Acoustic Emission Studies on a near α Titanium Alloy IMI 834 under Monotonic Loading Conditions

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Abstract

Prediction of growing defects is of significant importance for structural integrity assessment of critical components. Acoustic emission (AE) measurements have been acknowledged as an appropriate approach for monitoring these growing defects. Hence, in the present investigation, AE studies have been performed on a near α titanium alloy IMI-834 under monotonic loading condition. This alloy is used for aeroengine components, which have varying state of stress triaxiality. The effect of stress triaxiality on AE response was studied through smooth and notched tensile specimens. The notched specimen was found to generate higher rate of cumulative AE energy and lower total energy than smooth specimen due to presence of state of stress triaxiality at the notched region.

Keywords: Acoustic emission; IMI-834 titanium alloy; tensile loading

1. Introduction

Structural components may fail due to a variety of reasons such as growth of pre-existing defects or initiation and propagation of new defects in the component. Therefore, predicting the presence of such growing defects is of significant importance from the point of view of structural integrity assessment and failure prevention of components. Since, phenomena such as crack initiation and propagation lead to emission of high frequency acoustic waves, Acoustic Emission (AE) measurements have been acknowledged as an appropriate approach for monitoring the structural integrity of components [1]. AE signals are transient elastic stress waves generated by the sudden release of stored elastic strain energy by dynamic processes such as plastic deformation, and crack initiation and propagation from the material under stimulus [2-4]. In the present investigation, AE studies have been performed on a near α titanium alloy IMI-834, currently being used for aeroengine components. Unlike steels, titanium alloys have been reported to have complex damage micro-mechanisms [5-8] due to presence of multiple phases with varying morphologies and mechanical properties, thus necessitating characterization of AE corresponding to these micromechanisms. Apart from this, since a high state of stress triaxiality exists in the complex geometries like aeroengine discs, it becomes important to investigate its effect on damage micro-mechanisms, and the corresponding AE behaviour.

2. Experimental Procedure

2.1 Material

The near α titanium alloy IMI-834, has a composition conforming to Ti-5.8Al-3.0Sn-3.33Zr-0.38Nb-0.32Mo-0.33Si. The alloy was supplied in the standard thermomechanical heat treatment condition in the form of 25 mm diameter rod. The bimodal microstructure, shown in Fig.1, consists of ~12-15% volume fraction of primary α (white regions) within transformed β matrix. The material in heat-treated condition has yield strength of 928 MPa, ultimate tensile strength of 1032 MPa and total elongation of 13%.

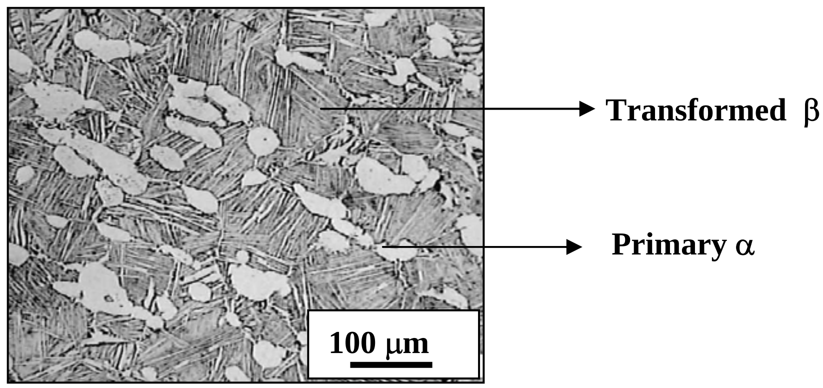


Fig.1. Bimodal microstructure of IMI-834 titanium Alloy

2.2 Tensile testing

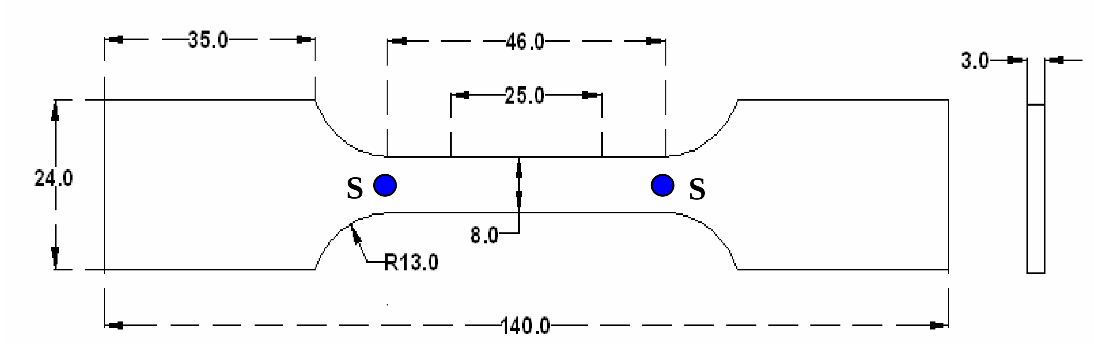
To investigate the effect of stress triaxiality on AE behaviour, flat tensile specimens of both smooth and notched geometries were used. These specimens had gauge length of 25 mm, width 8 mm and thickness 3 mm length as shown in Fig.2. Notched specimens had a notch root radius of 9 mm, equivalent to a stress triaxiality ratio of X=0.48 according to the Bridgman formula [9] as given in equation (1) below:

$$\frac{\sigma_m}{\sigma_e} = \frac{1}{3} + \ln\left(1 + \frac{d_o}{4R}\right) \qquad \text{----------} \ (1)$$

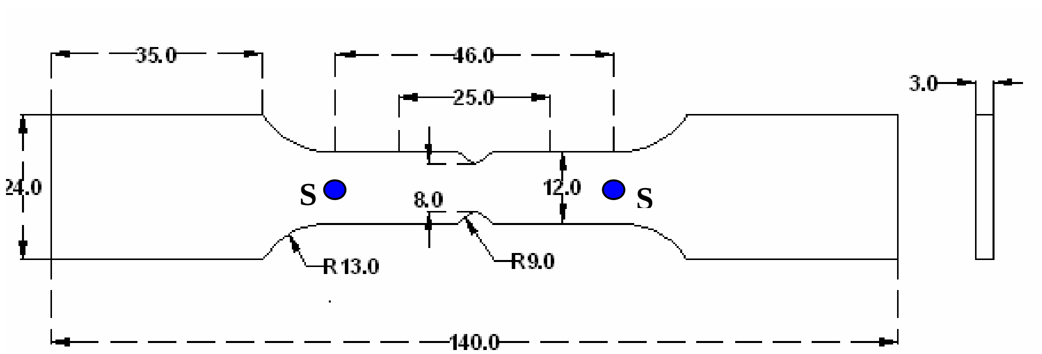
where σ_m is the mean or hydrostatic stress, σ_e the effective stress, d_0 the initial diameter and R the radius of the notch. The tensile testing was performed at ambient temperature on a MTS servo hydraulic test system at a strain rate of 3.3×10^{-4}/sec.

2.3 Acoustic emission testing

An 8-channel AE system (M/s. PAC, USA) with digital data acquisition and processing, and analytical software was used in the present study. Detection of AE signals was accomplished with small sized (5 x 4 mm) piezoelectric sensors having frequency response in the range of 200-750 kHz. These sensors were mounted on the surface of the specimen as shown in Fig.2. The sensor output was amplified through a high gain low noise preamplifier, filtered in order to remove any extraneous low frequency noise from hardware and high frequency electromagnetic noise.



(a)



(b)

Fig.2. Schematic of AE test specimens (S- AE sensor location)

(a) smooth specimen and (b) notched specimen

3. Results and Discussion

Various AE parameters such as events, counts, energy, peak amplitude and average frequency have been identified from the AE signals. AE signals have been used for qualitative interpretation of damage evolution in the alloy. The AE signals were analyzed in time domain and / or frequency domain depending on the type and characteristics of the AE signals. The damage signals from various locations along the gauge length in the specimen were also successfully recorded and analyzed.

3.1 Acoustic emission response of smooth specimen

From the experimental results obtained, it can be inferred that the AE activity is low during the initial loading in the linear elastic region, possibly associated with the incubation stage of damage, as shown in Fig.3. The released cumulative energy increases with further straining during higher plastic deformation regions and can be related to progressive damage in the material.

3.2 Effect of stress triaxiality on AE response

In the case of notched specimen (stress triaxiality ratio= 0.48), the rate of cumulative energy is found to be higher than that of the smooth specimen (stress triaxiality ratio= 0.33), whereas the maximum cumulative energy is lesser for the notched specimen than that of the smooth specimen (Fig.4). Also, the number of events in the notched specimen is more and confined to the notched area, whereas for the smooth specimen, the number of events are distributed throughout the gauge length of the specimen. This is due to the presence of high stress triaxiality in the notched specimen, which constraints the plastic deformation within the notched region of specimen. This phenomenon accelerates the process of fracture, which leads to higher rate of strain energy release.

Scanning Electron Microscopic (SEM) investigation of interrupted tensile specimens confirmed that plastic deformation in this alloy sets in initially due to the formation of slip bands within the softer primary α phase, thereby leading to nucleation and growth of voids. It is known that phenomenon of formation and growth of microvoids does not generate strong AE. Further deformation leads to fracture through interconnection of already formed voids and also the new voids that form in transformed β matrix as well as in primary α phase.

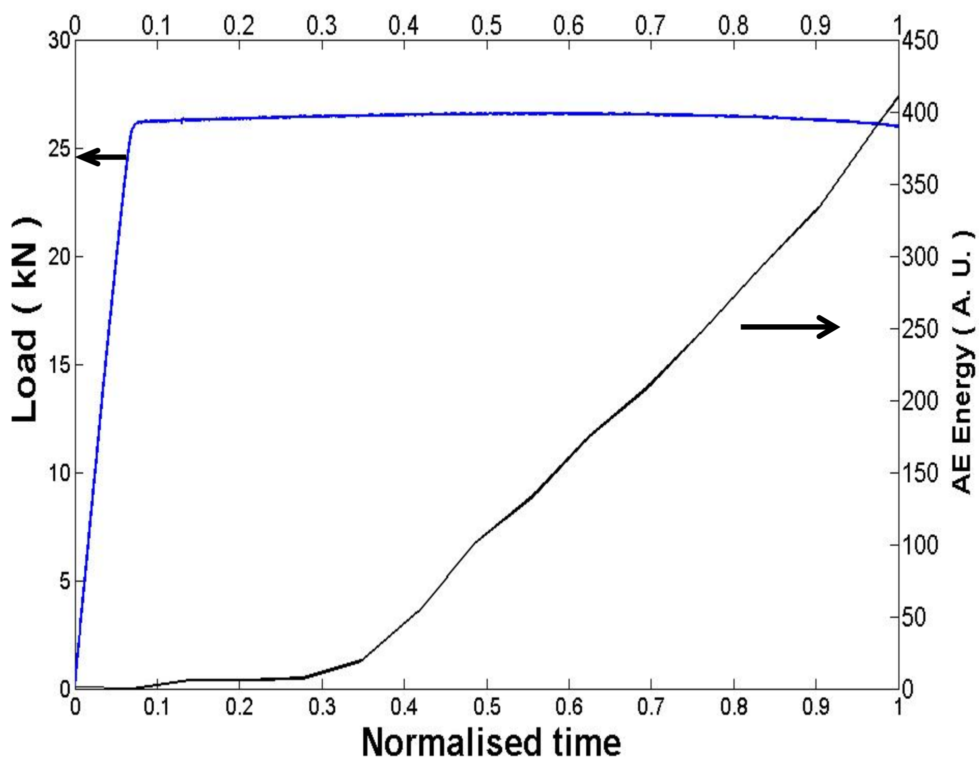


Fig.3. AE energy / load vs. normalized time curve for smooth specimen

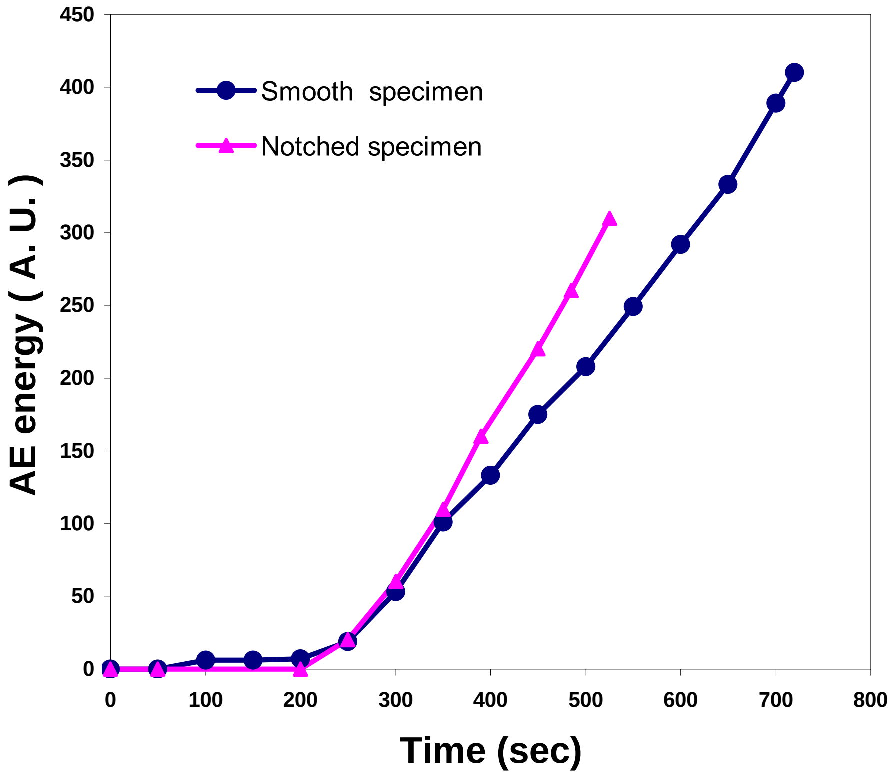


Fig.4. AE energy vs. time curve for smooth and notched specimen

4. Conclusions

I. The AE monitoring and data analysis is found to be a useful tool for the qualitative analysis of the damage evolution during monotonic loading of near α titanium alloy IMI-834.
II. The effect of stress triaxiality on AE response was studied by comparison of AE behaviour in smooth and notched tensile specimens.
III. The notched specimen responded with higher rate of cumulative AE energy than smooth specimen due to presence of state of stress triaxiality at the notched region and increased rate of deformation.
IV. The maximum cumulative energy is found lesser for the notched specimen than that of the smooth specimen due to presence of state of stress triaxiality.

Acknowledgement

The authors wish to acknowledge Dr. C.R. Prasad, Dr. G. Jayaraman and Dr. M.S. Rawat of Bharat Heavy Electricals Limited (R&D), Hyderabad for providing facilities for carrying out the experimental work. The constant support and encouragement from Director, DMRL and Director, IGCAR, is gratefully acknowledged. The authors would also like to thank DRDO, India for funding this activity.

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