DEVELOPMENT OF A CREEP CAVITY MODEL IN MOD. 9 Cr-Mo STEEL (MODEL & EXPERIMENT)

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Abstract

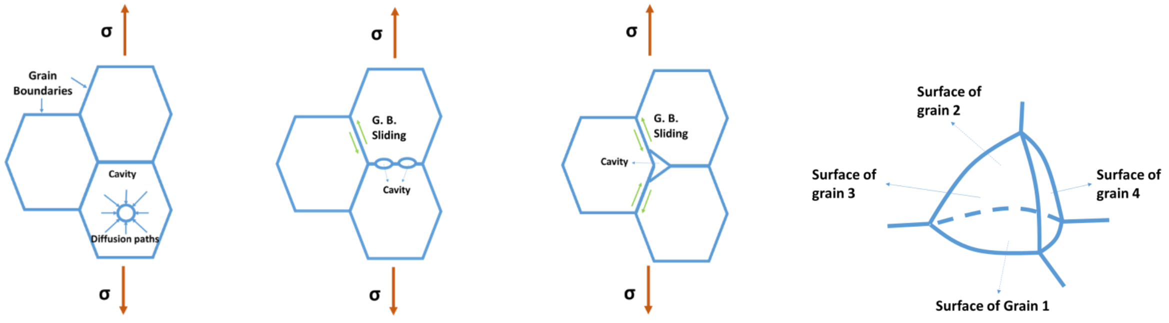
A model has been proposed to describe the nucleation and growth of creep cavities in crystalline material in service. In this work, the Becker-Döring (BD) nucleation model is applied for nucleation of cavities, while for the growth of pores, a vacancy flux model towards nucleated or existing pores is utilized. The model can describe nucleation and growth rates of pores in the matrix, at grain boundaries and at particles/inclusions. Nucleation and growth of pores in the creep process is determined to be a function of uniaxial or multiaxial external stress, internal stress due to the residual stresses, working temperature, local microstructure (nucleation and growth of particles), nucleation sites, interfacial energy of grain boundaries, phase boundary energies, diffusion rates in different paths and pore geometry, which are all considered in the present approach.

Systematic interrupted creep tests are performed under 66 MPa uniaxial creep loading at 650°C to track the pore evolution after 0, 2000, 4000, 5200 and 8000 hours for 9Cr-1Mo martensitic (ASME Gr.91) steels. The model results are then compared to experimental findings in terms of mean pore size and volume fraction. The comparison shows good agreement between experimental and simulation results [1].

Introduction

Nucleation sites of cavities

In this research, different nucleation sites of cavities in the bulk and at grain boundaries are considered and shown in Fig. 1. Fig. 1(a) shows less probable nucleation of a cavity in the bulk while Fig. 1(b) depicts vacancy condensation in a plane transverse to the external stress between two grains. Nucleation in this plane is more probable compared to the other ones displayed in Fig. 1 (c) and (d), because of larger nucleation sites [2]. Fig. 1(c) shows nucleation of a cavity at a triple line of boundaries (a line surrounded by three grains, which is called 3-grains) and Fig. 1(d) shows nucleation of a cavity at a point located in the intersection of four grains, which is called 4-grains. Other nucleation sites of cavities on precipitate's sidewall are also discussed.



(a) (b) (c) (d)

Fig. 1. Different nucleus sites of cavities during creep, (a) in the bulk (b) in a plane between two grains (c) in a line enclosed by three grains (3-grains) and (d) in a point surrounded by four grains (4-grains).

Experimental results

Fig. 2 demonstrates SEM result of creep cavities after 8000 hours at 650°C under 66 MPa tensile stress, which are mostly formed on the pre-austenitic grain boundaries.

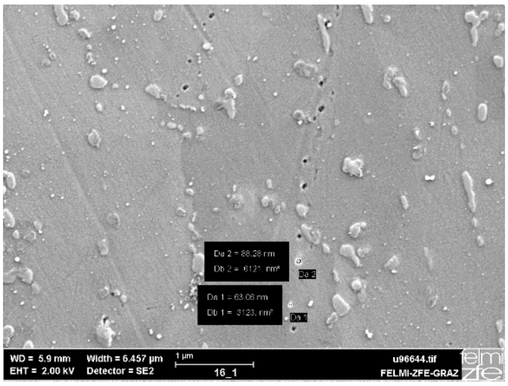


Fig. 2. Microstructure of the steel P91 after 8000 hours at 650°C under 66 MPa tensile stress.

Simulation results

In this work, the well-known model of Becker-Döring [3] is utilised for nucleation of cavities, and the proposed model of Svoboda et al. [4] is applied for the evaluation of cavity growth. Fig. 3 shows simulation results of number density and diameter of the formed pore in the matrix. As it is shown in this figure, the number density of cavities on grain boundaries is higher than 3- or 4- grains and they reach a mean diameter of 0.1 µm after 10,000 h creep.

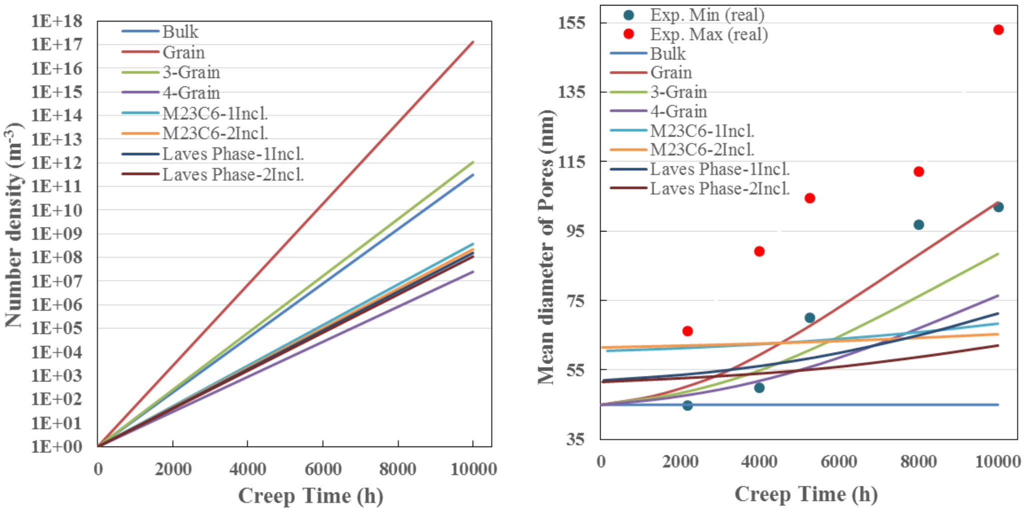


Fig. 3. Simulated results of (a) number density and (b) size of the formed pore in different regions of the crept material such as bulk, grain, 3-grain, 4-grain, $M_{23}C_6$ and Laves phase after 10,000 hours creep at 650°C and under 66 MPa tension.

[1] M.R. Ahmadi, B. Sonderegger, S. D. Yadav, M.C. Poletti, Modelling and simulation of diffusion driven pore formation in martensitic steels during creep, *Materials Science & Engineering A* 712 (2018) 466–477.
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[3] R Becker and W Döring. Kinetische Behandlung der Keimbildung in übersättigten Dämpfern. *Ann. Phys.* (Leipzig) 24, 719-752 (1935).
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