A Contact Method for Measuring Thermal Transport Properties of Solid Materials Using a Stamp Sensor

シャムスル, ハディ

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氏名・(本籍・国籍)	シャムスル ハディ Syamsul Hadi　　(インドネシア)
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論文調査委員	（主　査）教　授　髙　松　　洋 （副　査）教　授　森　　英　夫　　教　授　高　田　保　之 准教授　藏　田　耕　作

論　文　内　容　の　要　旨

A variety of methods have been developed to measure thermal transport properties of solid materials. While each method has advantages and limitations, only a few of these are appropriate for soft materials including biological materials. In the laser flash method, which is the most popular method for measuring solid materials, preparing a specimen of soft materials with precise dimensions is difficult. In the transient plane source method, where the thin sensor/heater is put between two identical samples, it is important to eliminate the thermal contact resistance. However, clamping soft specimens hard without deformation is difficult. Pressing a bead probe on a soft sample would alter the contact area in the point contact-probe method, although the method assumes point contact between the sensor and the sample. Although a technique to puncture a bead probe in a specimen has been applied to soft materials including biological tissues, it is not possible to completely avoid a problem resulted from the thermal contact resistance. Hence the goal of this research was to develop a convenient method for measuring thermal transport properties of solids, particularly soft materials. The method proposed here is a sort of contact method using a 'stamp sensor', which works for non-destructive in-situ measurement.

The thesis consists of 5 chapters. Chapter 1 introduced several methods that has been developed for the measurement of thermal conductivity and thermal diffusivity of solid materials. Based on their advantages and limitations summarized here, the objective of the present research was presented.

In chapter 2, the concept of a stamp sensor and the method to measure thermal conductivity and thermal diffusivity were presented first. The sensor is a thin metallic film, about 3 mm in diameter, which was deposited on a thin glass substrate. In the measurement, the temperature rise of the sensor that is pressed against a surface of a specimen is measured along with heating it by a direct current. The temperature is determined from the electrical resistance. The uniqueness of this method is to put a gel between a film heater/sensor and a sample to eliminate the thermal contact resistance. In addition, a shallow cavity with known dimensions is prepared around the sensor for the gel to give a rough estimation of the gel thickness. The thermal conductivity and the thermal diffusivity of the sample together with the thickness of the gel are then determined simultaneously by comparison of the measured temperature with the transient temperature rise obtained from the theoretical analysis. The values that yield the minimum deviation from the measured temperature rise are determined using a trial-and-error algorithm. The rest of chapter 2 dealt with a numerical study to check the feasibility of the method. The protocol to determining the thermal conductivity and the thermal diffusivity was examined using virtual experimental data that have been generated by adding an artificial scattering to a theoretical temperature change of the sensor. Then the effect of several parameters such as the scattering of the data, the heating power and the heating time on the measurement error was discussed. In addition, virtual measurements have been conducted using virtual experimental data for several kinds of materials. The results demonstrated that the heating of the sensor for 5 s with the power that results in the temperature rise of approximately 5 K would be appropriate for the measurement within acceptable errors. The thermal conductivity and the thermal diffusivity were determined within the error of approximately 2 % and 5 %, respectively.

Chapter 3 described the fabrication process of the sensor and the design of the experiment. The method to fabricate the stamp sensor, design of experimental apparatus, and the procedure of the experiment were presented. The method to determine the time at the start of heating, which is important in this method, was also discussed.

In chapter 4, the results of measuring thermal transport properties of different materials are summarized with discussions. The tested materials were an acrylic resin, an ager gel, a machinable ceramic and a stainless steel SUS 304. Five trials for each material demonstrated that the thermal conductivity and the thermal diffusivity were successfully determined within four to eight iterations by the proposed protocol. The difference from the literature values was approximately 5 to 10 % in the thermal conductivity and 1 to 36 % in the thermal diffusivity depending on the materials. The larger error in the thermal diffusivity was attributed to the fact that the temperature rise of the sensor is less sensitive to the thermal diffusivity than the thermal conductivity. The error was considerably larger than that estimated in the examination using virtual experimental data. This was resulted in part from the error in the temperature measurement and un-uniform thickness of the gel layer which have not been taken into account in the virtual measurement. However the present experiment demonstrated the feasibility of measuring the thermal conductivity of solid materials including soft materials conveniently within approximately 10 %, which would be acceptable for the in-situ measurement.

Finally, the conclusions of the present study were presented in Chapter 5. It was pointed out that developing the method to determine the time at the start of heating would be an important issue left for the future work.

論 文 審 査 の 結 果 の 要 旨

本論文は，スタンプ型センサを用いた熱輸送性質の新しい簡易測定法を考案し，種々の固体材料に加えて従来の方法では困難であった柔らかい材料の測定も可能であることを試作センサを用いて実証したものであり，熱工学上寄与するところが大きい．よって，本論文は博士（工学）の学位論文に値するものと認める．