Development of creep void nucleation model for high temperature structural material

Background

In the case of commercial heat resistant alloys for thermal power plants, nucleation, growth and coalescence of creep void are dominant damage mechanisms. Especially it takes long time for nucleation and growth of void because such alloys are used under relatively low stress condition in thermal power plants. Therefore, it is desired to develop the method which can quantitatively predict nucleation and growth behavior of void in order to establish a reliable remaining life assessment method for high temperature components in thermal power plants. So far, CRIEPI has proposed the void growth model, and shown a validation of that model in comparison with experiment [*1]. However, rational modeling of void nucleation remains a difficult subject because the basic mechanism is unclear. Accordingly, in order to establish a reliable remaining life assessment method for high temperature components in thermal power plants, it is necessary to develop the predictive method for nucleation of void in heat resistant alloys.

Objectives

The purpose of this study is to develop the void nucleation model which can predict incubation time for nucleation and void number density by an experimental observation and theoretical consideration for the mechanism of void nucleation using Cr-Mo-V forged steel.

Principal Results

1. Experimental observation of nucleation behavior of creep voids

Creep tests were conducted using turbine rotor material Cr-Mo-V forged steel with 154.5MPa and 853K (predicted rupture time is 10000 hours), and microstructure of interrupted specimens was observed by FE-SEM (Field Emission Secondary Electron Microscope). Creep voids were found to nucleate at the grain boundaries in sizes of ~0.5μm during 5% ~ 10% of the predicted rupture time and grow to ~1.2μm at 15%, ~2.6μm at 20%. In addition it was confirmed that creep voids nucleate at the interface between precipitate carbides at grain boundary and edge of grain boundary by EDS (Energy Dispersive Spectroscopy) analysis (Fig. 1).

2. Development and verification of creep void nucleation model

New nucleation model was developed based on the idea that creep voids nucleate by vacancy condensation at the interface between precipitate carbides at grain boundary and edge of grain boundary (Fig. 2). In addition, creep property was connected via the relationship between strain and vacancy density obtained from molecular mechanics simulation [*2]. Accordingly stress dependence on void nucleation behavior was formulated (Fig. 3).

Based on the above consideration, the model which can quantitatively predict void nucleation behavior in practical heat resistant alloy was developed by adding a statistical treatment of the different physical properties in all grain boundaries. Using the developed model, experimental nucleation time and void number density were successfully predicted based on the assumption that void nucleates when vacancy cluster reaches 0.1μm in diameter [*3]. Therefore, it was confirmed that present void nucleation model can predict the evolution of the void number density (Fig. 4).

Future Developments

By integrating the present developed void nucleation model with the previously developed growth model, unified damage prediction method will be constructed and its applicability for practical heat resistant alloys in thermal power plants will be examined. In addition, guideline for development of high strength material will be formulated by using the integrated damage prediction model.

Main Researchers:

Kaoru Nakamura, Research Associate, Materials for Thermal Power Plants Sector, Material Science Research Laboratory
Takashi Ogata, Ph.D., Senior Research Scientist, Deputy Director, Material Science Research Laboratory

Reference

K. Nakamura and T. Ogata, 2009, “Development of void nucleation model by observation of creep void nucleation behavior”, CRIEPI Report Q08008 (in Japanese)

＊1：T. Ogata, 2003, CRIEPI Report T03007 (in Japanese)
＊2：Atomistic simulation mehod using empirical interatomic potential. Static total lattice energy can evaluate.
＊3：Because previous reported void growth model can apply void beyond 0.1μm size, nucleation size was considered as 0.1μm.

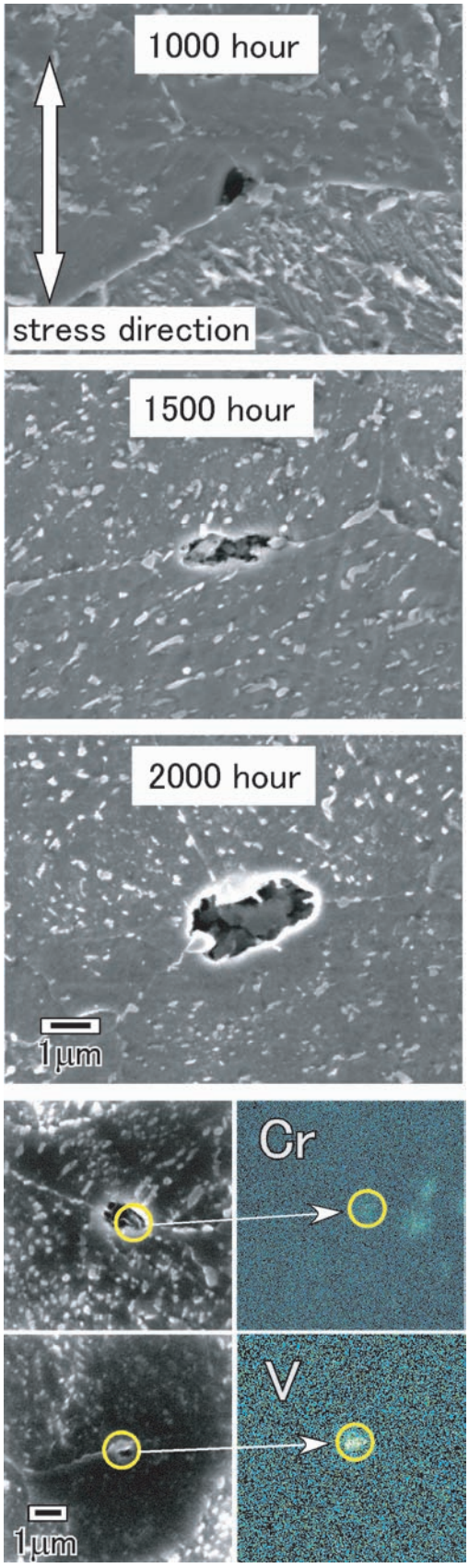

Fig.1 Observed voids and EDS mapping

Voids nucleate at grain boundary and Cr or V carbides were detected next to voids.

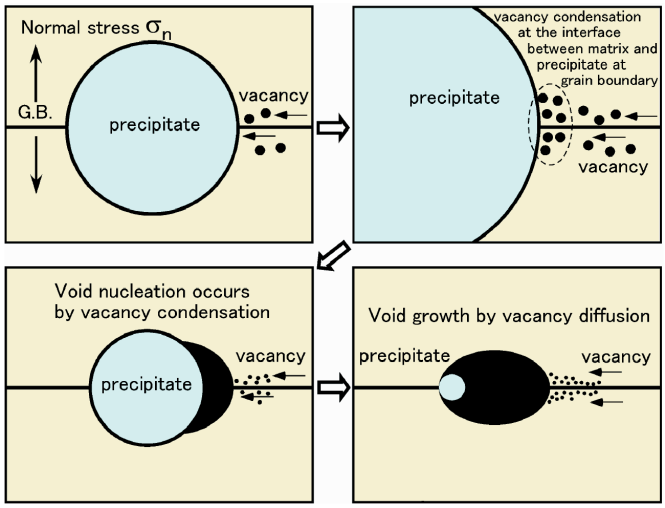

Fig.2 Schematic illustration of void nucleation

Voids nucleate by vacancy condensation at the interface between matrix and precipitate on grain boundary.

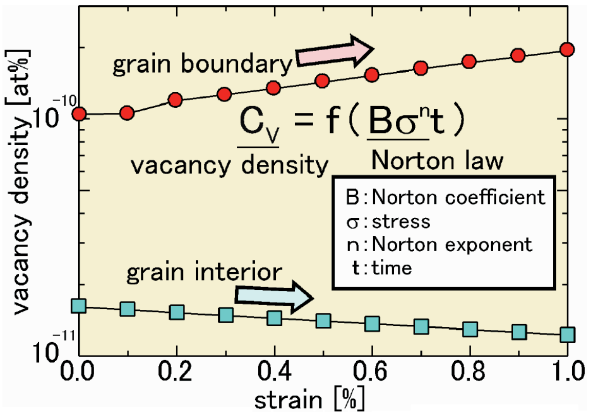

Fig.3 Change of vacancy density by strain accumulation.

Relationship between strain and vacancy density was analyzed by molecular mechanics simulation and connected with creep property. Accordingly stress dependence on void nucleation behavior was revealed.

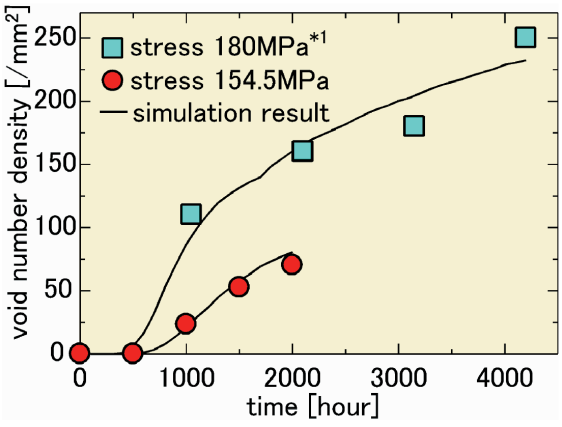

Fig.4 Comparison of void nucleation model with experiment.

Validation of developed void nucleation model was confirmed because void number density was measured not only by present creep condition but also by previous report*1.