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Advanced analysis of crack tip plastic zone under cyclic loading

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The different types of plastic zones found at a crack tip under cyclic loading of a commercially available aluminium alloy are studied based on 3-dimensional finite element simulations and mechanical testing. During the experiments, the local strain field at the crack tip is computed based on digital image correlation analysis of the specimen's surface under different load levels. The simulations with an elastic-plastic material model (bilinear isotropic hardening) predict the experimental surface strain field at the crack tip pretty well. The coupling of experimental results and finite element analysis allows for the accurate distinction into monotonic and cyclic plastic zone, and moreover, into backward cyclic plastic zone and forward cyclic plastic zone. Furthermore, it is possible to calculate the energy accumulation ahead of the crack tip which represents a very useful quantitative measure for the analysis of local fatigue damage accumulation inside the plastic zone ahead of a crack tip.

Keywords: Cyclic loading, Crack, Plastic Zone, FEM, Aluminium

1 Introduction

Preservation of resources is unquestionably one of the crucial challenges for today's engineers. One very effective measure is the application of lightweight design. In doing so, an inherent drawback is that lightweight constructions are generally prone to fatigue. Consequently, fatigue cracks and their propagation under cyclic loading need to be studied.

As a common matter of fact, linear elastic fracture mechanics (LEFM) is quite often applicable to analyse (fatigue) crack propagation. Nevertheless, the damage process itself usually takes place within the vicinity of the crack tip in the so called (fracture) process zone. In case of (quasi-)brittle materials microcracking or void formation occurs in this process zone ahead of the crack tip [1, 2]. In contrast, ductile materials preferably develop a plastic zone in front of the crack tip [3, 4, 5]. Thus, the study of this plastic zone can be a useful measure to gain insight into the interrelations of material properties, loading conditions, crack closure phenomena, damage evolution and fatigue crack propagation, respectively [5]. Consequently, numerous studies deal with numerical analyses of the plastic zone [4, 6-17]. Especially recent studies based on 3-dimensional finite element (3d-FE) simulations provide better understanding of the characteristics of the plastic zone as they clearly show that the shape of the plastic zone deviates significantly – depending on the specific configuration – from the classical "dog bone" model [12, 13].

It is well known, that the so called primary plastic zone develops during the first loading phase, while a secondary, much smaller, plastic zone develops during the subsequent unloading [15]. Further cycling results in another type of plastic zone, which is called cyclic plastic zone [5, 16, 17]. The cyclic plastic zone again can be subdivided into two more types of plastic zone, i.e. the forward cyclic plastic zone developing during loading and the even smaller backward cyclic plastic zone appearing during unloading, see [18] and the corresponding Figure 1, respectively. While recent studies dealing with the primary plastic zone [10-14] usually apply 3d-FE simulations, those dealing with the cyclic plastic zone are limited to 2-dimensional FE-models [16, 17].