Analysis of fatigue crack growth with overload effects through T-stress

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Abstract
Fatigue crack is a major concern to all industries for safety reasons. Fatigue life predictions for structural components such as railways or turbine disks are based on fracture mechanics analysis. Such components are inevitably submitted to underloads or overloads. The aim of this paper is to provide a DIC-BASED experimental analysis of overload 2D fatigue cracks using higher order terms in the Williams' series expansion.

1 Introduction
As an example, components in service rarely experience constant load amplitudes during the length of the service. The prediction of the fatigue life of these components is often based on crack propagation calculations. However, overloads and underloads perturb steady state fatigue crack growth conditions and affect the growth rates by retarding or accelerating growth. The application of overloads generates complex effects on the crack behavior which induce delays that are difficult to predict. The mechanisms that have been proposed to explain retardation after tensile overload include, e.g. residual stress, crack closure and plasticity ahead of the crack tip.
In this work, based on DIC (Digital Image Correlation) we use full-field measurements to obtain Linear Elastic Fracture Mechanics (LEFM) crack tip features (Stress Intensity Factor (SIF) and T-stress). Therefore, with these crack tip features, we propose to analyze the T-stress effect on the crack growth propagation.

2 Method and Results
The Single Edge Notch Tension (SENT) specimens made with Aluminium alloy were tested on standard testing machines to obtain da/dN curves. For all the experiments we fixed the load ratio at R=0.1. The maximum load is denoted F_{max} . We made two types of experiments, those without overload and others with different levels of overloading for comparison. Thanks to DIC we have the full strain fields during propagation. The local ΔK_1 value and crack tip position are computed by fitting the measured displacement fields with Williams' series. The fatigue crack length and its growth rate are evaluated by comparing the crack tip position from cycle to cycle. We study the influence of overloads based on the variation of ΔK_1 and $\Delta T-stress$ before and after the overload. The results of the testing are shown in Fig. 1 and Fig. 2. In this test we applied three overloads at $F_{ovl}=1,25.F_{max}$.
Fig. 1 is a logarithmic scale representation of the crack growth rate da/dN as a function of the crack length a. The crack propagated sufficiently before we applied the first overload which is represented in a gray square in the figure. We can notice a drop in the crack growth each time we apply an overload. This result illustrates the delay mechanism attributed to plasticity in the crack tip and crack closure.

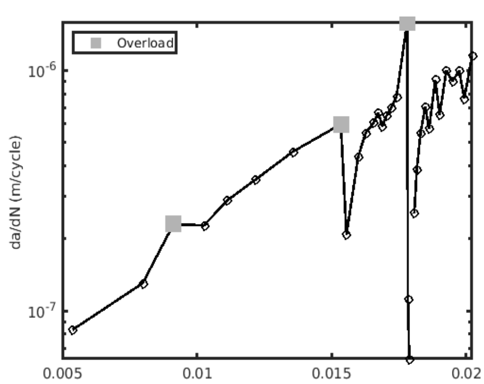

Fig. 1- Crack growth rate as function of crack length for Aluminium alloy

The values of $\Delta T - stress$ and ΔK_1 are represented with markers in Fig. 2. In the case of experiments without overload represented in Fig.2.1 we can observe a linear dependence between $\Delta T - stress$ and ΔK_1 . In Fig.2.2 for the first overload, as we expected we have a linear behavior in the load phase until F_{max} then we lost this linearity. To better understand this behavior we made a regression with piece-wise linear functions yielding. We obtain the continuous and the dashed lines approximation of the data. We can see the non-linear behavior in $\Delta T - stress$ and ΔK_1 hysteresis for the three overloads we applied. This is reminiscent of an elasto-plastic behavior. In the first overload we observe a superposition of the load and unload phase. In the second and third overload, we can notice that we have a linear behavior in the load phase until F_{max} then we lost this linearity probably due to the large plastic zone developed during overloading. Finally, we have linear unload with the same slope as during loading .

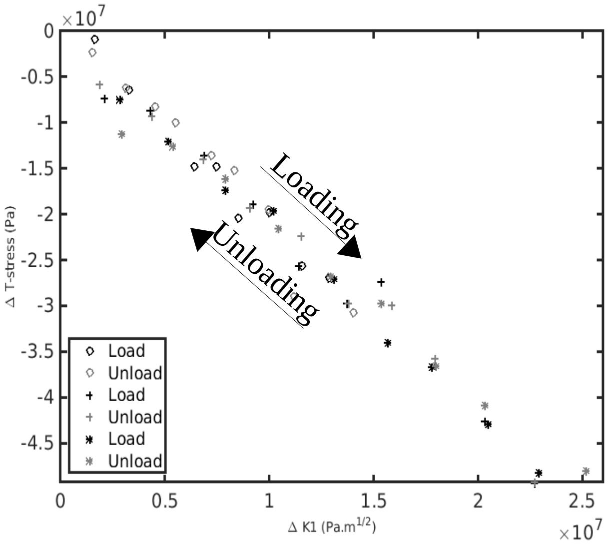

Fig. 2.1- $\Delta T - stress$ as function of ΔK_1 for Aluminium alloy without overload.

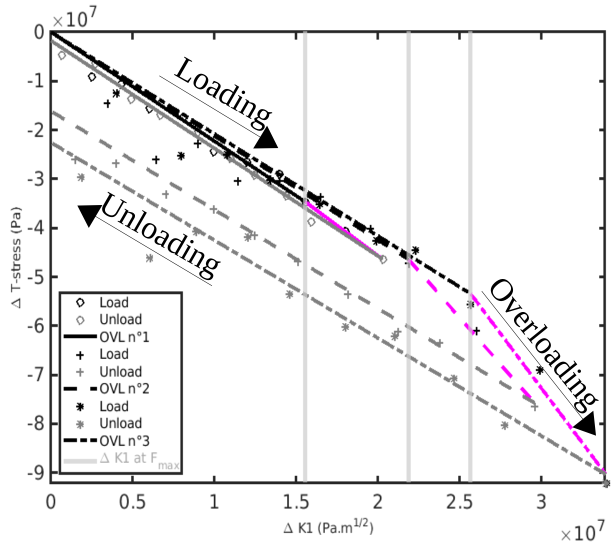

Fig.2.2- $\Delta T - stress$ as function of ΔK_1 for Aluminium alloy with overload.

3 Conclusion

In this work we study crack propagation with overload effects. We saw that (i) the application of an overload causes a delay in the fatigue crack growth rate (ii) a linear dependence between $\Delta T - stress$ and ΔK_1 in experiments without overload (iii) in the case of overload a $\Delta T - stress$ and ΔK_1 hysteresis.

Acknowledgments
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