Available online at www.sciencedirect.com
ScienceDirect
International Journal of Fatigue 29 (2007) 1772–1780
International Journal of Fatigue
www.elsevier.com/locate/ijfatigue

Computer simulation of fatigue crack propagation under random loading conditions

A. Bacila [a,b,*], X. Decoopman [a], R. Vatavu [c], G. Mesmacque [a], M. Voda [a,b], V.A. Serban [b]

[a] *Laboratoire de Mécanique de Lille, UMR CNRS 8107, IUT A GMP Le recueil. Rue de la recherche BP 179, 59653 Villeneuve d'Ascq, France*
[b] *Mechanical Faculty of Timisoara, Bd. Mihai Viteazu Nr.1, Timisoara 300222, Romania*
[c] *The "Stefan cel mare" University of Suceava, Universitatii 13, 720229 Suceava, Romania*

Received 7 September 2006; received in revised form 16 February 2007; accepted 26 February 2007
Available online 14 March 2007

Abstract

The aim of this study is to simulate fatigue crack propagation under random loading conditions using a simple algorithm based on the Wheeler model [Wheeler O. Spectrum loading and crack growth. J Basic Eng D 1972;94:181–86]. To create the computer simulation, a model based on the mechanical properties of the material has been used. These properties include the yield stress (σ_y) and Paris's constants C and m. The loading conditions (baseline loading ratio R, baseline stress intensity factor range ΔK and overload stress intensity factor K_{ol}, R_{ol}) are also required. The present model is validated with fatigue crack growth test data conducted on 12NC6 steel samples with four different heat treatments in order to have different types of mechanical behavior. The computer simulation and experimental results for crack propagation for different overload distributions (a single overload, a repeated overload, different overload magnitudes, random overload) are in good agreement.

Keywords: Fatigue crack propagation; Overload; Random loading; Computer simulation

1. Introduction

While periodic maintenance inspection programs are vital for the prevention of critical failures, they are both costly and time consuming. Even an overload test with a single overload takes about 20 h.

In particular, fatigue tests are very expensive, since they require a lot of human and machine time, so it is very important to find models and develop suitable software in order to simulate fatigue analyses.

A number of models for performing broad-spectrum fatigue analyses have been proposed, including non-linear damage summation models [2,3], strain–energy methods [4,5] and models that use modified strain–life curves together with a linear damage rule [6–8]. The major shortcoming of many of these models is that they are often material-specific and are therefore unsuitable for incorporation into computer simulation programs for general use.

We decided to solve the problem of predicting crack propagation evolution with simple software that does not need performant computer resources, but uses a simple mathematical model based on a traditional approach that can also reproduce the behavior of a structure in the case of different overload distributions.

The software can run various types of overload conditions.

Many experimental results have been compared with the simulated results. This comparison shows a good agreement.

2. Experiments

In order to establish a model for the initial delay in crack evolution in the case of overload, compact tension (CT) specimens, 15 mm wide and 80 mm long, made of

* Corresponding author. Address: Laboratoire de Mécanique de Lille, UMR CNRS 8107, IUT A GMP Le recueil. Rue de la recherche BP 179, 59653 Villeneuve d'Ascq, France.
E-mail address: bacila@ed.univ-lille1.fr (A. Bacila).

0142-1123/$ - see front matter
doi:10.1016/j.ijfatigue.2007.02.026

Nomenclature

a	crack length (mm)
a_{ol}	crack length where the overload was applied (mm)
a_d	crack length affected by overload (mm)
a_{min}	crack length associated with the minimum crack growth rate (mm)
C, m	Paris's constants
ΔK	baseline stress intensity factor range ($=K_{max} - K_{min}$) (MPa $\sqrt{m}$)
K_{ol}	stress intensity factor for overload (MPa $\sqrt{m}$)
K_1	stress intensity factor for the first crack propagation (MPa $\sqrt{m}$)
K_{1ol}	stress intensity factor for the first overload (MPa $\sqrt{m}$)
K_2	stress intensity factor for the second crack propagation (MPa $\sqrt{m}$)
K_{2ol}	stress intensity factor for the second overload (MPa $\sqrt{m}$)
N	number of cycles
R	baseline stress intensity factor ratio ($=K_{min}/K_{max}$)
R_{ol}	overload ratio ($=K_{ol}/K_{max}$)
σ_y	material yield stress (MPa)
ω_{ol}^{m}	overload monotonic plastic zone $= \alpha\ (K_{ol}/\sigma_y)^2$ (mm)
ω_{ol}^{c}	overload cyclic plastic zone $= \alpha\ ((K_{ol} - K_{min})/2\sigma_y)^2$ (mm)
ω_{base}^{m}	baseline monotonic plastic zone $= \alpha\ (K_{max}/\sigma_y)^2$ (mm)
ω_{base}^{c}	baseline cyclic plastic zone $= \alpha\ (\Delta K/2\sigma_y)^2$ (mm)
S_r	severity ratio $\left(= \frac{(da/dN)_{min}}{(da/dN)_{base}}\right)$

12NC6 steel were used. The dimensions of the samples are in accordance with the prescription ASTM E647 as in Fig. 1.

Four different heat treatments were selected in order to obtain four different types of mechanical behavior. Each treatment begins with an austenization at 880 °C for 1 h. The subsequent treatments are as follows:

- Treatment TR300, which is quenching with water followed by tempering to 300 °C.
- Treatment TR500, which is quenching with water followed by tempering to 500 °C.
- Treatment NA (normalizing in air), which is cooling with air.
- Treatment NF (normalizing in the furnace), which is cooling in the furnace.

The mechanical characteristics of 12NC6 steel are displayed in Table 1.

Crack tests (constant amplitude and overload) were carried out using an INSTRON 8500 test machine with a capacity of ±100 kN and a maximal frequency of 50 Hz.

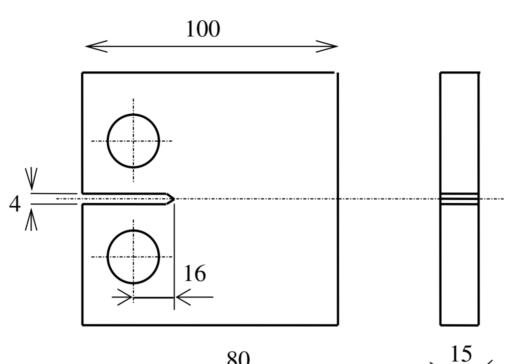

Fig. 1. Geometry of the samples (in mm).

These tests were carried out at room temperature. The test frequency was 30 Hz. The crack propagation length was measured on the front of the specimen. A binocular magnifying glass (20×) set on a micrometric table (50 mm stroke, 0.05 mm accuracy) was used. A camera views the other side of the specimen and thus enables the crack growth to be monitored. A stroboscopic lamp set at the fatigue test frequency allows the crack length to be measured.

The measurement of the crack closure is carried out on a 0.1 Hz frequency cycle. Data are recorded at each load adjustment as well as during pre-overload, during overload and post-overload cycles.

One of the objectives of this experimental study was to analyze the role of each plasticized zone in the delay in crack propagation.

It should be stressed that the loading parameters of in an overload test of the type defined here are determined by three values: two of these characterize the initial loading (the load ratio R and the baseline amplitude ΔK); the last relates to the amplitude of the overload (i.e., to the choice of K_{ol}, R_{ol} or τ_{ol}). Each of these three values produces an effect on one or more of the plasticized zones (four in the case of a single overload):

- $\omega_{ol}^{m} = \alpha \cdot (K_{ol}/\sigma_y)^2$: monotonic plastic zone of overload;
- $\omega_{ol}^{c} = \alpha \cdot (\Delta K_{ol}/2\sigma_y)^2$: cyclic plastic zone of overload;
- $\omega_{base}^{m} = \alpha \cdot (K_{max}/\sigma_y)^2$: monotonic plastic zone of basic loading;
- $\omega_{base}^{c} = \alpha \cdot (\Delta K/2\sigma_y)^2$: cyclic plastic zone of basic loading.

The material becomes monotonically plasticized during the first part of the cycle (loading), whereas cyclic plasticization occurs during the second part of the cycle (unloading) on a material that is already plasticized. The design