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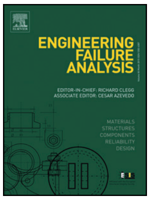

Analysis of crack propagation in stainless steel by comparing acoustic emissions and infrared thermography data

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ABSTRACT

The aim of this work is to provide, in a non-destructive way, information about the structural integrity of materials subjected to a sinusoidal fatigue loading. In particular, the crack propagation was studied in AISI 430F/1 by using Acoustic Emission (AE) and Infrared Thermography (IT) at the same time. The main advantages of both approaches refer to the possibility to monitor the whole history of the specimen; in fact, differently by ultrasound inspection, no scanning is required and moreover the measurement is simplified by the fact that access from just one side of the specimen is sufficient. For AE technique two sensors were placed on the surface of the specimen in order to detect the elastic waves emitted by the material under stress and due to the activation of inner defects. By analyzing the overall acoustic signals it is possible to correlate a part of them directly to the crack propagation phenomenon. At the same time a thermocamera was placed in front of the specimen to live monitor the variation of surface temperature. Above all, the rise of temperature around the crack tip was observed in order to evaluate the advancing of the crack during the test. Finally a comparison between the two techniques was carried out aiming to assess the capability of each approach in following the evolution of the damage process.

1. Introduction

Fatigue phenomenon of material and component is a topic of great relevance in mechanical engineering, because the large part of mechanical structures during work conditions of their lifetime is subjected to cyclic loads. The most common engineering failures are caused by crack propagation in a fatigue loading [1,2]. Fatigue failure is defined as the tendency of a material to fracture by means of progressive brittle cracking under repeated alternating or cyclic stresses of an intensity significantly below the normal strength [3]. Although the fracture is of a brittle type, it may take some time to propagate, depending on both the intensity and frequency of the stress cycles. Nevertheless, there is very little, if any, warning before failure if the crack is not noticed. The collapse of the structures can be avoided by planning periodic inspections. The frequency of these inspections could depend on previous experiences in the same fields or on specified requirements of standards. In any case, it results fundamental continuous monitoring of structures to obtain more information about the internal state of damage of materials.

In this paper the efficiency of AE and IT in monitoring damage propagation of specimens is critically analyzed. The importance of crack monitoring becomes deeply essential in case of critical part since unexpected failures could be dangerous not only for the structures but also for the users. In particular AE technique seems to be a unique method for evaluating the internal status of materials through the detection of the internal stress waves [4,5] connected with defect activity [6] and its use has been successfully

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investigated in many different applications including thermal loading [7–10] and mechanical loading [11–14]. Furthermore also IT is widely used for the analysis of different damage modes [15,16]; fatigue damage, in fact, is an irreversible process in which part of the total energy is dissipated in heat which contributes to a local rising of the temperature; being IT a full-field technique this also allows damage localization. Also AE allows localization of the damage through triangulation of more sensors placed upon the samples. A common benefit shared by both the techniques [17] is that they allow continuous monitoring [18] of the structure without the necessity to stop the test and unclamp the specimen. In this paper a comparison among the data from both AE and IT techniques is provided and indications about their capability of following damage evolution in stainless steel samples under a uniaxial fatigue loading are discussed.

Several works are present in literature showing capability of using a combined monitoring system based on AE and IT for monitoring damage evolution. However, most of them analyze what happens in composite both during static and fatigue tests. In Ref. [19] ceramic composites under a cyclic loading are analyzed, in Ref. [20] damage evolution in Nextel 312/Blackglas™ is studied by detecting AE during tensile test and recording change in surface temperature at the same time. Also the rate of damage evolution was studied in 2D carbon-fiber/SiC-matrix by Ref. [21] and in glass fiber matreinforce thermoplastic polypropylene by Ref. [22]. While the approach of combining AE and IT is widely studied in composite, almost no data are present in literature regarding their application to metals. The approach has only been attempted by Ref. [23] for aluminum alloy and by Ref. [16] for Ti grade 5. In this paper the combined IT + AE approach will be studied in stainless steel, expected results cannot be simply inferred by a test on other metallic samples due to the different thermal conductivity and critical shear stress, frictional stress and surface energy. In addition, limited to AE, it should be observed that several papers deal with their application in fatigue of metals in general [24] and also with steel in particular [25,26]. However they do not present a complete analysis of AE parameters and in particular of amplitude and location of an acoustic source as it will be done in this paper.

2. Materials and methods

Experimental tests were carried out on eight AISI 430F/1 specimens. It is a stainless steel having good machinability especially in the operation of metal cutting. Specimens have a rectangular cross section 40 × 4 mm^2 and are 400 mm long. Two notches were cut on each specimen in correspondence of the axial mid length on both edges symmetrically respect to the median line. Notches were obtained by laser cutting and have a curvature radius of 5 mm. They were cut in order to identify a precise location in which crack nucleated and propagated. The stress concentration corresponding to this geometry was computed by FEM analysis and it was found to be $k_t = 3$. In Fig. 1 it is possible to see the maximum stress concentration for a specimen subjected to a nominal unitary stress. In this way the stress at the crack tip corresponds to the stress intensity factor we are using.

Fatigue tests were performed using an Instron servo-hydraulic machine equipped with a 100 kN loading cell. A fully reversible sinusoidal loading was applied to the specimens by using a loading ratio $R = -1$ and a loading frequency $f = 3$ Hz. Three different levels of stresses were tested, respectively $\sigma_0 = 91.7$ MPa, $\sigma_0 = 125$ MPa and $\sigma_0 = 150$ MPa.

Acoustic emission events are identified by a set of shots (hits) [27]. The hits represent the number of times the voltage generated from the PZT sensor, shaken by the acoustic wave, overcomes a given threshold. Two piezoelectric sensors [28], properly coupled with the samples, were placed on the surface of the specimen along the longitudinal axis; they were 80 mm far one from each other and symmetrically located with respect to the transverse median line crossing the two notches (Fig. 2). This allows to perform 1D localization of the acoustic source along the longitudinal direction of the sample. The localization algorithm is based upon the recording of the arrival time of the acoustic signal on each sensor. If the relative distance of the two sensors and the speed of the sound in the material are known, it is possible to calculate the position of the event. The determination of the speed of the sound was preliminary done by the Hsu–Nielsen test. Namely a pencil test was broken at a given position on the sample in order to generate an acoustic event, as a consequence the proper speed of the sound was recovered. The threshold voltage was fixed, after a preliminary test to $V_{th} = 45$ dB. This value seems to be good to eliminate most of the noise and at the same

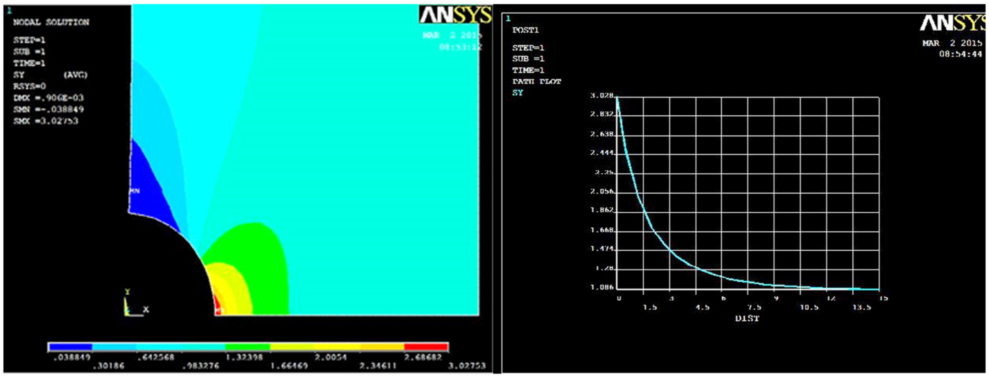

Fig. 1. Numerical model for stress intensity factor calculation.

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