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An Analysis of the Liquidus/Solidus Temperatures of U-Zr-Ce Metallic Alloy Fuel

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1. Introduction

A sodium-cooled fast reactor (SFR) is being developed in combination with the pyro-processing of spent fuel, so U-TRU-Zr metallic fuel is a reference fuel for the SFR.

In order to evaluate these phenomenological uncertainties, it is necessary and required to understand the characteristic behavior of molten fuel. Also, proof of the capacity of debris bed cooling that is one of the technical issues for the safety of Gen IV SFR, it is an essential condition for solving the problem of in-vessel retention of core debris.

Liquidus/solidus temperatures are also important in assessing the possibility of fuel melting during off-normal conditions. Some work has appeared in the literature on this subject in the past, but data for U-TRU-Zr was not available. To supply the needed data, a dual approach that involves the evaluation of data in the open literature and the experimental measurement of surrogate material is presently being employed.

In this study, a review of the data on the liquidus/solidus temperature of metal fuel was carried out. Surrogate material was selected to simulate the behavior of MA and RE. An analysis method for U-TRU-Zr from the surrogate material was established. Experimental specimens were fabricated, and equipment for these experiments was organized. The liquidus/solidus temperature of the metal fuel was measured and evaluated

2. Experimental Procedures

The metal fuel rods and experimental specimens are fabricated according to the following procedure: 99.99% pure U metal Ingot, 99.95% pure Zr metal and Ce are inserted together in a graphite crucible, and then these materials are dissolved by heating up to 1400 ~ 1600℃ with vacuum pressure 2 × 10^{-3}torr and heating rate 25 ~ 30℃/min. When these materials melt in the crucible, the quartz molds are immersed in the melt. Argon gas is injected into the vacuum pressure equipment, then the melt is injected to the quartz mold by the pressure difference. Vacuum-reduced pressure equipment is used for cases where the TRU materials are used as nuclear fuel in a sodium-cooled fast reactor. Fuel rods for a sodium-cooled fast reactor containing U-10%Zr-(2, 4, 6)%Ce were fabricated to check the effects of U-(5, 10, 15)%, Zr and Ce. The equipment used in this experiment for the measurement of melting and solidification temperatures was SETSYS Evolution 16(Setaram, France). In this experimental measurement, all specimens were heated from room temperature to 1500℃ with 5℃/min and cooled to 400℃ with 5℃/min, and then the furnace was cooled to room temperature.

3. Results and Discussion

<u>Change of liquidus/solidus temperature depending on the amount of Zr</u>

The change of melting temperature depending on the amount of Zr is indicated in Fig. 1. When the amount of Zr is increased, the melting temperature is also increased.

This is because the melting temperature of Zr(1852℃)[1] is higher than that of uranium(1133℃). The dotted line in the figure was calculated by using the melting point of uranium and Zr, and component ratio.

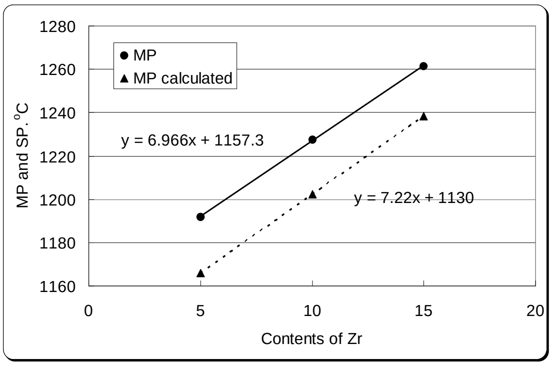

Fig.1. Change of melting temperature depending on the amount of Zr.

The measurement value through the experiment is about 30℃ higher than the calculated value.

The melting temperature of the sodium-cooled fast reactor fuel depending on the amount of Zr can be expressed as follows based on the result of the measurement:

$T_{mp}(℃) = 6.966 \times Zr + 1157.3$

Fig. 2 shows the change of solidification temperature depending on the amount of Zr. When the amount of Zr is increased, the melting point is also increased because of the high solidification temperature of Zr.

The melting temperature of the sodium-cooled fast reactor fuel depending on the amount of Zr can be expressed as follows based on the result of the measurement:

$T_{sp}(℃) = 3.953 \times Zr + 1185.5$

<u>Liquidus/solidus temperature depending on the amount of Ce</u>

The melting/solidification temperature of U-Zr-Ce obtained through this experiment is shown in Table-5. Due to impurities contained in U-10Zr, the melting/solidification temperature of U-10Zr-Ce was lower than that of U-10Zr.

Fig. 3 shows the change of melting/solidification temperature depending on the amount of Ce. When the amount of Ce is increased, the melting and solidification temperatures are also increased. Because the melting temperature of Ce is 798 ℃, the melting and solidification temperature should theoretically decrease. These results are due to the variation of Zr in the specimen.

According to the results of the chemical analysis for the specimen, it was found that the amount of Zr was not constant. A more accurate specimen must be fabricated to analyze the change of melting/solidification temperature depending on the amount of Ce.

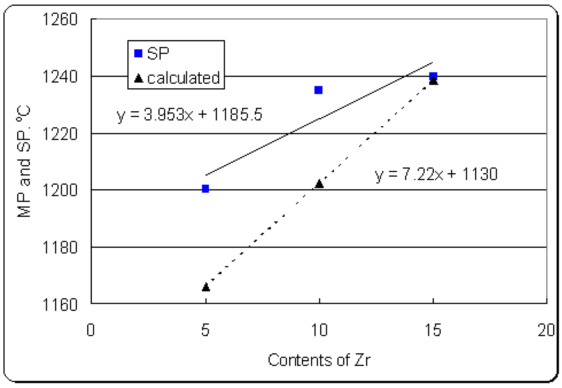

Fig.2. Change of solidification temperature depending on the amount of Zr

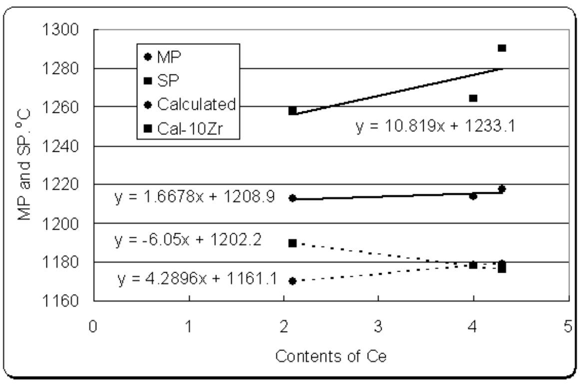

Fig.3. Change of melting/solidification temperature depending on the amount of Ce

4. Conclusions

The metal-fueled, sodium-cooled fast reactor system is expected to accommodate all credible malfunctions or accident initiators passively without damage to the core. However, the evaluation of the safety performance and the containment requirements for this system will most likely require consideration of postulated low-probability accident sequences that result in partial or whole core melting. For these sequences, some phenomenological uncertainties exist and more experimental data is needed for the modeling purposes. Two such aspects concern the potential for the freezing and plugging of molten metallic fuel in above-and below-core structures and possibly in inter-subassembly spaces.

The first basic data need is for data on the properties of metallic fuel/steel mixtures such as liquidus/solidus and mobilization temperatures.

This study was carried out to measure the data for the liquidus/solidus temperature of metal fuel for CDA modeling. An analysis method for determining the liquidus/solidus temperature for U-TRU-Zr from surrogate material was established. The surrogate material, Ce, was selected, and U-(2,4,6)Ce-Zr specimens were fabricated. The liquidus/solidus temperatures were measured by DTA.

ACKNOWLEDGMENTS

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