Thermal conductivity between the flash laser and the thermic method

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Abstract - The flash laser method was proposed by Parker Butler in 1961. It is the most popular method for measuring the thermal diffusivity of solids or Thermal conductivity. The thermal conductivity (λ) is a characteristic of each material. It is expressed in W/mK and it is only valid for homogeneous materials. There are several methods for measuring this coefficient. The ratio between a temperature difference and the resulting thermal flux density, i.e., thermal resistance, can be determined in any case correctly, irrespective of the mechanism of heat transfer through it. The best measurement accuracies (better than 1%) are obtained by the method of the hot plate kept. In the simpler case where the heat transfer is reduced to a single mode, that of conduction (steady state). The λ of the test piece can be calculated if its geometry and temperature differences are known. In this work we will quote and compare the Flash Laser method and the thermal method.

Key words: Fourier law, temperature, diffusivity, insulator, thermocouple

1. Introduction

Physically, thermal conductivity is the property of the ability of a material to transfer the heat and it is the Fourier law that expresses this conduction of heat. There are several ways to measure thermal conductivity. Each method is suitable for a limited range of materials. The thermal properties and the temperature of the medium play a big part in the measurement. In the procedure of the measurement we distinguish different techniques for the determination of the thermal conductivity and it depends on the regime (permanent or transient). The principle of the method is to subject a system to a short-term thermal disturbance (flash) and to observe the temperature response that it generates. The studied system can be a sample with parallel faces subjected to a thermal pulse on one of its faces, the evolution of the temperature being recorded on the opposite face [1-6]. It may also be a sample with cylindrical geometry subjected to an axial pulse, the temperature being recorded on an external generatrix of the cylinder [7, 8].

The most popular method for measuring the thermal diffusivity of solids or Thermal conductivity is

the flash laser method [1]. Improvements have been made on the Pakker model. The new model consitutes the three kinds of transfer, conduction, radiation and convection on the surface [9]. In 1963, another model was proposed that takes into account heat losses, finite impulse effects and the transient transfer regime [10]. In the same year, a more advanced model proposed high-level solutions for transient radial heat transfer and facial heat loss, non-linear regression in case of high heat loss and pulse length correction [11]

In this work we will make a simple comparison between the laser flash method and the classical method to determine thermal conductivity.

2. Materials and experience

2.1 Principle of the LF method

The laser flash apparatus (Figure 1.a) is distilled to measure thermal diffusivity and also the specific heat capacity of solid, liquid and thin films. It consists of: a pulsed laser, a fiber optic system, a water-cooled vacuum furnace, a high-speed infrared thermometer, a differential amplifier, and a vacuum pump (Figure 1.b). To perform a measurement, the bottom surface of a parallel plane sample (see Fig. 1-a,b) is heated by a brief pulse of energy. The resulting temperature change on the upper surface is then measured with an infrared detector

Figure 1-c shows the pulse of energy that heats one side of a sample. an increase in temperature that results from this impulse and it depends on time.

The flash laser method dates back to the studies by Parker et al. in 1961.

The LFA 1000 runs under *Proteus*® Software on Windows®. The *Proteus*®Software includes everything you need to carry out a measurement and evaluate the resulting data.

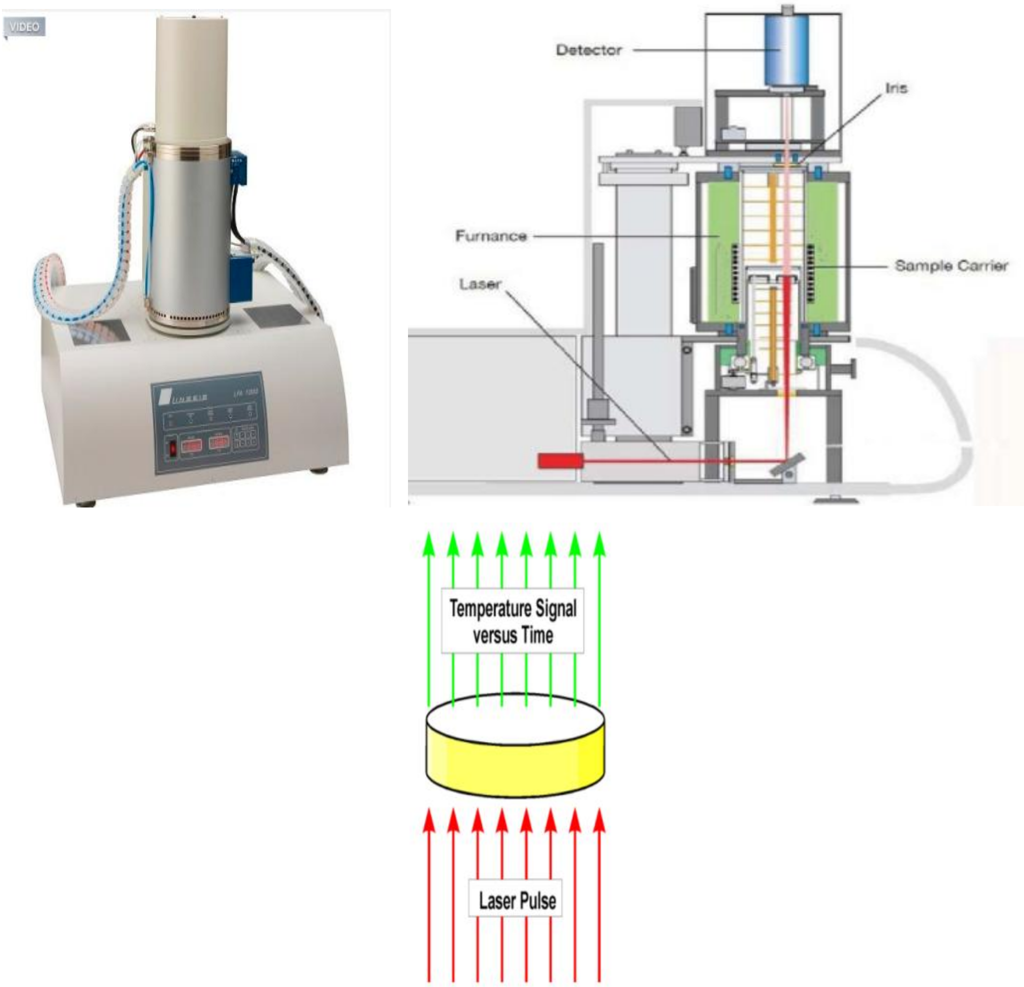

Figure 1.a LFA 1000,LINSEIS   Figure 1.b [12]   Figure 1.c

Figure 1. The LFA 1000 apparatus

2.2 Principle of the Theminal method

Thermal conductivity is a physical quantity that characterizes the behavior of materials during thermal transfer by conduction. This constant appears for example in the Fourier law :

$$Q = \lambda . S \, \frac{T_1 - T_2}{d} \qquad (1)$$

Q: thermal conductivity in J. m-1. K-1. s-1 or W. m-1. K-1.

It represents the amount of heat transferred per unit area and a unit of time under a temperature gradient.

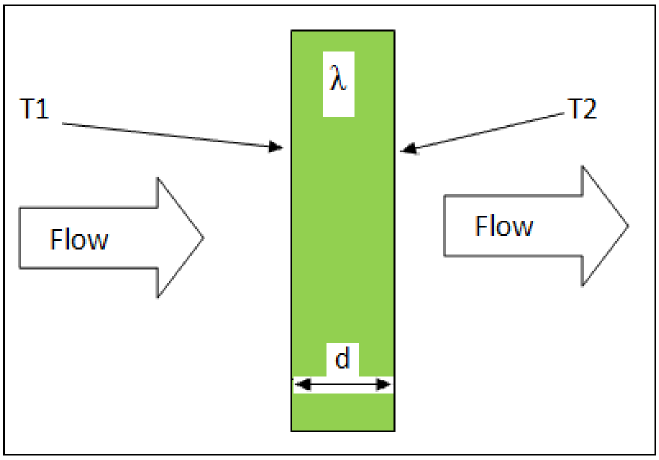

Figure 2. Measuring system

3. Resultat and discussion

3.1 The curve of flash laser method

The typical evolution of the signals is shown in Figure 2 (red curve). The greater the thermal diffusivity of the sample, the faster the signal increases.

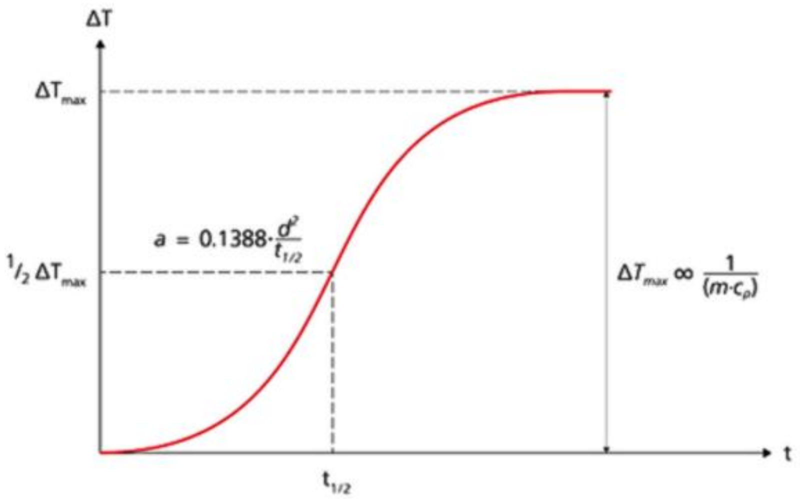

Figure 3. Evolution of signal as a function of time

Figure 2 shows the intermediate time ($t_{1/2}$, time value at the half-height of the signal) and the thermal diffusivity (a), the sample thickness (d) and the thermal conductivity (λ). λ can be determined by the formulas:

According to the theoretical solution proposed for insulation conditions, the sample backside temperature increases, and the temperature rise becomes a constant value (ΔT) after uniform temperature distribution is achieved. In previous analysis, the time t1/2 until the coefficient of thermal diffusivity **a** attained ΔT/2 results from **a** =0.1388d2/t1/2 (d is the thickness of sample). ($t_{1/2}$ method)

$$a = 0.1388.\frac{d^2}{t_{1/2}} \quad (2)$$

Thermal diffusivity (a) : A physical quantity that characterizes the ability of a material to transmit a temperature signal from one point to another of this material. (a) is expressed in m² / s.

$$\lambda\ (T) = a\ (T).\ C_p\ (T)\ .\ \rho\ (T) \quad (3)$$

Thermal Capacity C_p: The physical size that characterizes the ability of a material to store heat. Thermal capacity is expressed in J / K.

a: the thermal diffusivity

ρ: the Density

cp: the Specific heat

λ: the thermal conductivity

T: the temperature

d: the thickness of the sample

t1/2: the time to the half maximum

The solid specific heat (cp) can be determined by the signal height (ΔT_{max}) relative to the signal height of a reference material.

The flash laser method LFA measurements generally take less time than other measures such as Hot Plates Guarded (GHP), Fluxmeter (HFM) or Thermal Conductivity Tester (TCT). On the other hand, the thermic method takes a long time to determine the thermal conductivity of the materials.

3.2 The curvre of classic method

Figure 4 shows the evolution of the temperature (in °C) during 100 minutes. The curve has a normal shape as it was found in literature and having its maximum between 80 and 100 munites.

Thermal conductivity (λ) is a characteristic of each material.

It indicates the amount of heat that propagates by thermal conduction:

- in 1 second,
- through 1 m² of a material,
- 1m thick
- when the difference in temperature between the two faces is 1 K (1 K = 1 ° C).

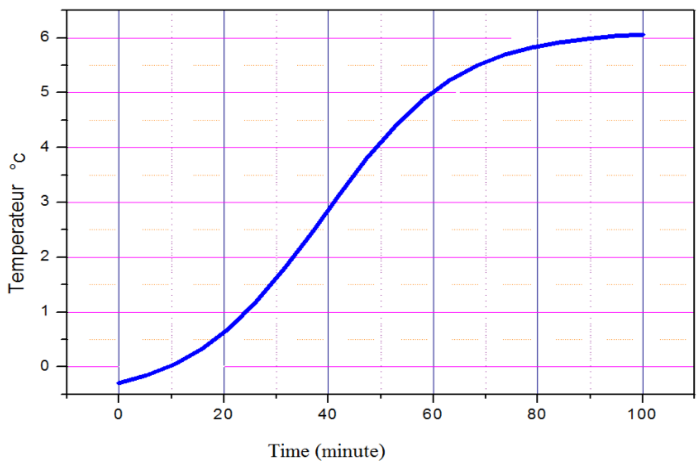

Figure 4. Evolution of temperature as a function of time

If flux, thickness and surface are known then it is possible to determine by the Fourier law (1) to determine the thermal conductivity (λ) of a material.

4. Conclusion

The thermal conductivity and diffusivity of homogeneous materials are determined under transient conditions using apparatus. These thermal characteristics are obtained simultaneously by the analysis of the temperature response of the face of the sample which receives the imposed flow. practically, the errors affecting the measurement of the temperature have a decisive influence on the accuracy of the method. A process by flash laser makes it possible to reduce the errors with the help of its high precision during the experiment.

Réference

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