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Influence of microscopically distributed inhomogeneity and anisotropy of grains on high-temperature crack propagation properties of directionally solidified superalloy

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Abstract

The fluctuation of J-integral, during high-temperature fatigue crack propagation, due to the microscopic inclination of crack and elastic anisotropy of each grain, is investigated by means of a series of finite-element-analyses on a cracked body. The simulated material is a nickel-based directionally solidified (DS) superalloy, where the DS axis, load direction, and crack propagation axis are set to be perpendicular to each other. The magnitude of J is estimated using two-dimensional models simulated after an experimental test: (i) with the actual crack shape and grain arrangement, (ii) with the actual crack shape in a homogeneous body, and (iii) with a straight crack in a homogeneous body (averaged deformation behavior of the material). The microscopic inclination of crack propagation direction causes the sporadic drop of J at the point where the crack direction is largely inclined from the direction normal to the load axis. The anisotropy of grains causes the stepwise change in the a (crack length) vs. J relationship. Such changes in J due to the microscopic inhomogeneity directly relates to the change of the crack propagation rate in the transgranular cracking. Then, J, which takes into accounts the anisotropy of grains, correlates well with the crack propagation rate in the transgranular cracking. The grain-boundary cracking possesses fluctuated J, and shows weaker resistance to the propagation than the transgranular one.
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Keywords: Fatigue crack propagation; J integral; Directionally solidified superalloy; Microstructure; Anisotropy

1. Introduction

Since a nickel based superalloy, used for gas turbine blades, presents high yield strength even at high temperatures (around 1150 K), the fatigue crack propagation in a polycrystalline superalloy is governed by the effective stress intensity factor range, ΔK_{eff} [1–3], on a macroscopic scale. ΔK_{eff} is also applicable to the crack

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propagation in a single-crystal superalloy [4–11]. However, some researchers have pointed out that some superalloys have eminent fluctuation on a microscopic scale due to the network of grain boundaries [12–16]. In other words, the grain is one of the strongest influencing factors on crack propagation. Considering a crack in a gas-turbine blade made of directionally solidified superalloy, the main crack size (3–4 mm) is insufficiently larger than that of the elongated grain, which is more than 100 mm on the major and about 0.2–5 mm on the minor axis. In such a case, the inhomogeneity and anisotropy due to the aligned multi-grains may have a characteristic influence on the crack propagation in fatigue. However, little research work has been carried out on the fatigue crack growth behavior of directionally solidified (DS) superalloys from the viewpoint of fracture mechanics [17–19].

In the present paper, the effects of microstructure (the microscopic inclination of crack and the elastic anisotropy of each grain) on the fracture mechanics parameters are investigated by means of an elastic finite element analysis (FEA).

2. Crack propagation experimentally observed in high-temperature fatigue of DS superalloy

In a previous paper [20], the present authors reported the occurrence of typical fluctuation of the high-temperature fatigue crack propagation rate in a directionally solidified superalloy. Here, a γ/γ'-precipitation-strengthened DS superalloy, whose chemical composition is C-0.10, Al-3.03, B-0.02, Co-9.56, Cr-13.93, Mo-1.56, Ta-2.77, Ti-4.90, W-3.86, Zr-0.01, Ni-Bal, in wt%, was machined into a crack-centered-plate specimen (Fig. 1a), and subjected to a load-controlled uni-axial cyclic loading under the temperature of 1143 K. Since the DS axis was set to be perpendicular to the flat section of the specimen, the crack edge was aligned

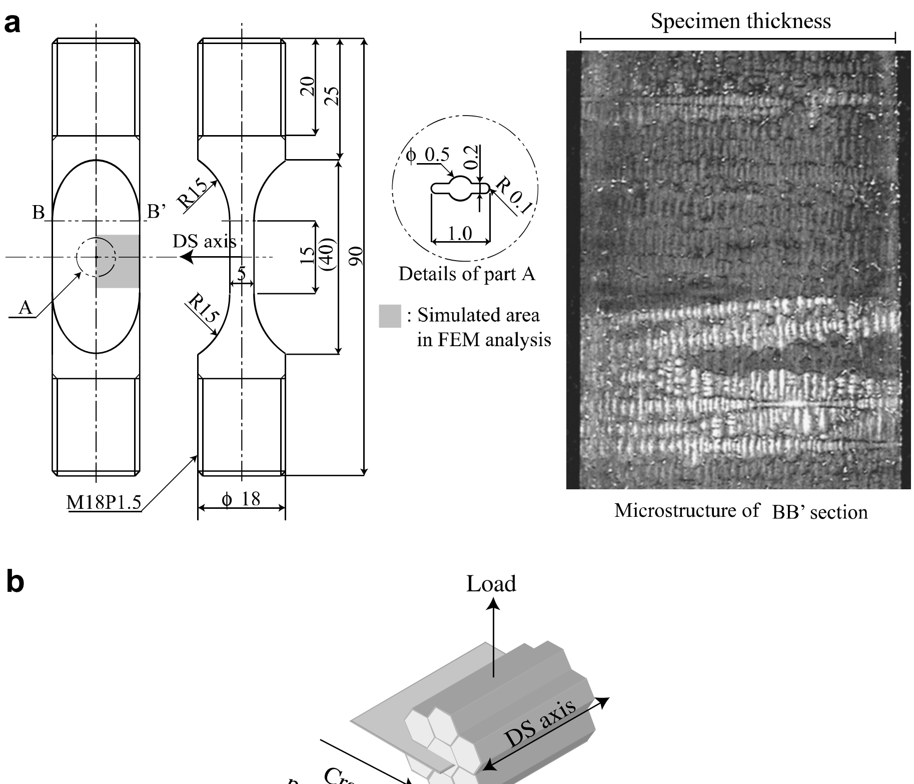

Fig. 1. Geometry of center-cracked plate specimen and relative orientation of grains and crack path: (a) specimen geometry and (b) relative orientation of grains and crack path.

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