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Uncertainty Evaluation of the Thermal Diffusivity Measurement Data

Kweonho Kang, Byeongjoo Yoon, Jaesoo Ryu, and Changhwa Lee
Korea Atomic Energy Research Institute
nghkang@kaeri.re.kr

1. Introduction

NFDC (Nuclear Fuel and materials Data Center) is designated as a one of the Data Center of National Standard Reference Center from Ministry of Trade Industry and Energy at Dec. 30 2008. The fields of designation were nuclear fuel and energy materials. NFDC produces standard reference data of nuclear fuel and materials. To ensure reliability of experimental data uncertainty should be estimated. There are two kinds of uncertainty: A-type uncertainty from tester and B-type uncertainty from experimental equipment. To reduce the former, the measurement should be repeated for sufficient amount of times, and to reduce the latter type uncertainty all equipment have to be calibrated.

In this study the uncertainty evaluation procedure was established in accordance with the GUM [1] to improve the reliability of thermal diffusivity measurement data using laser flash apparatus (LFA).

2. Uncertainty Evaluation

2.1. Measurement model

A thermal diffusivity measurement using LFA was conducted to measure the half time $t_{1/2}$ in which the rear-face temperature rise reaches half its maximum value, the resulting model can be expressed as follows [2]:

$$a(T) = 0.1388\,\frac{th^2}{t_{1/2}(T)} f_{cal} \tag{1}$$

where th is the specimen thickness, $t_{1/2}$ is the half, and f_{cal} is the correction factor. The correction factor is defined as follow:

$$f_{cal}(\mathrm{T}) = \frac{a_{ref-c}(T)}{a_{ref-m}(T)} \tag{2}$$

where $a_{ref\text{-}c}(T)$ is the thermal diffusivity of standard reference material in certificate and $a_{ref\text{-}m}(T)$ is the measured thermal diffusivity of standard reference material using LFA.

2.2. Factors affected on the uncertainty

The contributing factors to the uncertainty from equation (1) are uncertainties of thickness measurement of the specimen, half time measurement in LFA, and calibration of LFA.

2.3. Uncertainty of thickness measurement of the specimen, u(th)

Correction factor is considered in the thickness of the specimen measurement using micrometer:

$$\mathrm{th} = th_m + b \tag{3}$$

where th is the thickness of the specimen, th_m is the thickness measurement value of the specimen, and b is the correction factor of the micrometer.

The uncertainty of the thickness measurement value can be expressed as follow:

$$\mathrm{u(th)} = \sqrt{u(th_{m,r})^2 + u(th_{m,R})^2 + u(b)^2} \tag{4}$$

where $u(th_{m,r})$ is the uncertainty of thickness measurement data, $u(th_{m,R})$ is the uncertainty of resolution of micrometer, and $u(b)$ is the uncertainty of correction factor of micrometer.

2.4. Uncertainty of halftime measurement in LFA, $u(t_{1/2})$

Uncertainty of half time can be obtained from standard deviation of the mean of the repeated measurement.

$$\mathrm{u}\left(t_{1/2}\right) = s(t_{1/2})/\sqrt{n} \tag{5}$$

where $s(t_{1/2})$ is the standard deviation, n is number of repeat.

2.5. Uncertainty of the correction factor, $u(f_{cal})$

Uncertainty of the correction factor can be obtained from follow:

$$\mathrm{u}(f_{cal}) = \sqrt{c_{a_{ref-c}}^2 u^2\left(a_{ref-c}\right) + c_{a_{ref-m}}^2 u^2\left(a_{ref-m}\right)} \tag{6}$$

where $c_{xi} = \partial f_{cal}/\partial x_i$ is the sensitivity coefficient of each factor influencing the uncertainty, and $u(x_i)$ is the uncertainty of each factor.

2.6. Determination of the combined standard uncertainty, u_c

Combined standard uncertainty was calculated using the previously evaluated standard uncertainty, as follows:

$$u_c = \sqrt{c_{m(t)}^2 u^2(M(t)) + c_A^2\, u^2(A) + c_{fcal(T)}^2 u^2(f_{cal})} \tag{7}$$

where

$$c_{m(t)} = \frac{\partial}{\partial m}\left(\frac{M(t)}{A} f_{cal}\right) = \frac{1}{A}\ f_{cal}$$

$$c_A = \frac{\partial}{\partial A}\left(\frac{M(t)}{A} f_{cal}\right) = -\frac{M(t)}{A^2} f_{cal} = -\frac{m(t)}{A} \times f_{cal}$$

$$c_{cal(T)} = \frac{\partial}{\partial f_{cal}}\left(\frac{M(t)}{A} f_{cal}\right) = \frac{M(t)}{A} = m(t)$$

2.7. Calculation of expanded uncertainty, U

The expanded uncertainty U is obtained by multiplying the combined standard uncertainty u_c by a *coverage factor k*:

$$U = k\ u_c \tag{8}$$

If the effective degrees of freedom (DOF) v_{eff} is significantly high, the following can be carried out:

- Adopt k = 2 and assume that U = $2u_c$ defines an interval with a confidence level of approximately 95%.

Otherwise, for more critical applications:

- Adopt k = 3 and assume that U = $3u_c$ defines an interval with a confidence level of approximately 99%.

3. Conclusion

The uncertainty evaluation procedure was established in accordance with the GUM to improve the reliability of thermal diffusivity measurement data. The study can be summarized as follows:

(1) The uncertainty consists of the uncertainties of the measurement value of the thickness of the specimen, half time and correction factor.
(2) System correction was conducted using the standard reference material.
(3) The biggest factor affecting the uncertainty of LFA data is the uncertainty caused by system calibration.

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