Thermal conductivity measurement using thermoelectric module

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Abstract. In this study, thermoelectric module is used as a heater for thermal conductivity measurement of solid materials. Principle of temperature gradient is adopted in this measurement. Stainless steel is utilized as a reference material. Each temperatures are measured by t-type thermocouple and the thermal conductivity is then calculated. The result shows that the thermal conductivity of tested materials is 0.303 W/mK with maximum uncertainty of 3.79 %. To assure the result of this measurement, the thermal conductivity of tested material is also measured by laser flash method. The difference result of both measurement is below 5%.

1. Introduction

Thermal conductivity which is defined as a measure of the ability of substance to conduct heat is one of the important thermal properties. In engineering field, the information of this property is needed to select material so that it meets the requirements of applications [1]. Moreover, thermal conductivity is enhanced by using nano-material technology [2-3]. This causes higher performance at the applied technology. Several methods and improvements have been introduced to measure thermal conductivity of materials [4-10]. Two of them are temperature gradient and laser flash method. In the first method, the substance is heated by specific amount of heat from heating element so that temperature gradient occurs and the thermal conductivity can be calculated [4]. While in the second method, the substance is shot by laser radiation which causes the increasing of temperature. The time dependent of temperature is observed and thermal conductivity is then determined. [5].

Thermoelectric module is a device that can act as a heat pump. Figure 1 shows the sample of the module. When DC electric current is supplied to the module, the temperature difference between the two sides occurs. The temperature of one side is lower than ambient so it absorbs heat [11]. Contrarily, the temperature of another side is higher than ambient so it emits heat. This device has many advantages which is the dimension is relatively small, no moving parts, long life, easy to control, and use direct current electricity. This module can be used as heater element when the hot side is utilized.
In this study, thermoelectric module is experimentally used as a heater for thermal conductivity measurement by adopting temperature gradient method. The aim of the study is to build measurement system with reasonable accuracy with less than 5% error. The calibrated laser flash apparatus is used for the standard so that the result of experimental thermoelectric module is compared.

2. Experimental Setup

Figure 2 (a) shows the components arrangement. In this measurement, thermoelectric module with 4 x 4 cm surface area was used as a heater. Stainless steel block with the same surface area and 1 cm thickness was utilized as a reference material since its thermal conductivity was already known. The tested sample material was a 2 mm thickness of plastic material and its surface area was conditioned so that the same with the reference material. Heat sink and fan were used to enhance heat dissipation. Insulation materials were used to avoid heat loss from the vertical surface therefore heat loss from vertical surfaces were negligible.

Figure 2 (b) shows the scheme of heat flows. Heat transfer by conduction occur from the hot side thermoelectric module to the heat sink-fan. When the thermoelectric module was being turned on, temperature gradient occurred and temperatures at point $T_i$ to $T_j$ were measured by T-type thermocouple. Since heat conduction at the reference material was the same with at the tested sample, therefore the thermal conductivity was calculated by:

$$k_s = \frac{k_{\text{ref}} L_s (T_1 - T_2)}{L_{\text{ref}} (T_2 - T_3)}$$

where $k_s$, $k_{\text{ref}}$, $L_s$, $L_{\text{ref}}$ were the thermal conductivity of tested sample material, thermal conductivity of reference material, thickness of tested sample, and thickness of reference material respectively.

The experiment was performed ten times to analyze the uncertainty of measurement at different average temperatures between the two sides of tested sample material. Increasing the current flow was done to get higher average temperature. The obtained data were then plotted to the graph and analyzed. The thermal conductivity of tested sample material was also measured by calibrated laser flash apparatus. The result of this measurement was used as a reference to analyze the accuracy of the experiment.
3. Results and Discussion

The result of measurement using thermoelectric heater is shown in figure 3. The horizontal axis shows the average temperature of tested materials while the vertical axis is the result of thermal conductivity measurement. The result shows the thermal conductivity of tested sample material at 25 °C to 45 tends to decrease linearly if the average temperatures are increased. By using linear regression, the temperature dependence of thermal conductivity is expressed by:

\[ k = -0.0027 \, T_{avg} + 0.3709 \]  

Where \( k \) is thermal conductivity of tested sample and \( T_{avg} \) is average temperature. The uncertainty of this measurement is 3.79 % which is obtained from maximum error between experimental result and calculation result by using equation 2. The uncertainty is relatively good since t-type thermocouple for measuring temperature has 0.1 °C uncertainty.
The thermal conductivity measurement by using laser flash method is shown in table 1. The value of thermal conductivity is obtained 0.295 W/mK at ambient temperature of 25 °C. The precision of this measurement is very high with zero standard deviation based on three time repeated measurement. It also means that the uncertainty is very low. This result is used as a reference since the apparatus has been calibrated.

| No | T (°C) | k (W/mK) |
|----|--------|-----------|
| 1  | 25     | 0.294     |
| 2  | 25     | 0.294     |
| 3  | 25     | 0.294     |

The result of the thermal conductivity measurement by using thermoelectric heater at that is calculated by equation 2 and obtained 0.303 W/mK. The comparison shows that the difference with laser flash method is 0.0094 W/mK. It is concluded that the measurement result by using thermoelectric heater is reasonable since the error is 3.2%. The experiment result is relatively good since t-type thermocouple has very small uncertainty to measure temperature.

4. Conclusions
Thermal conductivity measurement using thermoelectric module as a heater has been performed in this study. Temperature sensor selection is one of the important step to get accurate result. T-type thermocouple is the best for this measurement system since its dimension is very small and it has very small uncertainty. The result shows that higher temperature causes the lower thermal conductivity of tested sample material. The uncertainty of measurement is 3.79 %. The thermal conductivity of tested sample material at 25 °C is 0.303 W/mK dan 0.294 W/mK by using thermoelectric module and laser flash method respectively. The error of measurement using thermoelectric is below 5%.

5. References
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