Modeling of Initiation of Creep Void at Precipitates in HAZ of 11% Cr Steel
—Study on Weldability of Heat-Resisting Ferritic Steel for USC Boilers (Report 6)—
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1. Introduction
Report 5 investigated the results of one pass creep welded joint specimen of 11% Cr steel. The results show that most creep cracks occur in fine grain heat affected zone (HAZ), in which many precipitates exist. The coincidence of cracks and precipitates implies the important role of precipitates in the initiation of creep void. Since properties of precipitates are different from metal matrix, stress concentration occurs around the precipitates because of inhomogeneous deformation, and it may result in void initiation. In this study, a FEM model is established in order to clarify the effects of several factors, such as Young’s modulus of precipitate, size of precipitate and creep rate, on the occurrence of stress concentrations.

2. Model
By referring to microstructure observations, the present 2-D plane strain FEM model is assumed to consist of 1/4 of a circular precipitate and a HCM12A matrix as shown in Fig. 1. The matrix is imposed a uniaxial tensile stress of 120MPa. The working temperature is 923K. Creep occurs in metal matrix but not in precipitate. This model involves elastic, plastic and creep deformation. Several factors are excluded in the model, such as effect of grain boundary, effect of diffusion, etc., to avoid the complexity. Combined with the Norton creep law $\dot{\varepsilon} = A\sigma^n$, stress and strain field in creep time can be calculated with creep function of ANSYS. Three factors are discussed in this model: Young’s modulus of precipitate varies from 400GPa to 800GPa, which can include most types of precipitates in 11% Cr steel; radius of precipitate varies from 0.1μm to 0.25μm, which is the same size as observed in experiment; and creep rates of HAZ and the base metal, introduced with different A and n as shown in Table 1.

3. Results and Discussions
Figure 2 shows the equivalent stress and equivalent strain field in different creep time. Stress concentration and strain concentration occur at the interface between precipitate and matrix and in the matrix near the precipitate. Equivalent stress decreases and equivalent strain increases during the creep. The strain and stress concentration at the interface is important for creep void initiation, thus the value of the mesh with highest strain in each condition will be used in the following discussion. Figure 3 shows the equivalent stress in the creep time in the conditions of precipitate existing and not. When precipitate exists, equivalent stress decreases at the beginning sharply but remain unchanged in the later time. Figure 4 shows the effect of Young’s modulus of precipitate on stress concentration. As Young’s modulus increases from 400GPa to 800GPa, equivalent stresses increase at the beginning, but they decrease to be equal in the later. It suggests that hard precipitate aggravates stress concentration and this effect diminish to zero fast. Figure 5 shows the effect of size of precipitate on strain concentration. When radius of precipitate changes from 0.1μm to 0.25μm, the distance of equivalent strain above 0.09 around precipitate increases from 0.067μm to 0.158μm, it shows large precipitate induces wide field of high strain and sequential void initiation. Figure 6 shows the effects of creep and other material properties of HAZ and base metal on strain concentration. Fine grain HAZ accelerates strain concentration.

Fine grain HAZ has large precipitates and high creep rate. As discussed above, both of them are important factors on creep void initiation. The results clearly indicate that creep void initiation is easy to occur in fine grain zone of HAZ. In addition, Young’s modulus of precipitate has little effect on creep void initiation.
References:

Fig. 1 Simulation model
Table 1 Creep properties

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<tr>
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<th>A (MPa·h⁻¹)</th>
<th>n</th>
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<tbody>
<tr>
<td>Fine HAZ</td>
<td>2.80 × 10⁻⁷⁴</td>
<td>9.8</td>
</tr>
<tr>
<td>Coarse HAZ</td>
<td>6.97 × 10⁻⁷⁵</td>
<td>10.2</td>
</tr>
<tr>
<td>Base metal</td>
<td>3.76 × 10⁻⁷³</td>
<td>13.6</td>
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Fig. 2 Equivalent stress and equivalent strain contours

Fig. 3 Equivalent stresses at interface in matrix as a function of creep time in the conditions of precipitate existing and not

Fig. 4 Equivalent stresses at interface in matrix as a function of creep time under different Young’s moduli of precipitates

Fig. 5 Equivalent strains of matrix in the 0.01μm vicinity of interface around precipitate under different radii of precipitates

Fig. 6 Equivalent strains at interface in matrix as a function of creep time for different zones