ANALYSIS OF FATIGUE CRACK INITIATION CAUSED BY CYCLIC MICROPLASTICITY

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The present paper concerns the fatigue crack initiation and evolution for metals subjected to loading at stress level below the conventional yield stress. The stress-strain curve exhibiting the hysteresis loops obtained during selected cycles with different stress amplitudes σ_{ai} below the yield stress σ_y highlighting the regime of micro-plasticity are presented in Fig. 1.

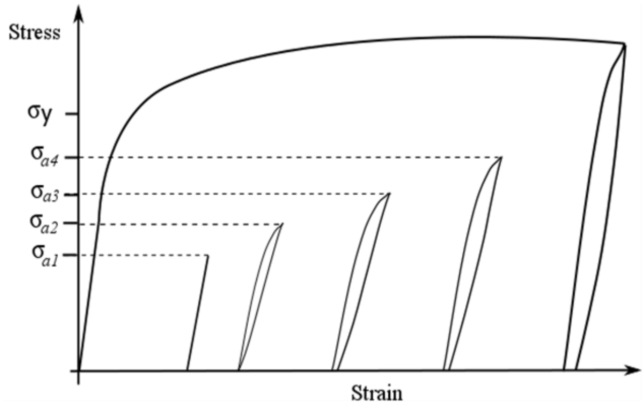

Fig. 1. Schematic stress-strain curve and the hysteresis loops showing the regime of micro-plasticity

The usual approach is based on averaged stress or strain amplitudes, with numerous fatigue conditions formulated for uniaxial or multiaxial stress states. However, the process of fatigue damage growth is of local nature and the account for stress fluctuations should be included [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 [2]. In the present work the analysis of strain localization preceding crack initiation was performed by means of the optical method ESPI, namely the Electronic Speckle Pattern Interferometry apparatus using the coherent laser light (Fig.2).

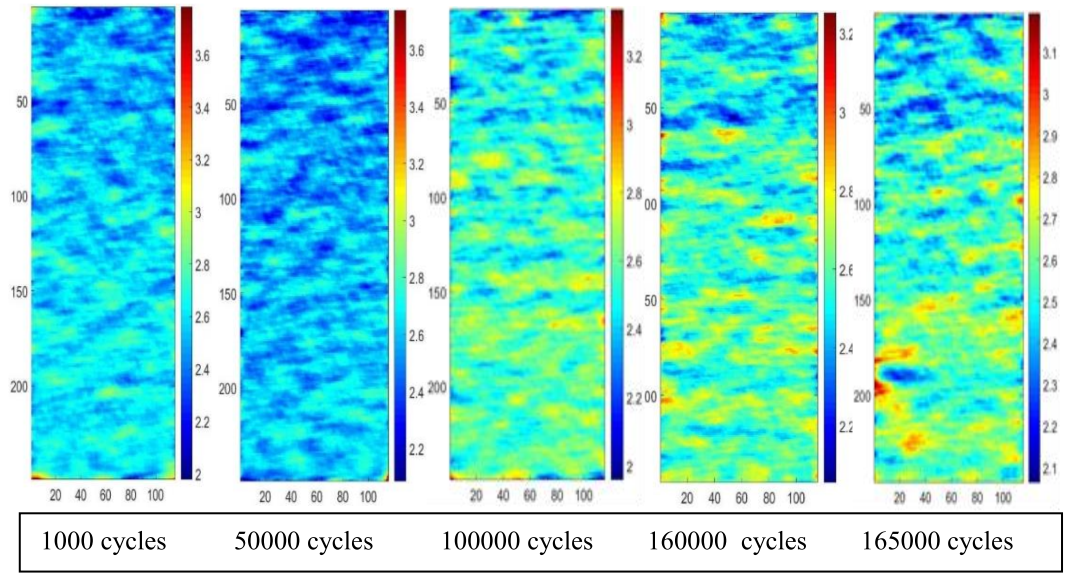

Fig. 2. Strain distribution maps on the plane specimen surface using ESPI for different stages of the fatigue process

The local stress-strain response in damage zones is analyzed by applying nano-indentation tests. The microindentation tests is a well established tool that enable to estimate local mechanical properties of macro-samples [3]. The load penetration curves are presented in Fig. 3.

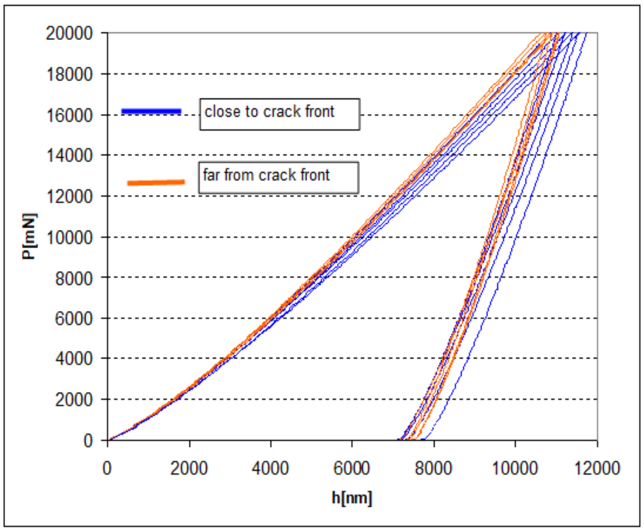

Fig. 3. Micro-indentation diagram close and distant to the crack front

It has been observed that the inclination of unloading curves far from crack front is lower than that measured close to the front end however, the residual penetration depth is practically the same. On can conclude that the elastic modulus is 10-12% lower in the regions of strain localization, while the hardness, that is a measure of plastic properties is practically the same in all regions. The micro tomographic analysis provides more detailed characterization of the damage state.

The mathematical model is formulated and applied to study damage evolution under cyclic tension. The proposed mathematical description of fatigue damage growth and crack initiation is based on the concept of critical plane. The condition of damage accumulation is formulated after Mróz et al., [4]

$$dD = A\left(\frac{\sigma_n - \sigma_0^*}{\sigma_c - \sigma_0}\right)^n \frac{d\sigma_n}{\sigma_c^* - \sigma_0^*} \tag{1}$$

The damage growth on the material plane is related to evolution of surface tractions. It is assumed that, when the critical stress condition is achieved on the material plane, a damage zone is generated. Afterwards, a growth of damage zone can be described. In the steady state the process of cyclic loading is described for the period of stress variation. It was noted that the local stress fluctuations occur at grain boundaries and on structure boundary components and their influence on the damage evolution and crack initiation is significant. The functions describing the grain and boundary fluctuations are proposed. The proposed model was applied to study damage evolution under cyclic tension, with its parameters calibrated by the experimental data.

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References

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