Materials and Design 86 (2015) 640–648

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/jmad

Fatigue curves of a low carbon steel obtained from vibration experiments with an electrodynamic shaker

Leila Khalij [a,*], Christophe Gautrelet [a], Alain Guillet [b]

[a] Normandie université, LOFIMS/INSA de ROUEN, France

[b] Normandie université, GPM UMR CNRS 6634, Université-INSA de Rouen, Technopole du Madrillet, Avenue de l'université, BP 08, 76801 Saint Etienne du Rouvray cedex, France

ARTICLE INFO

Article history:
Received 31 January 2015
Received in revised form 12 July 2015
Accepted 28 July 2015
Available online 31 July 2015

Keywords:
High cycle vibratory fatigue
Electrodynamic shaker ε–N_f curves
Real-time closed loop adaptive control
Failure criterion
Trans- and inter-granular fractures

ABSTRACT

This paper presents an original contribution for the establishment of the high-cycle fatigue curves ε–N_f (strain versus cycle number to failure) of low carbon steel under vibratory testing. These curves are obtained thanks to a vibrational fatigue bench composed of an electrodynamic shaker and a closed loop vibration control system. The main advantage of this is the high frequency excitation compared to conventional fatigue systems. Three criteria based on strain gauge measurements are implemented to provide cycle numbers to failure N_f and to plot the fatigue curves. Furthermore, cycle numbers to failure are also assessed from two modal parameters (resonant frequency and loss damping factor) and compared with the results obtained from these three criteria. Some micrographies of fractured samples observed by scanning electron microscope reveal fatigue striations but also intergranular fracture.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

Conventional fatigue tests are commonly performed with servo-hydraulic testing machines, where, for the most recent machines, the frequency ranges between 50 Hz and 1000 Hz [1]. Then fatigue tests to achieve a large number of cycles around the endurance limit are costly and time consuming. In order to perform a higher number of cycles in a short period of time and to study the dynamical response of specimen, accelerated vibrational fatigue testing with electro-dynamic shaker is preferably used. George et al. [2] give in 2004 a brief historical overview of these testing machines. More recently, different studies of vibratory fatigue damage, with complex excitations are found in the literature [3–8] for better prediction behaviour close to real-life service.

Compared to servo-hydraulic machines, these systems work on a wide frequency range, up to 1000 Hz and lead to a response amplification in the resonant area. Therefore, the strain or stress response level of the specimen can be high even if a relatively small excitation acceleration or force at the input is applied.

Characterization of material behaviour in the high-cycle fatigue domain is of a great interest for many authors. Indeed, the so-called S–N_f curves are established more quickly thanks to the vibrational testing mode. Murugan et al. [9] studied AZ91 magnesium alloy and compare the S–N_f curves obtained from an electro-dynamic shaker with the existing fatigue data. Allegri et al. [4] proposed a method to represent the S–N_f curves from random loading based on the root mean square stress value versus the total number of zero-crossing with positive slope. Other authors have chosen to establish D–N_f curves where D is the deflection, in order to investigate the performance of magnesium alloy under resonant conditions [10–12]. The resonant frequency is taken as the frequency leading to the largest deflection and is determined by varying the vibration frequency continuously.

In this paper, we present an improved accelerated vibrational fatigue-testing methodology using a real-time closed loop adaptive control. The dynamic response is used to establish the ε–N_f curves of a low carbon steel, where ε is the experimental strain range measured from gauges. After a certain number of cycles, a reduction of the structural stiffness occurs because of crack initiation. Systematically the strain amplitude decreases with time due to strength loss of the specimen. Three failure criteria are then defined from the reduction of the strain slope and are compared and confronted with modal parameter changes. Therefore, the transmissibility function is simultaneously recorded during the test in order to deduce the resonant frequency shift and the loss damping factor variation. Indeed, a decrease of the first resonant frequency is thus experimentally observed with accumulated damage. Cesnik et al. [13] present an experimental approach to perform fatigue test with simultaneous tracking of the modal parameter variation and particularly the natural frequencies and damping loss factors [14].

The first part presents the experimental setup and the protocol of the carried out experiments. A discussion based on obtained results is given on the second part. This discussion shows the link between the strain gauge measurement, the evolution of the modal parameters and

* Corresponding author.
E-mail address: leila.khalij@insa-rouen.fr (L. Khalij).

http://dx.doi.org/10.1016/j.matdes.2015.07.153
0264-1275/© 2015 Elsevier Ltd. All rights reserved.

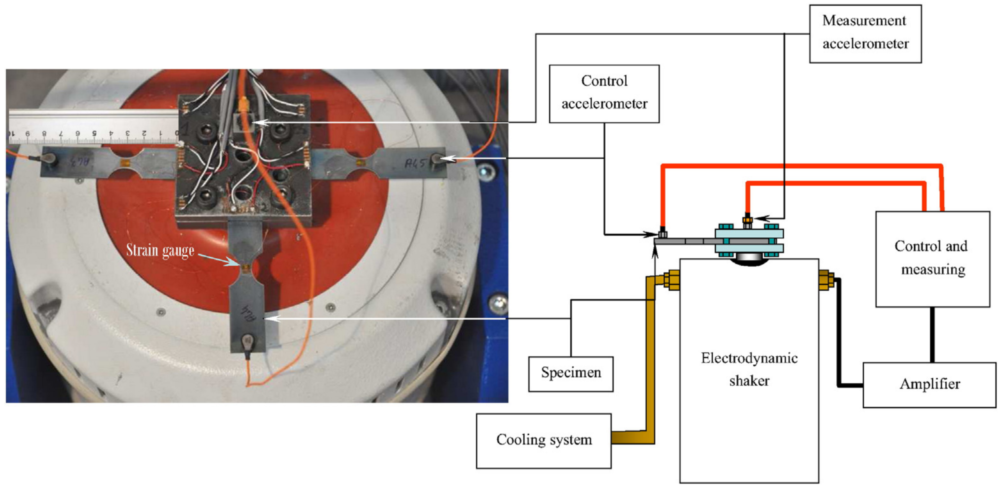

Fig. 1. Experimental set up of fatigue test: real and illustrative view.

the crack initiation. The last part concerns observations of fractured surfaces from scanning electron microscope (SEM).

2. Experimental setup and processing technique

2.1. Equipment for closed-loop testing

The experimental setup of fatigue testing consists in an air-cooled electrodynamic shaker with an acquisition control peripheral (ACP), power amplifier which converts the amplified signal to mechanical motion, rigid fixture, transducers and analysis system as presented in Fig. 1.

The ACP is a multi-shaker control software which can be used to control one or more shakers with multiple transducers. Furthermore, this system allows a closed loop vibration control, which guarantees a true control without loss of performance. This paper concerns only sinusoidal tests with a single shaker.

Dynamic tests are performed at constant amplitude acceleration and around a given frequency. The input acceleration is amplified by the power amplifier to a level sufficient to drive the shaker. The acceleration signals are measured with two accelerometers:

– One mounted on the clamped boundary in order to monitor and control the shaker.
– Another is installed at the free end of the sample to measure the fully reversed transverse acceleration response. The mass of this accelerometer is low (0.7 gr) in order to avoid measurement perturbation.

The transmissibility function corresponding to the output–input ratio, is constructed with both measures.

Three cantilever beams are used for each fatigue experiments. These samples are rigidly mounted on the vibration shaker through an appropriate fixture designed and machined for the experiments.

2.2. Fatigue specimen design and material

In order to design the specimen shape and to define the area of crack initiation, the natural frequencies and mode shapes were first computed by finite element analysis. The first mode (bending) is chosen because it leads to a higher deflection. The samples were then machined from plates (Fig. 2) with a stress raiser zone far from the clamp.

The strain measures are obtained during the experiments by sticking the gauges (Fig. 2b) at the centre of the stress raiser zone. This area is selected for 3 reasons:

1) To avoid the notch effects due to the discontinuity (dependent on the surface finish effects). The active grid length chosen is small in order to measure strain on a narrow area and to minimize the averaging error.
2) We choose to record the strain associated with a significant loss of rigidity as a criterion for crack initiation, although we are well aware that the actual crack initiation may occur before.
3) The localization of crack initiation is not easy to define and the duplication of sensors increases the rigidity of the system. Furthermore, Fig. 13a–b (SEM images of fractured surfaces) reveals a centerline and opposite striations which led us to think that the crack initiations occurred on both faces of the sample.

The material is a low carbon steel (wt.%C < 0.1) heat treated at 900 °C for 1 h under primary vacuum and then furnace cooled. The microstructure is mainly ferritic with few pearlitic colonies in agreement with the $Fe–Fe_3C$ phase diagram.

Monotonic tensile tests up to fracture, were also carried out at different strain rates on sub-sized specimen (35×5.41 mm^3), the results appear in Fig. 3.

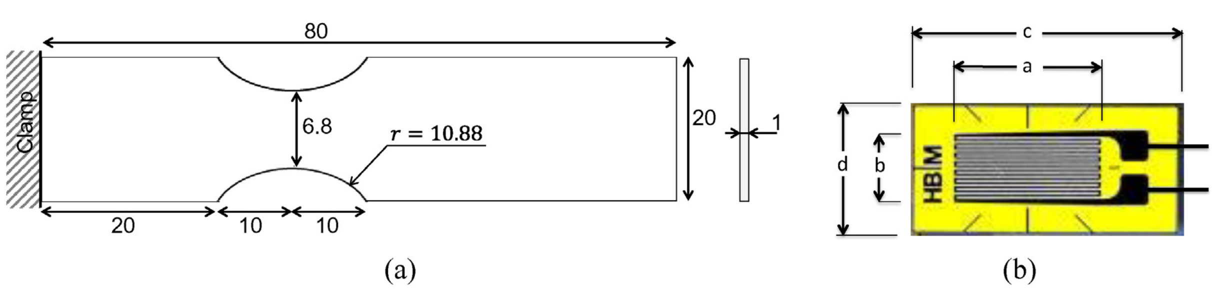

Fig. 2. (a) Shape and dimensions of specimen (mm). (b) Strain gauge dimensions: active grid length $a = 1.5$ mm, grid width $b = 1.2$ mm, matrix length $c = 6.5$ mm and matrix width $d = 4.7$ mm.

Download English Version:

https://daneshyari.com/en/article/7220549

Download Persian Version:

https://daneshyari.com/article/7220549

Daneshyari.com