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A Coupled Thermal-Stress Analysis of a Capsule for an Irradiation Test of the TRISO Buffer Layer in HANARO

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1. Introduction

Thermal and mechanical characteristics of an irradiation test capsule under a conceptual design are analyzed to evaluate its structural integrity in the irradiation test of a TRISO coating layer material in the research reactor, HANARO in KAERI. The cross-sectional view of the capsule considered in this study is shown in Figure 1. Test specimen is placed in the middle of the capsule. Specimen holder is a part of the capsule and designed to hold and support the test specimen. Outer diameter of the capsule is 11.3mm and the width of the specimen is 5mm. The tubes and the specimen holder of the capsule are made of molybdenum and the gaps are filled with helium gas. When the capsule is loaded into the reactor, it works as a heat source by a γ-ray irradiation.

A thermal and mechanical stress analysis was carried out by using the finite element analysis program, ABAQUS[1] to evaluate the structural integrity of the capsule and the buffer layer of a TRISO coated particle subject to a pressure and thermal loading in HANARO.

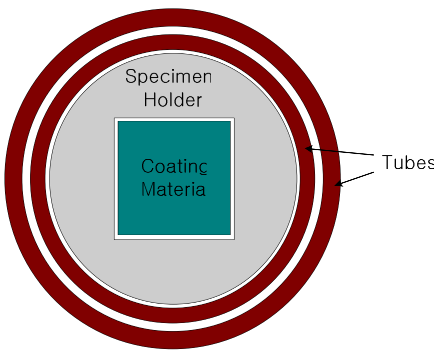

Figure 1. Cross-sectional View of the Irradiation Capsule

2. Methods and Results

2.1 Methods and Finite Element Model

Thermal and mechanical characteristics of the irradiation capsule were evaluated by the procedure shown in Figure 2. A physics code named MCNP is required to calculate the heat generation rate due to a γ-ray irradiation. User subroutines in FORTRAN for the ABAQUS solution were prepared for use in the heat flux and the gap conductivity calculations.

Figure 3 shows a 2-D finite element model for the thermal-stress analysis of the buffer material and the capsule components. It represents a quarter of the capsule and the test specimen. The elements are four-noded bilinear coupled temperature-displacement plane strain elements(CPE4T in ABAQUS). To enforce a cylindrical symmetry in the model, the nodes along the horizontal and the vertical surface of the model are constrained to move only in the radial direction. Pressure of the helium gas in all the gaps is 3 atm and the moderator of the reactor exerts a pressure of 1.3 atm to the external surface of the capsule. Temperature of the moderator is 40 ºC.

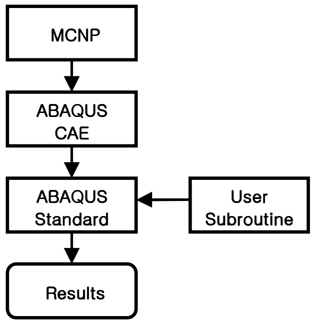

Figure 2. Procedure for the Thermal-Stress Analysis

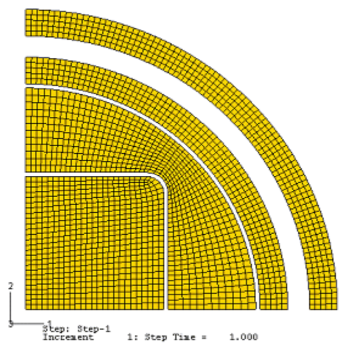

Figure 3. 2-D Finite Element Model

Density, thermal conductivity and specific heat of the molybdenum as a function of the temperature were found in Perry's Chemical Engineers' Handbook[2] and the mechanical properties as a function of the temperature were obtained from a company named PLANSEE, a German manufacturer of molybdenum[3].

The material properties are evaluated at the integration points in a cylindrical coordinate system: The first component direction is aligned along the radial direction, and the second is aligned in the hoop direction. The stress values reported below are taken from this intrinsic cylindrical coordinate system.

2.2 Results

Estimation of the thermal and mechanical characteristics in this case needs a fully coupled thermal-stress analysis because a stress analysis is dependent on a temperature distribution and a temperature distribution, on the contrary, depends on a stress solution. Therefore, thermal and mechanical solutions are obtained simultaneously rather than sequentially.

The temperature profile of the capsule in the radial direction is shown in Figure 4. The temperatures are taken from 8 nodal points along the nodes on the horizontal axis in Figure 3. The temperature of the specimen is about 353 ºC and higher than that of the specimen holder made of molybdenum. The temperature of the helium gas in the annular gap decreases rapidly along the radial direction since the thermal conductivity of the helium gas is lower than the other materials of the capsule. The temperature decreases the most in the gap between the two outside tubes because their gap is the biggest. From the temperature distribution, it can be concluded that the temperature of the specimen is considerably affected by the gap space.

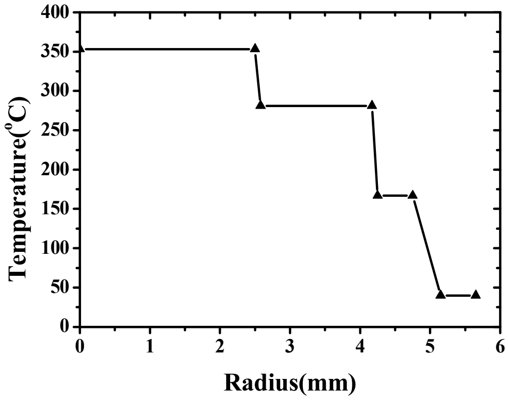

Figure 4. Temperature Profile of the Capsule in the Radial Direction

Figure 5 shows the Von-Mises stress profile of the capsule in the radial direction. The stress values are taken from 8 integration points of the elements along the horizontal axis in Figure 3. The maximum stress of the specimen holder is about 475 MPa which is bigger than the UTS of the molybdenum[3]. It means that this preliminary design of an irradiation capsule needs an optimization for its dimensional configuration.

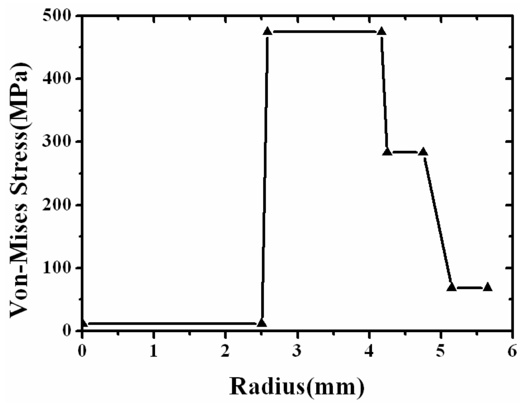

Figure 5. Stress Profile of the Capsule in the Radial Direction

Figure 6 shows the displacement contour of the capsule. The specimen holder shows a maximum displacement of 8μm, which is bigger than any other components of the capsule.

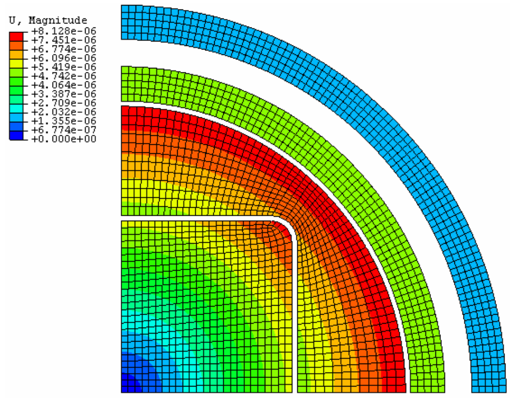

Figure 6. Displacement Contour of the Capsule

3. Conclusion

A thermal and mechanical stress analysis of a capsule for an Irradiation Test of the TRISO buffer layer in HANARO was carried out. The maximum temperature of the test specimen was about 353 ºC, which was much lower than the actual core temperature of the research reactor, HANARO. The maximum stress of the specimen holder was about 475 MPa which was bigger than the UTS of the molybdenum. Therefore, this preliminary design of an irradiation capsule needs an optimization for its dimensional configuration.

Acknowledgement

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REFERENCES

[1] Hibbitt, Karlson & Sorensen, Inc., ABAQUS/Standard User's Manual, Ver. 6.5-3, 2005.

[2] Perry, R.H. and D. Green, "Perry's Chemical Engineers' Handbook," Sixth Ed., McGraw-Hill Book Co (1984)

[3] Material Properties and Application - Molybdenum, PLANSEE