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Finite Pulse Time Effects for High Thermal Diffusivity Material

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1. Introduction

The determination of thermal conductivities of nuclear materials is increasingly accomplished by measurement of thermal diffusivities and use of the defining relation for the diffusivity, $k = \alpha \rho C_p$,. A variety of techniques for these measurements are in use, among the most widely employed is the pulse heating flash method proposed by Parker *et al*[1]. Parker's pulse heating flash method involves subjecting the front face of a thin flat sample to a short energy pulse and the resulting thermo-gram of the opposite face is recorded and subsequently analyzed to yield the thermal diffusivity. In the simplest form of the experiment, so-called adiabatic model, it is assumed that the heat flow is one dimensional, material is homogeneity, the heat pulse is uniform over the sample surface, there is no test piece heat loss and pulse duration is short pulse length compared to the heat transport times. These conditions are frequently not adequately met. Pulses often are not instantaneous and may, in fact, be comparable in duration with the heat diffusion time. The diffusivity α is computed from relation

$$\alpha \equiv \frac{a^2}{\pi^2 t_c} = 1.37 \frac{a^2}{\pi^2 t_{1/2}} \qquad (1)$$

Where a is the sample thickness and $t_{1/2}$ is the time from the ignition of the energy pulse till the rise of the rear face temperature has reached half of its maximum value. Equation 1 is based upon the duration of the energy pulse being short compared to $t_{1/2}$. If this is not case, then the details of the shape and duration of the energy pulse affect the rear face temperature response curve. This is known as the "finite pulse time effect". Cape and Lehman [2] derived a general expression which included the finite pulse time effects. Some others papers deal with finite pulse time function as square-wave, saw-tooth and triangle-wave form[3-5]. This paper will investigate experimentally finite pulse time effect for high thermal diffusivity material so that pulse duration τ is comparable in duration with heat transport times.

2. Experimental

The thermal diffusivity analysis equipment in experiment is LFA-427 Laser Flash supplied by NETZSCH. The laser pulse generator of equipment can make heat pulse duration from 0.3 ms to 1.2 ms. To maximize finite pulse time effect, we have to select high thermal diffusivity materials and very thin specimens. The available material is industrial pure cupper because of easy handling in experiment and machining in precise dimension. Six test specimens are machined to get disk type form with diameter 12.5 mm and thickness 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 mm respectively. Because generally for most pure metal thermal diffusivity decrease with temperature, it is needed to test in low temperature, for example room temperature. The experiment have performed under test condition varying with laser pulse duration 0.3 ms, 0,6 ms and 0.9 ms respectively for each specimen. And test temperatures are 24 ℃ and 50℃. Finally to determine real thermal diffusivity of specimen, test was performed for 3mm thick specimen being expected to neglect finite pulse time effect.

3. Results

3.1 Real thermal diffusivity of specimen

In order to verify the precision of testing equipment and ascertain the repeatability, the real thermal diffusivity of specimen for 3 mm thickness was measured by 0.6 ms laser pulse duration and this was repeated nine times. Measured average thermal diffusivity value and uncertainty is 121.98 ± 1.42 mm^2/sec in 95% confidence interval. The standard deviation of measured thermal diffusivity is 0.71 mm^2/sec. Due to such high thermal diffusivity property, finite pulse time effects are easily investigated even though generating laser pulse duration is limited.

3.2 Typical laser pulse shape and rear face thermo-gram(detector signal)

Laser pulse shape in experiment is almost square-wave for 0.9 ms and approximately triangle for 0.3ms as shown in Fig 1.

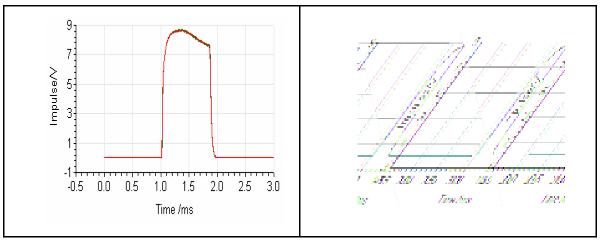

Fig 1. Typical pulse shape for 0.9 and 0.3 ms

Detector signal on rear face and shooting pulse shape are revealed typical thermo-gram related to finite pulse time effect as shown in Fig 2. In this figure, pulse duration time is 0.9 ms and half rise time($t_{1/2}$) is 2.044 ms. If the duration of the energy pulse is not short compared to $t_{1/2}$ then energy pulse affect thermo-gram on rear face and it increase the half rise time. As a result of increasing half rise time, the measured thermal diffusivity of sample is underestimated owing to finite pulse time effect.

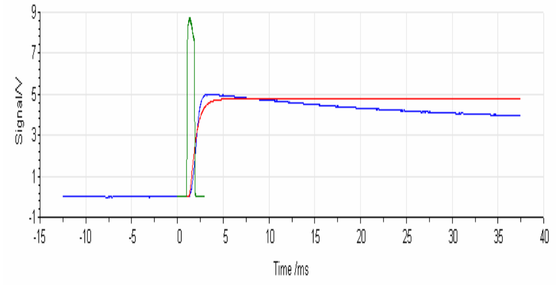

Fig 2. Typical thermo-gram on rear surface for 0.5 mm thickness Cupper with pulse duration 0.9 ms

3.3 Finite pulse time effects

All the test runs are repeated three times for each test condition. Results measured three times are averaged and are adopted representative value for each test condition. Adiabatic-no pulse correction model is assumed for thermal diffusivity due to the purpose to investigate finite pulse time effect. The calculated results are plotted in point of view for pulse duration versus time for a heat pulse to propagate the length of the specimen. Fig 3. and Fig 4. are plots of diffusivity change for pulse propagate time(specimen thickness change) and pulse duration time on room temperature and 50℃ respectively.

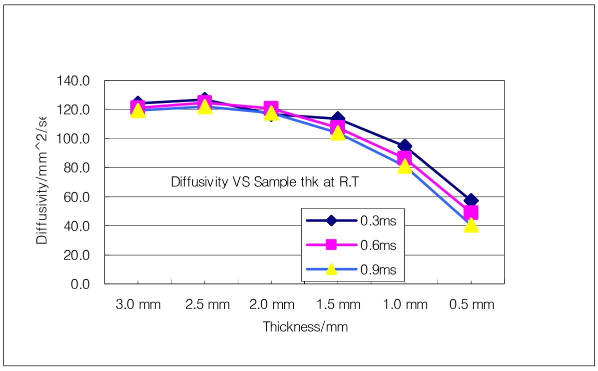

Fig 3. Diffusivity change for various specimen thickness and pulse duration on room temperature

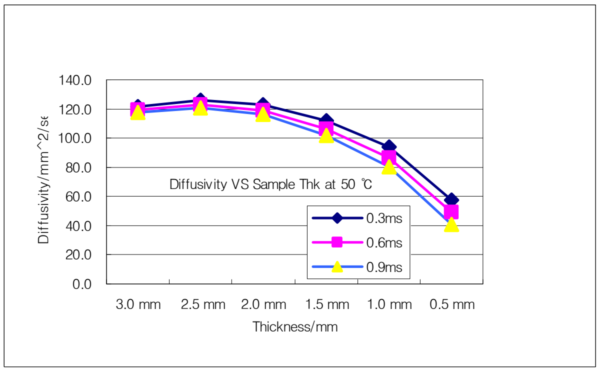

Fig 4. Diffusivity change for various specimen thickness and pulse duration on temperature 50℃

Fig 3. and Fig 4. reveal that sufficient specimen thickness is needed in order not to be affected by pulse duration time. Up to 2.0 mm specimen thickness there is not finite pulse time effect almost. But in the case below 2.0 mm thick, calculated diffusivity values are rapidly decrease with ratio of pulse duration time(τ) over pulse propagate time ($t_{1/2}$). Obviously there is appropriate ratio value ($\tau / t_{1/2}$) neglecting finite pulse time effect, e.g. $\tau / t_{1/2} \leq 0.04$.

4. Conclusion

For high diffusivity material, experimenters have to take account into finite pulse time effect for reducing measurement error. In the case of industrial cupper, above 2 mm thick sample the finite pulse time effect can be neglected. There is appropriate ratio value ($\tau / t_{1/2}$) neglecting finite pulse time effect.

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