Study of deformation microstructure and corresponding surface relief in high alloyed austenitic steel Sanicro 25 after low cycle fatigue

Milan Heczko[1], Veronika Mazánová[1] and Jaroslav Polák[2]

[1.] Institute of Physics of Materials ASCR, Žižkova 22, Brno, Czech Republic
[2.] CEITEC, Institute of Physics of Materials ASCR, Žižkova 22, Brno, Czech Republic

Introduction. The fatigue damage of material produced by cyclic loading is closely related to the deformation microstructure, in particular to internal dislocation configuration and its evolution. Within the process, localized bands of cyclic plastic deformation with a specific substructure called persistent slip bands (PSBs) arise and lead to the development of a characteristic surface relief in the form of persistent slip markings (PSMs) and subsequently to the initiation of fatigue cracks [1, 2]. In order to understand the cyclic stress-strain response as well as the fatigue crack initiation and to be able to perform its modelling, it is essential to study microstructural aspects.

Experiment. Polycrystalline high alloyed heat resistant austenitic steel Sanicro 25 was tested. Cylindrical specimens with the shallow notch were subjected to symmetric strain-controlled cyclic loading with constant strain rate in a wide interval of constant total strain amplitudes both at room and at elevated temperatures. The microstructure and spatial arrangement of dislocations in the bulk of the grains was determined using the technique of oriented foils. The specimen surface was investigated by scanning electron microscope Tescan LYRA 3 XMU FEG equipped with focused ion beam (FIB). The profiles of persistent slip markings (PSMs) developed on the surface were observed and documented simultaneously with the underlying dislocation structure by use of the technique of oriented TEM surface lamella produced by FIB. Thin foils were observed in JEOL-2100F TEM using S/TEM diffraction contrast. Burgers vector, character and orientation of dislocations were determined.

Results and summary. At room temperature cycling, strong planarity of dislocation slip prevails. Cyclic plastic deformation is localized into parallel high dislocation density bands separated by almost dislocation free areas (Fig. 1). This plastic strain localization leads to cyclic softening subsequently followed by saturation. High temperature cyclic straining is completely different. At all strain amplitudes, material shows extraordinary cyclic hardening. Cross-slip effects are enhanced at elevated temperature and as a consequence high density homogeneous dislocation distribution is found. Moreover, HRTEM observations revealed the presence of nanoparticles which act as obstacles for dislocation movement (Fig. 2). Along with high dislocation density distribution, they contribute to significant cyclic hardening of material. PSBs in the pure materials as copper have the well-developed ladder-like structure. In the case of structural materials the structure of the alternating dislocation rich and poor areas arranged parallel with the primary slip plane can be observed as well (Fig. 3). PSBs emerge as PSMs on the specimen surface. They consist of extrusion/s and one or more parallel sharp intrusions (Fig. 3). The intrusions can be formed on both sides of the extrusion. The shape of the PSMs and crack initiation sites in the case of the structural materials is more complicated in comparison with pure metals. However, intrusions represent crack-like defects in both cases. It was observed that cracks initiate from the deepest section of intrusions and grow in the primary slip plane, presumably by slip-unslip mechanism [3]. Analysis of experimental results revealed better agreement with Polák's model of fatigue crack initiation [1] than with the earlier EGM model [2].

References:

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[3] J Polák *et al*., Metall. Mater. Trans. A **47** (2016), p. 1907.

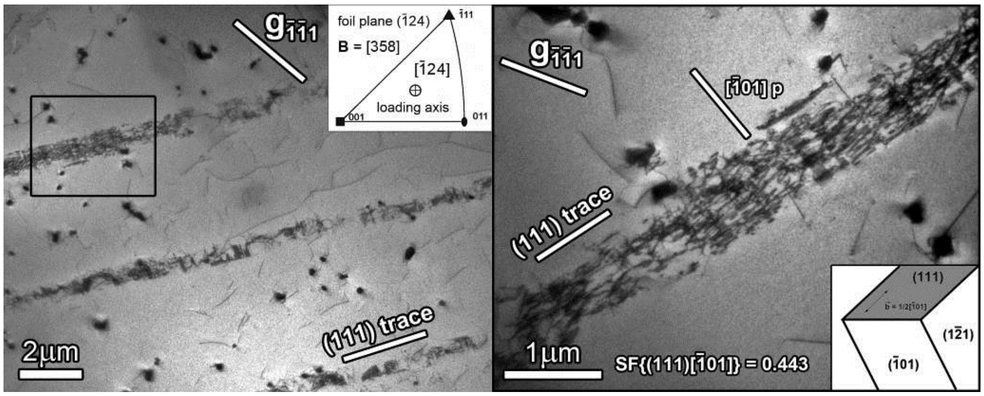

Figure 1. Planar dislocation structure consisting of dislocation rich bands where dislocation rich walls and dislocation poor channels alternate. Mostly edge segments of primary dislocations with Burgers vector $1/2[1\bar{0}1]$ are visible.

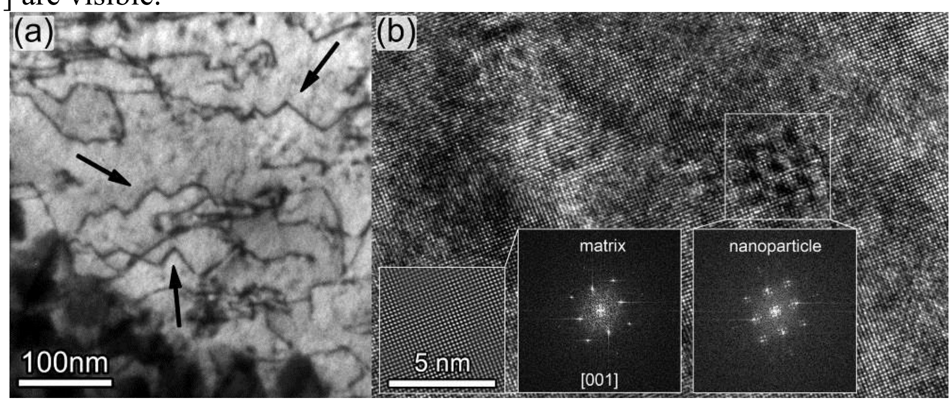

Figure 2. (a) Dislocations pinned by small hardly visible microstructural units. (b) HR-TEM image of nanoparticle in FCC matrix. Comparison of FFT made from the matrix and particle area indicates coherency of the nanoparticle and the matrix. Electron beam direction B = [001].

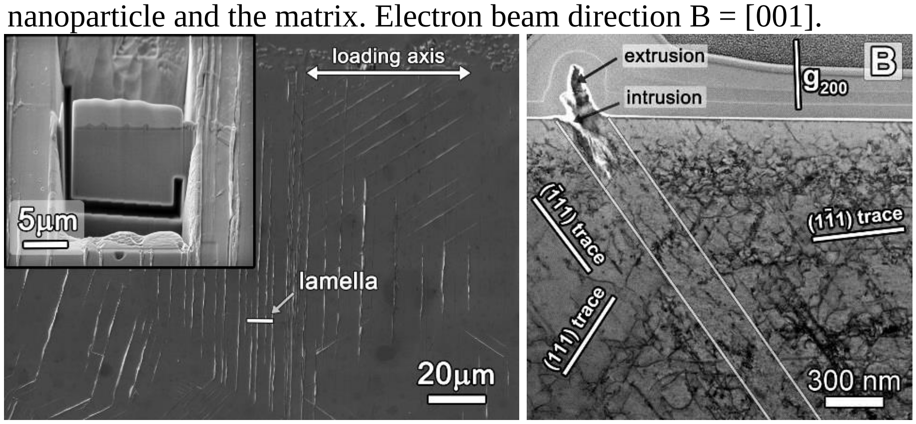

Figure 3. PSBs and the position of the lamella within the grain. On the right is an image of the PSM B consisting of extrusion and intrusion and a crack starting from the intrusion. Dislocation arrangement in the PSB is ladder-like.