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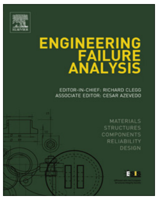

Damage accumulation modeling under uniaxial low cycle fatigue at elevated temperatures

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ABSTRACT

The paper presents a fatigue damage accumulation model, which allows us to predict fatigue life under low cycle uniaxial loadings at elevated temperatures. The structure of the model has been based on the stress–strain curves obtained during the experimental study. The model has been verified experimentally by applying experimental studies carried out on ENAW-2024T3 aluminum alloy and 2Cr–2WVTa steel. Moreover, a comparison between the results of fatigue life prediction using the proposed damage accumulation model was done with the results obtained on the basis of various generally applied models, based on the Manson–Coffin dependency. Furthermore this paper presents the results of experimental studies carried out on the aluminum alloy ENAW 2024 T3 under uniaxial low cycle fatigue loadings in the conditions of elevated temperatures. In the course of the study, material constants and the parameters of the stress–strain curve in the range of low cycle fatigue for four levels of temperatures (20, 100, 200 and 300 °C) were set.

1. Introduction

The process of fatigue damage accumulation modeling appears more complicated in the case when construction elements are utilized at elevated temperatures. Mechanical constructions are frequently subject to external loadings connected with the influence of elevated temperatures. Under such work conditions, the mechanical properties of the material undergo changes. Numerous scientists presuppose that the construction material, which has been exposed to elevated temperatures should not be regarded as the same material as it was at room temperature. It should be noted that such material undergoes certain physical–chemical changes, the structure of the material becomes rearranged: its crystal structure changes leaving a constant chemical composition. As a result, this approach can be used known from the literature strength and fatigue models and dependences, taking them material constants determined experimentally for the considered temperature [1–8].

Such approach causes that the fatigue damage accumulation criteria formulated for the ambient temperature can be spread onto elevated temperature conditions by introducing material constants determined for the analysed temperature scopes. It involves carrying out experimental studies, which will allow to determine characteristics of various materials at room temperature.

Attempts are made, therefore, to adopt the existing fatigue damage accumulation criteria, formulated with the purpose of fatigue life prediction for steel and aluminum alloys at ambient temperature in mind, to fatigue life prediction of a material at elevated temperatures. An example of this base criterion is the Manson [9] and Coffin [10,11] equation, with subsequent

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Nomenclature

A	material constants
B	material constants
b	exponent of the elastic fatigue life curve
c	exponent of the plastic fatigue life curve
E, ν	Young modulus and Poisson ratio
N_f	number of cycles to failure
σ'_f	coefficient of the elastic fatigue life curve
ε_{eq}	equivalent strain
ε_a	amplitude of total strain
ε_a^e	amplitude of elastic strain
ε_a^p	amplitude of plastic strain
ε'_f	coefficient of the plastic fatigue life curve
T	temperature
T_m	recrystallization temperature of material

modifications by Morrow. This criterion has a widespread practical application in conditions of low-cycle fatigue loads at room temperature. It forms the basis for the formulation of damage accumulation models in complex loading conditions. Written with the use of the equivalent range (in the Huber–von Mises sense), strain $\Delta\varepsilon_{eq}$ has the following form:

$$\frac{\Delta\varepsilon_{eq}}{2} = \frac{\sigma'_f}{E}(2N_f)^b + \varepsilon'_f(2N_f)^c, \tag{1}$$

where N_f is the number of cycles to sample's failure, E is Young's modulus. σ'_f, b denote coefficient and exponent of the elastic fatigue life curve respectively, ε'_f, c are coefficient and exponent of the plastic fatigue life curve.

Experimental studies regarding damage accumulation and cracking of metal alloys, especially at elevated temperatures, have both cognitive as well as practical values [7,13,14]. They are the basis of formulating computational models of fatigue life as well as the understanding of the material fatigue processes. The obtained characteristics of construction materials fatigue have a great practical importance, especially in the reliability and safety analysis of the construction [2–4,7,12,15–19]. The aforementioned studies are expensive and require advanced laboratory equipment, thus the number of experimental data of fatigue life at elevated temperatures available in the literature is insufficient in order to develop and modify computational dependencies. Therefore, there is a justified need to set the characteristics describing the fatigue damage accumulation process for new materials.

The aluminum alloy used for verification of proposed damage accumulation model is used to production of machine parts, mechanisms and equipment in the airplane industry. Due to a high durability in relation to mass, the alloy is used in the components that are exposed to high loads. Moreover, the material can operate, within some limits, in elevated temperatures without losing its strength properties. Such properties allow the alloy to be used in the production of elements that operate in the close vicinity of airplane engines where temperature is elevated. The literature available provides experimental data for EN AW 2024 T3 aluminum alloy. The data has been obtained from the study of rolled plate specimen. There is no detailed data for the rolled bar specimen, especially in the case of fatigue loading states.

2. Experimental studies of fatigue life of en AW-2024 T3 aluminum alloy under low-cycle loadings in elevated temperature

The range of the cyclic test was establishing the influence of elevated temperature on the mechanical properties of aluminum alloy EN AW-2024 T3. The study used rolled specimen of Ø 6.5 mm measuring diameter with the measuring gauge base of 25 mm and made with machining method. The specimen was heated up to the given temperature in the MAYTEC three-zone resistance furnace and after the temperature was levelled the specimen was loaded by uniaxial tension in the MTS 858 MiniBionix strength-testing machine. The constant heating speeds of 2; 3; 4 K/min were implemented depending on a given temperature. During the heating the specimen could freely deform as the result of temperature rise. After reaching the given temperature levels the process of kinematic loading of specimen was commenced. The following temperatures were used: 20, 100, 200, 300 °C. At each temperature, before the loading process, the specimen was being heated for 10 min in order to level the temperature on the whole specimen volume. The temperature difference between the temperature setting and the target temperature in the measuring part of the specimen was ±2 °C. The measurement was taken with 3 Type K thermocouples. Fig. 1 present the test stand used during the experiment.

The process of sample loading and displacement registration that occurred during the cyclic strain was controlled with a high-temperature biaxial dynamic extensometer Epsilon 3550HT-025M-005-005 of 25 mm measuring base. The tests examined low-cycle loadings, except for high volume plastic strains and necking effect.