Influence of the microstructure and defects on the high cycle fatigue strength of 316L stainless steel under multiaxial loading

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Abstract. In the present study, the effects of both the microstructure and defects on the high cycle fatigue behavior of the 316L austenitic stainless steel are investigated thanks to finite element simulations of polycrystalline aggregates. The numerical analysis relies on a metallurgical and mechanical characterization. To complete the experimental study, load-controlled fatigue tests are also carried out to determine the fatigue limits at 2.10^6 cycles under uniaxial and multiaxial loading conditions using both smooth specimens and specimens containing an artificial hemispherical surface defect. In the finite element models, where the grain morphologies are explicitly modeled, the anisotropic behavior of each crystal is described by the generalized Hooke's law and by a single crystal visco-plastic model. From the simulations carried out with different defect sizes and orientation sets, statistical informations regarding mesoscopic mechanical fields are analyzed. Then, using the FE results, the ability of a probabilistic fatigue criterion to predict the influence of defects and biaxiality on the average fatigue limits is evaluated thanks to a comparison with the experimental data.

1 Introduction

The aim of this study is to analyze the influence of an artificial defect on the multiaxial high cycle fatigue behavior thanks to finite element simulations of polycrystalline aggregates. This analysis relies on experimental data and more specifically on fatigue tests carried out on an austenitic stainless steel 316L using both smooth specimens and specimens containing a hemispherical surface defect.

2 Finite element modelling

The numerical simulations reproduce the load-controlled fatigue tests. A simplified description of the specimen in 2D is used (Fig. 1) along with a generalized plane strain hypothesis. With the size of the polycrystalline aggregate chosen, the smooth microstructure contains 3265 crystals in order to respect the average grain size. For each defect size studied, one polycrystalline aggregate and ten different orientations set are employed. Orientation sets are composed by triplet of Euler angles selected to be representative of the texture measured in the as-received material.

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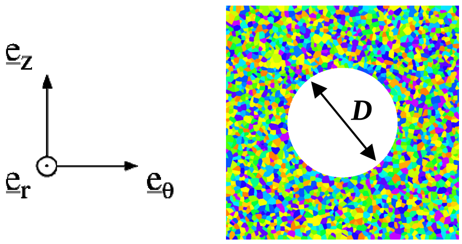

Figure 1. Polycrystalline aggregate geometry used in the FE model.

In order to study the effect of the anisotropy of the elastic behavior on the mechanical responses, two elastic constitutive models are assigned to the grains: isotropic elasticity and cubic elasticity. The effects of the single-crystal plasticity and of a 3D modeling on the mechanical responses at the grain scale, not presented here, will be discussed in the presentation.

3 Results and discussion

A large scatter, at the grain scale, of mechanical quantities used in fatigue criteria is highlighted thanks to the finite element results. It is also observed that the cubic elasticity increases significantly the values of the normal stress amplitude with respect to the isotropic elastic case.
The results of the finite element simulations of polycrystalline aggregates using the cubic elasticity are then used with a probabilistic fatigue criterion [1, 2] in order to predict the macroscopic average fatigue limit for some loading conditions and defect sizes *D*. These predictions are presented on figure 2 in addition to the experimental average fatigue limits. In the cases of fully-reversed tension, torsion and in-phase combined tension and torsion (with a biaxiality ratio $k_{\theta z}=\Sigma_{\theta z,a}/\Sigma_{zz,a}=0.5$), the predictions of the probabilistic criterion are in good accordance with the experimental fatigue limits.

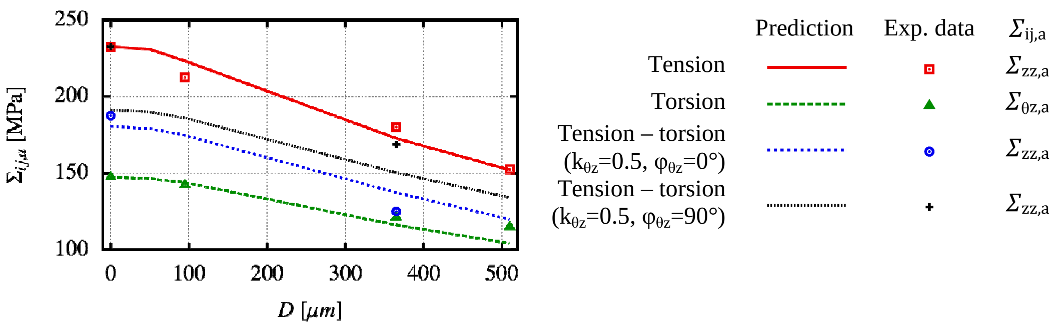

Figure 2. Comparison between the experimental fatigue limits and the predictions of the probabilistic fatigue criterion for some loading conditions and defect sizes *D*.

4 Conclusions

The distributions of mechanical quantities defined at the grain scale has been analysed thanks to the numerical modeling employed in this study. Then, the predictions provided by a probabilistic fatigue criterion have been compared to the experimental fatigue limits. A good agreement has been generally observed for the considered defect sizes and loading conditions.

References

1. F. Morel, N. Huyen, Theor. Appl. Fract. Mec. **49**, 98-127 (2008)
2. R. Guerchais, C. Robert, F. Morel, N. Saintier, Int. J. Fatigue. **59**, 64-75 (2014)