Thermal Behavior Analysis of U-Mo/Al Dispersion Fuel

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1. Introduction

According to the non-proliferation policy under the reduced enrichment for research and test reactors (RERTR) program, low enriched uranium(LEU) fuel such as uranium silicide dispersion fuels are being used in research reactors. Because of a lower enrichment higher uranium density fuels are required for some high performance research reactors[1,2]. Some uranium alloys with a high uranium density such as U-Mo alloys have been considered as one of the most promising candidates for a dispersion fuel due to the good irradiation performance. An international qualification program to replace the uranium silicide dispersion fuel with U-Mo dispersion fuel is being carried out under the RERTR program[3].

Although U-Mo powders are conventionally supplied by the mechanical comminuting of as-cast U-Mo alloys, KAERI developed a centrifugal atomization method in order to simplify the preparation process and improve the properties[4]. The centrifugally atomized powders have a rapidly solidified gamma uranium structure and a spherical shape[5].

During the in-reactor operation of a dispersion fuel, interdiffusion or chemical reactions between the fuel particles and the matrix occurr[6]. Intermetallic compounds in the form of UAl$_x$ are formed as a result of the diffusional reaction. Because the intermetallic compounds are less dense than the combined reactants, the volume of the fuel element increases after the reaction. In addition to the effect on the swelling performance, the reaction layers between the U-Mo and the Al matrix induces a degradation of the thermal properties of the U-Mo/Al dispersion fuels[7]. It is important to investigate the thermal behavior of U-Mo/Al dispersion fuel according to reaction between the fuel particles and the matrix with the burnup and linear power.

In this study, a finite element analysis was used for the calculation of the temperature distribution of the U-Mo/Al dispersion fuel with a burnup and linear power. Kinetics data of the reaction layers such as the growth rate and activation energy were obtained from the high temperature annealing of the U-Mo/Al dispersion fuels and the U-Mo vs. Al diffusion couples[8]. Thermal conductivity of the U-Mo/Al dispersion fuel was measured by using the laser flash method.

2. Results

The growth rate of the reaction layers and the activation energy for the growth of the reaction layers of the U-10Mo/Al dispersion fuels were obtained by the reaction kinetics models after a high temperature annealing test from 500°C to 550°C. The activation energies of the growth of the UAl$_3$ structured reaction layers were 277 kJ/mol based on Jander's model and 316 kJ/mol according to the Ginstling-Brounshtein model.

Figure 1 shows the formation of the reaction layers after the irradiation test of U-7Mo/Al dispersion fuel in HANARO. Because a formation of the UAl$_x$ intermetallic phase decreases the thermal conductivity of the dispersion fuel, the centerline temperature of the U-Mo/Al dispersion fuel is affected by the volume fraction of the reaction layers. Thermal conductivity of the U-Mo/Al dispersion fuel increases with the temperature as shown in Figure 2.

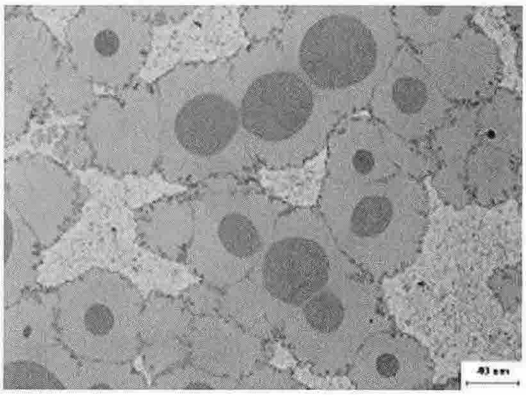

Figure 1. An optical micrograph showing the reaction layer formation between the U-7Mo particles and Al matrix after an irradiation in HANARO.(BU : 50 at% U-235, $\Delta V/V = 8.0\%$, T(BOL)=145.5°C, Linear Power : 76.4 kW/m)

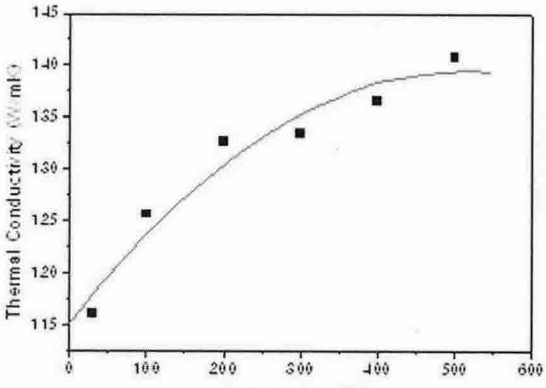

Figure 2. Thermal conductivity of the U-7Mo/Al dispersion fuel with temperature.

However, the thermal conductivity of U-Mo/Al after an annealing to form the reaction layer shows a decreasing trend with the volume fraction of the reaction layer as shown in Figure 3.

Axisymmetric finite element analysis was used to calculate the radial temperature distribution of the U-Mo/Al dispersion fuel as shown in Figure 4. Non-linear thermal analysis was carried out because of the temperature dependency of the thermal conductivity. Dispersion fuel area was divided into multiple rings with a different reaction layer volume fraction. The volume fraction of the reaction layer in a ring was changed with the burnup according to the time and temperature dependency of the reaction layer formation.

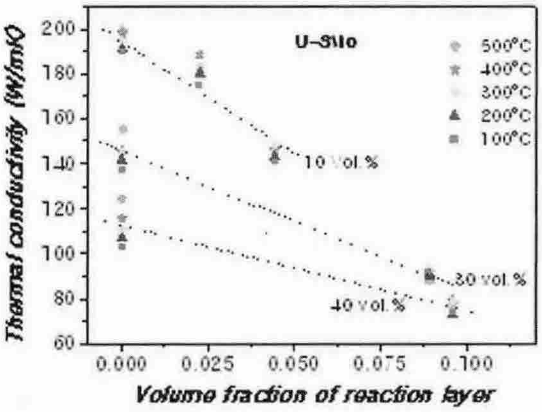

Figure 3. Thermal conductivity degradation with the volume fraction of the reaction layer in U-8Mo/Al dispersion fuel.

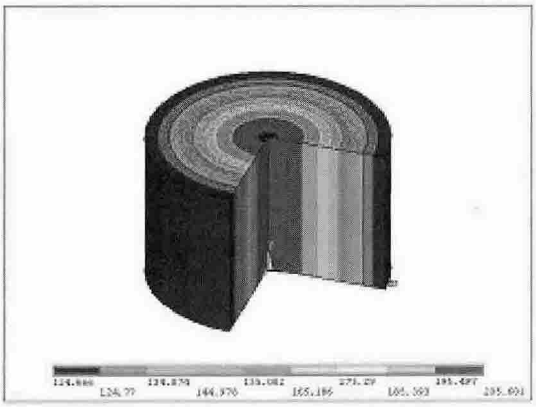

Figure 4. Finite element analysis for the BOL temperature distribution for the U-7Mo/Al dispersion fuel with a linear power of 120 kW/m.

Centerline temperature of the U-Mo/Al dispersion fuel was estimated as in Figure 5. When a typical power vs. burmup profile is applied, the initial temperature can be increased by more than 800°C if the whole dispersion fuel is reacted into the UAl_x phase. Considering the formation of the UAl_x phase, the centerline temperature of the U-Mo/Al dispersion fuel increases with the burnup until the formation of the intermetallic reaction layers is saturated although the linear power decreases with the burnup.

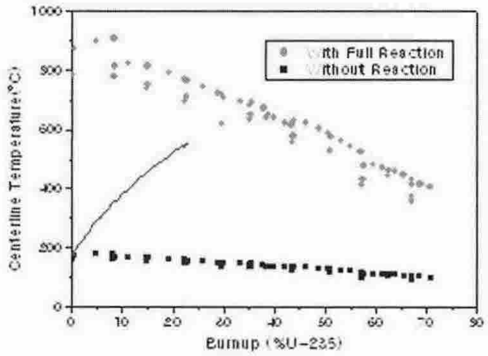

Figure 5. Estimated centerline temperature of the U-Mo/Al dispersion fuel without a reaction and with a full reaction between the U-Mo particles and Al matrix.

3. Conclusion

Thermal behavior of the U-Mo/Al dispersion fuel was analyzed by an experimental measurement and a finite element analysis. Formation of the interdiffusional reaction layers between the U-Mo particles and the Al matrix decreases the thermal conductivity of the dispersion fuel. The volume fraction of the reaction layers was calculated from the growth rate and the activation energy measured from diffusion couple tests. A computational calculation for the central temperature of the U-Mo/Al dispersion fuel shows a feedback effect of the reaction layers with the burnup and linear power.

Acknowledgement

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