International Journal of Fatigue 77 (2015) 95–104

Contents lists available at ScienceDirect

International Journal of Fatigue

journal homepage: www.elsevier.com/locate/ijfatigue

Effect of crystal orientation and texture on fatigue crack evolution in high strength steel welds

Amin S. Azar [a,*], Lars-Erik Svensson [b], Bård Nyhus [a]

[a] SINTEF Materials and Chemistry, Trondheim, Oslo, Norway
[b] Department of Production Technology, University West, Trollhättan, Sweden

ARTICLE INFO

Article history:
Received 20 October 2014
Received in revised form 27 February 2015
Accepted 8 March 2015
Available online 14 March 2015

Keywords:
Crystal orientation
Torsion
Fatigue
EBSD
Crack trajectory

ABSTRACT

In the present study, electron backscattered diffraction is used to analyze the fatigue crack evolution in a high strength steel weld that was loaded cyclically in the plastic regime. Three prominent regions of a fatigue crack are investigated separately: crack tip, crack trajectory and crack initiation. Taylor and Schmid factors are mapped with respect to the defined loading matrix. Possible effective mechanisms are proposed based on the local plasticity properties like lattice rotation and misorientation. The analyses of the crack tip and trajectory regions show that although the critical resolved shear stresses in some regions are low, small deformation resistance of these regions can compromise the dislocation immobility and cause local fracture. It is shown that if the crack grows transgranularly, at least one side of the crack may show low lattice rotation or strain equivalent values, which indicates the relaxation of elastic stresses after fracture. The crack initiation is determined to be dominantly controlled by transcrystalline mechanism of initiation that takes place under plastic loading conditions. It is also shown that the secondary $\langle 1\,2\,3\rangle\{1\,1\,\bar{1}\}$ type of slip systems were the most activated under such loading conditions.

1. Introduction

The weight reduction policy in automotive industry is a central subject that leads to utilization of high strength materials in the structural and load-bearing components of vehicles. In some of the parts, requirements may vary throughout the component. Thus, a multi-material component with different properties in different regions becomes an interesting option. One of the possible and most cost-effective production procedures of such components is dissimilar metal welding. However, the associated issues in welding require deep insight of materials' properties and behavior.

In the present paper, fatigue crack propagation is examined in a multi-material steel welded component, with special reference to the influence of plastic deformation and other microstructural effects on the crack growth. The investigated component consists of three dissimilar regions: bar section, plate section and the welds to join the former two sections. All the regions are bcc high strength steels and the detailed data is given in the experimental section. A brief review of earlier investigations will thus be given first.

Azar and Svensson [1] have reported the lifetime analysis of a torsion-loaded component and simulated the possible crack paths using linear elastic fracture mechanics (LEFM). They have shown that the fatigue cracks under torsion loading tend to initiate and grow in the weld toe region, where the structural stress concentration is the highest. Newman [2] showed how the load ratio and process zone ahead of the crack tip play significant roles in causing load interaction effects on crack growth rate. Lal [3] investigated the combined effects of the stress ratio and yield strength on the fatigue threshold condition. He concluded that the fatigue threshold value is independent of yield strength at high stress ratios. This shows that the crack growth is governed by plastic deformation mechanisms at high load ratio. Miller and Chandler [4] analyzed tubular sections under torsion fatigue and argued that the effect of specimen geometry is more important in high strain fatigue process due to the spread of crack initiation zones. Nevertheless, the effect of crystal orientation and anisotropy of different grains is not considered in their simplified approaches.

Iron at room temperature has bcc lattice structure and it contains up to 48 possible slip systems. However, most of them require heat to be activated. In polycrystalline materials, the applied stress can be resolved in a number of crystallographic directions to estimate the activation of different slip systems [5]. Wright and Field [6] investigated the effect of local texture on materials failure using the electron backscattered diffraction

* Corresponding author at: SINTEF, Department of Materials and Chemistry, Forskningsveien 1, 0314 Oslo, Norway. Tel.: +47 96833668.
E-mail address: amin.azar@sintef.no (A.S. Azar).

http://dx.doi.org/10.1016/j.ijfatigue.2015.03.008
0142-1123/

technique. They presented that various crystallographic parameters affect the crack behavior and the acquired data for polycrystalline materials can be described in the context of statistical distribution. Yun et al. [7] analyzed the slip systems and crack initiations in polycrystalline materials under cyclic torsional loading. They used Schmid's plastic theory [8] (Schmid factor) to identify the grain with the highest susceptibility for activation of a slip system in fcc materials. Chu et al. [9] studied the fatigue crack initiation and propagation in a polycrystalline α-iron material. They found that at low stress amplitude, the transgranular propagation dominates, while at high stress amplitude, a mixed transgranular and intergranular mode takes place. It was delineated that the intergranular fracture is assisted by slip band cracking at higher stress amplitude. Navarro and De Los Rios [10–12] further developed the theories of mentioned scientists and laid the foundation of a theory that was accounting for the influence of crystallographic misorientation. According to their model (ND-model), the crack propagates along a persistent slip-band through the grain. Hence, the crack propagation rate is calculated by the amount of plastic displacement along the slip system in front of the crack-tip. In short, this theory investigates the transition of crack from short microstructural crack to a macro-scale crack that propagates through a number of grains.

Davidson and Chan [13] examined the effects of crystallographic orientation on fatigue crack initiation for coarse grain Astroloy. They used the Taylor factor analysis to determine the grains with higher susceptibility of cracking. The Taylor factor shows the predicted yield response of a grain relative to the stress state and its interaction with the surrounding grain structures. Grains with lower Taylor factor value are considered to have orientations suitable for slip activation in the given loading condition while higher Taylor factor means that the grain orientation under given loading condition is less likely to yield and may thus assist the transgranular type of fracture. Merriman et al. [14] related the calculated Taylor factor to the evolution of dislocation structure during deformation of aluminum. They found that some grains with high Taylor factor might not deform until the grains with low Taylor factor are deformed and the resolved shear stress reached to a sufficient level for activation of the slip systems in high Taylor factor grains.

In general, Schmid factor is required to describe the cracking phenomena in a single crystallographic orientation disregarding the existence of surrounding grains and misorientation levels, however, Taylor factor is considering the generic conditions of the deformed grains under a non-uniform multi-axial stress state of each grain to allow multiple slip phenomena.

In this study, fatigue cracks in a load-bearing component of a truck chassis are investigated using EBSD. This component has undergone cyclic plastic torsion loading in the weld region. Welding affects the crystal orientation and texture of the material that may also influence the fatigue properties. The intention is to gain more insight into the details of metallurgical processes that can potentially affect the lifetime of the components.

2. Experimental and background

The test component consists of a bar and two plates that are joined using gas metal arc welding (GMAW). Fig. 1 shows the component and the test set-up. The material of the plate is Weldox-700E (delivered from SSAB) and the material used in the bar section is 33MnCrB5 (delivered from Ovako). OK Autrod 13.29 (delivered from ESAB) was used as welding consumable. The chemical composition of the weld metal is given in Table 1. The design procedure of the tested component based on the initial requirements is given in detail elsewhere [1,15]. 40 kN of force was applied to one end of the bar cyclically at the radial distance of 160 mm resulting in maximum torque level of about 6400 Nm. The force level was obtained by rain-flow analysis of the field test data of

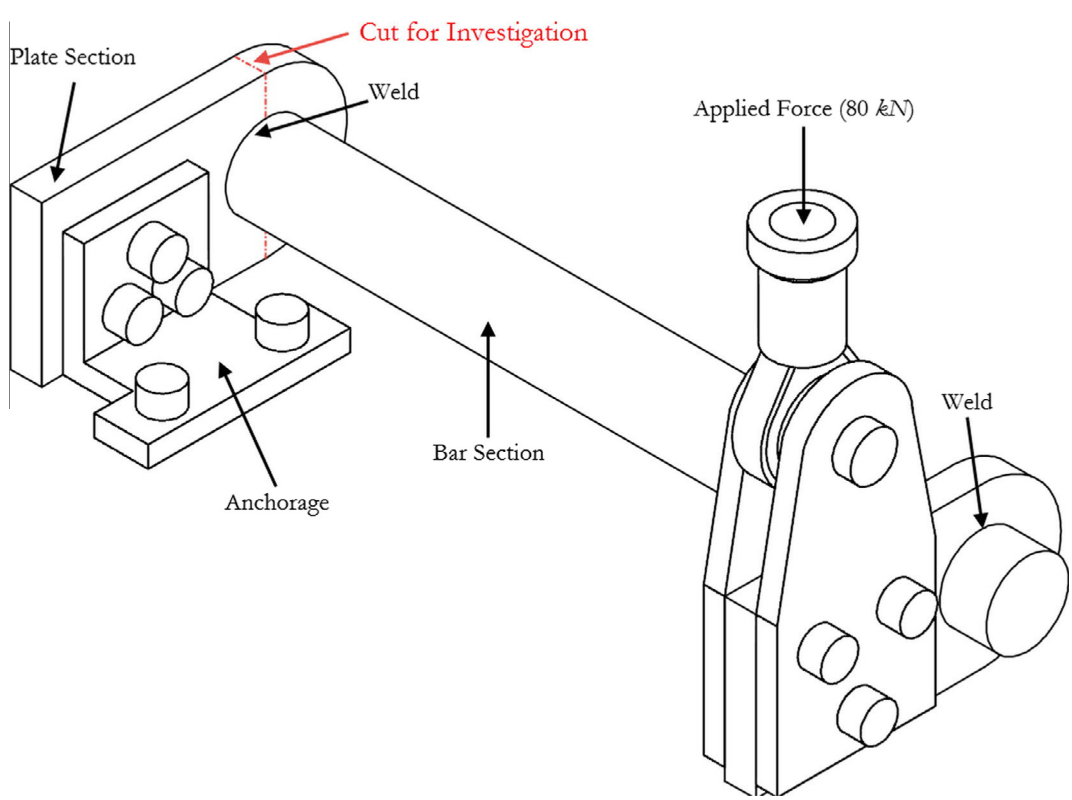

Fig. 1. Load bearing component and the test set-up.