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Acoustic sources from damage propagation in Ti grade 5

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ABSTRACT

In this paper fatigue test results are presented for titanium grade 5 specimens subjected to uniaxial cyclic loads. The material behavior of titanium was studied by comparing the Acoustic Emission (AE) detection technique with the Infrared Thermography (IT). The AE technique consists on attaching a couple of piezoelectric sensors on the surface of the sample in order to allow real-time recording of acoustic activity occurring in the material during the test and to localize the acoustic source, based on the assumption that part of the acoustic activity depends on the crack propagation process. All typical data of AE were collected during the tests and some of them were properly post-processed by using filters or derivative functions in order to better understand the crack propagation phenomenon. At the same time, thermographic analysis was also carried out during the experiments by continuous monitoring of surface temperature of the sample. Results of the fatigue behavior of the analyzed material beside the acoustic emission track and the thermal images of the sample are analyzed and critically discussed, in order to assess the capability of each technique in predicting the imminent failure of material.

1. Introduction

Much interest appears today in studying titanium grade 5 (Ti6Al4V). Aircraft industry, in particular, is greatly pushing toward the introduction of new materials allowing obtaining lighter structures, which would lead to a reduced fuel consumption and, as a consequence, cost and emissions reduction [1]. In this context titanium grade 5 in view of its very good strength-to-density ratio beside a significantly good corrosion resistance, can represent a good solution for many structural parts [2,3]. Nevertheless, besides these properties, it also displays an high biological compatibility; this occurrence expands the fields of application of this materials also to the biomechanics where it can be adopted, for example, for the manufacturing of prostheses [4,5]. However still few data on fatigue characterization of titanium alloy are presented in literature [6–8] and much more insight is required to fully understand fracture mechanisms in this material.

Having this in mind, in this paper, results in terms of acoustic emission (AE) recorded during uniaxial fatigue testing of Ti grade 5 are presented. AE technique is a monitoring approach based upon the detection of acoustic waves generated inside a sample [9–11], which is subjected to some thermal or mechanical loading. The signal detection is obtained by properly placing two piezoelectric sensors on the sample surface. Possible sources of acoustic emissions can be related with crack nucleation and propagation, motion of dislocations, residual stress relaxation and so on [12,13]. The innovative application of this kind of non-destructive monitoring approach on fatigue tests allows to continuous monitor tests [14] without any necessity to stop them and could really provide some evidences about what is happening to the sample during the performed test. In the last years this approach was successfully applied on different experiment configurations as a local annealing treatment [15–18], the monitoring of crack propagation in aluminum samples [19], in steel [20] and also in titanium [21,22] introducing considerations about the source localization and the choice of amplitude and spatial filter respect to [23,24].

At the same time also IT (Infrared Thermography) was applied on samples subjected to the same cyclic loads. It is a full-field technique allowing fatigue damage localization due to the local rising of the temperature caused by the total energy dissipated in heat [25].

In this paper the AE detection system was used together with IT in order to have a comparison between the two techniques about their capability to follow the damage evolution in the samples [26,27].

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2. Materials and methods

Seven samples obtained by laser cutting of titanium grade 5 sheet were tested. They have a rectangular cross section of 40 mm × 4 mm and a length of 200 mm. Two notches having $r = 5$ mm radius were laser cut at the middle length of each sample, in order to introduce a stress concentration area in which the crack initiation was localized. Samples were subjected to three different maximum stresses (91.7 MPa, 125 MPa and 150 MPa) in elastic sinusoidal loading conditions ($R = -1$) and a loading frequency $f = 3$ Hz, by a uniaxial Instron servo-hydraulic machine ($F_{max} = \pm 100$ kN). The detection of the acoustic waves was performed by two piezoelectric sensors Mistras Picosensor having a 250–750 kHz bandwidth and a 500 kHz resonance frequency [28].

The two sensors were placed along the longitudinal line (y direction) of the sample, symmetrically with respect to the line of the notches and far one from each other 80 mm (Fig. 1). Signal from the sensor are preamplified with a 40 dB gain and then transmitted to the PC for further elaboration and for storage. By knowing both the speed wave velocity characteristics of titanium and the mutual distance of the two sensors it is possible to identify the precise in-axis location of the events considering the difference in terms arrival time of the signal on each sensor.

For the thermographic image acquisition the sample was dark painted on one face by black matt spray having an emissivity coefficient of 0.97 thermal emission was recorded in real time during the fatigue test by a NEC H2600 thermocamera having a 640 × 480 pixel detector and a FOV, at the adopted working distance, of 0.2 m × 0.15 m (horizontal × vertical). The thermocamera was placed perpendicularly in front of the specimen at a distance of 55 cm and at the frequency acquisition rate was set to 30 Hz. The set-up including thermocamera, loading machine, sample and piezoelectric sensors is shown in Fig. 2.

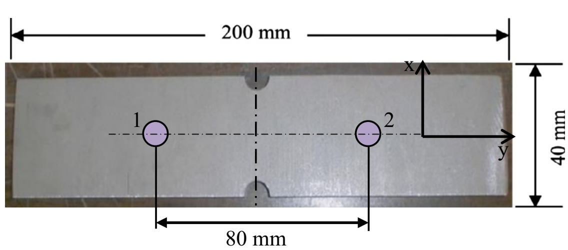

Fig. 1. Geometry of Ti grade 5 samples and disposition of the 2 acoustic sensors on each sample.

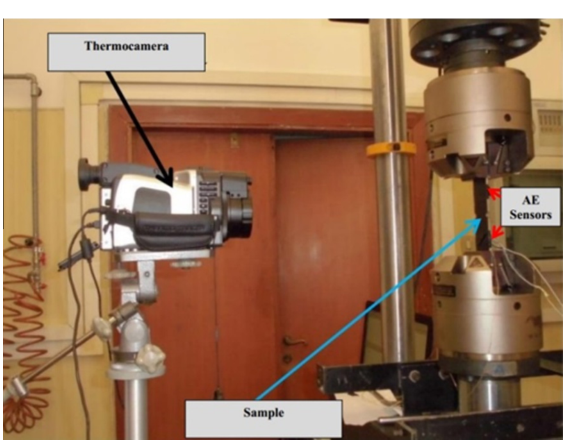

Fig. 2. Thermocamera NEC H2600 used for temperature images recording.

3. Results and discussion

In Fig. 3 the σ_a vs N graph is reported on a double logarithmic diagram where N represents the total number of cycles. The stress results show that, as obviously expected, samples subjected to higher amplitude loads reached the failure in shorter time than the ones subjected to lower loads. It is interesting to note also that at the same amplitude loads not all the specimen were broken; furthermore an evident variation in the number of cycles necessary to break the sample was observed. Only two samples were not broken during the test, but in both cases it was stopped at about five millions cycles, they are indicated in the graph by two arrows. The equation reported in the graph is obtained considering that σ_a–N relation can be quite well fitted by a power law, since all the specimen lay in the intermediate range of fatigue life, that is to say between 10^3 and 10^7 cycles [29].

In Fig. 4 the density activity ρ of acoustic is reported as a function of $\tilde{N}$ that is to say the number of cycles normalized to the total number of cycles of the entire test. The density activity ρ represents the number of hits [30] recorded into two given reference volumes. This volumes have the same extension (10 mm × 10 mm × 4 mm), and are placed respectively close to the notches and far from them. The control volume near to the notches lays exactly at the center of the specimen that is to say centered along the axis connecting the two notches. The control volume far from the notches lays at 32 mm from the axis connecting the two slots. The system is capable to discriminate between the events occurred in the two areas by using the information on the difference of the arrival time on the two PZT sensors. It is possible to see that most of the acoustic signals occur in the stress

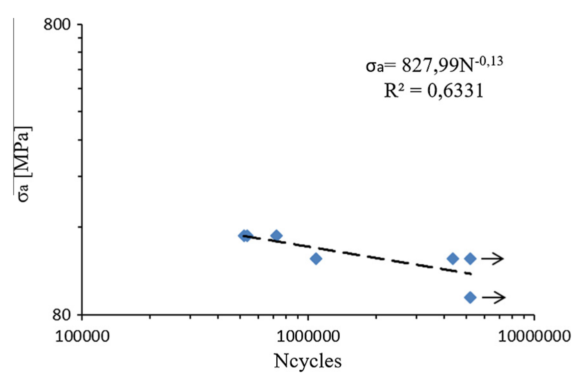

Fig. 3. Wöhler graph obtained for the titanium grade 5 tested specimens; arrows indicates the samples not broken at the end of the test.

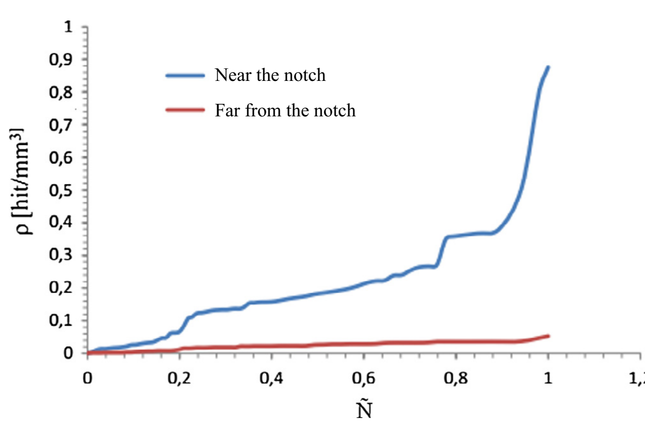

Fig. 4. Trend of density of hits recorded in two different region, close and far from the notch, as a function of the normalized number of cycles.