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Experimental Uncertainty for the Thermal Expansion of a Simulated Fuel

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1. Introduction

Thermal expansions of a simulated fuel (SS-1) were measured by using a Dilatometer (DIL402C) from room temperature to 1900 K. The main procedure of an uncertainty evaluation followed the strategy of the UO_2 fuel. Referring to the ISO (International Organization for Standardization) guide, the uncertainties of the thermal expansion were quantified in three parts - the initial length, the length variation, and the system calibration factor. The uncertainty of the thermal expansion for a simulated fuel was also compared with those of UO_2 fuel.

2. Methods and Results

To develop a new concept for fuels, it is necessary that fuel performance tests such as the material thermal, mechanical and chemical properties, irradiation behavior and a verification of the in-pile robustness tests are performed. With the above fundamental data, many fuel performance code systems have been developed by using the thermal, mechanical, and chemical models of a nuclear fuel.

Thermal expansion as well as thermal conductivity is one of the most important thermophysical properties of a nuclear fuel. Most solid materials expand when heated up and shrink when cooled down. The thermal expansion is defined as a variation of the length with a temperature change, which is expressed as follows,

$$\Delta l / l_0 = (l_f - l_0)/l_0 = \alpha_l (T_f - T_0) \quad (1)$$

where

l_0, l_f : length at temperatures T_0 and T_f, respectively,

α_l : linear coefficient of a thermal expansion.

From the experiments, the linear coefficients of a thermal expansion for an UO_2 fuel are distributed from $1.03 \times 10^{-5}\ K^{-1}$ to $1.08 \times 10^{-5}\ K^{-1}$.

In this study, a method to obtain the uncertainty of a thermal expansion of a simulated nuclear fuel[1] is suggested based on a previous approach. The weight percent of the impurities of the simulated fuel in this study are given in Table I.

2.1 Uncertainty Assessment for the Simulated Fuel

Thermal expansions of the simulated fuel are measured by using a horizontal type dilatometer (DIL402C, Netzsch) from room temperature to 1900 K under an argon environment.[2] It is expected that there exists an uncertainty in the measurement, which should be quantified based on statistics.

Table I. Weight Percent of the Impurities of the Simulated Fuel

Impurity	Weight Percent	Impurity	Weight Percent
SrO	0.057	La_2O_3	0.143
Y_2O_3	0.04	CeO_2	0.665
ZrO_2	0.23	Nd_2O_3	0.49
		Total	1.625

The approach for an uncertainty of the thermal expansions of a simulated fuel starts from the following formulation,[3]

$$f_E(T) = (l(T) - l_0)/l_0 \times f_{cal} \quad (2)$$

where

$f_E(T)$: thermal expansion, or output of experiments,

l_0 : sample length at the room temperature (mm),

$l\ (T)$: sample length at T ^oC (mm),

f_{cal} : ratio due to system calibration.

The factor of f_{cal}, which was introduced for the previous approach, has a unit value and its uncertainty comes from a system calibration test with the reference material. If the results of the system calibration lie within a proper criterion, the system (DIL 402C) is thought to be a normal state and no other calibration is performed. It contains two kinds of an uncertainty: the first one is an iterative experiments uncertainty with a reference material (u_{fcal1}, type A) and the second one is a reference material uncertainty from a report (u_{fcal2}, type B) Table II shows the uncertainty factors for the thermal expansion experiments.

2.2 Uncertainty of Thermal Expansion

Thermal expansion of a simulated fuel was performed by following the above procedure. Fig. 1 depicts the expanded uncertainty of the simulated fuel for various temperatures. And Fig. 2 shows the thermal expansions of the simulated fuel and UO_2 fuel. From Fig. 2, The thermal expansion of the simulated fuel is higher than that of UO_2, which is due to the impurities in the simulated fuel.

Table II. Uncertainty Parameters for the Thermal Expansion of a Simulated Fuel

Parameter	Type of Uncertainty	Degree of Freedom
Initial Length (l_0) - resolution (l_{01}) - calibration (l_{02}) - temperature variation (l_{03})	 B (rectangular) B (normal) B (rectangular)	 Inf. Inf. Inf.
Length (l(T)) - iterative measurement	 A (normal)	 4
System Calibration (f_{cal}) - calibration test (f_{cal1}) - CRM report (f_{cal2})	 A (normal) B (normal)	 4 Inf.

In Table III, the uncertainties of the thermal expansions of the simulated fuel are given at the temperatures of 500 ^oC and 1000 ^oC, respectively. The combined standard uncertainty of the initial length is 1.755 X 10^{-3} mm, which is the same for all the cases. The standard uncertainties of the iterative experiments of the length variation increase as the temperature increases. But the combined standard uncertainties of the calibration decrease as the temperature increases due to the behavior of the calibration report. In this table, contribution factors are defined as the ratio of the squares of the combined uncertainties for each factor. From the results, a system calibration is the most important factor which affects the overall combined uncertainty for the temperature ranges. Initial length has a large effect on the uncertainty for a low temperature, but as the temperature increases the contribution of the uncertainty of the initial length slightly decreases. The obtained coverage factors are about 2.0 for a 95% confidence. From the results, the expanded uncertainties of the thermal expansion of the simulated fuel increases as the temperature increases and the uncertainties were obtained as 7.340 X 10^{-4} and 8.791 X 10^{-4} for 500 ^oC and 1000 ^oC, respectively.

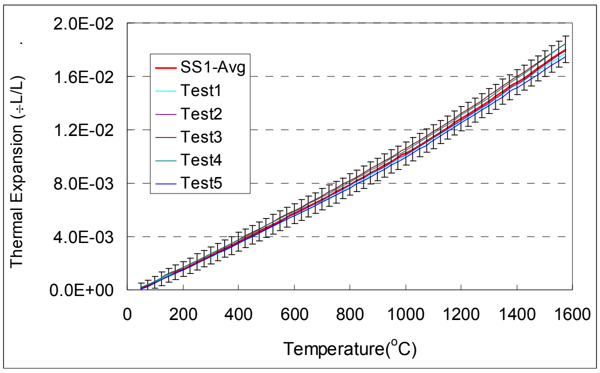

Fig. 1. Thermal expansion and uncertainty for the simulated fuel as a function of the temperature.

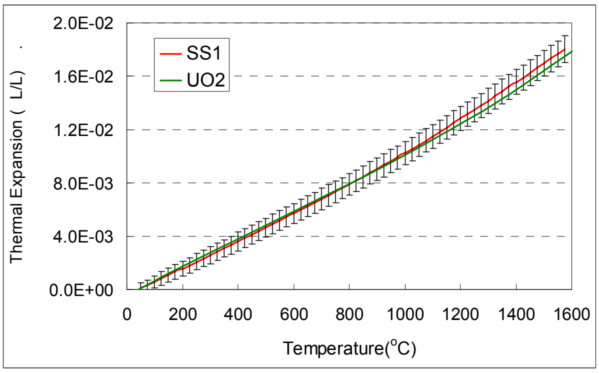

Fig. 2. Comparison of the thermal expansion of the simulated fuel and UO_2 fuel.

Table III. Uncertainty Budget for the Thermal Expansion of a Nuclear Fuel (95% confidence level)

Parameter	Uncertainty (500 °C)		Uncertainty (1000 °C)	
	Standard	Combined	Standard	Combined
Initial length (l_0), - resolution (l_{01}) - calibration (l_{02}) - temp variation (l_{03})	 0.001 $4.37X10^{-4}$ $1.39X10^{-3}$	$1.76X10^{-3}$ (0.27)*	 0.001 $4.37X10^{-4}$ $1.39X10^{-3}$	$1.76X10^{-3}$ (0.19)
Length (l(T)) -iterative measurement	$6.50X10^{-4}$	$6.50X10^{-4}$ (0.04)	$1.02X10^{-3}$	$1.02X10^{-3}$ (0.06)
Sys calibration (f_{cal}) - calibr. test (f_{cal1}) - CRM report (f_{cal2})	 $6.56X10^{-2}$ $5.29X10^{-3}$	$6.58X10^{-2}$ (0.69)	 $3.68X\ 10^{-2}$ $4.68X10^{-3}$	$3.71X10^{-2}$ (0.75)
Overall Combined Uncertainty (u_{total})	$3.66X10^{-4}$		$4.38\ X\ 10^{-4}$	

* contribution factor = $Ci^2\ u_i^2\ /\ u_{total}^2$
Ci = sensitivity coefficient

3. Conclusion

Thermal expansion is measured with a dilatometer for a simulated fuel and its uncertainty is calculated as the temperature changes. There are three main uncertainty parameters including the initial length, the length at a temperature, and a system calibration with a reference material. From the results, the expanded uncertainty increases slightly as the temperature increases. And a system calibration is a major contributor to the overall expanded uncertainty in the thermal expansion experiments. As a conclusion, this study will be helpful in providing a fundamental approach to produce more reliable measurement data for the thermophysical properties of a nuclear fuel.

REFERENCES

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