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Evaluation on Measurement Condition of Laser Flash Method for Aluminum 1060 Thermal Dffusivity

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1. Introduction

The aluminum 1060 is using for cladding material of HANARO nuclear research reactor fuel. Generally, the performance of cladding material for nuclear fuel element must have good thermal conductivities, anti corrosion, small neutron absorption cross section and sufficient mechanical strength, etc. The thermal conductivity of nuclear materials is mostly accomplished by a measurement of thermal diffusivities and the use of a 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. The diffusivity α is computed from relation

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

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 and heat loss effect. We want to measure precise thermal diffusivity of spent fuel element in the future. As part of plan, Un-irradiated HANARO nuclear fuel cladding material is performed to measure with various test condition in order to decide optimum condition. This paper will experimentally investigate which test condition is better than others e.g. pulse duration time, specimen thickness and thermal diffusivity calculation model.

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 for laser pulse power. In the experiment, to maximize finite pulse time effect we have to select very thin specimens and long laser pulse duration. To get accurate measured results we have to use sufficiently thick specimen and appropriate laser pulse duration. As such reason, eight test specimens are prepared. Disk type form specimen has geometry with diameter 12.5 mm and thickness 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 and 4.0 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 experiments have performed under test conditions with varying laser pulse durations, 0.3 ms, 0.6 ms and 0.9 ms respectively for each specimen. And the test temperatures are 24 ℃, 50℃ 100 ℃. Finally to verify the real thermal diffusivity of a specimen, test was performed for a 4mm thick specimen by being expected to neglect the finite pulse time effect.

3. Results

3.1 Standard thermal diffusivity of aluminum

In order to verify the accuracy of testing results we need standard reference values of aluminum thermal diffusivity. The values are taken from the TPRL-Books Bulk Density: 2.70 g/cm³ at room temperature. Temperature dependent density values based on thermal expansion measurements were employed for the calculations.

Table 1. Thermo-physical property of Aluminum

Temperature / °C	Specific Heat / J/(g*K)	Thermal Diffusivity / mm²/s	Thermal Conductivity / W/(m*K)
0	0.874	98.2	231.7
25	0.882	96.8	230.5
50	0.891	96.0	230.4
100	0.911	94.4	230.8
125	0.921	93.4	230.6
200	0.959	90.1	229.0
300	1.009	85.1	227.14

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

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

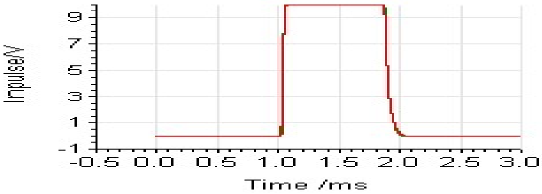

Fig 1. Typical pulse shape for 0.9 ms

Detector signal on a rear face and a shooting pulse shape are given in Fig 2. And are revealed as typical thermo-gram

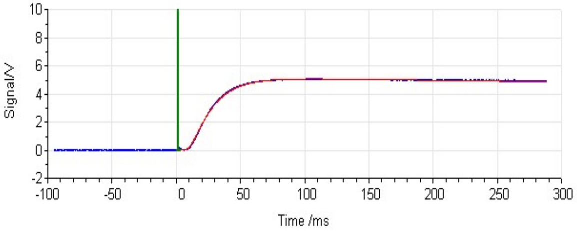

Fig 2. Typical thermo-gram on rear surface for 4.0 mm thickness Aluminum with pulse duration 0.9 ms

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 adopt a representative value for each test condition. The Fig 3. reveal as typical thermo-gram related to a finite pulse time effect as shown in Fig 3. In this figure, pulse duration time is 0.9 ms and the half rise time($t_{1/2}$) is 2.205 ms for 0.5 mm specimen thickness. If the duration of the energy pulse is not short compared to $t_{1/2}$ then the energy pulse affects the thermo-gram on a rear face and it increases the half rise time. As a result of increasing the half rise time, the measured thermal diffusivity of a specimen is underestimated owing to the finite pulse time effect.

Adiabatic-no pulse correction model is assumed for thermal diffusivity due to the purpose to investigate finite pulse time effect. Fig 4. and Fig 4. are plots of the diffusivity change for a pulse propagated time(specimen thickness change) and pulse duration time at room temperature and 100℃ respectively.

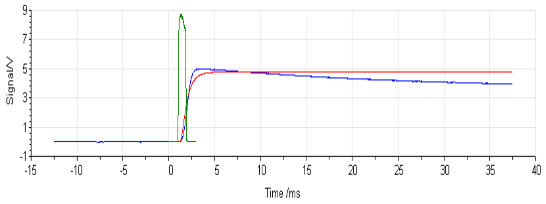

Fig 3. Typical thermo-gram on rear surface for 0.5 mm thickness Aluminum with pulse duration 0.9 ms

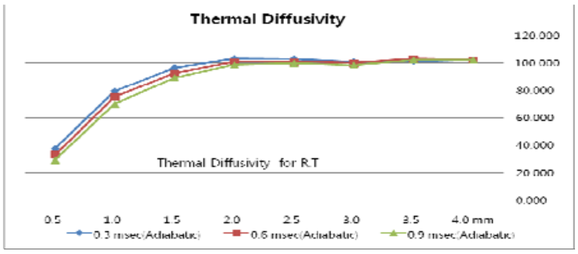

Fig4. Diffusivity change for various specimen thickness and pulse duration on room temperature

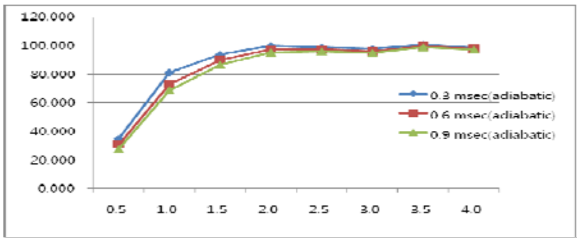

Fig 5. Diffusivity change for various specimen thickness and pulse duration on temperature 100℃

3.4 Measured value using various calculation models

For the 4 mm thick specimen, the measured data are analyzed and calculated adiabatic, Cape-Lehman and Cape-Lehman plus pulse corrected model. Those value are compared with TPRL standard thermal diffusivity values in Table 2.

Table 2. TPRL and measured value using various models

Diffusivity unit : mm^2/sec

Temp ℃	TPRL	Adiabatic		Cape-Lehman		C-L +pulse	
Pulse width (ms)		0.3	0.9	0.3	0.9	0.3	0.9
25	96.8	102.3	102.1	99.2	98.6	99.8	101
50	96.0	102.5	102.1	98.3	96.9	98.8	99.1
100	94.4	98.6	94.0	95.5	93.82	95.9	95.6

4. Conclusion

Sufficient specimen thickness is needed in order not to be affected by a pulse duration time. For above 2.0 mm thickness there is almost no finite pulse time effect. More accurate model is Cape-Lehman model. Adiabatic calculation model is over-evaluated than the Cape-Lehman model for aluminum. In the case no finite pulse time effect, long pulse duration is better than short pulse duration.

REFERENCES

[1] Parker, W.J., Jenkins, R.J., Butler, C.P., and Abbott, G.L., "A Flash Method of Determining Thermal Diffusivity, Heat Capacity, and Thermal Conductivity" Journal of Applied Physics, 32 (9), 1961, pp. 1679-1684.

[2] Cape, I.A., Lehmann, G.W.: "Temperature and Finite Pulse-Time Effects in the Flash Method for Measuring Thermal Diffusivity", Journal of Applied Physics Vol.34 (4), 1963, pp. 1909-1913