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Fatigue crack growth from handling surface anomalies in a Nickel based superalloy at high temperature

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Abstract. Aircraft engine manufacturers have to demonstrate that handling surface anomalies in sensible areas of discs are not critical for in-service life of a component. Currently, the models used consider anomalies as long cracks propagating from the first cycle, which introduce a certain degree of conservatism when calculating the fatigue life of surface flaws. Preliminary studies have shown that the first stages of crack propagation from surface anomalies are responsible for the conservative results. Thus, the aim of the study is to characterize the crack propagation from typical surface anomalies and to establish a new crack growth model, which can account for the micro-propagation stage.

1. Introduction

Damage tolerance approaches are used by jet engine manufacturers to demonstrate that components meet the certification requirements in terms of handling damage tolerance. Indeed, during maintenance, rotor discs can be subjected to the introduction of flaw-type surface anomalies. Therefore damage tolerance approaches can be used to calculate the fatigue life of a crack propagating from the surface flaw. Currently, the crack propagation models consider surface anomalies as a semi-elliptical long crack propagating from the first cycle. Such approaches often result into conservative predictions due to the fact that the model does not directly address the phenomena controlling crack initiation and the subsequent micro-propagation stage. Several factors may cause this conservatism as potential short crack behaviour from the notch formed by the anomaly or potential geometry and residual stresses effects.

Thus, the aim of the study is to characterize the influence of surface flaws on the propagation in the complex stress field surrounding the surface anomaly, in order to establish a new crack growth model that can account for the various phenomena observed. The material used in the present study is a Nickel based superalloy γ/γ'. For confidentiality reasons, it is not possible to provide further details on the designation and the chemical composition of this material. However additional results obtained in the Nickel based superalloy Inconel 718DA is shown. For the same reasons, the figure is provided without labels.

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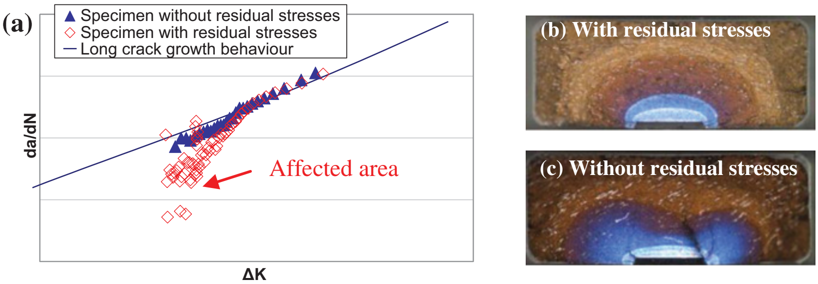

Figure 1. Effect of residual stresses on crack propagation rates (a) and on front crack morphologies (b, c) – Inconel 718DA.

2. Effect of residual stresses on fatigue crack growth

To evaluate the behaviour of surface anomalies, fatigue crack growth experiments were carried out in load control conditions on specimens with a rectangular cross-section of 3.5×8.3 mm containing two surface anomalies located on two opposite edge of the test piece. Two types of surface flaws are considered: scratches and dents. Indeed, scratches and dents are the most common surface anomalies observed on discs. In the present study they both have the same V-type profile in order to uncouple the effect of stress concentration induced by the flaw geometry from the influence of residual stresses on crack initiation and propagation Fatigue results corroborate the statements enounced in the introduction: experimental fatigue life is higher than calculated fatigue life for all testing parameters. According to fatigue crack growth rate data, the fatigue life seems to be controlled by the early stages of crack propagation. Indeed, a decrease in the crack growth rates is measured over a few hundreds of microns below the anomaly. Once this affected area is exceeded, the experimental crack growth rate increases to reach the material long crack growth behaviour (Fig. 1 empty diamond markers).

Several authors measured a compressive residual stress field below dynamic dents [1, 2] but also quasi-static dents [3], associated with a tensile residual stress state at the surface. Compressive residual stresses under the anomaly could explain the slower crack propagation observed. In order to demonstrate the effect of the residual stresses below the surface flaw on the crack propagation rate, fatigue crack growth experiments were carried out on specimens of Inconel 718DA exhibiting surface flaws after heat treatment to release residual stresses. These experiments also contribute to improve the understanding of the particular crack morphologies observed. Indeed the compressive residual stress induced by the introduction of the dent is such that the crack growth is difficult in-depth but more favourable in corner. In the other side, the crack morphology in the specimen without residual stresses is not affected and is semi-elliptical in shape in accordance with the assumption made. These experiments clearly indicate that after heat treatment the crack growth rates are similar to the long crack data (Fig. 1 full triangle markers), which shed into light the influence of the residual stress field beneath the surface flaw on the crack growth rate and the crack morphology. Consequently, residual stresses seem to be one of the parameters to take account for modelling the crack propagation from surface anomalies. The modelling strategy can be divided into several steps: numerical simulations of the introduction of a surface anomaly (scratch or dent) can be carried out in order to obtain the residual stress field. Then, numerical simulations of the crack propagation in this complex field can be computed for all testing parameters in order to calculate the stress intensity factor along the entire front crack and finally the specimen fatigue life. This strategy set up should permit to predict less conservative and more accurate fatigue lives.

References

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