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POLYCRYSTAL VISCOELASTIC FINITE ELEMENT ANALYSIS OF CREEP DEFORMATION BEHAVIOR OF A WELDED JOINT IN MODIFIED 9Cr-1Mo STEEL

Yuji Nakasone*[1] and Jumpei Suzuki[2]

[1] Department of Mechanical Engineering, Tokyo University of Science
6-3-1, Niijuku, Katsushika-ku, Tokyo 125-8585, Japan
nakasone@rs.kagu.tus.ac.jp
[2] Graduate Student, School of Engineering, Tokyo University of Science
6-3-1, Niijuku, Katsushika-ku, Tokyo 125-8585, Japan
j4513629@ed.tus.ac.jp

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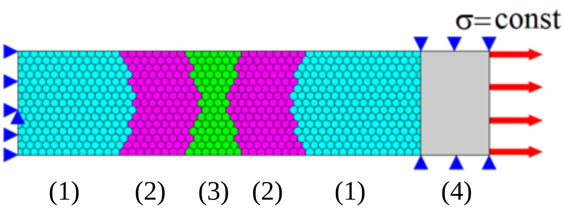
Due to low thermal activation, modified 9Cr-1Mo steel can maintain steady-state deformation during long-term creep. Because of different creep strain rate in the parent metal and the heat-affected zone (HAZ), however, creep deformation can be accelerated and stress augmented in fine-grained HAZ to cause detrimental Type IV cracks in this zone. In this study, the present authors have been developing finite element analysis codes [1] which adopt Norton's law as a constitutive relation and take into account different aggregates of slip systems in crystal grains in polycrystal materials. The polycrystal viscoelastic finite element analyses were made by one of the developed codes on long-term creep of up to over 10,000 hours in double U groove welded modified 9Cr-Mo steel having typical microstructures in the welded region.

Figure 1 schematically shows typical microstructure found near a weld joint in modified 9Cr-1Mo steel; i.e., (1) weld metal, (2) heat-affected zone (HAZ) and (3) base metal. The Type IV cracking is often reported to be initiated within the HAZ [2]. These microstructures were modelled as polycrystal structures having slip systems approximated by Asaro's double slip model [3]. Boundary conditions are also depicted in Fig. 1; i.e., the triangular symbols indicate the displacement constraint imposed in the direction perpendicular to the bottom sides of the triangles, and the arrows tensile uniform constant traction force applied in the horizontal direction, or the longitudinal direction of the plate specimen. The traction force was applied via a rigid plate having sufficiently large stiffness so as to prevent the bending deformation of the plate. Table 1 lists the aggregate mechanical properties of the materials used for the present FE analyses.



(1) Base metal (2) HAZ (3) Weldment (4) Rigid chuck

Fig. 1 Polycrystal model of a welded joint in a plate specimen.

Table 1 Mechanical properties of the materials used for the present FE analyses.

Material	Young's modulus, E, GPa	Poisson's ratio, ν	Coefficient in Norton's law, A	Exponent, n
Base metal Weldment	165	0.33	3.76E-33	13.6
HAZ	165	0.33	3.21E-28	12.0
Rigid chuck	50000	0.33	0	0

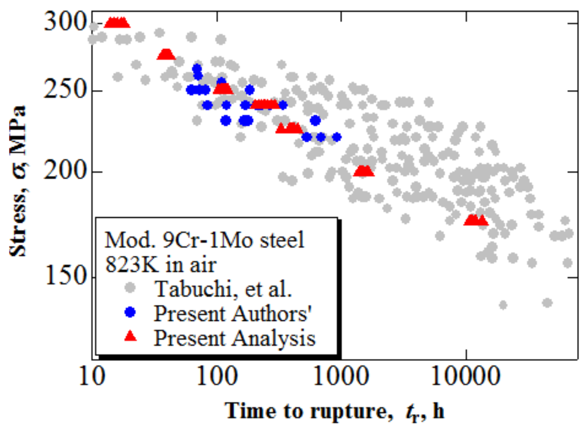


Fig. 2 Comparison of the creep rupture diagrams obtained by the present analysis with those by experiments.

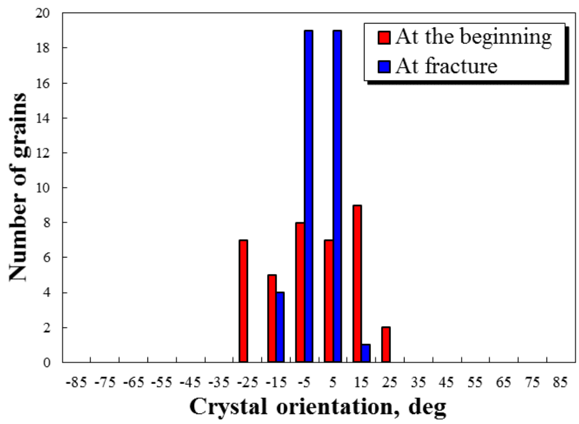


Fig. 3 Histogram plots of the distributions of crystal orientation in HAZ at the beginning and at the end of the creep process simulated by the present FE code.

FE analyses were made on the polycrystal models having the 10 different distribution patterns of slip systems crystal grain aggregates. The applied stress vs. time to creep fracture relations obtained by the present analysis are indicated by the solid triangular symbols, the experimental results obtained by the present authors by the solid circular symbols and those by the grey circular symbols in Fig. 2. The present results show good agreement with the experimental ones [4, 5] except for much smaller variations.

Figure 3 shows the histogram plots of crystal orientation distributions in HAZ, where necking occurred, at an applied stress of σ=250MPa at 823 K in air, indicating that the frequencies of crystal orientation became more than doubled at angles between -5 and 5 degrees around the tensile axis at a macroscopic strain of ε=20% at which strain rate became so large that creep fracture was supposed to take place at that strain level in the present analysis. This result implies the formation of deformation-induced texture which was also observed in our experiments [5]. At ε=20%, misorientation of larger than 5 degrees were observed among many elements in grains in HAZ which had the same orientations at the early stage of creep simulated, implying grain refining phenomenon which was also observed in our experiments [5].

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