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Increase of stress intensity near interface edge of elastic-creep Bi-material under a sustained load

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Abstract

The transition from small-scale creep to large-scale creep ahead of a crack tip or an interface edge with strong elastic stress singularity at the loading instant causes stress relaxation and the decrease of stress intensity in general. However, this study shows that the stress near the interface edge of bi-material with no or weak elastic stress singularity increases after the loading instant and brings about the stress concentration during the transition. In addition, the creep strain distribution of this bi-material after the loading instant is different from that occurred in the transition of an interface edge with strong elastic stress singularity or a crack tip (notch root). The criterion for the increase or decrease of stress intensity near the interface edge proved by the finite element method is proposed in this study. The stress intensity near the interface edge increases when the elastic stress singularity is lower than the creep stress singularity ($\lambda^{el} < \lambda^{cr}$) and vice versa.

Keywords: Creep; Interface edge; Bi-material interface; Stress intensity; Small-scale creep; Large-scale creep; Stress relaxation; Stress concentration; Stress singularity

1. Introduction

The mechanical behavior of bonded dissimilar materials is of interest in many advanced engineering disciplines including electronics, aerospace and nuclear engineering. The stress usually concentrates near the interface edge between the dissimilar elements due to the deformation mismatch and it is deleterious to the reliability of structures. In actual applications, the bonded dissimilar material sometimes operates at elevated temperatures; hence, the stress field near the interface edge between the dissimilar elements under creep has been concerned.

The stress field near the interface edge of bi-material under creep was originally investigated in the previous paper (Kitamura et al. [1]). We numerically indicated that at an interface edge of silicon/epoxy bi-material

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Nomenclature

A	power law creep coefficient ($\mathrm{MPa}^{-n}\,\mathrm{s}^{-1}$)
E	Young's modulus (MPa)
K^{el}	elastic stress intensity
$\overline{K}_{ij}^{\mathrm{cr}}$	normalized creep stress intensity
n	power law creep exponent
$\bar{t}$	normalized time
W	model width (mm)
$\bar{\varepsilon}_{ij}$	normalized strain
$\bar{\varepsilon}_{ij}^{\mathrm{cr}}$	normalized creep strain
$\dot{\varepsilon}^{*}$	von Mises equivalent strain rate
$\dot{\bar{\varepsilon}}_{ij}$	normalized strain rate
$\lambda_{\mathrm{stress}}^{\mathrm{el}}$	elastic stress singularity
$\lambda_{\mathrm{stress}}^{\mathrm{cr}}$	creep stress singularity
v	Poisson's ratio
σ^{*}	von Mises equivalent stress (MPa)
σ_{g}	gross section stress (MPa)
$\bar{\sigma}_{ij}$	normalized stress

where the strong elastic stress singularity appears at the loading instant, the transition from small-scale creep (SSC) to large-scale creep (LSC) occurs and the stress field near the interface edge under a sustained load has the stress relaxation. It is similar to that occurred in the cracked (notched) body of homogeneous material [2–7] or in the bi-material interface crack analyzed by Biner [8]. Thus, the decrease of the stress intensity is a common phenomenon in creep.

However, for several bi-materials with no or weak elastic stress singularity at the loading instant in which they are widely used in the electronic devices [9], the time-dependent behavior of these bi-materials has not been investigated yet. The strong stress singularity due to creep may appear during the transition and it causes the stress concentration under a sustained load. This suggests the unusual phenomenon that the stress increases under a sustained load and strong stress concentration occurs, if the creep stress singularity is stronger than the elastic stress singularity. In this study, we inquire the unusual phenomenon of bi-material with no or weak elastic stress singularity at the loading instant by finite element simulation and elucidate the fundamental behavior.

2. Simulation procedure

We carried out the creep analysis under plane strain by finite element method (FEM) using a commercial code, ABAQUS 6.5. The two-dimensional analysis model of bonded dissimilar materials and its mesh division are shown in Fig. 1. The interface edge shape of creep and elastic materials is set to 90°–90°. The applied tensile stress of 10 MPa (the gross section stress, σ_{g}) is distributed on the upper boundary. On the right and bottom boundaries of the analysis model, the symmetric condition is assumed. The interface between the elastic and creep materials has a perfectly bonding condition. The model width and length (W_v and W_l) are equal to W (= 10 mm). Though simulations with different ratios of model width to length (W_v/W_l) were also conducted, the results under $W_v/W_l = 1$ will be mainly discussed in the following sections. The finite element model is constructed using eight-node quadrilateral elements. In order to reproduce precisely the stress field, the region near the interface edge where the stress concentrates due to the deformation mismatch is carefully meshed into fine element. The smallest element size near the interface edge is 3×10^{-6} of the model width.

The materials are assumed to be isotropic, and the material properties are listed in Table 1. The stress–strain response of creep material is assumed to obey the power law constitutive equation: