Thermal Fatigue and Creep Assessment for the ITER Tritium SDS bed

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1. Introduction

The main loads applied to ITER tritium SDS bed are thermal loads. As the tritium is absorbed and desorbed, the primary vessel is heated to 500℃ and cool down to the room temperature. During this procedure, high alternating thermal stress occurs in the primary vessel. Fatigue analysis is conducted with the information of the magnitude and the number of the calculated cyclic load. In case that the duration for which the bed stay in high temperature increases, thermal creep effects should be evaluated. This paper describes the thermal fatigue and creep assessment for the SDS bed.

2. Evaluation Methodology

2.1 Analysis procedure and analysis model

The main loads applied to ITER tritium SDS bed are thermal loads. The primary vessel is heated to 500℃ and cool down to the room temperature iteratively for the absorption and desorption of tritium from and to the bed. These iterative operations induce thermal fatigue to the primary vessel of the SDS bed.

The primary vessel is made of SS316 steel. Its operation temperature range is in the thermal creep temperature region. The internal pressure increases as the primary vessel is heated. Therefore, the tritium SDS bed should have sufficient design stress intensity under the high temperature operating conditions. It should also be free of damage due to fatigue during the design life.

Analyses for the fatigue and creep consist of the thermal analysis by which the temperature distribution is calculated and the structural analyses by which the thermal stress is calculated from the temperature distribution. And in the fatigue and creep assessment, whether the fatigue and creep occur is determined according to the criteria in code standards.

The structural integrity was evaluated by applying the design criteria in ASME Section Ⅲ, Division 1, Subsection NB. The thermal fatigue and creep influences were evaluated through Subsection NH, which is the code standard for the structure under high temperature since the tritium SDS bed was heated to hot temperature region where creep occurs.

The thermal and structural analysis were performed by the commercial software ANSYS. There were two finite models. One is for temperature distribution calculation, and the other for stress calculation. The finite model to calculate stress distribution due to the internal pressure and thermal loads is shown in Fig. 1. In this model, elements for ZrCo powder was eliminated from the FE model for heat transfer.

2.2 Model Verification

NFRI had conducted heating and cooling experiment with tritium SDS bed test model. The primary vessel has chosen the way of heating the outer wall by the wound cable heater. The geometry of bed and the thermocouple arrangement are shown in Fig. 2. In Fig. 2, the notation of TC06 represents the temperature of the surface of the upper cable heater and TC07 represents that of the lower cable heater.

For the thermal analysis, heat flux was applied to the contact surface between outer wall and cable heater in the finite element model. For the inside of the primary vessel, natural convection condition was applied, and for the outer wall, equivalent convection condition was applied though the radiative thermal transfer occurred in reality.

The boundary conditions in thermal analysis were set through trial and error method based on the basic information to simulate a temperature distribution history similar to those of experiment under the operating condition.

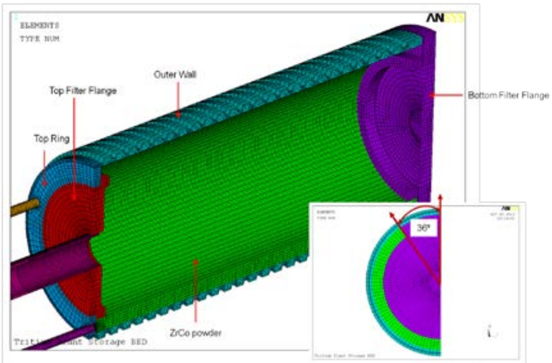

Fig. 1. FE model of primary vessel of tritium SDS bed

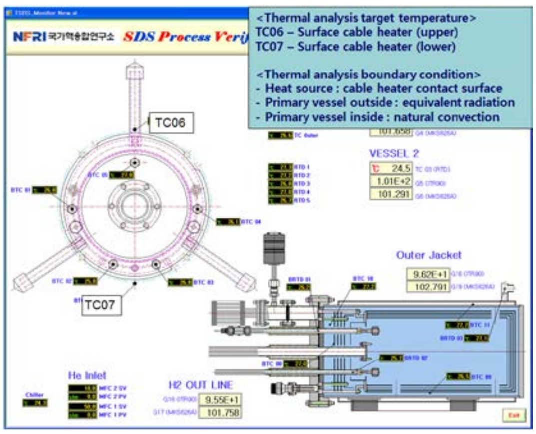

Fig. 2. Thermocouple location during test

3. Thermal Fatigue and Creep Assessments

Temperature histories from the test and analysis results under heating condition are represented in Fig. 3. It shows that the temperature histories of analysis are quite similar to those measured in test. The stress distribution at the time when the maximum stress happens is shown in Fig. 4. Based on the distribution of the primary stress and secondary stress results, two cross-sections for evaluation were selected. The evaluation showed that the calculated membrane, bending, and secondary stress values from the analysis satisfied all of the allowable values such as 1.0 S_m, 1.5 S_m, 3.0 S_m of the design code requirements respectively. For the fatigue assessment, the number of design cycle of SDS bed is 10,000 cycles. The maximum cumulative usage factor at 10,000 cycles was 0.0078, which is much less than 1.

The procedure of thermal fatigue and creep assessment is shown in Fig. 5. Based on the operation temperature history and the calculated stress, the results from fatigue and creep assessment are represented in Table. I. Thermal fatigue was very small due to relatively low temperature and low stress. The creep effect was almost negligible because of short duration at creep region. Both sections satisfied the design criteria for lifetime against assumed design cycle.

Based on the assessment results, new operation procedure to obtain more structural integrity and design margin was recommended. In Fig. 3, we can find that the slow temperature rise through change of heating rate reduced the thermal stress, which is estimated to be able to increase the design margin of the structure.

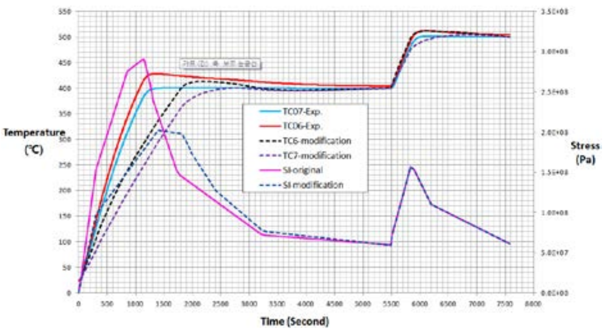

Fig. 3. Variation of temperature and stress intensity in heating condition

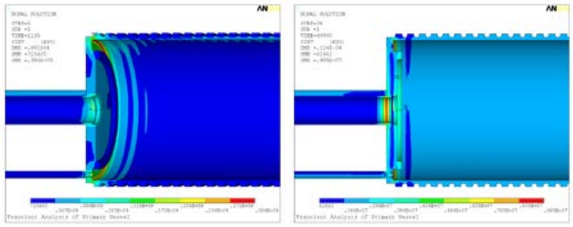

Fig. 4. Max. stress and stress under internal pressure only

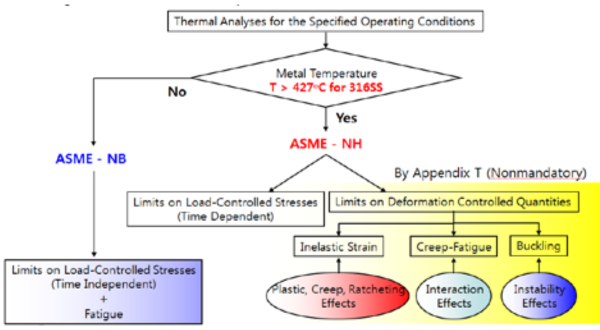

Fig. 5. Thermal fatigue and creep assessment procedure

4. Conclusions

For the ITER tritium SDS bed, thermal fatigue and creep assessments were performed. As a result, thermal fatigue was small since the relatively high stress occurred in local region and the magnitude was not so big. Due to short high temperature region, creep effect was negligible. And a new operation procedure to obtain more integrity margin was recommended. On the contrary, the other operation procedure should be considered which makes the rapid heating and cooling operation possible at the cost of giving up the marginal integrity.

REFERENCES

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Table I: Thermal fatigue and creep assessment results

Evaluation Items		Section-1			Section-2		
		Calculated	Limit	Check	Calculated	Limit	Check
Primary Stress Limits (MPa)	Membrane	1.1	107.7	OK	1.4	107.6	OK
	Membrane + Bending	5.4	161.8	OK	6.1	161.8	OK
Inelastic Strain Limits	Elastic analysis	0.665	1.0	OK	0.933	1.0	OK
	Simplified inelastic analysis	0.000 (79MPa)	1.0%	OK	0.000 (107MPa)	1.0%	OK
Creep-Fatigue Limits	Fatigue Damage	0.005	0.906	OK	0.014	0.895	OK
	Creep Damage	0.040	0.989	OK	0.045	0.968	OK