EFFECT OF RESIDUAL STRESS AND STRAIN ON THE FATIGUE CRACK PROPAGATION IN AL2024T351 STRUCTURES

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Abstract: *This study highlights the contribution of residual stress/strain fields generated in service or by manufacturing processes in an aluminum alloy structure with respect to the fatigue life. As study example to expose phenomenon, bending of an Al2024T351 structure is investigated. First a thorough mechanical characterization of a material and identifying of a plastic anisotropic behavior model is carried out. Second, residual stress and strain computation in this component is carried out. Then, fatigue tests on CT and oligocyclic specimen have been conducted on as-received and pre-deformed material to further develop a fatigue crack propagation model to predict the residual life of the component including the effect of the residual stress and strains fields.*

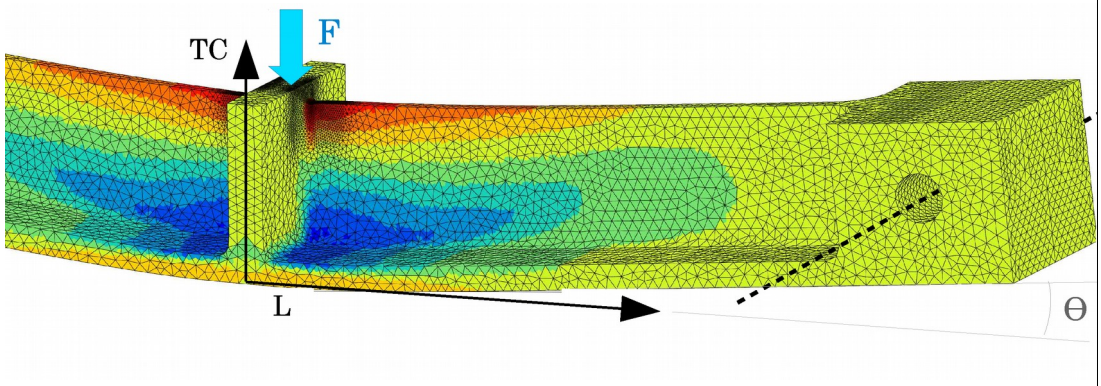
1. Introduction

Manufacturing processes commonly require to bend, stretch and deform material to give its final shape to machined components. Loading and manipulations in-use can change their geometry. All of these events can induce both residual stresses and significantly high plastic strains in localized regions of the component. At the same time, fatigue strength is in many cases, a crucial factor in certification especially for structural elements. Previous studies showed that residual stresses are likely to influence fatigue fracture by load transfer [1,2]. It was observed that pre-strain in a steel structure would reduce fatigue crack growth rate [3].
In this work, the case of a structure made of an aluminum alloy with a bend has been chosen. In particular, the effects of residual stresses and strain fields induced by the bending process, on the fatigue crack initiation and propagation are studied. In order to understand interactions between both phenomena, a combination of experimental testing and finite element simulations are used.

2. Approach

First, an anisotropic elasto-plastic Hill model has been chosen to describe the mechanical behavior of the material. The yield criterion, expressed by $f(\boldsymbol{\sigma}) = \boldsymbol{\sigma} - R(p)$, has been chosen to describe both the material anisotropy and non-linear plasticity $\boldsymbol{\sigma}$ is the equivalent stress [4] and R(p) an exponential isotropic hardening function, with p the cumulative plastic strain. A large set of mechanical tests was conducted and used to identify the material parameters Al2024 T351 thick sheets. The model reproduces very well the material anisotropy with respect to the (L,T) directions as well as the properties heterogeneity in the plate thickness direction. A finite elements analysis of the structure geometry and the identified model has been performed to establish the residual stress/strain fields resulting from a bending process (cf.. Figure 1).
The conclusion about study structure bending simulation is that the structure presents high residual stresses and strains due to bending, as shown by the simulation. According to the initial position of the sample in the aluminum plate and to the bending load, these stress and strain fields develop in the rolling direction. Compressive plastic strain shows a strong gradient with a maximum as high as 25% localized at the top of the structure. Residual stress

fluctuate from compression to tension but remain in tension where compressive plastic strain is at its highest level.



1: Residual stress in study structure specimen after bending

Next, the fatigue properties of the plate and of the homogeneously pre-deformed material have been characterized. Olygocyclic specimen for crack initiation and CT specimen for crack growth were used in both cases to assess the effect of the pre-strain on the fatigue strength of Al2024T351. As final test, the studied structure will be cyclically loaded and a crack growth will be expected where residual strain/stress are concentrated.
All of these experimental data are used to identify a fatigue crack initiation criterion and a LEFM Paris-like propagation law which takes into account crack closure.
The final goal of this work is to quantify contribution of residual stress/strain on fatigue crack behavior. A crack growth simulation within the study structure under cyclic loading will be conducted to compare the results with a scale 1 experiment.

References

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