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Accumulation and mechanism of the fatigue damage for a nickel based superalloy

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Abstract

The fatigue damage accumulation investigations were performed for high and low cycle fatigue loading regime for the nickel based superalloy frequently used in the aviation industry. Definition of the damage parameter proposed by Johnson in [2], modified to be applicable for cyclic loading, was used to quantify damage. In the modified definition, the accumulated equivalent plastic strain was used as the damage indicator instead of axial strain. Analysis of the variations of hysteresis loop allowed to plot damage indicator as the function of load cycle number and finally to plot damage parameter as the function of the life ratio. This kind of plot, known as the Damage Curve, enables identification of the fatigue damage accumulation model appropriate for the investigated material and applied loading regime. Fractography and structural observations performed on damaged specimens allowed to identify damage mechanism for the alloy in question.

Keywords: superalloys; plastic deformation; damage parameter; fatigue.

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1. Introduction

For elastic-plastic materials like metal alloys, at the initial stage of the process, damage of structure of the material is run by plastic deformation. This statement is valid for all schemes and sequences of loading, including monotonic and cyclic loading under simple or complex stress states. Most of damage parameters related with microstructure quantification, like for example dislocation density or shear band spacing are linked to accumulated plastic, as mentioned in a review paper [1]. For a monotonic loading a simple model was proposed by Johnson in [2] to quantify damage for the uniaxial tension. A definition of damage parameter for the sequence of tensile deformations was:

$$\boldsymbol{D} = \sum \frac{\Delta\boldsymbol{\varepsilon}}{\boldsymbol{\varepsilon_f}}, \tag{1}$$

where $\Delta\varepsilon$ stands for the increment of axial plastic strain and ε_f is an accumulated axial plastic strain corresponding to material failure, which can be assumed as constant for the particular loading scheme.

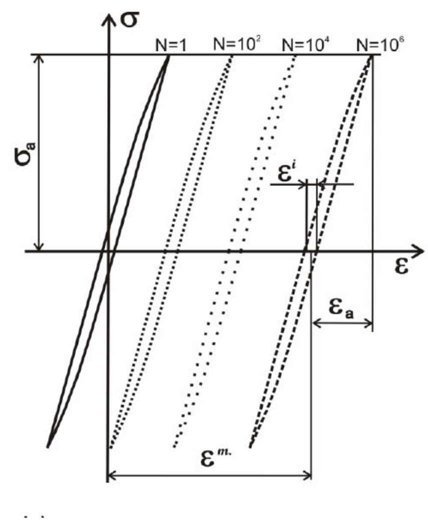

Fig. 1. A Scheme of hysteresis loop for cyclic loading.

This definition can be easily extended to quantify damage in the case of the stress-controlled uniaxial tensile-compressive cyclic loading, which is a typical scheme for laboratory fatigue testing routine. A plot of the hysteresis loop for this kind of loading scheme is shown in Fig. 1. To calculate accumulated plastic strain, one has to use the following definition [3]:

$$\sum_{n=1}^{n} \Delta\boldsymbol{\varepsilon} = \sum_{n=1}^{n} \left[2\left|\boldsymbol{\varepsilon}_n^i\right| + \left|\boldsymbol{\varepsilon}_n^m - \boldsymbol{\varepsilon}_{n-1}^m\right| \right], \tag{2}$$

where n stands for the number of the load cycle, ε^i denotes inelastic response (width of the hysteresis loop) and ε^m denotes a ratcheting strain.