Thermo-mechanical fatigue crack growth investigation for cast austenitic stainless steel

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Abstract

This paper describes a complete experimental program and its numerical counterpart to investigate and predict failure analysis (crack initiation and propagation) of a cast 1.4837 heat-resistant austenitic stainless steel commonly used for automotive turbochargers. Fatigue crack growth analysis is the focus of this paper considering both isothermal and anisothermal loading for both experimental and finite element analysis. On this basis fatigue crack growth rate model is derived accounting for complex interaction of large levels of plasticity and subsequent crack closure.

1. Introduction

The constant increase of gas temperature for new generation of automotive engine yields high damage rate in most of their components. Among the most critical are turbochargers that bear typical thermo-mechanical fatigue when experiencing large thermal and subsequent mechanical gradients. To gain both understanding and extended lifetime for such components (usually design only for avoiding crack initiation), the use of damage tolerant design through fatigue crack growth (FCG) analysis is of major interest. This study therefore aims at deriving from real component analysis the driving condition leading to crack growth. It focuses on grade 1.4837, an austenitic stainless steel commonly used for turbochargers.

2. Results

A metallurgical characterization is first carried out on stainless steel 1.4837 where the chemical composition, the various phases of the microstructure and the grain size were analysed, highlighting a coarse microstructure (grain size being about 1 mm) and a significant dispersion of Young's moduli. Fatigue crack propagation tests under both isothermal and anisothermal loads (calibrated according to the loads measured on the turbochargers) are then carried out in order to analyse the fatigue crack propagation rates as a function of temperature, stress or strain amplitude and loading ratio. The tests were performed on notched specimens, under uniaxial loading and for a test temperature ranging between 300°C and 950°C. For the studied stainless steel, fatigue cracks propagate in transgranular mode irrespectively of the coarse grains size: the crack paths are almost orthogonal to the loading direction, only local slight crack oscillations being observed from grain to grain, and the fatigue crack growth rate (FCGR) is also insensitive to sampling effect. However, general plasticity is observed in the tested condition that pushes the need to model FCGR in the framework of nonlinear fracture mechanics. Explicit meshing of the crack path associated to a G-theta method was used to model crack propagation in both isothermal and anisothermal conditions [1,2]. First, a dependence on the test temperature was modelled and then, the mutual contribution of the plastic energy dissipated per stabilized cycle and the elastic opening energy, allows to take into account the effects of crack closure and mean stress [2,3].

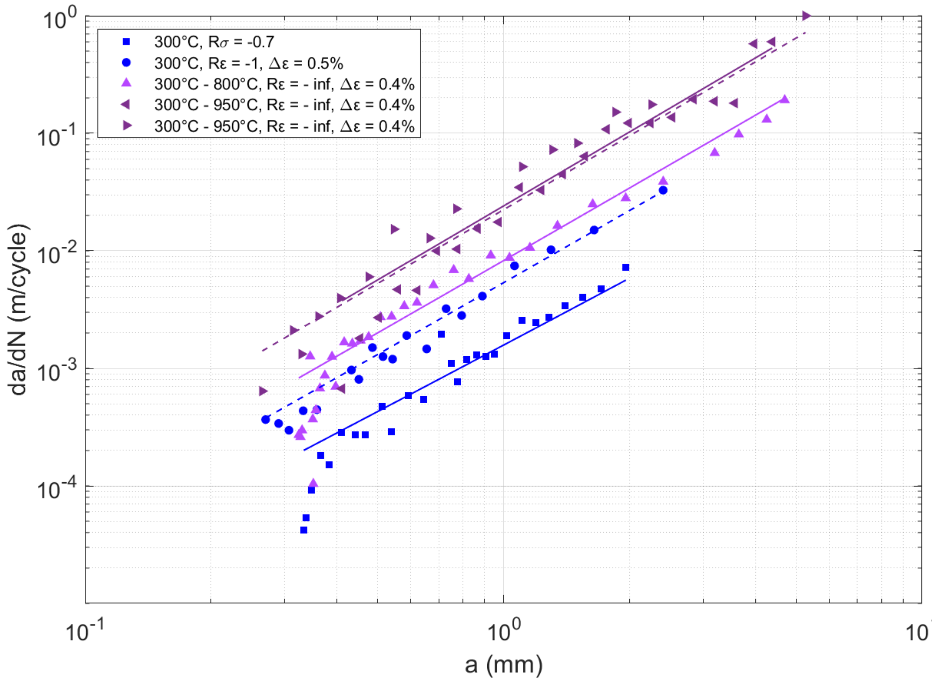

Fig.1 – FCGR behavior of 1.4837 cast stainless steel

3. Conclusion

A formulation relying on micro-crack growth rate model with strain energies as driving forces has been validated for different loading levels and temperatures as seen on Fig.1 and can then be introduced in the numerical design protocols.

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