Transactions of the Korean Nuclear Society Spring Meeting
Chuncheon, Korea, May 25-26 2006

High Temperature Creep-Fatigue Damage Evaluations by the ASME-NH Rules

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1. Introduction

In most LMR (Liquid Metal Reactor) designs, the operating temperature is very high at over 500°C and the design lifetime is generally 60 years. Therefore, a time-dependent creep rupture, excessive creep deformation, cyclic creep ratcheting, creep-fatigue, creep crack growth and a creep buckling become very important for a reactor structural design. In this paper, the creep-fatigue damage evaluation procedures by the ASME-NH rules [1] are investigated in detail and an example of an application with two cycle types is carried out by using the SIE ASME-NH Code [2, 3], which has a computerized implementation of the ASME Pressure Vessels and Piping Code Section III Subsection NH rules to be developed for the structural integrity evaluations for the next generation reactor design subjected to elevated temperature operations.

2. Rules of Creep-Fatigue Evaluation

The linear damage summation rule is adopted in the ASME-NH code. As a rule, an accumulated creep and fatigue damage should satisfy the following relation for a combination of the Level A, B, and C Service Loadings.

$$\sum_{j=1}^{p}\left(\frac{n}{N_d}\right)_j + \sum_{k=1}^{q}\left(\frac{\Delta t}{T_d}\right)_k \le D \qquad (1)$$

where
D = total creep-fatigue damage
P = number of different cycle types
$(n)_j$ = number of applied repetitions of cycle type, j
$(N_d)_j$ = number of allowable cycles for cycle type, j
q = number of time intervals for the creep damage calculation
$(T_d)_k$ = allowable time duration determined from the stress-to-rupture curves

The total damage, D, should not exceed the creep-fatigue damage envelope curves given in Fig. 1.

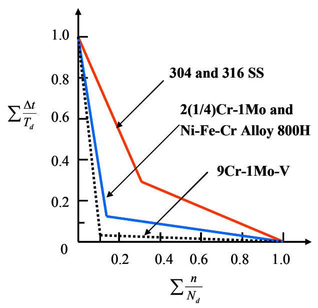

Fig. 1 Enveloped Stress Relaxation Time History

2.1. Fatigue Evaluation Procedures

The general procedures to evaluate the fatigue damage term in Eq. (1) by using the elastic analysis method are as follows;

[Step 1] Calculate the elastic strain time history for each cycle type, j
[Step 2] Select one of the extreme time points for the cycle (set subscript o)
[Step 3] Calculate the strain ranges for all the components at each time point as

$$\Delta\varepsilon_{xi} = \varepsilon_{xi} - \varepsilon_{xo},\ \Delta\varepsilon_{yi} = \varepsilon_{yi} - \varepsilon_{yo},\ \text{etc..}$$

[Step 4] Calculate the equivalent strain range for each point in time as

$$\Delta\varepsilon_{equi,i} = \frac{\sqrt{2}}{2(1+\nu^*)}\left[\left(\Delta\varepsilon_{xi}-\Delta\varepsilon_{yi}\right)^2+\left(\Delta\varepsilon_{xi}-\Delta\varepsilon_{yi}\right)^2+\left(\Delta\varepsilon_{xi}-\Delta\varepsilon_{yi}\right)^2+\frac{3}{2}\left(\Delta\gamma_{xyi}^2+\Delta\gamma_{yzi}^2+\Delta\gamma_{zxi}^2\right)\right]^{1/2}$$

[Step 5] Define $\Delta\varepsilon_{max} = Max(\Delta\varepsilon_{xiequiv,i})$
[Step 6] Modify $\Delta\varepsilon_{max}$ with a local geometric stress concentration and the multiaxial effects
[Step 7] Calculate the total strain range as $\varepsilon_t = K_v\Delta\varepsilon_{\text{mod}} + K\Delta\varepsilon_c$
[Step 8] Find the allowable number of cycles, N_d from the design fatigue curves corresponding to ε_t
[Step 9] Calculate the fatigue damage by $\sum_j^p\left(\frac{n}{N_d}\right)_j$

2.2. Creep Evaluation Procedures

The general procedures to evaluate the creep damage term in Eq. (1) of the creep-fatigue damage rules are as follows;

[Step 1] Define the total number of hours expended at an elevated temperature, t_H
[Step 2] Define the hold temperature, T_{HT}
[Step 3] Define the average cycle time, $\bar{t}_j = t_H / n_j$
[Step 4] Determine the stress level, $S_j|\varepsilon_t$ from time independent isochronous stress-strain curve corresponding to T_{HT}
[Step 5] Obtain the stress relaxation time history curve at dwell stress S_j and a hold temperature, T_{HT}
[Step 6] Modify the stress relaxation time history curve by considering the load-controlled transient effect
[Step 7] Define the cycle transient temperature
[Step 8] Repeat Step3 through to Step 7 to make j=1 for the P sets of the stress relaxation time histories and superpose these onto the results in the envelope stress-time history as shown in Fig.2

[Step 9] Determine the integration time step size, $(\Delta t)_k$, the stress, $(S)_k/K'$, and the temperature, $(T)_k$

[Step 10] Obtain the allowable time duration, $(T_d)_k$ for each time interval from the expected minimum stress-to-rupture curve

For the weldment evaluations, the allowable time duration T_d should be determined from a stress-to-rupture curve obtained by multiplying the parent material stress-to-rupture values by the weld strength reduction factors [1].

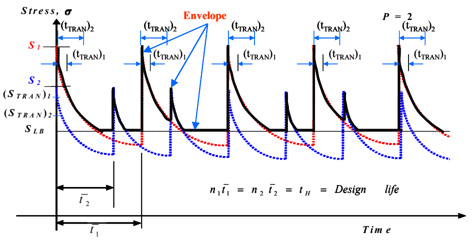

Fig. 2 Enveloped Stress Relaxation Time History

3. Example of Application

Fig. 3 shows the axisymmetric finite element analysis model and the applied boundary conditions for the shell to head junction type structure with a gross structural discontinuity. For an example of the multi-transient cycle types, two representative cycle types are assumed during the total design lifetime. For cycle type 1, the coolant temperature starts to decrease down to T_1=500°C from the normal operating temperature, T_{ss}=550°C for 5 hours and next it gradually increases to T_2=650°C for 5 hours and then it recovers the normal operating temperature again after 5 hours. Therefore, the total transient duration is 15 hours. For cycle type 2, the coolant temperature starts to decrease down to T_1=400 °C from the normal operating temperature, T_{ss}=550°C for 5 hours and next it increases up to T_2=600°C for 5 hours and then it recovers the normal operating temperature again after 5 hours. The total transient duration is 15 hours, the same as that of cycle type 1.

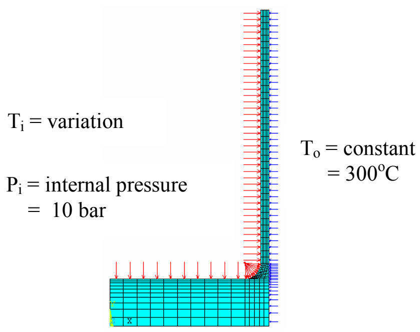

Fig. 3 Axisymmetric FEM Model

The number of each cycle type for the creep-fatigue damage evaluations are defined to be 10 for cycle type 1 and 15 for cycle type 2. From the fatigue evaluation by following the above procedures, it is negligible.

Fig.4 shows the obtained enveloped stress relaxation time history curve for a creep damage calculation. From this, the calculated creep damages are 0.4686 for point 1 and 0.3480 for point 2 as shown in Fig. 5. For the case of point 1, the calculated creep damage from the enveloped stress relaxation time history is larger than 0.4588 for a single cycle type 1 or 0.4449 for a single cycle type 2 [2]. Therefore, it is found that the creep damage increases due to the effects of cycle type 2 during cycle type 1. Actually, it is expected that the higher the stress levels used for the expected minimum stress-to-rupture curve at the given hold temperature are, he larger the effect of the enveloped stress level will be on the creep damage.

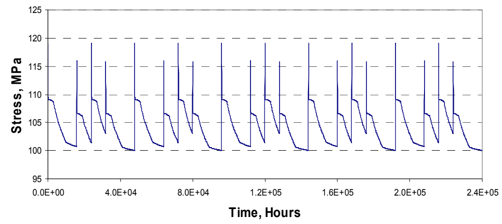

Fig. 4 Calculated Stress Relaxation Time History

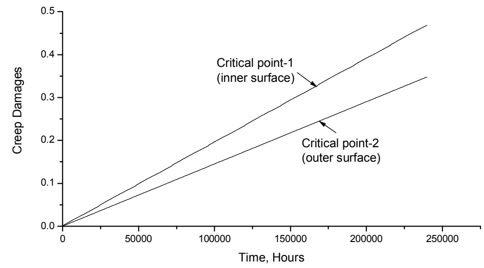

Fig. 5 Calculated Creep Damage Time History Curve

4. Conclusions

In this paper, the high temperature creep-fatigue damage evaluation procedures by the ASME-NH rules are investigated in detail and an example of an application by using the two cycle types is carried out to substantiate the actual multi-cycle types of a creep-fatigue damage evaluation by the ASME-NH.

ACKNOWLEDGMENTS

This project has been carried out under the Nuclear R & D Program by MOST.

REFERENCES

[1] ASME Boiler and Pressure Vessel Code Section III, Subsection NH, ASME, 2004

[2] G.H. Koo and J.H. Lee, Computer Program of SIE ASME-NH Code, KAERI/TR-3161/2006

[3] G.H. Koo and J.H. Lee, "SIE ASME-NH Program for the Structural Integrity Evaluations of A LMR Subjected to Elevated Temperature Operations," ASME PVP Conf, 2006.