Localized plasticity and Crack Initiation during Very High Cycle Fatigue of Engineering Alloys

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Most applications in transport, power generation and mechanical engineering imply cyclic loading up to very high numbers of cycles, e.g. high speed trains with 1 billion wheel revolutions. Fatigue-life assessment for such applications is usually based on Wöhler diagrams and/or the fatigue limit concept. Here, the evolution of fatigue damage is not considered in an explicit way; it is believed that in the HCF and VHCF regime the occurrence of local plastic deformation is blocked by grain and phase boundaries or by work hardening. However, detailed studies on VHCF-loaded specimens of duplex steel, tempered steel and cast aluminum alloys have revealed that even after 10^8 cycles plasticity causes surface modifications in form of pronounced slip bands that are extending with an increasing number of cycles. By means of scanning electron microscopy (SEM) in combination with electron back-scatter diffraction (EBSD) and atomic force microscopy (AFM) being applied after certain intervals during fatigue loading of the specimens, the appearance of the slip bands was correlated with the crystallographic misorientation distribution and the phase arrangement within the microstructure. In the case of austenitic-ferritic duplex steel, plastic deformation of the austenite is present for all stress amplitudes of technical relevance, manifesting itself by the generation of heat. The existence of a fatigue limit in engineering alloys is believed to depend quantitatively on (i) the efficiency of microstructural barriers (e.g., grain and phase boundaries or hardening phases), and (ii) the free slip length within the soft phase patches. The experimental observations have been served as input for the development of short crack modelling concepts using both a finite-element and a boundary-element approach, which are outlined and discussed in the present paper.