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Inelastic Analysis of the Creep Fatigue Damage for a Reactor Internal Structure

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1. Introduction

The main characteristics in the design of a Sodium Cooled Fast Reactor(SFR) are low pressure and high temperature according to the use of the liquid metal as coolant. The severe thermal stresses are occurred by the large temperature difference in structures because of high temperature condition. Furthermore, the plastic and creep deformations easily occur the decrease in the yield strength of the material and high thermal activation energy. Additionally, under low pressure condition, the possibility of ductile fracture and creep rupture is low. Consequently, the ratchet deformation and the creep fatigue damage due to the cyclic thermal stress are considered as the dominant failure modes in the SFR components. In this study, the evaluations for the creep fatigue damage for the reactor internal structure in an Advanced Burner Test reactor(ABTR) are carried out by using the inelastic analyses, the constitutive equations and the design procedures based on the inelastic analysis results.

For the inelastic analysis it is necessary to prescribe the thermal boundary condition and calculate the metal temperatures for the complete loading cycle. The stress calculations are performed for the complete loading cycle from heat up to cool down. Two kinds of constitutive equations are used in the inelastic analysis of a reactor internal structure. One is a Chaboche model. The other is a creep model with the isotropic hardening.

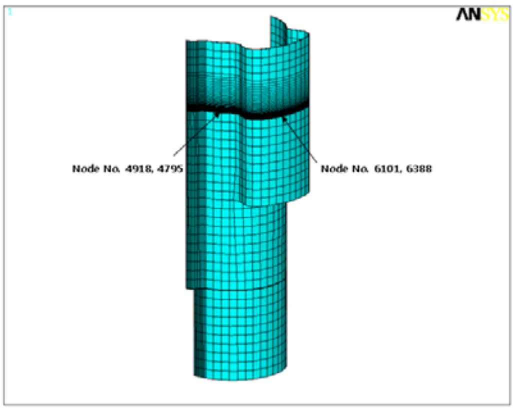

Fig. 1 Finite Element Model of a reactor internal structure for inelastic analysis

2. Inelastic Finite Element Analysis

2.1 Modeling and Loading Condition

The finite element mesh of a reactor internal structure as shown in Fig. 1 is performed using the ANSYS Code[1]. Two evaluation sections (A1 and A2) of the cold pool free surfaces through the thickness direction are evaluated to confirm the structural integrity of a reactor internal structure. The finite element model is calculated for the mechanical and thermal loads. The mechanical loads consider the dead weight.

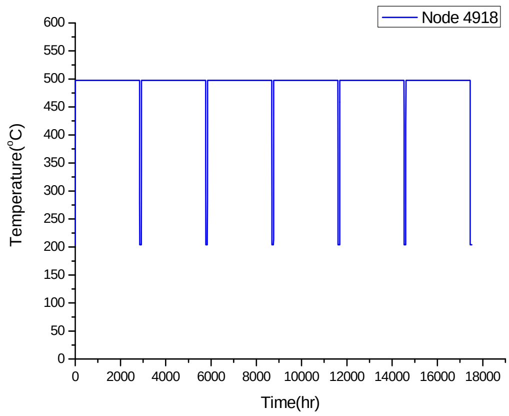

Fig. 2 Temperature time history at the inner surface of the evaluation section A1

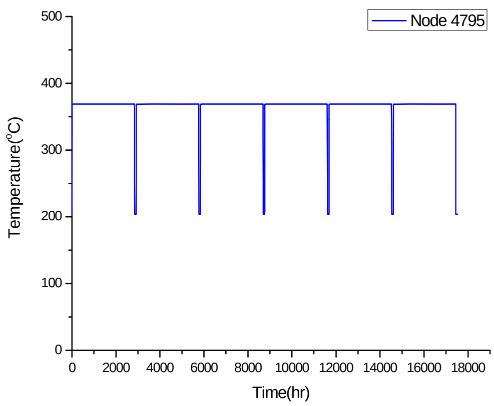

Fig. 3 Temperature time history at the outer surface of the evaluation section A1

The loads and time durations for the thermal analyses consider the refueling to full power operation condition based on the ABTR duty cycle events given by ref.[2]. In this cycle type, the maximum temperature of the hot and cold regions is 510 ^{o}C and 355 ^{o}C, respectively. The number of the repeated cycles is 180.

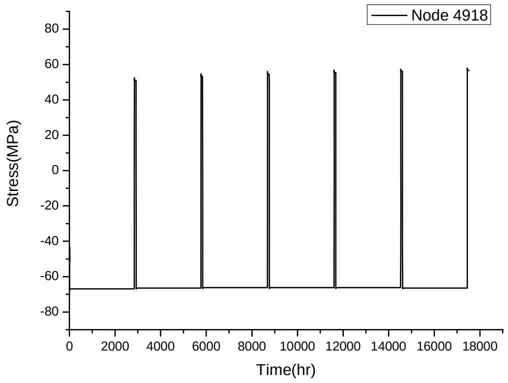

Fig. 4 Maximum principal stress time histoty at the inner surface of the evaluation section A1(Chaboche)

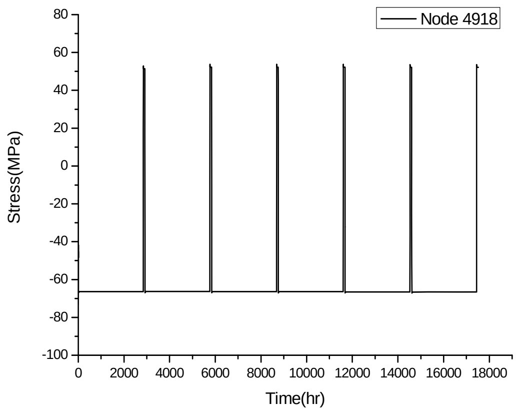

Fig. 5 Maximum principal stress time histoty at the inner surface of the evaluation section A1(Creep+BISO)

2.2 Thermal and Structural Analysis Results

Fig. 2 and Fig. 3 show the temperature time history at the evaluation section A1. From these figures, we can see that the maximum temperature at the inner surface and outer surface reaches 497 ^oC and 369 ^oC for 6 cycles, respectively. The results of the thermal analyses are used to perform the detailed structural analyses with elastic-plastic-creep behavior.

3. Results and Discussions

The creep fatigue damage evaluation by the inelastic analysis is performed with the results obtained after 6 complete cycles are applied. Fig. 4 and Fig. 5 indicate the maximum principal stress time histoty at the inner surface of the evaluation section A1. From these figures, one can see that the stress levels are very similar in two constitutive models.

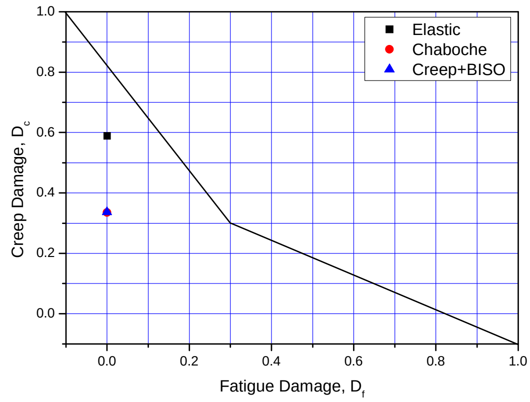

Fig. 6 Creep fatigue damage evaluation results

Fig. 6 represents the evaluation results indicated in the creep fatigue damage envelope. From this figure, we can see that the calculated creep fatigue evaluation results calculated by the elastic and inelastic methods satisfy the design limits of ASME-NH Code[3]. The fatigue damages for the given cycle type are totally negligible in comparison with the fatigue design limits. The creep damage is predicted to be more conservative by an elastic analysis. The maximum creep damage is 0.5886 in the elastic analysis method and 0.3367 in the inelastic analysis method, respectively, at the inner surface of A1 section.

4. Conclusions

The creep damage is evaluated to be more conservative by the elastic analysis than the inelastic analysis. In the case of the inelastic analysis, the results of the creep fatigue damage for two constitutive models are nearly similar for two constitutive equations.

Acknowledgements

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REFERENCES

[1] ANSYS User's Manual for Revision 11.0, ANSYS Inc.
[2] I-NERI Technical Annual Report, Sodium-Cooled Fast Reactor Structural Design for High Temperatures and Long Core Lifetimes/Refueling Intervals, 2007-007-K, 2008.
[3] ASME Boiler and Pressure Vessel Code Section III, Subsection NH, ASME, 2004.