D} S \qquad (1)$$

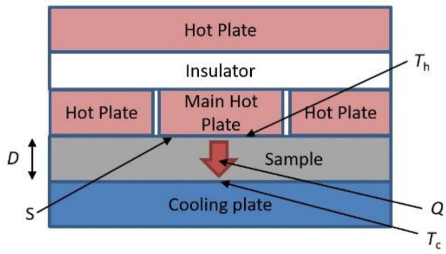

Figure 1: Measuring principle of measurement of the guarded hot plate method (single plate method)

2.2 Comparison Methods

There are various comparison methods. In this section, the heat flowmeter method is described. The heat flowmeter method is one of the practical measurement methods. It is widely used because it is easier to measure than the guarded hot plate method. A sample and a heat flowmeter are combined for measurement. There are some that use a single heat flow meter and sample, and others that use multiple samples and heat flow meters. [3,4]

Standards include JIS A1412-2 and ASTM C 513. Figure

2 shows a schematic diagram of the heat flowmeter method. In the guarded hot plate method, the electric power given to the main hot plate is used as the heat quantity, whereas in the heat flowmeter method, the heat quantity is measured by a heat flowmeter. In the configuration shown in Figure 2, heat flowmeters are installed on both sides of the sample and each measurement is observed to evaluate and correct for the presence of heat loss to the surroundings.

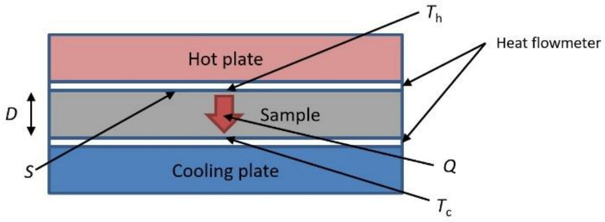

Figure 2: Measurement principle of the heat flowmeter method

A similar measurement method to the heat flowmeter method is the flat plate comparison method. A temperature sensor is placed on both sides of a standard plate of known thermal conductivity to determine the heat flow rate. The standard plate serves the same function as a heat flowmeter. For example, it is specified as Annex A flat plate comparison method in JIS A 1412-2.

The beforementioned standard is a measurement method for insulation materials, but there are also measurement methods that use the same concept to measure samples with high thermal conductivity, such as TIM (Thermal Interface Material). Heat flow rate is determined using a heat flow meter in the heat flow meter method or a meter bar equivalent to a standard plate in the flat plate comparison method. Meter bars are used in the same manner as the standard plates for the flat plate comparison method described above. The standards include ASTM D5470, which corresponds to TIM, and ASTM E1530, which combines a heat flow sensor and a guard heater installed around the sample. When measuring a sample with high thermal conductivity, the effect of interfacial thermal resistance may not be negligible because the thermal resistance of the sample is small. In general, multiple samples of varying thickness are prepared, and the interfacial thermal resistance is predicted by plotting the thickness of the sample on the horizontal axis and the thermal resistance on the vertical axis and extrapolating to zero thickness.

3. Measuring Equipment

3.1 Features

Bethel's SS-H40 steady-state thermal conductivity measurement system has the following two features by using a heat flow sensor, measurement time is shorter than conventional methods. Two measurement modes, load mode and thickness mode, are available to accommodate both elastic and flexible specimens.

Examples of samples to be measured include TIM (Thermal Interface Material), printed circuit boards, encapsulation resins, insulation materials, rubber, adhesives, thermal conduction grease, and others.

3.2 Equipment Configuration

Figure 3 shows the SS-H40 steady-state thermal conductivity measurement device. Figure 3 shows the main unit of the measurement device. The front door of the device is opened, and the sample is installed. Setting of measurement conditions and data acquisition are performed from an external personal computer. To provide a temperature gradient to the sample, a heater and a cooling section are built in. The cooling section is supplied with cooling liquid from an external chiller.

4.Examples of Thermal Conductivity Measurements.

Table 1 shows examples of thermal conductivity measurements of zirconia and alumina measured with this system. The errors are within 10% compared to the catalog values.

Fig. 3 Steady-state thermal conductivity measurement system SS-H40

Table 1 Example of thermal conductivity measurement results

Specimen name	Thermal conductivity / $Wm^{-1}K^{-1}$	
	Measured value	Catalog values
Zirconia	2.92	3.0
Alumina	23.5	25

5. Summary

The principle of the steady-state method features and configuration of Bethel's steady-state thermal conductivity measurement system, and examples of thermal conductivity measurements were presented. This system can be used for a wide range of thermal conductivity measurements, including those in the electronics field.

6. References

[1] Kenichi Kobayashi et al., Basics of heat transfer engineering and examples of thermal property measurement and heat countermeasures, R&D Support Center, P70
[2] Ichiro Hatta, Latest Heat Measurement, Agne Technology Center, P218
[3] Kenichi Kobayashi et al., Basics of heat transfer engineering and examples of thermal property measurement and heat countermeasures, R&D Support Center, P79
[4] Ichiro Hatta, Latest Heat Measurement, Agne Technology Center, P214

*The measurement results listed in this data sheet are typical results and do not guarantee individual measurement results.
*Product specifications listed in this data sheet are subject to change without notice.

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