Fatigue Testing of Ni-based Superalloys for Gas Turbine Blades

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SFB/Transregio 103
SUPERALLOY SINGLE CRYSTALS

Research Objectives

Characterizing the influence of microstructural features on elementary fatigue mechanisms under high temperature fatigue for single crystal (SX) superalloys

Experimental

Miniature specimens and test fixture are developed for Low Cycle Fatigue (LCF) testing at high temperatures. Miniaturization allows preparing of specimens with different crystallographic orientations from cast slabs (Fig. 1).

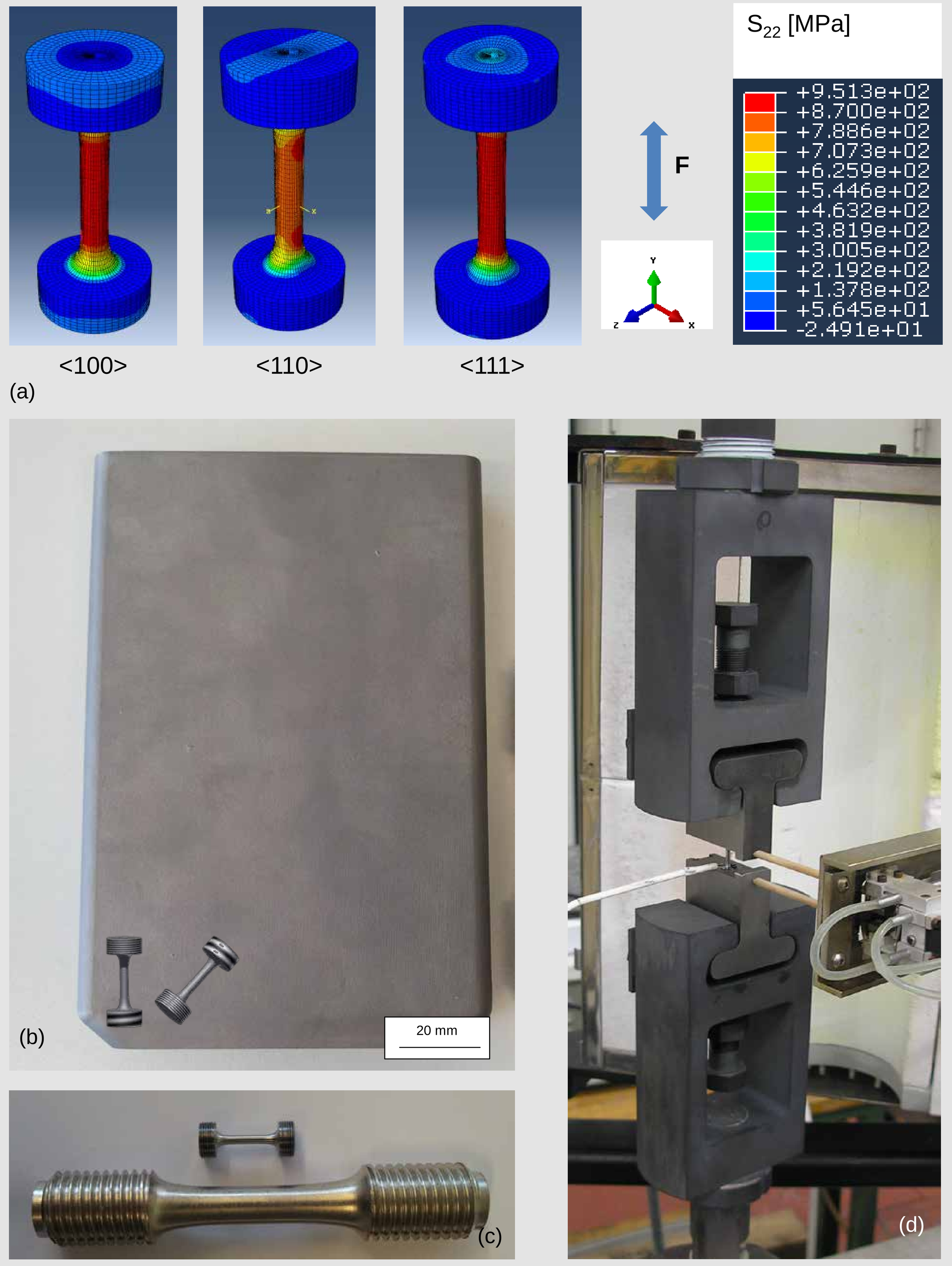

Figure 1: Development of miniaturized high temperature LCF testing (a) specimen design by means of FEM calculation considering different crystallographic orientations, (b) specimen and cast slab, (c) miniature specimen and standard specimen and (d) fixture for high temperature LCF

Stress- and strain-controlled LCF tests have been performed at 950°C on SX material with the nominal chemical composition of CMSX-4®. The alloy solidification was dendritic with γ/γ' precipitation microstructure. In first experiments loading was parallel to the <100>-direction. The specimens were tested until fracture and afterwards investigated by microscopic and microanalytical methods.

Results

LCF parameters and lifetime are displayed in Fig. 2(a). Fractured specimens show slip steps at the surface due to slip along {111} planes, Fig. 2(b). Length sections reveal aligned inter-dendritic pores, acting as crack initiation sites, Fig. 2(c, d).

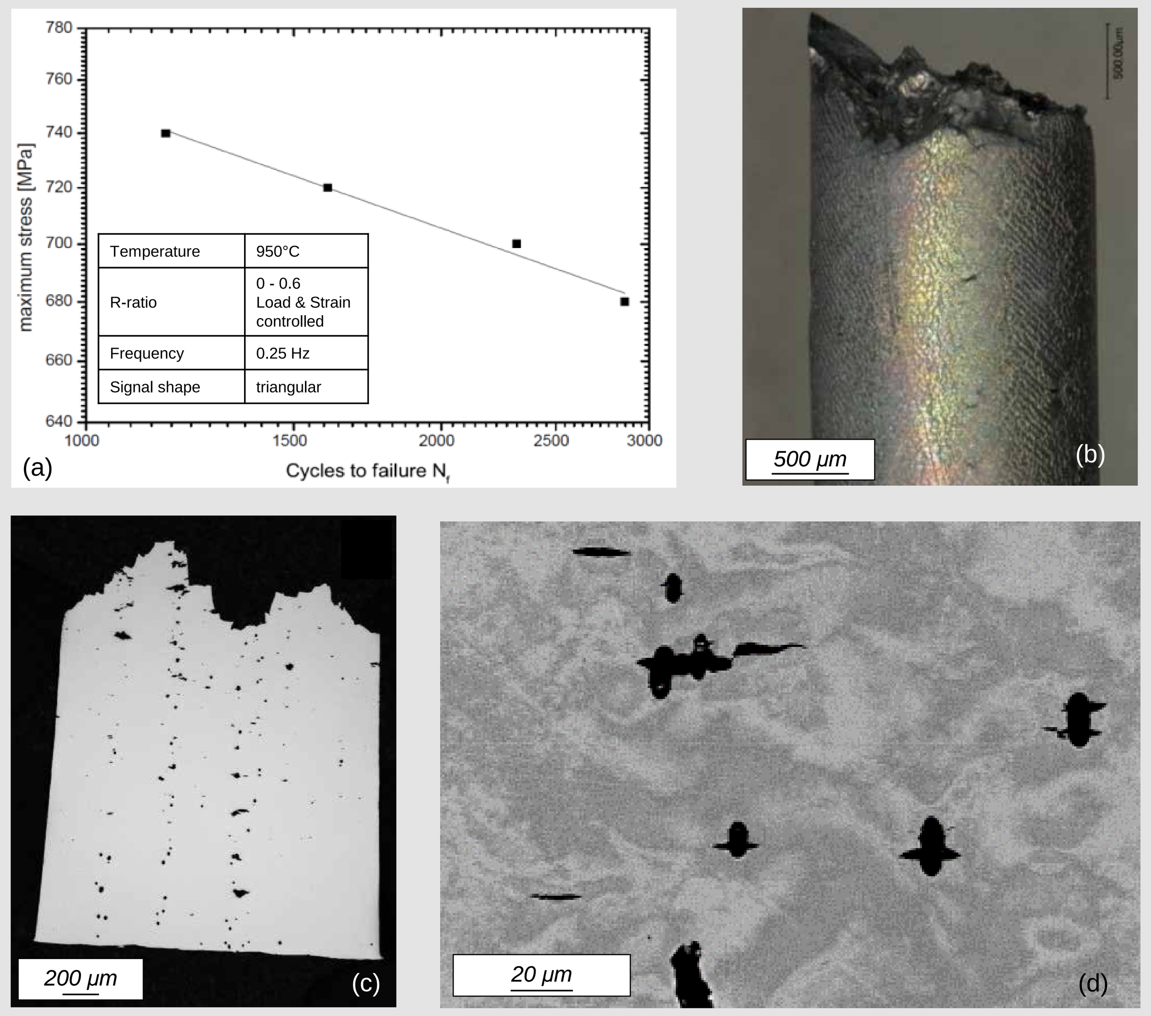

Figure 2: Lifetime data, fractured specimen, and crack initiation at interdendritic pores

Crack propagation occurred either through γ-channels perpendicular to the load, Fig. 3 (a, b) or along {111} planes, Fig. 3(f). At pores, slip bands, and cracks or near the specimen surface precipitates are found (Fig. 3 (a-c, f), showing high concentration of Co, Cr, Re, and W, which is characteristic for topologically closed packed (TCP) phases [1, 2].

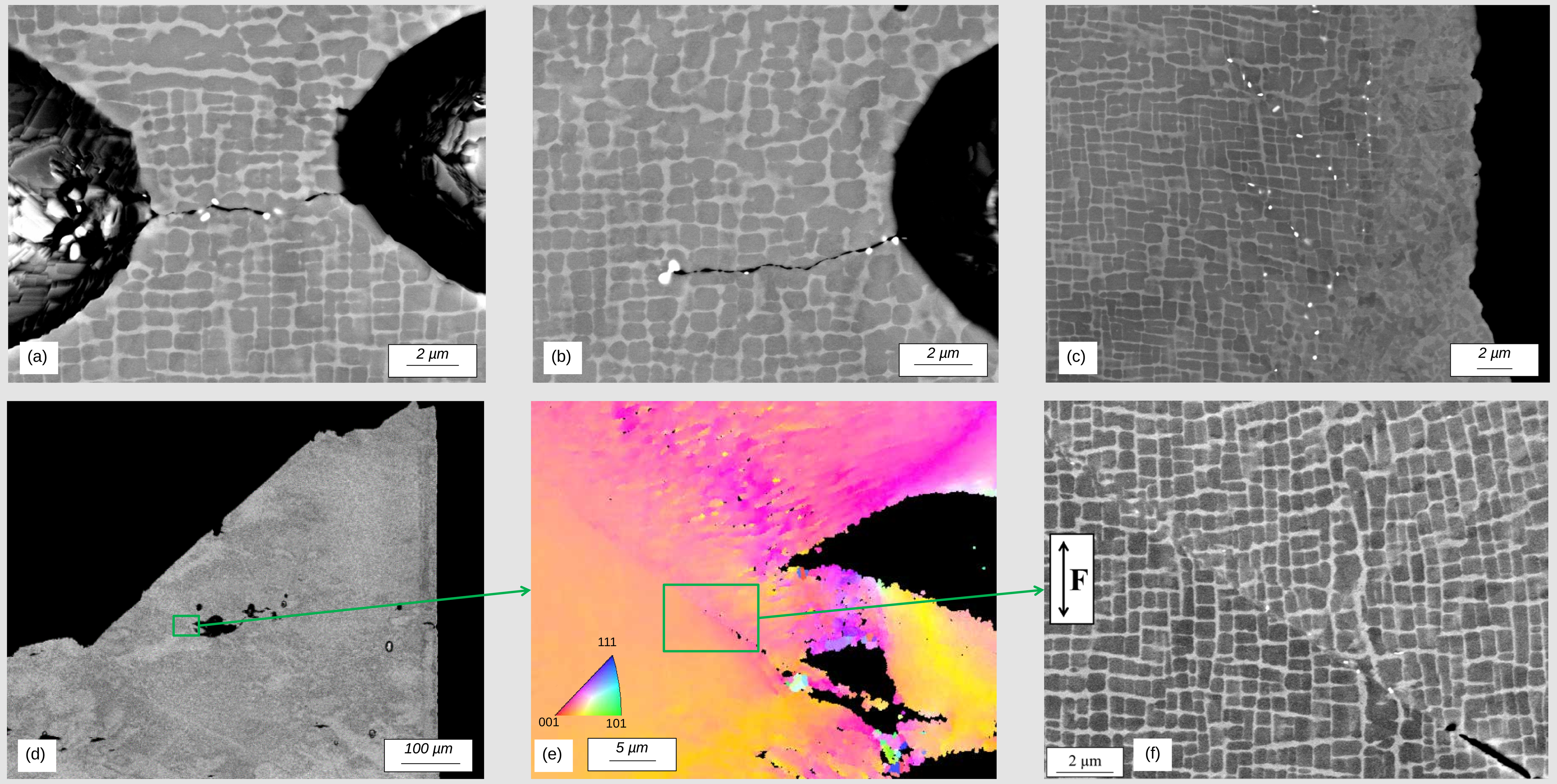

Figure 3: Crack paths and formation of TCP phases

During formation of slip bands, γ' precipitates are sheared, and subsequently cracks can open, Fig. 3 (f). Shearing is accompanied by crystallographic misorientation, as displayed by preliminary EBSD imaging, Fig. 3(e). Details of sheared γ/γ' microstructure and probably newly formed TCP-phase are shown in Fig. 4 (a, b). Especially near the surface, TCP phases occurred aligned along slip planes but without slip bands or sheared γ'-precipitates, Fig. 3 (c).

Conclusions

Stress concentrations resulting in elevated local strain seem to promote TCP precipitation [3]. TCP formation entails depletion of solid solution hardening elements of the γ-phase with deleterious effect on creep properties [4] and negative influence on the fatigue properties [5]. However, own observations indicate that formation of TCP phases can reduce the crack propagation velocity since they seem to act as obstacles, causing slight deviations of crack paths at TCP phases, Fig. 3 (a, b).

In the case of slip band formation the evolution of TCP phases may impede further slipping and enable subsequent healing of the sheared microstructure by diffusion processes.

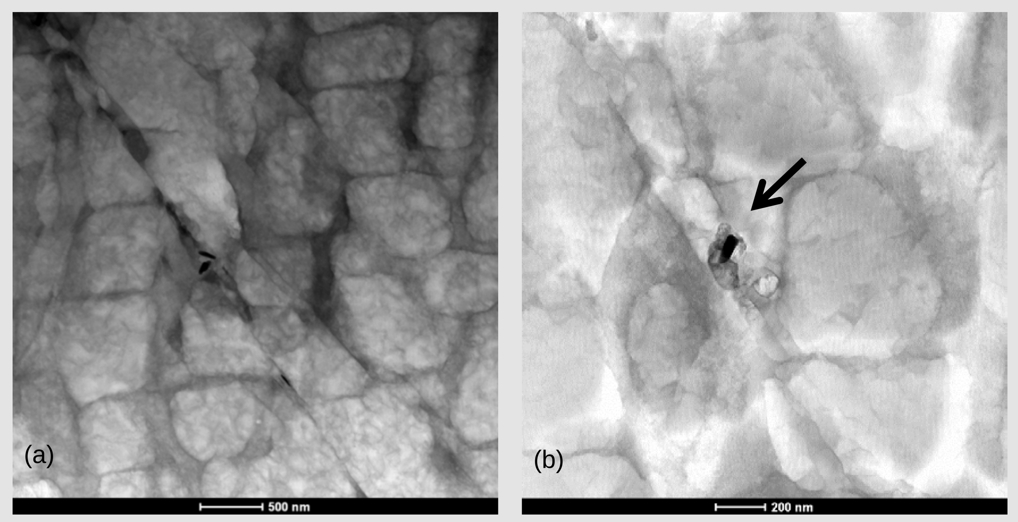

Figure 4: TEM images of slip bands with sheared γ'-cubes and TCP phases, (b) detail of TCP-phase

Acknowledgements

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