Accepted Manuscript

Numerically Predicted High Cycle Fatigue Properties Through Representative Volume Elements of the Microstructure

Karl Gillner, Sebastian Münstermann

PII: S0142-1123(17)30367-5
DOI: http://dx.doi.org/10.1016/j.ijfatigue.2017.09.002
Reference: JIJF 4455

To appear in: *International Journal of Fatigue*

Received Date: 17 May 2017
Revised Date: 1 September 2017
Accepted Date: 3 September 2017

Numerically Predicted High Cycle Fatigue Properties Through Representative Volume Elements of the Microstructure

Karl Gillner[1], Sebastian Münstermann[1]

[1]*Steel Institute, Intzestraße 1, 52072 Aachen, Germany*

Abstract

The investigation of high cycle fatigue (HCF) properties of materials is elaborate in experimental design. To reduce the costs, a multiscale numerical approach to predict the HCF-strength is proposed in this study. The intention is to correlate the microstructural features and their related microdeformation mechanisms with the macroscopic fatigue properties. The approach involves a series of numerical and mechanism-based analytical models. The microstructural features, including phase fraction, grain size and grain shape, are statistically characterized and represented in the generated representative volume element (RVE) model of the microstructure of a two phase steel. The underlying microdeformation mechanism is captured by an extended crystal plasticity (CP) model incorporating kinematic hardening on slip systems for cyclic loadings. The CP parameter set was calibrated on strain controlled low cycle fatigue tests. The numerical simulations of the cyclically loaded RVEs resulted in local plasticity fields. The highest plastically deformed grain of each RVE was identified and its grain size averaged plastic strain value extracted for further analysis. These scattered plasticity values fit extreme value distribution density functions. The parameters, which describe the shape of the functions, were used to calculate the HCF-strength. The obtained values showed a good agreement to experimental results.

Keywords: Fatigue indicator parameter, representative volume element, microstructure

1. Introduction

1.1. Motivation

Up to 90% of the world wide fracture of metallic components is dedicated to fatigue failure (1). Components need to fulfill high requirements in quality, withstand high loads and ensure their structural integrity under cyclic loading. However, the effort in improving these factors faces limitations. In the case where the appearance of the component is immutable, the selection of material and even the design of the material microstructure come into focus. A trial-and-error based improvement of the microstructure with regard to fatigue properties by experiments requires a lot of resources and time. For this reason, a numerical approach which quantifies the lifetime of components under fatigue loading based on microstructural features will be presented and validated by experiments. This approach reduces the experimental effort for the determination of the mean stress influence on high cycle fatigue strength.

The microstructure contains the important factors which determine the level of applicable forces under cyclic loading conditions. Several investigations claim a clear relationship between the endurance strength and quasi-statically determined mechanical properties like yield and tensile strength (2; 3; 4). Therefore, increasing the fatigue strength is feasible with the same measures as for increasing the yield and tensile strength (5). However, the relationship between both is not proportional. The fatigue strength approximate a constant value with increasing tensile strength.

For modeling fatigue failure, the approaches have to replicate the physical mechanisms. HCF can be defined to be material failure under cyclic loading which does not exceed the material's yield strength. However, microscopically plasticity effects in the length scale of only few grain diameters are locally damaging the material. Equivalent to the findings of Bauschinger (6), the irreversible motion of dislocations under reverse loading leads to their accumulation which is the reason for local plasticity increase. Polák et al. (7; 8; 9) showed in laborious scanning electron microscope (SEM) investigations the fatigue crack initiation at persistent slip bands (PSB) in steel. These PSBs are the result of dislocation accumulation in grains which are in a favorable crystallographic orientation to the applied cyclic loading. With the built up of ex- and intrusions, short cracks initiate at these PSBs. These cracks are promoted or hindered in growth by microstructural features e.g. grain boundaries, grain orientation and inclusions (10; 11; 12; 13) to mention a few. Therefore, CP models in interaction with finite element method (FEM) representations of the microstructure are the models of choice for the modeling of fatigue failure.

1.2. Crystal Plasticity

CP material models are used to calculate dislocation activity on slip systems. They consider the grain's crystallographic

Email address: Karl.Gillner@iehk.rwth-aachen.de
Sebastian.Muenstermann@iehk.rwth-aachen.de (Karl Gillner[1], Sebastian Münstermann[1])