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Interactions between grain size and geometrical defects in pure aluminium in the high cycle fatigue regime

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Abstract

In this study, the influence of geometrical defects on the High Cycle Fatigue (HCF) resistance of aluminium is investigated, with emphasis on the impact of local microstructure on fatigue crack initiation. In order to meet this objective, an experimental approach, using a commercial purity polycrystalline aluminium alloy, is proposed.

First, different thermomechanical treatments are applied to the aluminium alloy to obtain two homogeneous microstructures with respective mean grain sizes of 100 and 1000 µm. Then, fatigue specimens with an artificial hemispherical surface defect of diameter 1000 µm are subjected to fully reversed stress-controlled cyclic loading conditions. *In-situ* observations are carried out to monitor the crack length during fatigue tests. It is noted that, for a higher grain size, the number of cycles needed for the initiation of a 100 µm-long surface crack is lower.

A study of the influence of the defect size relative to the grain size is also conducted. Two sizes of defects are used, and the influence of characteristic sizes seems to be explained by the role of cyclic plasticity in the crack initiation process.

Keywords: high-cycle fatigue, cyclic plasticity, microstructure, defect, crack initiation, aluminium

1. Introduction

In metallic alloys, defects can originate from many factors [1, 2, 3, 4], and act as stress concentrators, having a detrimental influence on the High Cycle Fatigue (HCF) resistance [5]. The fatigue resistance is all the more pronounced that the defect is large. Endo *et al.* [6] and Lukás *et al.* [7] also showed that there exists a critical defect size below which the fatigue behavior is no longer affected. The dependence of this critical size regarding microstructural features remains unclear, although its knowledge is important to design fatigue-resistant structures.

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While important experimental efforts have been made to characterize the role of microstructural features on the fatigue behavior in the absence of defects [8, 9, 10, 11, 12, 13], very few attempts have been made to relate the influence of defect size and microstructure size. When the influence of local microstructure in the vicinity of a defect is studied, the grain size is generally held constant [14, 15, 16]. To explore the connection between grain size and defect size, Karry *et al.* [17] carried out an experimental investigation. They observed a reduction of the defect sensitivity with an increasing grain size: the decrease in fatigue limit from a smooth specimen to a specimen with defect (and same grain size) was lower. Lorenzino *et al.* [18] carried out fatigue tests on pure aluminium specimens with different grain and defect sizes. They showed that, as far as crack propagation is concerned, the governing parameter on fatigue behavior is the relative defect size rather than the absolute one. Indeed, by normalizing the fatigue limit by the fatigue limit of smooth specimens with the same grain size, and the defect size by the grain size, all data points fall onto the same line in a fatigue limit/notch size diagram. Vincent *et al.* [19] came to the same conclusion for pure iron. Those two studies focus on the number of cycles to failure rather than to crack initiation, but they demonstrate the interest of varying both characteristic sizes.

In the present work, an experimental campaign is carried out to investigate the joint influence of defect size and grain size on the HCF behavior of pure aluminium polycrystals, focusing on crack initiation rather than propagation. The results, obtained from reversed uniaxial tension-compression loading conditions, are discussed to establish a connection between plasticity and crack initiation.

Nomenclature

d	diameter of the hemispherical defect
ϕ	mean grain size
σ_a	stress amplitude
N_i	number of cycles to crack initiation
$\Delta\varepsilon^p$	plastic strain range ($\Delta\varepsilon^p_{s-h}$: value at the transition between the softening and the hardening stages)

2. Experimental procedure

2.1. Material description

The material used in this study is AA1050, a polycrystalline aluminium alloy of commercial purity for which the aluminium weight concentration exceeds 99.5%.

Two different thermomechanical sequences have been applied to control the grain size ϕ. The two obtained microstructures have respective grain sizes of 100 µm and 1000 µm. They are denoted ϕ_s and ϕ_l, and referred to as small grain microstructure and large grain microstructure. The yield stresses, determined for a 0.2% offset, are respectively 17.8 and 16.1 MPa.

2.2. Fatigue specimens

Fatigue specimens have been machined from previously prepared aluminium samples, making the loading axis coincides with the rolling direction. The gauge section is 15 mm-long and 30 mm-wide, and the thickness is 5 mm.

Hemispherical surface defects have been introduced in the gauge area of fatigue specimens with an hemispherical drill, the defect size d being thus given by the drill diameter. In the present work, two defect sizes have been considered: d_s = 100 µm and d_l = 1000 µm, where subscripts s and l denote respectively the small and the large defect size.

A heat treatment has finally been applied to fatigue specimens to relieve the residual stresses resulting from machining operations.