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PROBABILISTIC FATIGUE ANALYSIS OF STRUCTURAL METALLIC COMPONENTS

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ABSTRACT

Probabilistic fatigue analysis enables to assess the failure probability and to quantify the relative influence of variability and uncertainty in all of the input. We are interested here in the probabilistic estimation of the lifetime of metallic structural parts. The aim of the proposed approach is to go beyond semi-probabilistic methods which consist in using a conservative deterministic fatigue law and in applying it to the most loaded point of the structure. A totally probabilistic approach of the “weakest link” type is preferred. The probabilistic fatigue law of the volume element is then intimately coupled with the scale effects and heterogeneity of the constraints present in the structure. The methodology has been applied on both low and high- K_t specimens.

Keywords: fatigue, metallic components, weakest link theory, log Weibull, probabilistic approach.

INTRODUCTION

Defects in metallic materials constitute potential sites for crack initiation. These defects are distributed randomly within the material and are the main cause of the lifetime dispersion for this type of material. It is important to consider for the lifetime assessment scale effects during the transition from the volume element to the structure. For this, a completely probabilistic description of the problem is proposed through an approach of the "weakest link" type (the structure survives if and only if none of its volume elements breaks) in which the lifetime is probabilised using an accelerated Log-Weibull model.

RESULTS AND CONCLUSIONS

In this work, a Weibull law has been used to model the dispersion of the log of the lifetime where the loading S is linked to the average lifetime (comparable to the scale parameter of the law) thanks to a Basquin law (power law in S shape). In addition, a linear evolution of the dispersion with the mean (constant coefficient of variation) has been considered. The choice of an accelerated Weibull law for the log of lifetime is more conservative by nature than a Normal law conventionally used (heavy-tailed distribution and asymmetry) in fatigue. This choice is all the more relevant as it facilitates the transition from the volume element to the structure through numerical integration in post-processing.

A mixed criterion in stress and strain [1], but which also considers the effect of the mean stress of the cycle, has been applied. This criterion makes it possible to connect the characteristic quantities of the stabilized cycle $\{\varepsilon_a, R_\varepsilon, \sigma_a, R_\sigma, \sigma_{moy}\}$ to a number of cycles to crack initiation. More precisely, the parameters $\{A, \alpha, B, \beta\}$ of the criterion have been identified by considering

a Manson-Coffin type lifetime function. We thus work with a “master” quantity, defined by the

$$\sigma_{a_{eff}}^{alt} = E \sqrt{\varepsilon_{e_a}^{alt} (\varepsilon_{e_a}^{alt} + \varepsilon_{p_a}^{alt})} = E \sqrt{ABN_f^{-\alpha-\beta} + B^2N_f^{-2\beta}}.$$

In the model, this effective stress was partitioned into two distinct contributions, one coming from the plastic behaviour of the material (at high loading and low lifetime or LCF regime) and the other coming from its elastic behaviour (at lower loading and long lifetime or HCF regime). Each of the contributions has been modelled by a Basquin law (power law of life). We used a maximum likelihood identification method whose numerical efficiency (Iteratively Reweighted Least Squares) allows coupling with the bootstrap technique, for bias correction and confidence estimation. This notion of confidence has been integrated in order to offer a conservative distribution taking into account the uncertainty of identification. The model regression gives results in the standards since the conservative curves R90C95 resulting from the linear identification effectively have a percentage of points below these lower than 10% (9% for the elastic regime and 1% for the plastic regime). However, the statistical tests still tell us that Weibull's law is a wise choice for modelling long lifetimes.

Both low and high- K_t specimens have constituted the structural cases of this study, Figure 1. The mere consideration of the HCF regime proved to be insufficient to correctly estimate the structural lifetimes and led us to consider the entire database and the two regime contributions. Indeed, we need to integrate the stress levels of the points at the origin of the rupture on the simulated specimen, which correspond to the LCF regime of our data. The results obtained for the samples with low K_t are still too conservative while those obtained for the samples with high K_t seem in agreement with the experiment.

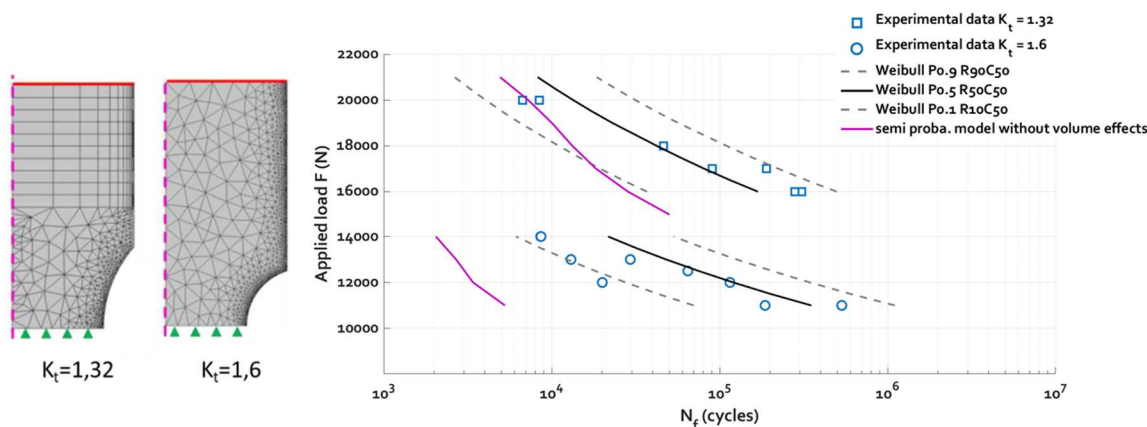


Fig. 1 - Mesh of both specimens (left) and fatigue prediction (right) with fully probabilistic method (Weibull P=0.1; 0.5 and 0.9) and semi probabilistic method without considering neither volume nor gradient effects [2].

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