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LOW CYCLE FATIGUE AND ANALYSIS OF THE CYCLIC STRESS-STRAIN RESPONSE IN SUPERALLOY INCONEL 738LC

J. Tobiáš[*], A. Chlupová[**], M. Petrenec[***], J. Polák[****]

Abstract: *The paper describes the results of fatigue behavior study on cast polycrystalline nickel based superalloy tested at 23 and 800 °C. Cylindrical specimens of Inconel 738LC were cyclically strained under total strain control to fracture and multiple step tests were performed to study the effect of temperature on the internal and effective cyclic stress components. Fatigue life curves were approximated by the Basquin law. The resulting curves were shifted to lower fatigue lives with increasing temperature. The evolution of the effective and internal stress components and effective elastic modules were derived from the hysteresis loops which were analyzed according to the statistical theory of hysteresis loop. Cyclic stress-strain response at both temperatures and the changes of internal and effective stress components were discussed in relation to microstructural parameters of the superalloy.*

Keywords: ***Low cycle fatigue, Inconel 738LC, hardening/softening curves, cyclic stress-strain curve, fatigue life curve.***

1. Introduction

Nickel based superalloy Inconel 738 LC is precipitation strengthened to achieve excellent high temperature strength and hot corrosion resistance. This material is widely used for production of structural parts such as blades and disks for gas turbine engines subjected to repeated elastic-plastic straining in a wide range of temperatures (Donachie, 2002). In a design for high temperature applications the thorough knowledge of fatigue behaviour of IN 738 LC is crucial. The hardening and softening behaviour as well as the cyclic stress-strain curves were studied at temperatures 23 and 900°C (Jianting, 1983, Jianting et al. 1983, Wahi et al. 1997).

The aim of the present work is to describe results obtained in the study of low cycle fatigue behaviour of material IN 738 LC having chemical composition 16.22Cr, 8.78Co, 2.63W, 1.71Mo, 1.77Ta, 3.37Ti, 3.35Al, 0.84Nb, 0.2Fe, 0.1C, 0.04Zr, 0.008B, the rest Ni (wt. %). Microstructure of the material is dendritic and consists of large γ grains having average size about 3 mm and 59% of γ′ precipitates with near-cuboidal shape and average diameter of 670 nm. Specimens with diameter 15mm and gauge length 6mm were fatigued in electrohydraulic testing machine MTS 880 in regime of strain control, strain rate was $2 \times 10^{-3} s^{-1}$ and loading was fully reversed. Analysis of the hysteresis loop shape allows determining and splitting total cyclic stress in two components: effective and internal stress (Polák 1991). Therefore the stress-strain history was recorded, the first and the second derivatives of the hysteresis half-loops were determined. The second derivative of the hysteresis half-loop contains information about the effective stress and the probability density distribution of the critical internal stresses (2x Polák et al. 2001). Effect of temperature on the internal and effective cyclic stress components in repeated loading performed in total strain control was studied in air at two temperatures: 23°C and 800°C.

2. Results and discussion

Cyclic hardening/softening curves were analysed. At room temperature: the saturation for low levels of strain amplitude was observed, for middle amplitudes the initial hardening is followed by the slow softening and the secondary hardening and for high amplitudes the continuous hardening becomes

[*] Ing. Jiří Tobiáš: IPM, AS CR, Žižkova 22; 616 62, Brno; CZ, e-mail: tobias@ipm.cz
[**] Ing. Alice Chlupová, Ph.D.: IPM, AS CR, Žižkova 22; 616 62, Brno; CZ, e-mail: prasil@ipm.cz
[***] Ing. Martin Petrenec, Ph.D.: CEITEC IPM, AS CR, Žižkova 22; 616 62, Brno; CZ, e-mail: petrenec@ipm.cz
[****] Prof. RNDr. Jaroslav Polák, DrSc., dr.h.c.: CEITEC IPM, AS CR, Žižkova 22; 616 62, Brno; CZ, e-mail: polak@ipm.cz

more pronounced. At elevated temperature (800°C): for low levels of applied strain amplitude the behaviour is saturated, nevertheless for high strain amplitudes initial hardening and later slow and weak softening up to the end of the fatigue life can be seen.

The cyclic stress-strain curve (CSSCs) and fatigue life curve in the form of Basquin curve exhibits strong temperature dependence.

Analysis of saturated hysteresis half-loops according to the statistical theory of hysteresis loop allowed the estimation of contribution of effective stress and of the distribution of the critical internal stresses at both temperatures.

The first and the second derivatives of tensile parts of hysteresis loops for two temperatures (23°C and 800°C) and their evolution with the number of cycles were followed. The initial drop of the second derivative corresponds to the relaxation of the plastic strain under decreasing effective stress. The first minimum corresponds to effective modulus E_{eff}.

Two peaks of the second derivative are characteristic for a two-phase alloy and correspond to the subsequent plastic deformation of γ and γ′ phases within a cycle and approximate the probability density function of the critical internal stresses of both components. The analysis of the hysteresis loop shape obtained in room temperature cycling reveals only poorly defined first maximum. This first peak is more pronounced for elevated temperature. The second peak is well developed for both temperatures and its position at room temperature changes with increasing number of applied cycles, i.e. it is moving to higher fictive stresses, which corresponds to the cyclic hardening. It is in agreement with cyclic hardening/softening curves.

The effective stress in γ and γ′ phases was found precisely enough only in cycling at 800°C. The effective stress in γ′ phase is high which is in agreement with the difficult movement of dislocations in an ordered structure. Approximate estimation at the room temperature shows that this quantity is nearly temperature independent.

The effective stress of the γ phase is low but increased when the cycling temperature increased to 800 °C. This can be the result of continuous annihilation of dislocations at elevated temperature and resulting in a drop of dislocation density. In order to achieve the same strain rate the dislocation velocity is high and thus the effective stress increases.

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