Development of Grain Boundary Local Stress Analysis Method for High Temperature Structural Materials
− Application to Void Growth Simulation under Creep Condition −

Background

Creep voids are observed in detailed microscopic inspections for high temperature structural components of thermal power plants. The voids grow up to microcracks under a long term creep condition. In order to predict the void growth behavior under the creep condition quantitatively, a void growth simulation program [*1] was developed. The stress used for the void growth simulation is calculated geometrically in this program. It might be possible to predict the void growth behavior with higher accuracy by using grain boundary local stress values.

Objectives

This study aims to develop an analytical method and a finite element analysis program to analyze grain boundary local stress under creep condition quantitatively. The developed program is applied to analyze grain boundary local stress and to void growth simulation under creep condition.

Principal Results

1. Development of a grain boundary local stress analysis method

A grain boundary local stress analysis method was developed (Fig.1). In this method, a crystal plasticity model [*2] was applied to consider the crystal orientation dependence of material properties. By incorporating this method into a finite element analysis program, it became possible to quantitatively analyze the grain boundary local stress distribution of polycrystalline materials under creep condition. Reduction of calculation time was achieved by introducing an automatic mesh generation procedure into the developed program.

2. Application to a void growth simulation under creep condition

A grain boundary local stress analysis and a void growth simulation were performed for a turbine rotor material (Fig.2) under creep condition (580℃, 180MPa, and 5000 hours duration). Results were obtained as follows.

(1) It was observed that the distribution of grain boundary local stress (Fig.3) and creep strain (Fig.4) were inhomogeneous under the creep condition. Moreover, it was revealed that the normal stress on each grain boundary changed with time respectively because of stress redistribution near grain boundaries (Fig.5). The change in grain boundary local stress under creep condition with time could be analyzed by applying the developed program, while it is difficult to conduct by conventional analysis based on continuum mechanics.

(2) By using grain boundary local stress values, a void growth simulation was performed. As a result, the change of maximum void length with time by the void growth simulation agreed well with that observed by a microscope (Fig.6).

Future Development

This method will be improved to analyze grain boundary local stress under creep-fatigue condition. Using the modified method, a quantitative void growth simulation of high temperature structural materials will be carried out.

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Reference

T.Sakai et al, “Development of Grain Boundary Local Stress Analysis Method for High Temperature Structural Materials - Application for Void Growth Simulation under Creep Condition”, Technical Report Q07011 (in Japanese)

*1：T.Ogata, 2003, “Clarification of creep void growth behavior and development of void growth simulation program”, CRIEPI Report T03007 (in Japanese)

*2：Constitutive model to calculate inelastic deformation amount from movement of dislocation in crystal grain

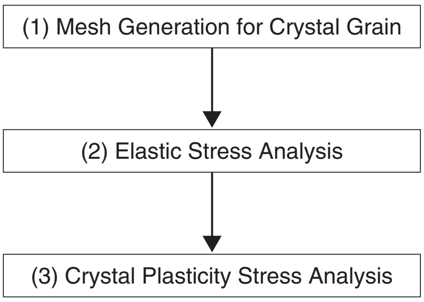

Fig.1 Flow of grain boundary local stress analysis

(1) All crystal grains are divided into finite element meshes.
(2) Elastic stress analysis is carried out.
(3) Crystal plasticity stress analysis is performed.

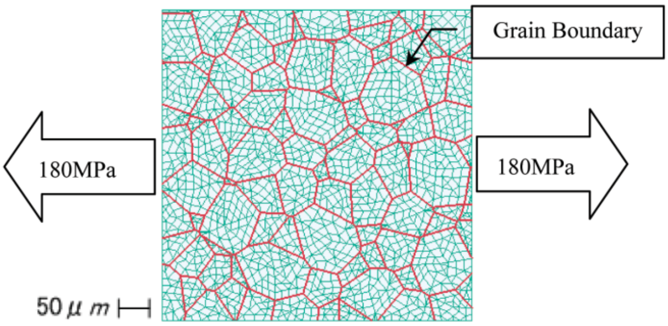

Fig.2 Analysis model
(result of automatic mesh generation)

Tensile stress of 180MPa was applied in horizontal direction under temperature of 580 ℃ and kept for 5000 hours. Experimental creep rupture time under the same condition was about 4200 hours.

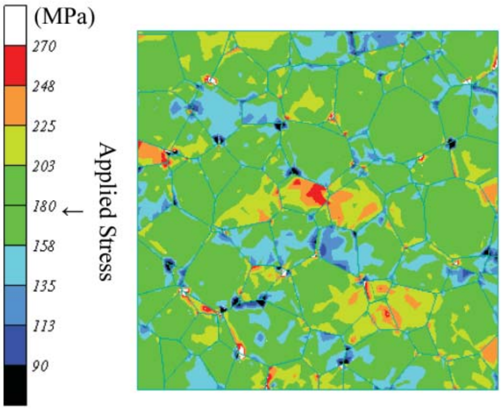

Fig.3 Stress distribution in applied loading direction
(after 5000 hours stress duration)

Stress distribution became inhomogeneous because the crystal grains mutually constrained creep deformation in each other.

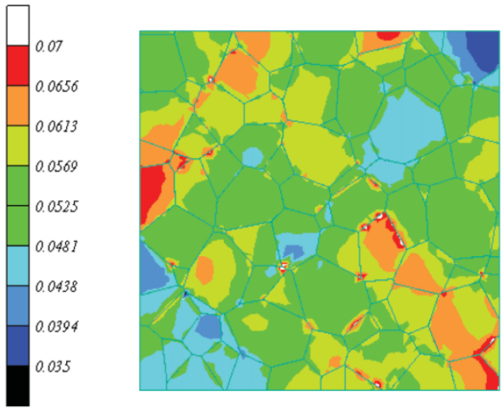

Fig.4 Creep strain distribution in applied loading direction
(after 5000 hours stress duration)

By performing a crystal plasticity analysis, it became possible to simulate the band of creep strain concentration.

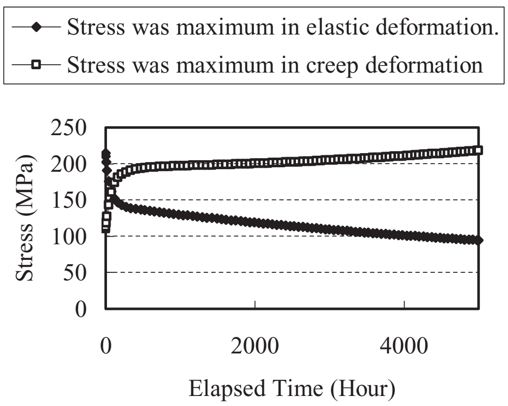

Fig.5 Time change of grain boundary normal stress

The normal stress of one grain boundary was the maximum at first but gradually reduced with the progress of creep deformation. On the other hand, that of another grain boundary was the minimum at first but increased oppositely.

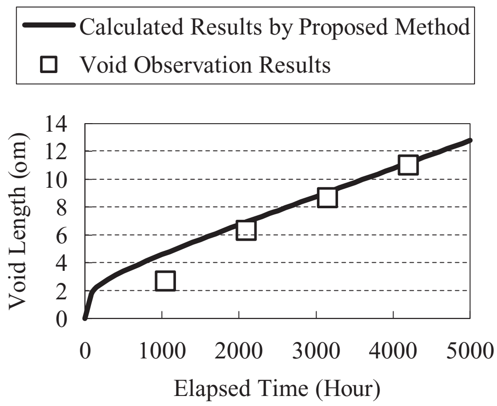

Fig.6 Time change of maximum void length

By considering grain boundary local stress condition, it became possible to obtain creep void simulation results that agreed well with the experimental observation results.

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