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A homogenized primary creep model of nickel-base superalloys and its application to determining micro-mechanistic characteristics

Pengyang Zhao[a,*], Michael J. Mills[a], Yunzhi Wang[a], Stephen R. Niezgoda[a,b]

[a]*Department of Materials Science and Engineering, The Ohio State University, 2041 College Road, Columbus, OH 43210, USA*

[b]*Department of Mechanical and Aerospace Engineering, The Ohio State University, 201 W. 19th Avenue, Columbus, OH 43210, USA*

Abstract

A primary creep model of nickel-base superalloys is developed for the low-temperature-high-stress regime, which provides insight into the active micro-mechanisms, extracted from features of the experimental creep curves. A two-parameter model is established to account for the accumulated primary creep strain, which contains a "threshold stress" representing the possible shear resistance during primary creep. Consideration of this threshold stress leads to a stress exponent n in the order of $3 \sim 4$, in sharp contrast to the conventional analysis that gives an ultra high value of $n > 10$. A general stress-dependence of dislocation velocity is then proposed based on the framework of thermally-activated deformation, which leads to another two-parameter primary creep rate model. Applications to two superalloys demonstrate a good agreement between the model and experimental data. In addition, two micro-mechanistic characteristics of creep, i.e., dislocation drag coefficient and activation volume, can be unambiguously determined from the model parameters. The values of these physical quantities obtained for the two superalloys considered suggest a coupled dislocation motion of glide and climb at the γ/γ' interface as the rate-controlling mechanism during primary creep in superalloys.

Keywords: Dislocation creep; Microstructure; Stress exponent; Dislocation velocity; Dislocation climb.

1. Introduction

At creep conditions, pure metals or simple alloys (e.g., single-phase solid solutions) typically exhibit a well-defined "three-stage" process, i.e., primary, secondary, and tertiary creep. Conversely, the γ'-strengthened superalloys, which have been engineered and commercialized for a wide range of structural applications at elevated temperatures, usually show a short primary creep regime in the first 10-100 hours before transition into a regime of progressively increasing creep rate without a clear distinction between secondary and tertiary creep (Dyson and McLean, 1990). This difference is illustrated in Fig. 1. Mechanistically, the short period of primary creep in Fig. 1a is mainly associated with the development of a stable dislocation substructure and the resulting hardening that decreases the creep rate. Most studies on creep of pure metals or simple alloys have focused on understanding and modeling the secondary stage, usually termed "steady-state creep", where the majority of plastic strain is accumulated before the failure (tertiary creep) sets in. Experimentally, it has been confirmed that for pure metals

*Corresponding Author
Email address: zhao.247@osu.edu (Pengyang Zhao)

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