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Correction Effect of Finite Pulse Duration for High Thermal Diffusivity Materials

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1. Introduction

In the laser pulsed flash method, a pulse of energy is incident on one of two parallel faces of a sample. The subsequent temperature history of the opposite face is then related to the thermal diffusivity. When the heat pulse is of infinitesimal duration, the diffusivity is obtained from the transient response of the rear face temperature proposed by Parker *et al*[1]. 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 required for the rear face temperature to reach half-maximum, and $t_c \equiv a^2 / \pi^2 t_{1/2}$ is the characteristic rise time of the rear face temperature. When the pulse-time τ is not infinitesimal, but becomes comparable to t_c, it is apparent that the rise in temperature of the rear face will be retarded, and $t_{1/2}$ will be greater than 1.37 t_c. This retardation has been called the " finite pulse-time effect." Equation (1) is accurate to 1% for $t_c > \sim 50\tau$. For many substances, this inequality cannot be achieved with conventional optical sources (e.g. $\tau \approx 10^{-3}$ sec for a solid state laser) unless the sample thickness is so large that its rise in temperature is too small for accurate measurement. One must therefore make an appropriate correction for the retardation of the temperature wave.

Purpose of study are to observe impact of finite pulse time effect in appropriate sample thickness and to verify the effect of pulse correction using Cape and Lehman [2] method for high thermal diffusivity materials.

2. Experimental

2.1 Test Apparatus and specimen

The thermal diffusivity analysis equipment 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. The available material is industrial pure copper because of easy handling in experiment and machining in precise dimension. 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. But we only use 3.0 mm thickness specimen. Because we want to know what effect of finite pulse duration is occurred in proper specimen thickness for various laser pulse duration.

2.2 Test method and condition

The experiments have performed under test conditions with varying laser pulse durations, 0.3 ms, 0.6 ms and 0.9 ms respectively for specimen. And the test are performed from room temperatures(24℃) to 250 ℃. All the test runs are repeated three times for each test condition. Results measured three times are averaged and adopt a representative value for each test condition

2.3 Typical laser pulse shape

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

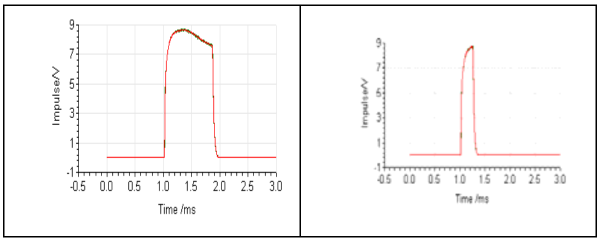

Fig 1. Typical pulse shape for 0.9 and 0.3 ms

3. Results

3.1 Impact of various input pulse duration

In order to verify impact of input pulse duration for sufficient sample thickness, experiments are performed varing with laser pulse duration for same specimen. The Fig 2. shows impacts of input pulse duration for each temperature condition. The measured results with Cape-Lehman no pulse correction are plotted from the view for a pulse duration.

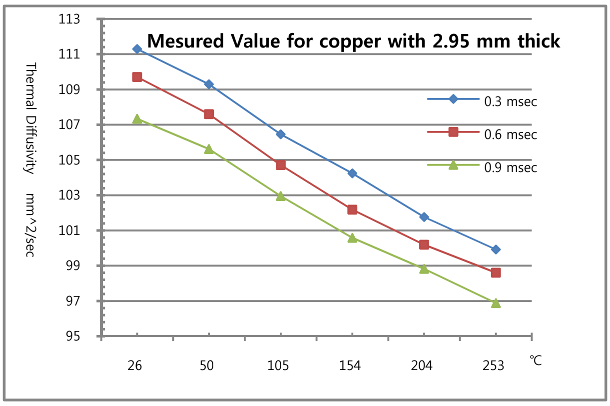

Fig 2. Thermal diffusivity with various pulse duration

Even though sufficient thickness sample is selected for high thermal diffusivity materials, there is no way to avoid finite pulse time effect. Maximum difference due to pulse duration is about 3 % even if we use sufficient thickness specimen and usual pulse duration.

3.2 Effect of pulse correction for pulse duration

Fig 3. – fig 5. show difference between measured thermal diffusivity and corrected thermal diffusivity using Cape-Lehman pulse correction technique for high thermal diffusivity materials e.g. copper. For the case 0.3 ms pulse duration, differecce of measured and corrected value is about 1% below. The longer pulse duration, the lower measured thermal diffusivity . For the case 0.6 ms and 0.9 ms pulse duration, relative difference is about 2.5 % and 4 % respectively.

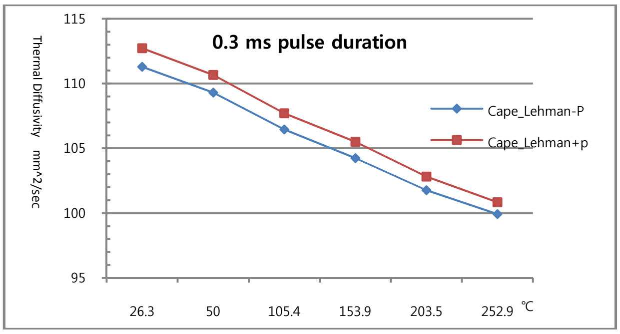

Fig 3. Difference of measured and corrected thermal diffusivity using Cape-Lehman technique for 0.3 ms

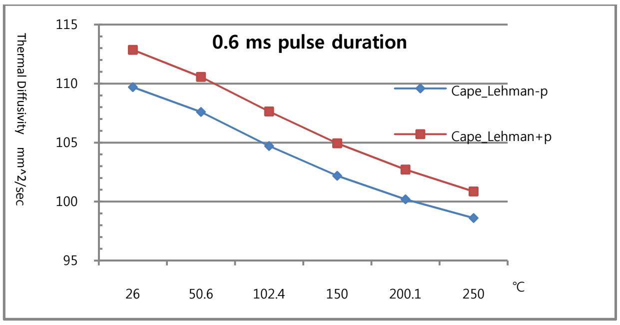

Fig 4. Difference of measured and corrected thermal diffusivity using Cape-Lehman technique for 0.6ms

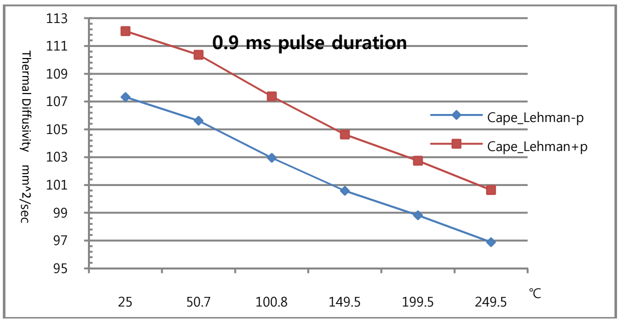

Fig 5. Difference of measured and corrected thermal diffusivity using Cape-Lehman technique for 0.9ms

3.3 Correction effect of finite pulse duration

The correction of finite pulse-time effects have been studied by Cape-Lehman for rectangular and sawtooth pulse theoretically. Tayer and Cape[3] have examined them experimentally. Larson and Koyama [4] have given results for a particular exponential pulse characteristic of their flash tube. Heckman [5] deal with triangle-wave form. Because thermal diffusivity measuring model is Cape-Lehman and input pulse form is rectangular, we adopt the Cape-Lehman correction technique. Fig 6. are plots of the corrected diffusivity for a pulse duration time. Results are almost coincided each other so that we could apply this technique for high thermal diffusivity materials even if long input pulse duration.

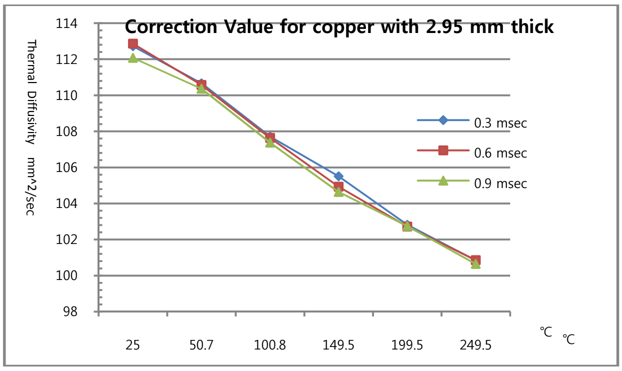

Fig 6. Corrected diffusivity results using Cape-Lehman correction technique

4. Conclusion

The important thing to avoid finite pulse effect for high thermal diffusivity materials is to use appropriate short duration pulse and sufficient specimen thickness. First above all, sufficient specimen thickness is needed in order not to be affected by a pulse duration time. Even though corrections of finite pulse time effects are performed for a thin specimen, we cannot achieve accurate results without selection of an appropriate sample thickness. But for the case of 3mm thickness copper (sufficient specimen thickness), Cape-Lehman pulse correction method are evaluated to efficient technique. Because of practical reason e.g. if specimen is too thick to get enough signal on rear surface, then experimenters only have choice to use long input pulse duration. In the case, the Cape-Lehman pulse correction technique is available.

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