Creep Fatigue Evaluation for Stainless Steel Welded Joints using Elastic Analysis

S. H. Kim, H. Y. Lee, Y. S. Joo, J. H. Lee
Korea Atomic Energy Research Institute, Daejeon 305-600, Korea, shkim5@kaeri.re.kr

1. Introduction

Actual plant experience has shown that the structural integrity of welded components subjected to an elevated temperature service is important. Creep fatigue load can lead to a weldment cracking in a number of Liquid Metal Reactor components. This paper carried out the creep fatigue evaluation which included the multiaxiality, creep, relaxation consideration and associated adjustment factor. In this paper, a creep fatigue evaluation of a welded cylinderical shell has been carried out according to the US high temperature design code ASME-NH.

2. Methods and Results

2.1 Damage Equation

The combination of Level A, B, and C Service Loadings shall be evaluated for an accumulated creep and fatigue damage, including the hold time and strain rate effects. For a design to be acceptable, the creep and fatigue damage shall satisfy the following relation:

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

D : total fatigue creep damage

$(N_d)_j$: number of design allowable cycles for a cycle type, j, determined from one of the design fatigue curves(Figs. T-1420-1[1]) corresponding to the maximum metal temperature occurring during the cycle.

$(T_d)_k$: allowable time duration determined from Figs.I-14.6(stress to rupture curves) for a given stress and the maximum temperature at the point of interest and occurring during the time interval, k.

2.2 Strain Range Determination

The equivalent strain range is computed as follows. The peak and valley condition at an extreme for the cycle can be referred to this time point by a subscript i and o.

$$\Delta\varepsilon_{xi} = \varepsilon_{xi} - \varepsilon_{xo} \qquad (2)$$

$$\Delta\varepsilon_{yi} = \varepsilon_{yi} - \varepsilon_{yo} \qquad (3)$$

$$\Delta\varepsilon_{equiv,i} = \frac{\sqrt{2}}{2(1+\nu^*)}\Big[(\Delta\varepsilon_{xi} - \Delta\varepsilon_{yi})^2 + (\Delta\varepsilon_{yi} - \Delta\varepsilon_{zi})^2 + (\Delta\varepsilon_{zi} - \Delta\varepsilon_{xi})^2 + \frac{3}{2}(\Delta\gamma_{xyi}^2 + \Delta\gamma_{yzi}^2 + \Delta\gamma_{zxi}^2)\Big] \qquad (4)$$

The total strain range is calculated as:

$$\varepsilon_t = K_v \, \Delta\varepsilon_{\text{mod}} + K\Delta\varepsilon_c \qquad (5)$$

$$K_v = 1.0 + f\,(K_v^{'} - 1.0) \qquad (6)$$

K : local geometric concentration factor

K_v : the multiaxial plasticity and poission ratio adjustment factor

$\Delta\varepsilon_c$: the creep strain increment

$\Delta\varepsilon_{\text{mod}}$: the modified maximum equivalent strain range

ε_t : the total strain range that is used to enter one of the design fatigue curves of Figs. T-1420-1 to determine the allowable number of cycles, N_d

2.3 Evaluation of the Fatigue and Creep Damage

The above total strain range is used to determine the fatigue damage by entering one of the design fatigue curves of Fig. T-1420-1 in ASME-NH[1]. The stress response during the stress cycle, defined to include the sustained normal operation holdtime between repeated events, is assessed first by entering the code isochronous stress strain curve at the holdtime temperature[2].

2.4 Creep Fatigue Reduction Factors for a weldment

In the vicinity of a weld(defined by ± 3 times the thickness to either side of the weld centerline), the creep fatigue evaluation of T-1400 shall utilize the reduced values of the allowable number of design cycles N_d and the allowable time duration T_d in eq.(1)[3]. The N_d value shall be one-half the value permitted for the parent material(Figs. T-1420-1). The T_d value shall be determined from the stress-to rupture values(Table I-14.6) by the weld strength reduction factors given in table I-14.10, and defined in NH-3220. The factor $K^{'}$(Table T-1411-1) must still be in this determination of T_d .

2.5 Analysis Model

The test specimen is a welded cylinder type which is composed of 316L stainless steel as shown in Fig. 1. The thermocouples were attached along the inner surface of the cylinder and the temperature history was measured. The measured data shows that the temperature of the mid part of the cylinder is about 600°C and those of the lower and upper parts are relatively low as shown in Fig. 2. Also, the tension load is applied to the welded specimen in the axial direction at the top surface as shown in Fig. 3. The ANSYS finite element model of the welded specimen is a 2D axisymmetric model and the boundary conditions applied in the model are shown in Fig. 3[4].

2.6 Analysis Results

The creep-fatigue damage was evaluated for 300 load cycles. The equivalent strain ranges at three points in the vicinity of a weld were calculated. The maximum equivalent strain range was decided in the HAZ region with the height of 22.9Cm from the bottom. Thus, the total strain range calculated using eq.(5) is 0.000413. The fatigue endurance limit and rupture time for the welded part were calculated as 1.80 x 10^6 and 9.76 x 10^6, respectively. Also, the fatigue and creep damage were evaluated as 0.0001667 and 0.00307 (K=1). For the equivalent stress concentration factor K of 1.5, the fatigue and creep damage were evaluated as 0.000231 and 0.0304, respectively.

3. Conclusion

In this paper, the creep fatigue damage was evaluated using the ASME-NH Code to check the structural integrity of a welded cylinderical specimen at an elevated temperature. The evaluation results showed that the creep damage(0.0304) was greater than the fatigue damage (0.000231) for 300 load cycles when K is 1.5. The actual observation results for the welded zone using an optical microscope did not show any visible damage over 300 creep fatigue load cycles, which is in agreement with the present evaluation results.

Acknowledgements

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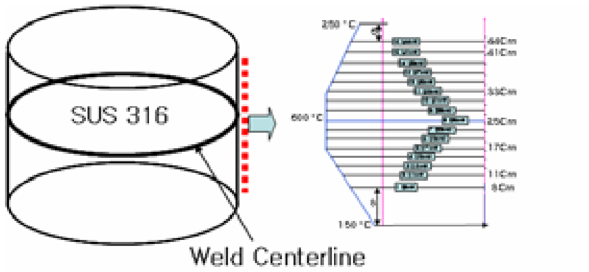

Fig. 1 Welded specimen and the position of thermocouples

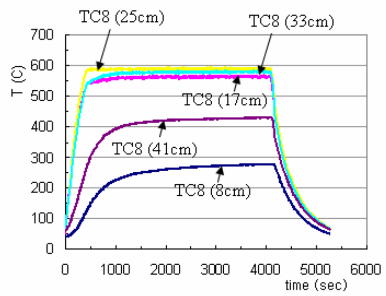

Fig. 2 Distribution for the measurement temperature of thermocouples

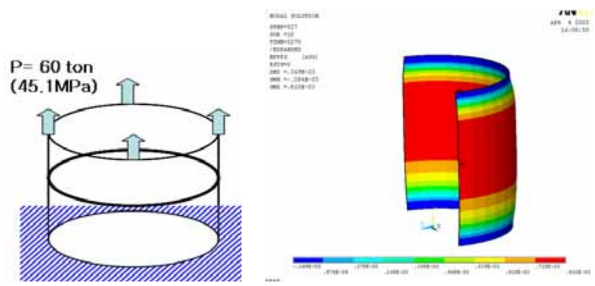

Fig. 3 Boundary condition and distribution of total hoop strain in welded specimen