An Investigation of Void Formation on a Bonded Interface of Power Law Creep Materials Containing a Cylindrical Particle

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With 7 Figures

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Summary

Three stress solutions for a cylindrical particle on an interface bonded with two identical materials are obtained by using the pseudo-stress function developed previously. The stress solutions correspond to three different bonding mechanisms of a particle interface: 1) complete bonding of a rigid cylindrical particle, 2) radial bonding of the cylindrical rigid particle, and 3) complete bonding with deformable cylindrical particle in a perfectly viscous material. Using stress analysis results, the steady-state vacancy flux distribution at the interface of two materials (material interface) may be expressed as an in terms of the second derivative of normal stress on the interface with respect to two-dimensional space.

The behavior of a vacancy sink or a vacancy source is found to be dependent on particle size, relative magnitude of material vs. particle properties, and bonding mechanisms, and loading conditions. In the case of the third stress solution, decohesion at the interface may be prevented by controlling a dimensionless parameter $\Theta_1$, which is a function of $\sigma_0^p/\sigma_0$ and the external stress and strain rate hardening exponent, where $\sigma_0^p$ and $\sigma_0$ are associated with the particle and matrix constitutive equation, $\sigma_0^p = \sigma_0 \dot{\varepsilon}^m$ respectively.

1. Introduction

When a material, containing particles in a metal matrix composite, or second phase particles produced through a process, is subjected to stress at high temperature, it deforms plastically with time. It is well known that this damage is caused by void nucleation and coalescence on the grain boundary, or particle interface decohesion between the matrix and particle.

Many investigators have studied void nucleation and void growth rate for one or more particles on a grain boundary. For example, Hull and Rimmer [6] studied growth of microscopic cavities. Raj and Ashby [9] have calculated the rate of nucleation of cavities on grain boundaries, and on second phase particles which are located on grain boundary. Grain boundary diffusion creep
of materials containing particles was investigated by Burton and Beere [1] and Beere [2], who showed that vacancy diffusion can reduce the stress concentration on the particle. Cocks [3] showed that the stress at a particle is a function of its size and increases as the void area fraction increases.

Hirth and Nix [5] found the free energy of vacancy condensation including applied and internal stress by using the classical nucleation theory under locked or unlocked vacancy sink and source environments. Hirth and Nix [5] mentioned that, in the treatment of local stress as an applied stress, the thermodynamic distinction between internal and applied stress has been blurred.

Herring [4] derived that energy potential in the grain boundary is proportional to the normal stress on the grain boundary. Raj and Ashby [9], and Burton and Beere [1], expressed vacancy flux in terms of normal tractional stress on the grain boundary. Raj and Ashby [9] expression is used for a study of void formation or decohesion of the material interface in present paper.

The normal stress on the material interface depends on loading conditions and on the bonding constraints between the matrix and the particle. Void formation and interface decohesion depend on these constraints. These constraints would result to different creep damage mode.

When two materials are bounded by diffusion bonding, for example, foreign particles such as oxides can be introduced during a bonding process. When this bonded material is subjected to an external load and high temperature, debonding can occur in the particle/matrix interface, or in the material/material interface. The structural integrity will be destroyed. The early stage of the damage can be caused by void formation. The location of void formation may be different depending on the particle properties, strength of bonding and stress values in the interfaces.

This paper deals with effects of particle/matrix bonding mechanism on void formation location in the bonded interface of two identical materials (material interface). Three different bonding mechanisms are considered: 1) a rigid cylindrical particle in the material interface is bonded completely with the matrix, 2) the particle in the material interface is bonded radially with matrix, and 3) a deformable cylindrical particle in the material interface is bonded completely with the matrix. The above three cases have three different bonding mechanisms. The flux calculation is performed by finding the second derivatives of the normal stress in the material interface with respect to two dimensional coordinates at the interface. The stress is analyzed by using the pseudo-stress function developed previously by Lee and Smith [8].

Investigations in the paper consist of two parts:

1) Three stress analyses associated with a cylindrical particle on an interface of a power law creep material are performed.

2) Mass flux on the interface is computed, using the second derivative of normal stress with respect to two dimensional space coordinates.