Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 101 (2015) 485 – 492
Procedia Engineering
www.elsevier.com/locate/procedia

3rd International Conference on Material and Component Performance under Variable Amplitude Loading, VAL2015

Influence of the transient material behaviour in the fatigue life estimation under random loading

A. Tomasella[a]*, R. Wagener[b], T. Melz[a,b]

[a] Chair of System Reliability and Machine Acoustics SzM, TU Darmstadt, Magdalenenstrasse 4, 64289 Darmstadt, Germany
[b] Fraunhofer Institute for Structural Durability and System Reliability LBF, Bartningstrasse 47, 64289 Darmstadt, Germany

Abstract

The estimation of the fatigue life under variable amplitude loading is a fundamental step in the design phase. To consider variable amplitudes in the fatigue design the linear damage accumulation is applied, thus disregarding non linearity. When materials show cyclic hardening/softening, the hypotheses from Palmgren and Miner are not valid and this causes appreciable errors in the fatigue life estimation. Fatigue tests were carried out on the steel HC340LA. The influence of strain softening and mean stress relaxation is shown. A simplified method for considering this transient phase is presented. More accurate results can be achieved by applying this method.

Peer-review under responsibility of the Czech Society for Mechanics

Keywords: cyclic material behaviour; strain softening; mean stress relaxation; fatigue life estimation; local strain approach.

1. Introduction

In the fatigue design of components the consideration of real service conditions is a necessary step in order to guarantee the required durability while reducing costs, weight and dimensions at the same time. Especially in

* Corresponding author. Tel.: +49-6151-705-8295; fax: +49-6151-705-214.
*E-mail address:*tomasella@szm.tu-darmstadt.de

Peer-review under responsibility of the Czech Society for Mechanics
doi:10.1016/j.proeng.2015.02.058

Nomenclature

D	damage
N_F	cycles to failure
ε_a	strain amplitude
ε_m	mean strain
σ_a	stress amplitude
σ_m	mean stress
E	Young's modulus
K'	cyclic strength coefficient
n'	cyclic strain hardening exponent
$\Delta\varepsilon$	strain range
$\Delta\sigma$	stress range

components that are subjected to variable amplitude loading conditions during service, the proper approach considering the variable amplitude loading fatigue can lead to a drastic reduction of component weight and cost, as shown with a representative simple example in [1]. In this example the consideration of the spectrum shape, moving from the constant amplitude loading to a straight line distribution implies a reduction of the diameter of a round bar of about 27%, with a reduction of weight of about 47% for the same estimated fatigue life.

In order to carry out a fatigue life estimation considering the variable amplitude loading during service, several approaches and damage rules were formulated since the first investigations performed by Palmgren [2] and Miner [3]. A comprehensive review of these methods was presented in [4].

Due to its simple and quick application, the linear damage accumulation from Palmgren-Miner is in the standard practice the most used method for the calculation of the fatigue life of components. According to this rule, each loading cycle is responsible of the same fatigue damage, under the assumption that the total work absorbed produces failure and no work hardening occurs. If this hypothesis is valid, under constant amplitude loading the damage induced by one single loading cycle corresponds to:

$$D_i = \frac{1}{N_{F,i}}$$

with N_i corresponding to the fatigue life at failure (D = 1).
The hypothesis can be directly extended to the case of multiple load amplitudes as shown in Eq. (1).

$$D = \frac{n_1}{N_{F,1}} + \frac{n_2}{N_{F,2}} + ... + \frac{n_X}{N_{F,X}} = \sum_{i=1}^{X} \frac{n_i}{N_{F,i}} = 1 \quad (1)$$

This rule can easily be extended to all materials and load cases, even if the original formulation was limited to aluminum alloys [3]. By applying this rule, load sequence, load interaction and load levels are disregarded, which was proved to be a source of inaccuracy in the determination of the fatigue life.

For the application of the local strain approach, several damage parameters were formulated and used in combination with the linear damage accumulation. Among these, the parameter of Smith-Watson-Topper [5], the energy approaches considering the dissipated hysteresis energy, for example in the formulation of Golos and Ellyin [6] and the P_J, based on mechanics and growth of short cracks [7], are worth to be mentioned.

In order to apply these methods the reconstruction of the stress-strain paths is necessary and the procedure used for this reconstruction can deeply affect the quality of the estimations. In literature many material models, considering material memory, kinematic and isotropic hardening were formulated, for example the ones reported in [8-12].