Influence of T-stress on fatigue crack propagation

François Brugier, Yoann Guilhem, Sylvie Pommier

Influence of T-Stress on Fatigue Crack Growth

François Brugier[a,b], Yoann Guilhem[a], Sylvie Pommier[a]

[a] *LMT/ENS Cachan/CNRS/Université Paris-Saclay, 61 avenue du Président Wilson, 94230 Cachan, France*
[b] *SNECMA, Groupe Safran, Rond-point René Ravaud, 77550 Moissy-Cramayel, France*

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1. Introduction

Mechanical components of aircraft may suffer from shocks and scratches during their assembly. Under service, these structures are subjected to fatigue loading. This might lead to the initiation of micro-cracks, which will propagate, and in the worst cases, the fracture of the component might occur. Quantifying the total fatigue lifetime requires a good knowledge of mechanisms and kinetics of propagation throughout the evolution of the crack.

In the case of a crack, subjected to mode I, in the Fracture Mechanics framework, according to Irwin's plastic zone theory [1], the size of plastic zone at the crack tip will change with the presence of a not null T-stress. Especially a negative T-stress will increase this size. So, considering that crack propagation is governed by confined plasticity at the crack tip, as proposed by Laird [2] and Pelloux [3], it may affect fatigue crack growth rate. In the case of mechanically short cracks, this effect will be enhanced. Therefore, loading a long crack with a negative T-stress should mimic short fatigue crack conditions. The aim is to characterize the influence of T-stress on both long and short fatigue cracks growth and to propose a model accounting for this effect.

2. Experimental setups

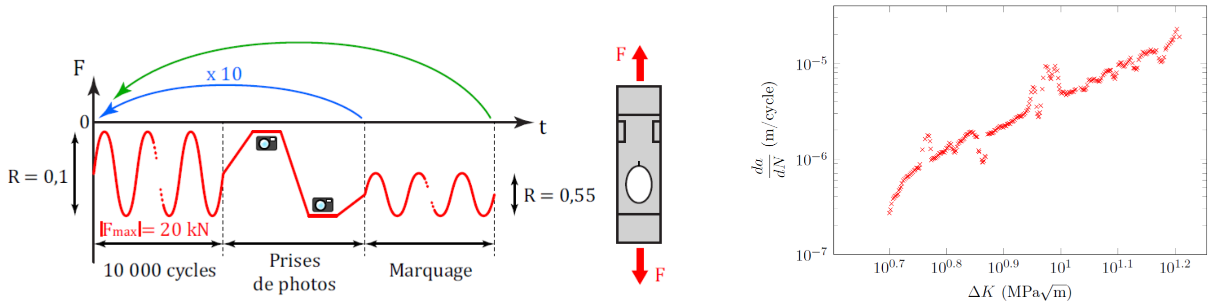
Two kinds of INCO 718 DA specimens are subjected to fatigue loadings similar to the one undergone by a short fatigue crack tip. The loading is composed of periodic blocks of:

- 10 000 fatigue cycles at $R = 0.1$, on both axes in case of biaxial test ;
- followed by a static loading stage to take an image of the open crack ;
- marking stage by increasing the loading ratio to 0.55, exclusively on second axis if $T \neq 0$.

Crack length is determined during both tests via potential method, using a crack tracker. Forces are measured through the loading cells. Stress intensity factors are deduced from the measured crack length and reported into Paris diagrams.

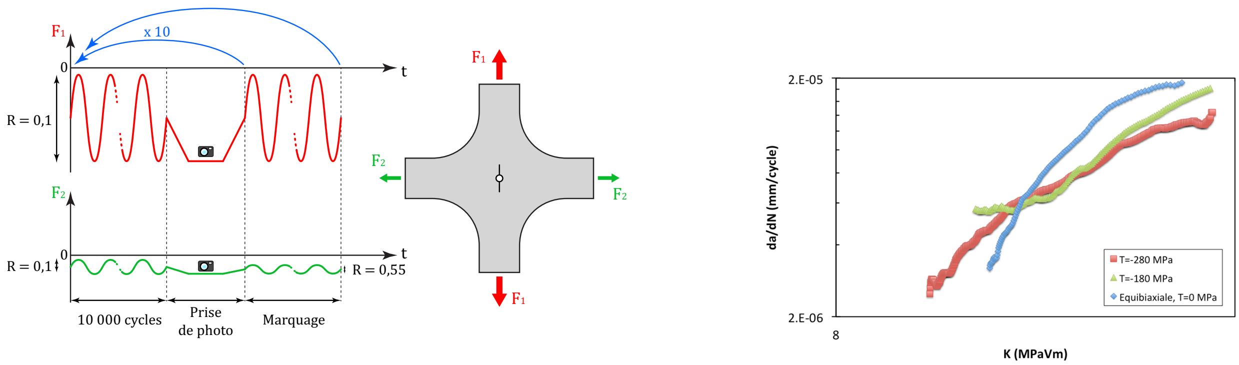
Short fatigue crack. Tension-compression fatigue tests under displacement control are processed on a notched elliptic hole specimen (see figure 1a). Results are reported on figure 1b.

Long fatigue crack with T-stress. Biaxial fatigue displacement controlled tests are carried out on cross-shape specimen (see figure 2a), using four actuators of the triaxial tension-compression hydraulic machine ASTREE. Null T-stress and negative T-stress biaxial fatigue loadings are considered. The first corresponds to an equibiaxial mode. T-stresses can be generated by applying a compressive load in the first axis, parallel to the crack, whereas the loading applied on the second axis, perpendicular to the crack, is either tension or compression depending on the T-stress range. Two negative T-stress configurations are considered: $T = -280\,\text{MPa}$ (respectively $T = -180\,\text{MPa}$) corresponding to a $100\,\mu\text{m}$ (respectively $150\,\mu\text{m}$) short crack.



(a) (b)

Figure 1: (a) Short fatigue crack experimental setup and the associated (b) Paris diagram.



(a) (b)

Figure 2: (a) Long fatigue crack experimental setup and the associated (b) Paris diagram, with various T-stress values (null and negatives).

3. Results and discussion

Once the results are reported in the Paris diagram (see figure 2b), it appears that in presence of a T-stress, compared to null T-stress case, crack growth rate close to the propagation threshold is higher, whereas crack growth rate at higher stress intensity factor range becomes lower. The first result is in good agreement with the classical observations on short fatigue cracks, but the second remains unexpected. It might lead to the conclusion that the effect of T-stress on short fatigue cracks is temporary. A better analysis could be given by taking into account the ratio of stress intensity factor over the T-stress.

A model is also proposed through a modified Paris law, based on a non-propagation criterion taking account of T-stress. As the ratio between T-stress and Stress Intensity Factor increases, as it would be for a short crack, short fatigue crack regime is well simulated. However, there are no effect on the long crack regime which remains identical to Paris law.

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