Analysis of Measured Thermal Conductivity for an Attrition-milled MOX Fuel

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1. Introduction

In-site storages have been crammed full with FAs from LWRs and stockpiles of plutonium have been continuously accumulating worldwide by the reprocessing of spent fuel and weapon device disarmaments. The excess plutonium can be utilized adequately by incorporating it into a MOX fuel, thereby generating electricity while properly securing a non-proliferation and reducing severe burden of ensuring repository.

To adopt MOX fuel in LWRs, many researches have already revealed the comparable properties of MOX to UO2 fuel. KAERI have been also developing the MOX fuel related technology, particularly, a performance code and fabrication. The MOX fuel was manufactured by using an attrition milling and then was successfully tested in-pile in Halden reactor [1].

In the present paper, we described the out-of-pile measured thermal properties for attrition-milled MOX fuel. In addition, the measured thermal conductivity was analyzed and compared with model developed for considering the burnup effect in MOX fuels with various plutonium contents.

2. Measurement of Thermal Properties

MOX fuel pellets were fabricated by an attrition milling which enables to obtain their microstructure as homogenous as possible. The pellets contain plutonium contents of ~8w/o and a density of ~10.4 g/cm^3.

Then several samples were prepared in the form of small disks of ~5 mm in diameter and 1 mm thick to measure the thermal diffusivity and specific heat by a laser flash method in a lead-shielded glove box.

The samples were heated at the measurement temperature in a furnace in a vacuum or under a helium atmosphere of 0.1 bar. A laser pulse was applied to the front surface of the sample and then the emerging temperature perturbation on the opposite surface was recorded by a photodiode pyrometer. Thermal diffusivity, specific heat and various heat losses were calculated by a numerical fitting procedure.

Since MOX fuel is a dark material with good emissivity in the investigated temperature range, specific heat of the MOX samples were simply measured. Fig. 1 displays the measured specific heat capacity together with the prediction by Kopp's law. The precision of the measurement was approximately 5%. It can be seen that the measured specific heat of the MOX fuel agreed values predicted by the Kopp's law and increases linearly with the temperature.

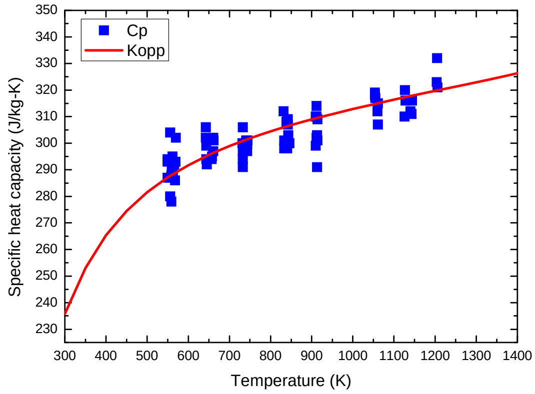

Fig. 1. Measured specific heat and predicted specific heat by Kopp's law.

The thermal diffusivity was also measured for the MOX samples. The measured thermal diffusivity is shown in Fig. 2 as a function of the temperature. The first measured thermal diffusivity at a low temperature was approximately 10% below the values obtained after a thermal cycle up to ~1200K. The lower thermal diffusivity was recovered after the first run up to a high temperature. After this "recovery" the thermal diffusivity was insensitive for subsequent runs up to 1200K.

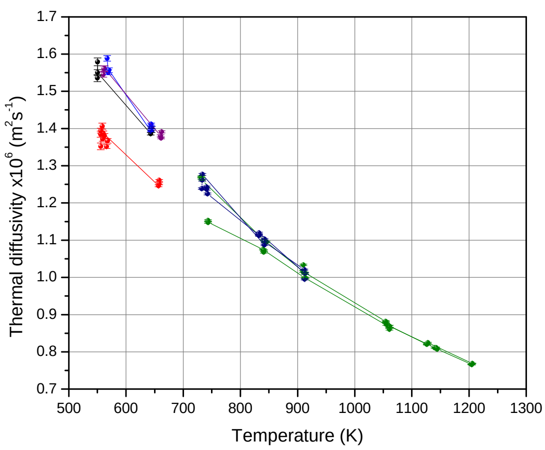

Fig. 2. Measured thermal diffusivity.

Thermal conductivity of the MOX fuel samples was derived from the measured thermal diffusivity, specific heat and density by a simple well-known relationship ($\lambda = \rho\alpha C_p$). The derived measured value is plotted as a function of the temperature in Fig. 3. More than that, the thermal conductivities of a UO_2 fuel estimated by HRP and PuO_2 were also plotted. It is observed that the MOX thermal conductivity is slightly lower than that of the UO_2 fuel, particularly in the higher temperature.

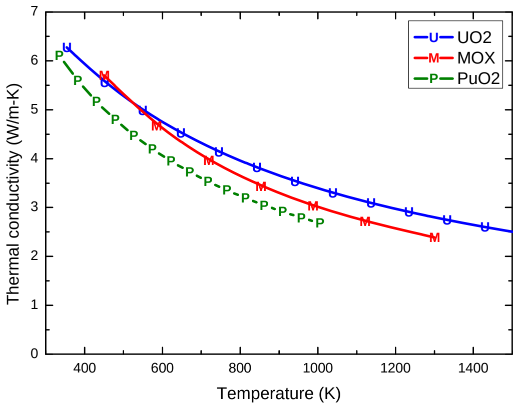

Fig.3. Thermal conductivity derived from measured specific heat and thermal diffusivity.

3. Comparison between Measured and Calculated Thermal Conductivity

A mechanistic thermal conductivity model was developed for the MOX fuel and the detailed description was introduced elsewhere [2].

The developed thermal conductivity model had been partially validated by comparing the calculated and measured temperature obtained from the in-pile test results for MOX fuel [3].

In addition to the comparison of the measured and calculated fuel temperature, the developed thermal conductivity was directly compared with the out-of-pile measured thermal conductivity described in Section. 2. Fig. 4 demonstrates a comparison between the measured and model-calculated thermal conductivity. The thermal conductivity model calculated its value for a fresh MOX fuel. Comparison shows that the measured thermal conductivity is slightly higher in the lower temperature region than that estimated by the developed model. With the temperature approaching 800K, both the model-predicted and measured thermal conductivities are very comparable. Accordingly, the developed thermal conductivity is consistent with the measured value for the range of the temperatures of the in-pile irradiation tests, consequently, being reasonably applicable for the performance analysis of the irradiation test of the MOX fuels with due consideration of a burnup degradation and a various plutonium contents.

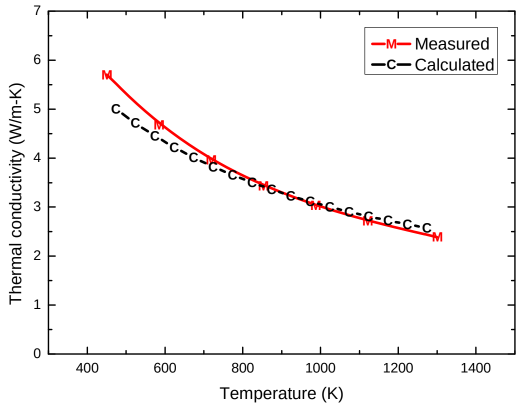

Fig. 4. Comparison between measured and calculated thermal conductivity.

4. Conclusions

Specific heat and thermal diffusivity of a MOX fuel fabricated by an attrition milling were measured. The measured thermal conductivity of the MOX fuel is slightly lower than that of the UO_2 fuel as expected. The measured thermal conductivity was compared with the thermal conductivity estimated by the developed model. Both the measured and model-calculated thermal conductivities are comparable, which confirms that the developed model can be applied to predict the in-pile behaviours of a MOX fuel with due consideration of a burnup degradation effect on the thermal conductivity.

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