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ANALYSIS OF FATIGUE CRACK INITIATION CAUSED BY CYCLIC MICROPLASTICITY

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The present work is devoted to simulation of fatigue crack initiation in materials subjected to cyclic loading within the nominal elastic regimes. The stress and strain states $\sigma(x)$, $\varepsilon(x)$ in material elements are respectively composed of mean values $\bar{\sigma}(x)$, $\bar{\varepsilon}(x)$ and fluctuations $\tilde{\sigma}(x)$, $\tilde{\varepsilon}(x)$, thus $\sigma(x) = \bar{\sigma}(x) + \tilde{\sigma}(x)$, $\varepsilon(x) = \bar{\varepsilon}(x) + \tilde{\varepsilon}(x)$. When a polycrystalline metal or alloy element is subjected to mechanical loading inducing uniform mean stress and strain states, the fluctuation fields develop due to material inhomogeneity related to grain anisotropy and inhomogeneity, and at the nano-scale due to atomic interactions activating dislocation motion. The plastic yielding develops at the low mean stress level in some grains due to local strain concentrations at their boundaries. These stress fluctuations, developing at a fraction of the macroscopic elastic limit, are the source of initial structural defects and microscopic plastic mechanisms controlling the evolution of defect ensemble toward the state of advanced yielding. The mechanism responsible for damage accumulation during cyclic loading below the yield point remains elusive and requires classification. The purpose of this work is to provide experimental and analytical description of stress and strain fluctuations and incorporate them into the fatigue criteria based on the local stress values. The analysis is also aimed at development of consistent description of the microplastic state of material [1].

Using the potential offered by the novel experimental techniques, it is possible to identify physical phenomena and to describe the mechanisms of degradation and fatigue damage development in modern structural materials. The analysis of the stress and strain localization preceding crack initiation is performed by means of the optical method ESPI (Electronic Speckle Pattern Interferometry), apparatus using the coherent laser light. The nano-indentation method is used to estimate local mechanical properties.

The new proposed concept of constitutive modelling of crack initiation mechanisms assumes that damage occurs due to action of mean stress and its fluctuations induced by crystalline grain inhomogeneity and free boundary effect [2]. Results of the numerical analyses are correlated with the experiments in order to identify the parameters of the constitutive model, and to demonstrate its validity. The microindentation and ESPI measurement parameters provide the input for metal parameter calibration. The unique feature of the proposed damage model is based on physical micromechanics. The constitutive model takes into account the relations between parameters and state functions at micro-, meso- and macro-scopic levels.

References

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