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Short crack behavior during low-cycle fatigue in high-strength bainitic steel

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Abstract

Nowadays, the most modern bainitic steels are designed with much reduced carbon and other alloying element concentrations exhibiting excellent mechanical properties and are widely applied in industry. However, many engineering components contain a variety of stress concentrators such as grooves, fillets, holes or non-metallic inclusions and these components are exposed to dynamic cyclic loading. It has been observed that fatigue failure usually occurs as a result of crack initiation and growth from these stress raisers. The proposal of this work is to analyze the mechanisms involved in the initiation and propagation of microcracks during low- cycle fatigue in the bainitic steel 16CrMnV7-7. From scanning electron microscopy observations (SEM) in combination with electron backscattered diffraction (EBSD) measurements, the slip systems and their associated Schmid factors are analyzed in the bainitic ferrite blocks and correlated to the short crack path. Moreover, the dislocation structure developed was analyzed and correlated with the formation and propagation of microcracks. The principal results show that the microcracks initiate along slip systems with the highest Schmid factor and that the highly misorientated bainitic ferrite blocks are strong barriers to crack propagation.

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Keywords: Low-cycle fatigue; bainitic steel; microcracks nucleation and propagation.

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1. Introduction

The high-strength bainitic steels are processed using accelerated cooling in order to obtain the necessary bainitic microstructure. In the bainite transformation, the prior austenite grain is divided into a three-level hierarchy similar to the lath martensite structure in terms of morphology: packet, block and lath. The packet consists of one, or several set of blocks that are individually further subdivided into a group of laths with the same habit plane with respect to the parent austenite and similar orientation [1]. Furthermore, the fine laths of bainitic ferrite are separated by carbon-enriched regions of austenite with or without martensite [2-4]. These steels exhibit excellent mechanical properties and are widely applied in the automobile industry as crash reinforcement bars to protect against sidewise impact and for injection lines (under pulsating loads) in common rail diesel engines [5]. Moreover, many engineering components contain a variety of stress concentrators such as grooves, fillets, holes or non-metallic inclusions and these components are exposed to dynamic cyclic loading. It is well known that fatigue failure usually occurs as a result of crack initiation and growth from theses stress raisers. Then, the correct estimations of stress/strain concentration and crack development in the critical region are essential for practical machine design in service cyclic loading. In previous studies, Scanning Electron Microscopy (SEM) has been used to analyze the fracture surfaces, related to the fatigue behavior of the bainitic steels. Branco et al. [6] studied the fatigue damage mechanism of high strength steel after low-cycle fatigue testing and concluded that the microcracks initiate along the slip band on the sample surface and they grow through the grain boundaries and eventually form a coalescence of short cracks, which further coalescence propagates into the bulk perpendicularly to the stress axis. Sankaran et al. [7, 8] revealed that crack initiation occurred at slip band extrusions/intrusions on the surface under mixed mode (ductile and brittle) in multiphase (ferrite/bainite/ martensite) microstructures. Recently, using Electron Backscatter Diffraction (EBSD), Rementeria et al. [9] identified the active slip systems in the bainitic ferrite and the crack deflection at grain boundaries in nanobainitic steels with high-carbon (0.67C) and high-silicon (1.67Si). They reported that the crack initiation occurs at the surface during Low Cycle Fatigue (LCF) and the crack initiates on inclusions during High Cycle Fatigue (HCF). Moreover, the results showed that the crack grows along the ferrite slip (110) <111> with the highest Schmid factor and that the microstructural features control the crack deflection. A similar study is proposed to analyze the mechanisms involved in the initiation and propagation of microcracks during LCF in the reduced carbon bainitic steel 16CrMnV7-7. Furthermore, from scanning SEM in combination with EBSD measurements, the slip systems and their associated Schmid factors are analyzed in the bainitic ferrite blocks and correlated to the short crack path. Additionally, the dislocation structure developed will be analyzed and correlated with the formation and propagation of microcracks.

Nomenclature

EBSD	electron backscatter difraction
HCF	high cycle fatigue
LCF	low cycle fatigue
SEM	scanning electron microscopy
SF	Schmid factor
TEM	transmission electron microscopy
XRD	x-ray diffraction

2. Material and experimental procedure

The material considered in this work is the bainitic steel 16CrMnV7-7 with a nominal chemical composition as given in Table 1. The material was supplied by Georgsmarienhütte Steel (Germany) in the form of hot-rolled cylindrical bars of 30 mm in diameter. Optimal material properties are achieved by a controlled cooling down until 350 ºC.