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EFFECT OF DYNAMIC EMBRITTLEMENT ON FATIQUE CRACK PROPAGATION MECHANISM AND CRACK GROWTH RATE IN IN718

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Abstract
IN718 is a commonly used nickel-base alloy for high temperature applications, e.g., in gas and steam turbines. At elevated temperatures, this and other superalloys are prone to the failure mechanism "dynamic embrittlement". In order to reveal the mechanism of dynamic embrittlement, high-temperature fatigue crack propagation tests were carried out at 650°C applying various dwell times and testing frequencies. Most of the tests were performed in laboratory air, but some experiments were run in vacuum as well, in order to eliminate environmental effects and, hence, to define the reference fatigue crack propagation behavior. Based on the results obtained, a model was developed for the range of test parameters, where intergranular and transgranular areas exist side by side in the fracture surface. This model provides a quantitative mechanismen-related description of the effect of dynamic embrittlement on fatigue crack propagation rate.

1. Introduction

In the literature, many attempts can be found to model the dynamic embrittlement process. Besides sole phenomenological approaches which are based on a plain description of experimental data, numerical concepts have been introduced. These concepts combine the modeling of the oxygen grain boundary diffusion in the stress gradient ahead of the crack with a visco-plastic material deformation model and need a rather high number of fitting parameters.
Often a quasi-fracture-mechanics approach is applied by considering the contribution of each damage mechanism to the crack growth rate individually and superimposing these contributions. Fatigue crack propagation under the influence of dynamic embrittlement is mostly assumed to be affected by two damage mechanisms only. One is the time-independent cyclic plastic deformation and the second is the time-dependent damage resulting from the oxygen attack and at sufficiently high temperatures from creep. These contributions are in the simple case linearly combined ignoring the mutual interactions of the damage mechanisms. Alternatively, exclusively the term is considered which results in the fastest crack propagation, or the different term are weighted by individual weighting factors.
In the investigation presented, the dynamic embrittlement of the Ni-base superalloy IN718 was studied by putting the focus on the development of a detailed understanding of the mechanisms controlling the dynamic embrittlement process. The results were used as a sound basis for the development of a mechanism-related model of the dynamic embrittlement phenomenon aiming at a reliable and unerring fatigue life assessment.

2. Results

The experimental observations confirm that the effect of dynamic embrittlement increases in air with decreasing test frequency and increasing dwell time leading to an acceleration of the crack propagation rate by several orders of magnitude. The fracture surface morphology depends accordingly on these test parameters and changes also with the acting value of ΔK during the individual test. Tests with relatively long dwell times in air resulted in a entirely intergranular fatigue crack growth. Tests applying shorter dwell times or a high test frequency showed both transgranular and intergranular areas coexisting side by side in the fracture surface. As expected, the surface morphology formed in the vacuum tests is completely transgranular. The fraction of intergranular fracture surface is in correlation with the degree of dynamic embrittlement and the increase in crack growth rate. This is shown in Fig. 1 at four different values of ΔK. For the sake of clarity, the intergranularly fractured areas are dyed black and the corresponding value of the area fraction is given as percentage number under each micrograph. At higher magnification, striations are visible in the transgranular areas. Clearly, in this frequency/dwell time range, where a mixed fracture surface is formed, the intercrystalline fraction increases with decreasing frequency and decreasing Δ*K*.

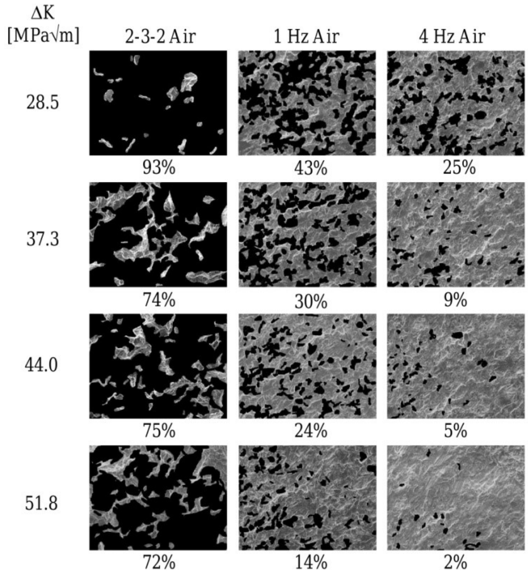

Fig.1 – Fracture surfaces of three crack propagation tests at different values of Δ*K*; the intergranular fraction is dyed black and specified in %.

A new approach is proposed for the simulation of fatigue crack propagation based on the experimental findings of this study. This approach makes use of the idea that a damage zone is formed during the dwell time by tensile-stress-assisted grain boundary diffusion of oxygen. The crack is assumed not to grow during dwell. Rather, exclusively the cyclic loading between two dwell times leads to crack extension. The length of this extension is dictated by the size of the previously formed damage zone. The direct connection of damage mechanism and fracture area appearance allows for an utilisation of the fractographic information within the framework of the crack growth calculation.

The agreement between simulation and experiment was found to be very reasonable. This indicates that the model proposed has a sound physical basis in terms of the assumptions used. Hence, the conclusion seems to be justified that in the loading parameter range considered in the model, dynamic embrittlement results from an alternating process consisting of damage zone formation during dwell time in tensile (or during the part of high tension of a sinusoidal loading) and a subsequent crack growth through the damage zone during the load change prior to the next dwell time.

Conclusions

Fatigue crack growth of IN718 at 650°C in air is strongly affected by dynamic embrittlement., In fatigue tests performed in vacuum, dynamic embrittlement is completely suppressed demonstrating the decisive role of environment (in particular oxygen). The effect of dynamic embrittlement on the fatigue crack propagation rate, in terms of an accelerated crack growth, increases with increasing dwell time and decreasing stress intensity range. Dynamic embrittlement is directly linked to the occurrence of intergranular crack propagation. The experimental results are in very satisfactory agreement with the idea that dynamic embrittlement occurs according to the damage zone model. This means, a damage zone ahead of the crack tip is formed during the dwell time and crack propagation through this damage zone takes place in the cyclic (fatigue) part before the next dwell time.

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