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Detection of fatigue crack initiation in titanium alloy under single-edge-notch (SEN) specimen by Acoustic Emission procedure

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Abstract : *The characterization of material behavior is one issue which may be exemplified made diverse method like theoretical or experimental procedures. The experimental procedures could be done by d estructive, partial destructive or nondestructive methods. In th is way recording the mechanical responses of material during the cyclic loading, using Acoustic Emission (AE) device, provide for us effectiveness guaranty in application of nondestructive technique to description of fatigue life of metal.*

In this context determination of fa tigue initiation in titanium alloy using AE technique represent one remarkable challenge.

Keywords: *Acoustic Emission technique, notch analysis, fatigue crack initiation life, Finite Element Method*

1. Introduction

Ab initio phase of fati gue of material represent the starting point to use one o f the approaches noted by Zerbst et al [1] as: Fail-safe design, damage tolerant design, periodic proof testing, periodic removal of the crack, fracture mechanics based fatigue limit and infinite lifetime concept. These approaches focused in description of duration of mechan ical life made characterization of size and shape of crack in the body material.

In fact, the problem concerning description of life of material is v ery important due to high impact, especially in industry sector, represented by the Aeronautical field, Naval Architecture Series, Automotive industry respectively in life science which includes the biomedical area.

Although, the titanium alloy meets the requirements to the development of advanced technology in Engineering of Aerospace field and biomedical industry, in which t he materials must have certain characteristics well defined, it has a high sensitivity of the fati gue crack initi ation process

2. Objectives

Characterization of notch field was done by many researches using diverse shape of specimen, from rounded piece to plate like specimen. In the analytical model, Cheng [2] used the V-notch, in order to present stress field on the Fracture Criteri on. He

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applied the Maximum circumferential stress (MCS) criterion to predict the fracture of material. In which the direction of the initial crack can be expressed as :

$$\left.\frac{\partial \sigma_{\theta\theta}}{\partial \theta}\right|_{\theta=\theta_c} = 0, \left.\frac{\partial^2 \sigma_{\theta\theta}}{\partial \theta^2}\right|_{\theta=\theta_c} < 0 \qquad (1)$$

which $\sigma_{\theta\theta}$ represent the normal stress.

On the other hand, in experimental research between many techniques used to characterize the me chanical behavior of material, in last d ecade, Nondestructive Method play one fundamental role. These techniques seem to be very useful due to rapidity and ch aracterization of material without deterioration.

For example by using ultrasonic fatigue test, we could apply, cyclic stressing of material at frequencies typically in th e range of 15 to 25 kHz. The major advantage of using ultrasonic fatigue is its ability to provide near-threshold data within a reasonable length of time.

Ultrasonic measurements comprise two stages. The first stage involves obtaining the signal from the crack, and the second stage involves the interpretation of this signal to estimate crack size and shape.

In partial destructive process, Experimental work shows the possibility of created site of nucleation of cracks fatigue by intrusion and protrusion. These studies are represented by AFM (Ato mic Force Microscopy).

As initial issue, our study is focused i n description of first stage of fatigue of material by nucleation of initial crack in the experimental way. In that case, we use to carry out our results, t he U-notch plate specimen applying Nondestructive techniques through Acoustic Emission activity.

3. Material and Methods

To emphasize the in itiation of fati gue process, some tests were do ne under Instron 1341 machine, to which was attached the Acoustic Emission d evice, in order to record the specimen behaviour during cycling test. The values of material properties used in this st udy are reported by Casavola et al [2], Pruncu et al [3] in their articles.

In Table 1 and 2 are presented one sh ort summary of the material characteristics: mechanical properties and chem ical composition.

Chemical composition of titanium alloy grade 5 Table 1

Titanium grade 5	C	Al	V	Fe	H	N O	
ASTM B265	<0.08	5.5-.75	3.5-4.5	<0.30	<0.015	<0.03	<0.025

Mechanical properties of titanium alloy grade 5 Table 2

Titanium grade 5	Modulus of elasticity E [MPa]	Ultimate tensile strength R [MPa]	Yield tensile strength R_{02} [MPa]
ASTM B265	1.138	956.4	760

The shape of s pecimen used in this study, meets the standar ds required for single-edge-notch (SEN), specimen which contain one n otch. In that case, the specimen plate used in our study, single-edge-notch (SEN) is U-notch, which contain next dimension: length = 203.20 mm, width = 58.40 mm, thickness t = 3 mm and the notch magnitude are concluded by two diverse size 20.32 mm respectively 25.40 mm. The diverse sizes of notch are used in order to clarify the correctly number of cycle required to crack initiation. Profile of our specimen is presented in Figure 1.

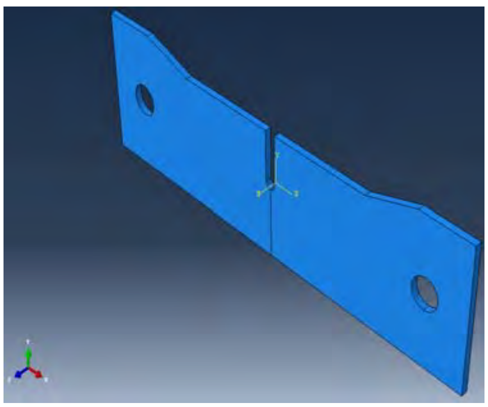

Fig.1. Shape of single-edge-notch (SEN)

For numerical analysis we had applied 3D model, presented in Figure 2. The mesh done in this model has approximate global size 1.2, in whole sample, excepting the area near of the notch which contains more fine size of grain.

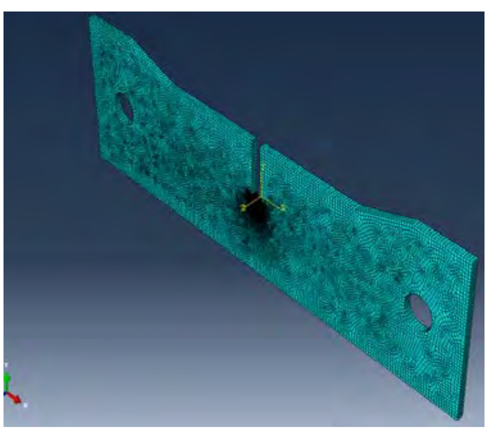

Fig.2. Mesh of the SEN specimen

In the experimental technique, the specimen was subjected to the uniaxial loading, in cyclic mode, under low frequency at 20Hz, in presence to an applied charge of 4.5 kN. Under the Instron 1341 machine was placed one microscopic system. The microscopic set up was employed to correlate the emission acoustic activity in order to obtain the accuracy in results. In this direction, has been focus one surface around the notch specimen, for envision the activity of possible crack or defect with microscopic system in material, near the notch shape. That surface focused was created made sturdy light provided and increased through a stroboscopic devices. Finally, we have recorded the main activity, during the cycling test, by using two sensors coupled at Acoustic Emission system. All equipment is represented in Figure 3 and 4.

Fig.3. System of fatigue test with applied AE sensor and microscopy device

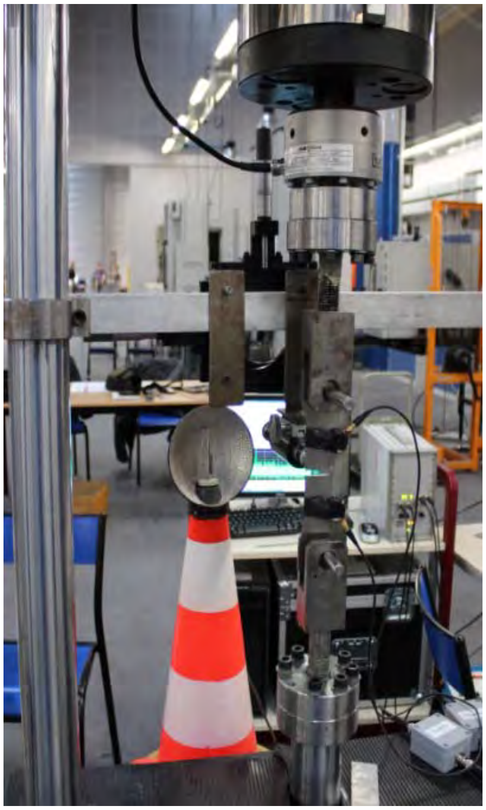

Fig.4. AE sensor with preamplifier device and system of AE unity

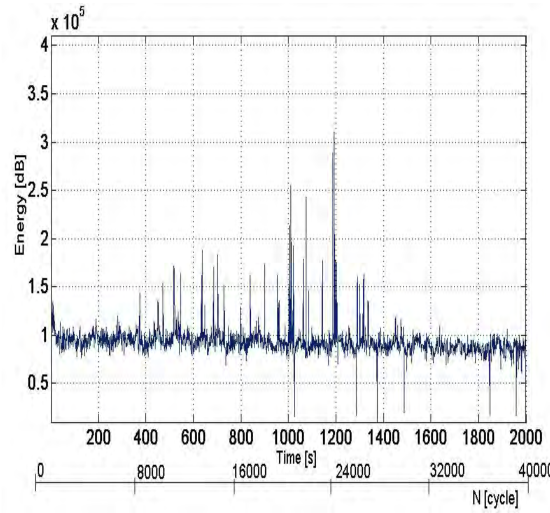

Fig.5. Image of AE signal during the crack initiation life

4. Results and Discussion

Every time the interpretations of results represent the key point in expression o f gratitude of work. We have plotted the Experimental results emphasized by AE activity and recorded du ring the test in manner energy versus time. Activity represented in Figure 5. These results are in good agreement with shape of signal detected by Abo-El-Ezz [4]. In our case, we had associated the shape of signal for the number of fatigue cycles with the time series. The initial crack unsafe, we may consider to be at which the amplitude of signal touch the first maximum peak.

The specimens broken after cycling activity were subjected to Scanning Electron Microscopy SEM ob servations. During post-examination fractographic analysis of the fracture surface, first of all, the sample was cleaned and drie d. In Figure 6, we show the area of nucleation of fatigue in notch area.

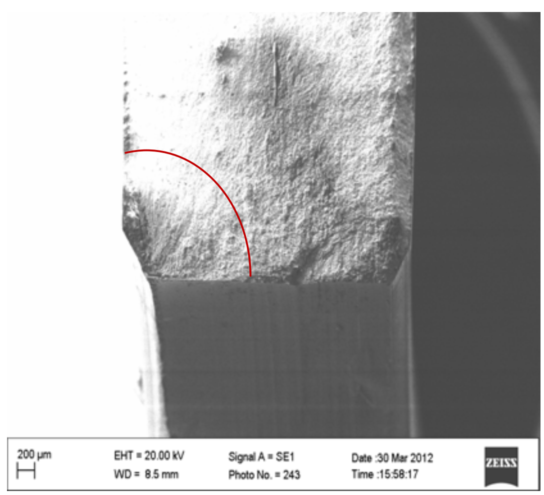

Fig.6. Typical shape of Notch Crack initiation under SEM observation

On the other hand numerical simulations with ABAQUS software show to us, that the high concentration of s tress is located in top of t he notch. The distribution of maximum stress in front of the notch is plotted in figure 7.

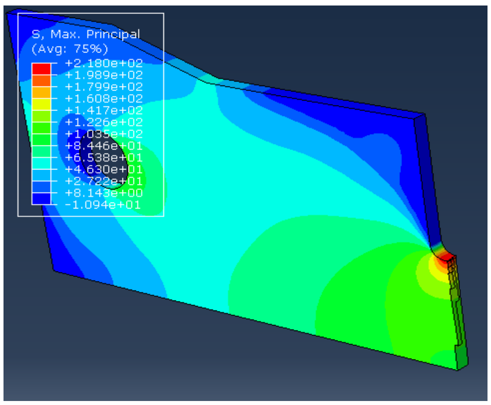

Fig.7. Distribution of maximum stress in the notch area

Although, in n umerical study we fin d that, maximum stress have two differen t value of intensity for each length of notch. In our case, by using the AE ac tivity, we find the same period of nucleation of crack, indifferent of the notch length. These two magnitudes of intensity are plotted in figure 8.

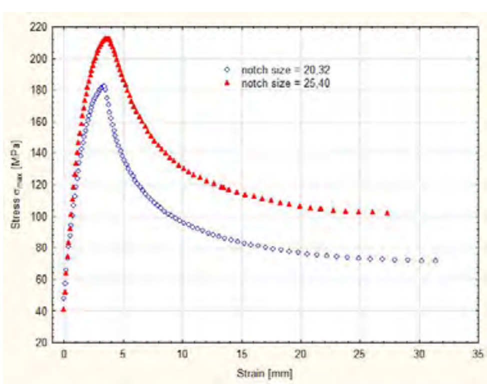

Fig.8. Distribution of maximum stress for two different length of notch

5. Conclusion

In this paper we d escribe shortly the results of AE activ ity. This activity was done during the f atigue test in order to show the fatigue crack initiation process.

The results show that, the crack initiation fatigue life i s sited in Low Cycle fatigue area at about 24000 cycles. The experimental results are correlated by applied numerical Finite Element Method.

Our direction in the future work is based on finding the influence of the inclusion in fatigue crack nucleation in titanium alloy.

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