Accepted Manuscript

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PII: S0142-1123(16)30410-8
DOI: http://dx.doi.org/10.1016/j.ijfatigue.2016.12.003
Reference: JIJF 4154

To appear in: *International Journal of Fatigue*

Received Date: 28 June 2016
Revised Date: 29 November 2016
Accepted Date: 2 December 2016

Please cite this article as: Wilhelm, F., Affeldt, E., Fleischmann, E., Glatzel, U., Hammer, J., Modeling of the deformation behavior of single crystalline Nickel-based superalloys under thermal mechanical loading, *International Journal of Fatigue* (2016), doi: http://dx.doi.org/10.1016/j.ijfatigue.2016.12.003

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Modeling of the deformation behavior of single crystalline Nickel-based superalloys under thermal mechanical loading

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Abstract

The focus of this paper is the simulation of the thermal-mechanical fatigue behavior (TMF) of two single crystalline Nickel-based superalloys in a temperature range between 400°C and 980°C. The newly developed rhenium-free alloy Astra-3OptW and the rhenium-free alloy CMSX-6 are analyzed concerning the basic deformation mechanisms, i.e. elasticity, time-independent and time-dependent plasticity contributing to hardening. In detail, the relevant parameters for high temperature deformation are identified from isothermal creep experiments and used in a numerical model to simulate the deformation behavior under instationary thermal and mechanical loading. Special attention is focused on the determination of the hardening by the second phase (γ´-precipitates) and their influence on time-dependent deformation and relaxation mechanisms. Therefore, the parameters describing the stress and temperature dependence of the creep rate (i.e. stress exponent n and activation energy Q) are interpreted in terms of a threshold stress taking into account the hardening contribution of the γ´-phase. Thus, only a reduced effective stress is active for plastic deformation. Particular attention is focused on the accurate determination of the threshold stress as a function of temperature and applied stress from the Langeborg-Bergmann-plot. The comparison of the simulated TMF-deformation to the experimental TMF-data clearly indicates the accuracy of the model in predicting the resulting stresses induced by instationary thermal and mechanical loading.

Keywords:

Single crystalline Nickel-based superalloys, Thermal-mechanical fatigue, Threshold stress concept, Modeling, Creep, Plasticity.

1. Introduction

Single crystalline Nickel-based superalloys have been used for turbine blades in gas turbines, first in the aerospace industry and later in the power industry for over 30 years [1]. The outstanding high-temperature properties of these materials are attributed to solid solution strengthening and, above all, to the cubic γ'-phase which is coherently precipitated in the matrix γ. To improve the high temperature-strength of the matrix Rhenium was added and the alloying content was continuously increased up to 6wt.-% [2]. However, due to the dramatic

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