Volume Fraction Dependent Thermal Performance of UAl_x-Al Dispersion Target

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1. Introduction

Unlike U-Al alloys, properties of UAl_x-Al dispersion target can be highly sensitive to volume fraction of UAl_x in a target meat due to the interface resistance between target particles and matrix. The interface resistance effects on properties of the target meat including thermal conductivity, thermal expansion coefficient, specific heat, elastic modulus and so on. Thermal performances of a dispersion target meat were theoretically evaluated under normal operation condition of KJRR (Kijang Research Reactor) during short effective full power days (EFPD) of 7 days, based on reported measured thermal conductivities of UAl_x-Al dispersion fuels.

2. Methods and Results

In this section Voigt-Reuss and Hashin-Shtrickman models were used to determine volume fraction dependent thermal conductivity of UAl_x-Al dispersion target meat, which help predict thermal performance of a target meat. Uranium density in a target meat is 2.6 g-U/cm^3 at 293 K.

2.1 Voigt-Reuss Model

Voigt-Reuss model is normally used to roughly predict the properties of composite materials, not considering interaction effects between particles and matrix **[1,2]**. Voigt-Reuss equation is

$$k = \varphi_1 k_1 + \varphi_2 k_2 \quad (Voigt) \qquad (1)$$

$$k = \frac{k_1 k_2}{\varphi_1 k_2 + \varphi_2 k_1} \quad (Reuss) \qquad (2)$$

, where k, k_1 and k_2 are effective thermal conductivities of UAl_x-Al target meat, UAl_3-Al and UAl_4-Al dispersion fuels, respectively, which depend on volume fraction of UAl_x in going from 50 to 70 volume fraction (%) in a target meat for 2.6 g-U/cm^3. φ_1 and φ_2 are the volume fractions of UAl_3 and UAl_4 in UAl_x phases.

2.2 Hashin-Shtrickman Model

Hashin-Shtrickman model is identical to predict the thermal properties of two-phase materials with the microstructure **[3,4]**. Hashin-Shtrickman model is

$$k = \varphi_1 k_1 + \varphi_2 k_2 - \frac{\varphi_1 \varphi_2 (k_1 - k_2)^2}{3k_1 - \varphi_1 (k_1 - k_2)} \ (upper\ bound) \quad (3)$$

$$k = \varphi_1 k_1 + \varphi_2 k_2 - \frac{\varphi_1 \varphi_2 (k_1 - k_2)^2}{3k_2 + \varphi_2 (k_1 - k_2)} \ (lower\ bound) \quad (4)$$

, where definition of parameters is same as that of Voigt-Reuss model of 2.1 section.

2.3 Results

As shown in Figure 1, volume fraction of UAl_3 decreases and volume fraction of UAl_4 increases with an increase of volume fraction of UAl_x in UAl_x-Al target meat because physical density (6.8 g/cm^3) of UAl_3 is higher than that (5.7 g/cm^3) of UAl_4.

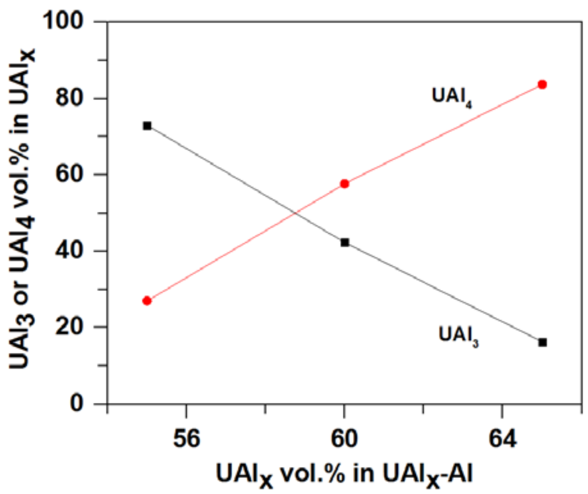

Fig. 1. Volume fraction of UAl_3 or UAl_4 in UAl_x phase, which result in volume fraction of UAl_x in UAl_x-Al target meat.

Figure 2 shows effective thermal conductivity of UAl_x-Al target meat, depending on volume fraction of UAl_x in target meat and not considering pore effects. Effective thermal conductivity of target meat was calculated based on reported measured thermal conductivities of UAl_x-Al dispersion fuels **[5,6]**. Effective thermal conductivity increases with an increase of volume fraction of UAl_x in UAl_x-Al target meat due to an increase of volume fraction of UAl_4 in UAl_x phase and higher thermal conductivity of UAl_4-Al than that of UAl_3-Al.

Figure 3 shows calculated maximum temperature of a low enriched uranium (LEU) dispersion target for Mo-99 production. Mo-99 in KJRR is going to be produced from irradiated UAl_x particles in Al matrix (UAl_x-Al). As shown in Figure 4, dispersion target assembly which is composed of 8 plates will be loaded in and taken out from six irradiation holes in the core, one by one consecutively after about 7 days irradiation. The burnup of dispersion targets located in a IR3 hole via the Monte Carlo N-Particle (MCNP) code is highest (4.13%). The amount of target maximum temperature during normal operation (Figure 3) were evaluated through a variety of models considering swelling, oxidation and so on **[7,8]**.

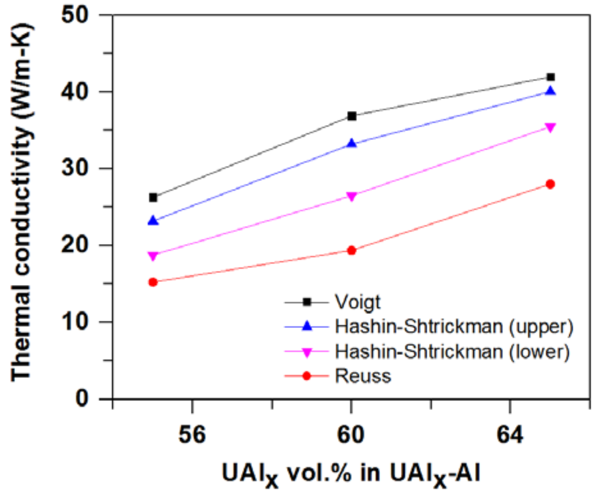

Fig. 2. Effective thermal conductivity of UAl_x-Al target meat, which estimated using Voigt-Reuss and Hashin-Shtrickman models.

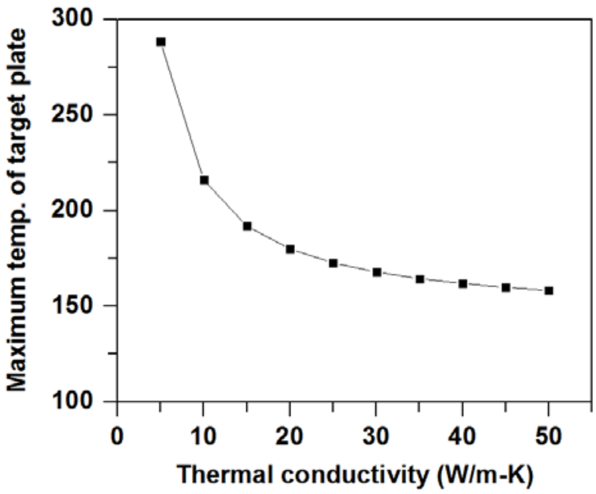

Fig. 3. Maximum temperature of target plate depending on thermal conductivity of UAl_x-Al target meat.

As shown in Figure 3, maximum temperature of UAl_x-Al dispersion target plate decreases with an increase of effective thermal conductivity of UAl_x-Al target meat. Effective thermal conductivity of target meat is one of main parameters determining maximum temperature of dispersion target plate. To decrease maximum temperature of target, target meat with high conductivity has to be designed without degradation of other target properties including elastic modulus, yield strength, thermal expansion coefficient and so on. From the viewpoint of safety analysis, effective thermal conductivity of UAl_x-Al target meat can be estimated using lower bound of Hashin-Shtrickman model identical to predict the thermal properties of two-phase materials with the microstructure, conservatively.

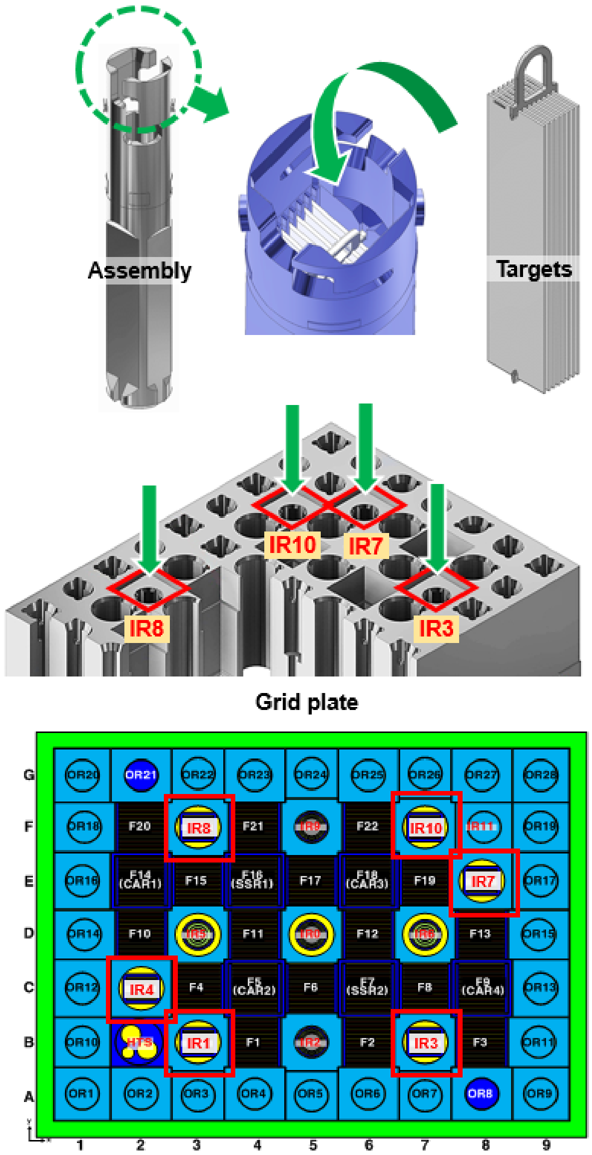

Fig. 4. Schematic diagram of dispersion target assembly loaded in irradiation holes of KJRR

3. Conclusions

Effective thermal conductivity of UAl_x-Al target meat, estimated using Voigt-Reuss and Hashin-Shtrickman models is dependent on volume fraction of UAl_x phase in target meat. Effective thermal conductivity determines maximum temperature of dispersion target plate. And for that volume fraction of UAl_x in target meat has to be determined considering manufacturing of target plate without degradation of physical and mechanical characteristics. In this paper estimated effective thermal conductivity being as a function of volume fraction of UAl_x in Al matrix will provide a better insight to design UAl_x-Al dispersion target.

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