EFFECT OF PRIOR PLASTIC DEFORMATION AND CREEP STRAIN ON FATIGUE DAMAGE FOR A HIGH-TEMPERATURE ALLOY

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A procedure is developed, an experimental study is provided, and a comparative evaluation is given for the effect of prior plastic deformation and creep strain on fatigue damage for high-temperature metallic materials on the example of alloy EI827. A different effect is demonstrated for prior plastic deformation and creep strain on fatigue damage of this alloy at 1073 K. In the case of prior creep a marked difference is established from the hypothesis of linear summation for damage in the direction of weakening during evaluation of the overall fatigue and static damage both in the form of relative endurance and relative strain.

During operation many critical components of modern power machinery are subject to transient force loading characterized by the alternate action of static and cyclic strains. There has been considerable research into this subject and a number of important features have been established. In particular the effect of prior plastic strain on low-cycle fatigue [1, 2], on endurance with multicycle loading [3-6], on fatigue crack generation and growth [7-9], and on cyclic crack resistance [10-12] has been studied. In this work there is an experimental study of the effect of prior plastic deformation and creep strain on fatigue damage.

The overwhelming majority of research carried out recently is connected with evaluating the effect of prior plastic strain on mechanical behavior. This is mainly due to the possibility of developing strengthening technology on this basis. However the effects which are obtained are not entirely clear. It is established that prior plastic deformation may cause both strengthening and weakening effects in subsequent material reaction under cyclic loading conditions. This reaction depends on the class of material, heat treatment schedule, the level and nature of prior plastic deformation, the form of subsequent loading, and the nature of the test procedure.

An increase in the fatigue characteristic is mainly connected with small plastic deformation whereas with large strains strengthening is replaced by weakening caused by the occurrence of microplastic failure [3, 4]. It is also established that prior surface [8] and bulk [9] plastic deformation increases the resistance of structural steels to fatigue crack generation. However, crack growth rate depends on the material reaction to cyclic loading. In cyclically strengthening materials crack growth rate (CGR) is reduced, but in cyclically weakening materials it increases [10, 11]. In the case of titanium alloys prior plastic deformation does not generally affect the threshold value of the stress intensity factor or CGR [12].

There are almost no similar studies for evaluating the effect of prior creep strain on subsequent material resistance to multicycle fatigue failure. These questions arise in evaluating the endurance of structural elements operating both under conditions of high temperature and prepared by strengthening technology in a creep regime.

A procedure is suggested in the present work, an experimental study is carried out, and there is comparative evaluation of the effect of prior plastic deformation and creep strain on fatigue damage for high-temperature materials on the example of alloy EI827.

Study Procedure. The test object was high-temperature nickel alloy EI827 used in power machinery construction for preparing turbine rotor blades. Smooth specimens of round section with a gage length diameter \( d_g = 6.0 \text{ mm} \) and gage length \( l_g = 5 \times d_g \) were tested. Blanks for specimens cut from bar 25 mm in diameter were heat treated by the standard technology. Testing was performed at 1073 K which is the operating temperature for the alloy in question.
The values chosen for prior plastic deformation were prescribed from the tensile curve $P - \Delta l$ converted taking account of test specimen dimensions into the stress curve $\sigma - \varepsilon$ (Fig. 1a). With tension for a specimen levels of relative plastic deformation were plotted on the paper of a two-coordinate self-recorder type PDS along the abscissa axis with a zero load corresponding to carriage movement. Lines were drawn through the points obtained parallel to the linear section of the tensile curve. Corresponding values of plastic deformation were prescribed with specimen tension up to intersection of the curve with the constant linear section. The static deformation rate was within the limits $0.25 \cdot 10^{-3} - 0.5 \cdot 10^{-3}$ sec$^{-1}$ and the deviation of prior residual strain from that prescribed did not exceed $\pm 0.03\%$. Shown in Fig. 2a as an example is the stress curve for alloy EI827 at 1073 K and the level of prior plastic deformation $\varepsilon_p = 0.25$ and 0.5%.

Prior creep strain $\varepsilon_c$ was prescribed with tensile testing under constant stress conditions (Fig. 1b). The level of stresses was chosen taking account of the time for reaching with prescribed strain the start of the accelerated creep stage when damage processes are intensified. Given in Fig. 2b are creep curves with stress $\sigma_m = 450$ MPa up to accumulation of the prescribed prior strain. Also shown are creep curves for specimens taken up to failure and used as basic curves.

Values of residual cyclic endurance, curves for the growth of fatigue cracks for damaged specimens, and partial measurements of damage of the Palmgren–Miner type were chosen as a measure of fatigue damage. In this case partial measurements of damage due to the action of prior plastic deformation may be prescribed in the form

$$\omega_p = \varepsilon_p / \varepsilon_{\tau},$$

where $\varepsilon_p$ is plastic deformation; $\varepsilon_{\tau}$ is plastic deformation corresponding to ultimate strength $\sigma_{\tau}$. 