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Titanium Alloy Subjected to Tensile testing under Ambient and Cryogenic Conditions using Acoustic Emission Techniques

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Abstract: Titanium (Ti) alloys are strategic aerospace materials used in relatively severe working environment. Owing to the excellent properties such as high rigidity to weight ratio, elevated temperature strength, corrosion resistance and toughness in ambient as well as cryogenic environment, Titanium alloys find high technology applications in aerospace industries. As the Ti alloy finds application in aircraft engines, compressor blades and gas turbines, it is necessary to characterize the performance of this material under stress conditions. Acoustic Emission (AE) is a high sensitivity technique for detecting active microscopic events in a material under stress. The processes that are capable of changing the internal structure of a material such as dislocation motion, directional diffusion, creep, grain boundary sliding and twinning which are usually associated in plastic deformation and fracture are the sources of Acoustic Emission. Thus, using AE signals, it is possible to evaluate the performance of material under stress. The data acquired can be used to predict the performance of products made of Ti alloy. With this view, the acoustic emission response of Ti alloy subjected to tensile testing under ambient and cryogenic conditions have been studied.

Keywords: Titanium (Ti) alloys, corrosion, Acoustic Emission, corrosion resistance, strength, etc.

I. INTRODUCTION

Performance of a product is largely dependent on design, manufacturing and maintenance. Material characteristics influence significantly on the three aspects. Any material under stress will respond according to the nature of stress and environment. Material response is to be carefully monitored, especially in the case of critical parts such as part in aerospace and related applications. The response of the material can be assessed in terms of observable / visible feature such elongation, contraction or other deformation related visible feature. These are macroscopic effects. However, if the response of the material is to be evaluated even in microscopic level, then suitable indicators have to be monitored. Acoustic Emission is a relative indicator for identifying the status of material under stress. Acoustic Emission (AE) as the transient elastic wave generated by the rapid release of energy from a localized source or sources within material when subjected to a state of stress. This energy release is associated with the abrupt redistribution of internal stresses and as a result of this, a stress wave is propagated through the material. The definition of AE given above Indicates that processes that are capable of changing the internal structure of a material such as dislocation motion, directional diffusion, creep, grain boundary sliding and twinning, which result in plastic deformation, phase transformations, vacancy coalescence and decohesion of inclusions and fracture are sources of acoustic emission; of processes said above, only plastic deformation and fracture are of

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significance in metal cutting. Out of the four plastic deformation process mentioned, generally, dislocation motion is the dominant mechanism in crystalline materials which are widely used in practice [3]. AE study is used as a condition monitoring process by different researchers [13] and [14].Studies the acoustic behavior of screws under tensile load. The significance of the results for the in-process monitoring of screws is explained in this work. AE technique for the integrity evaluation of aerospace pressure chambers made of M250 Maraging steels is carried out by [4]. Due to the excellent properties to titanium alloy, such as good ductility, high temperature strength, corrosion resistance and lower density, this alloy finds under high technology application aerospace, chemical and petrochemical industries, it is necessary to acquire a thorough knowledge on the behavior of the material. The acoustic response of titanium alloy subjected to a tensile testing reveals the behavior of the material during fracture. Only limited literature is available in this area. The AE response of the material can indicate microstructure – property relationships. [7] Studied the AE produced during tensile straining and fracture to have a better understanding of the titanium aluminide alloy behavior. [12] Investigated the effects of matrix microstructure and interfacial properties on the fatigue and fracture behavior of a metastable titanium matrix composite. The damage behavior of the titanium matrix composite, during monotonic and cycle loading were studied through AE. [1] Conducted AE studies to locate and to observe the damage of the titanium matrix composite. The results were supported by SEM analysis carried out on the fractured surfaces.The relationship between microstructure and AE of Ti-641 – 4v has been studied by [11]. Different microstructures of Ti-641-4v alloy have been obtained through different grain sizes and different heart treatment procedures. The AE response of these different microstructures subjected to mechanical deformation rest has been studied. A detailed study on the micro fracture mechanism in fracture toughness test of Ti-8A1-1Mo-1v alloy was examined by AE wave analysis by [5]. The widespread use of cryogenic fluids for several industrial applications such as frozen food, metal industry, space application, superconductors and biomedical applications has to be studied. Suitable materials have to be selected, in such a way that selected material should have toughness, ductility and weld ability at this low temperature. Titanium by its inherent properties meets the requirements of cryogenic technology. As the titanium alloy finds application in aerospace and cryogenic in industries, the behavior of this material under both the working conditions has to be investigated.

2.0 ACOUSTIC EMISSION TECHNIQUE

2.1 Principle

The Acoustic Emission Technique (AET) is relatively recent entry in the field of non-destructive evaluation which has particularly shown a very high potential for material characterization and damage assessment in conventional as well as non-conventional material.

2.2 Definition

Acoustic emission (AE) is the class of phenomenon where transient elastic waves are generated by the rapid release of energy from localized sources within a material, or the transient elastic waves so generated. In other words, AE refers to the stress waves generated by dynamic processes in materials. Emission occurs as a release of a series of short impulsive energy packets. The energy thus released travels as a spherical wave front and can be picked from the surface of a material using highly sensitive transducers, (usually electro mechanical type). The picked energy is converted into electrical signal which on suitable processing and analysis can reveal valuable information about the source causing the energy release. The flow chart of typical AE system is shown in Figure 1.

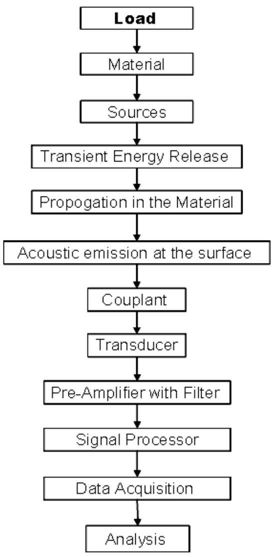

Figure 1: Flow Chart of Acoustic Emission System

The load applied on the material results in the transient energy release from the source. It obviously travels as a spherical wave front. As these pressure wave propagate through the material it undergoes distortion and attenuation. The volume and characteristics of AE generated are dependent on the nature. Type and characteristics of the source: the main characteristics being its initial severity, present state, local metallurgical structure and the environment. These are converted in to electrical signals by mounting Piezo electric transducer in suitable locations on the material by pasting them with complaints. As the stress waves pass through the compliant and

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transducers they further undergo distortions depending upon their transfer function characteristics. In order to increase strength of the signals, a preamplifier with filter leads the AE signals to the signal processor where ambient noise and unwanted frequency comportment of the signal are eliminated. This also helps to increase the signal to noise ratio. It further leads to data acquisition unit for analysis.

2.3 Sources Of Acoustic Emission

Sources of AE include many different mechanisms of deformation and fracture. Sources that have been identified in metals include moving dislocation, slip, twinning, grain boundary sliding, crack initiation, crack growth etc. Other mechanisms like leaks, cavitations, friction, growth of magnetic domain wells, phase transformations also fall within definition and are detectable by Acoustic emission equipment. These sources are termed as secondary or pseudo sources.

Acoustic emission signals are transient in nature (burst emission). The transducer output can be modeled crudely as a decaying sinusoid. This model is applicable only for signal which can be identified as individual bursts with discernible time gap between two successive events. If the burst rate is very high, events may occur very close to one another and sometimes even overlapping, in which case it termed as 'continuous emission". Thus we can broadly divide AE signals into burst type and continuous type. The characteristics of these are compared in Table 1.

Table 1: Comparison of AE Signals

Characteristics	Burst Type	Continuous Type
Ringtown Counts	Low	High
Rise Time	Reduced rise Time	More rise time
Event duration	Shorter	Longer
Frequency	High	Low
Event Rate	Low	High

3.0 TITANIUM ALLOY

Titanium is a low density metallic element that is abundant in the earth's crust. Metallic titanium became available in the early 20th Century. Titanium is relatively expensive compared with other common metals (iron, copper, aluminum, Magnesium) but frequently, by virtue of its attractive properties, may be more cost effective than these other metals. Ti alloys can be cast, rolled, forged and otherwise produced in a variety of mill product forms or special shapes. The initial use of Ti alloy is aircraft engines, compressor blades (Pratt & Whitney Aircraft J – 57, Rolls – Royce Avon) and then as disks, (Pratt & Whitney Aircraft JT – 3D). In fact, the existence of Ti alloys made possible the fan – type gas turbine engines now in use. Ti and Ti alloys are noted primarily for outstanding strength –to – weight ratios, elevated temperature properties and corrosion resistance. They also possess high rigidity – to – weight ratios, good fatigue strength and toughness and, in some cases, excellent cryogenic properties. Because of these characteristics and improved fabrication technology, Titanium and its alloys are now important materials for aircraft and processing equipment.

Ti and Ti alloys are classified into three major categories according to the predominant phases present in the microstructure. These are

- Alpha Alloys
- Alpha + Beta Alloys
- Beta Alloys

4.0 EXPERIMENTAL SET UP

Acoustic Emission (AE) is the stress waves produced by sudden movements in stressed materials, the classic source of AE are defect related deformation. Elastic waves are generated due to the local changes in source region. These waves propagate as mechanical disturbances through the structure causing a time varying surface displacements/in this experiment using Titanium Alloy under tensile load in Universal Testing Machine (UTM) has been carried out for the AE Study.

The tensile specimens used have been machined out from Titanium Alloy (Ti-641-4V) Plates, which were in received condition, are subjected to annealing before the machining process. The axis of the specimen has been kept coinciding with the rolling direction of the plate. Care has been exercised to ensure that the radius of curvature at the gauge and has been as smooth as possible. The major interest in this class of specimens is toe study AE signature at the pre – yielding onset of yielding. As such no strict quality control measures have been affected to control the width or thickness of the specimen within close tolerance at the gauge length portion. The tensile specimen is

subjected to the required loading / load cycle on Servo controlled SCHENCK TREBEL RM 250 Universal Testing Machine, 250 KN Capacity with the provision for fatigue cycling as well as displacement controlled loading machine cells for necessary screening if the genuine emission events from the specimens under test are to be acquired.

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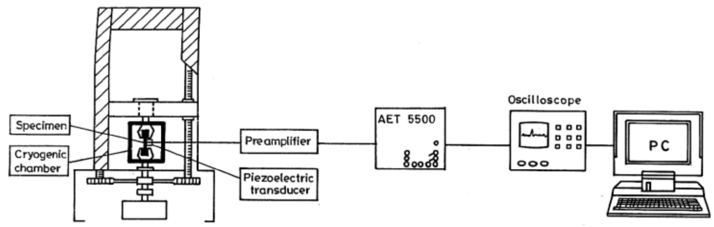
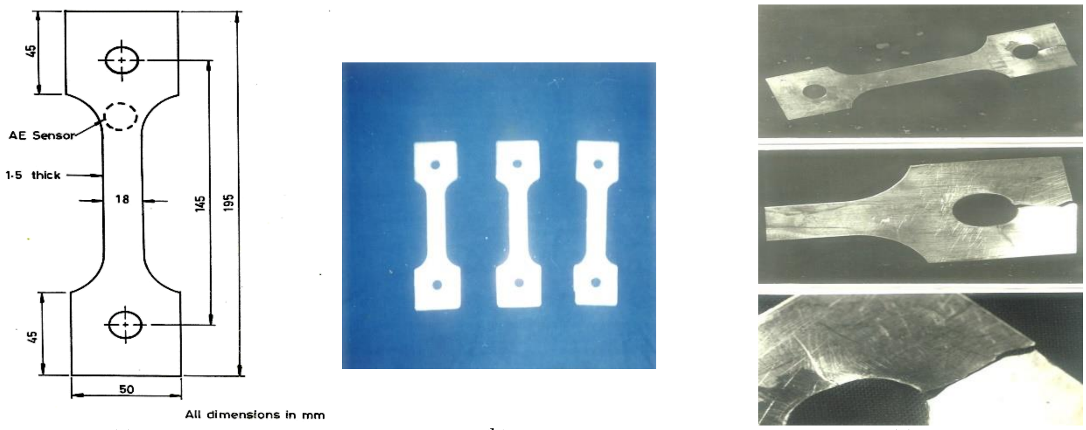


Figure 2: Schematic diagram of the experimental setup

Tensile test specimen of 1.5 mm thickness and 18 mm width, made of 6% Aluminum and 4% Vanadium, 9% of Titanium alloy is tested with tensile loading in an universal testing machine of 250 KN capacity. It is seen that as the load increases there is a steady improvement in activity; around certain critical/threshold load, the test material becomes active, associated with deformation and dislocation movements, the material exhibiting permanent set. This is associated with emission of continuous AE signal. As the load applied increases, the material tries to attain the threshold/permissible stress beyond which degradation/failure sets-in. Hence, as the material is subjected to increasing loading, acoustic stability is attained; with the result the material may even become inactive over the permissible stress region. Beyond that stress, failure of material sets-in associated with localized burst signals. An Oscilloscope has been used to acquire the amplified and filtered data. The 2 K pts resolution of the Oscilloscope and the storage duration of second/signal limited the signal rate and precision. The trigger threshold was adjusted exactly to just above the noise level. The signal exceeding this threshold (together with the elongation, load and speed of the crosshead) was recorded and the signal from the sensor was magnified by a pre-amplifier for increasing load.



(a) (b) (c)

Figure 3: (a) Tensile test Specimen (b) Typical Tensile specimen (c) Typical fractured tensile specimen

The raw signals were monitored using a data-logger. The acquired signal was analyzed separately using a suitable PC based data acquisition system at a sampling frequency of l MHz for spectrum analysis. The time duration signal consisting of 25 and 50 observations were considered of the purpose of analysis. The recorded data were used to calculate the AE rate and the frequency spectra. The AE signals were obtained under the ambient and cryogenic conditions.

5.0 RESULTS AND DISCUSSION

The titanium (Alpha + Beta phase) material was tested to uni-axial tensile loading. Typical observed load – extension characteristics of the test material are illustrated in 5.1. It is seen that up to around 13% (2mm) elastic behaviors can be observed; beyond that elongation the material undergoes plastic deformation associated with viscous yielding. This is indicated by the occurrence of staircase type load-extension characteristics. The response of the titanium alloy to tensile loading was monitored on-line by sending the acoustic emission signal emanation from the test specimen by suitably positioning a broad band AE sensor the recorded signal was characterized in terms of rms value and dominating frequency.

Typical observed r.m.s value of the acoustic emission signal monitored is illustrated in fig 5.2. It can be seen that with tensile load on, there is a gradual reduction in r.m.s value indicating that slow degradation of the material with applied load/stress. The r.m.s characteristics is of zigzag nature; form this it can be inferred that after certain cumulative yielding the test material experiences localized bursting associated with a reduction of r.m.s value. Titanium alloy is relatively low strain hardening material; hence it

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experiences higher order strain before failure. During stressing the test material experiences straining of localized lump of material after certain order of strain, this may experience discrete burst/fissures resulting the reduced acoustic emission i.e. Titanium alloy under tensile loading experiences localized yielding and burst depending upon the load sequence, till failure, of course with continuous reduction in r.m.s value.

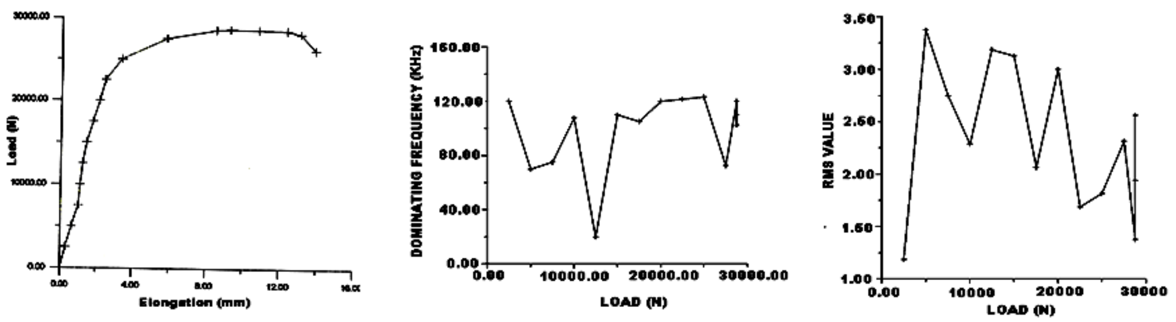
From the recorded raw acoustic emission signal, the dominant frequency was noted. Typical variation of the domination frequency with load is illustrated in fig 4. Referring to the illustration on r.m.s value and dominant frequency, it can be seen that especially with higher testing load, there is a reduction in the r.m.s value of the acquired acoustic emission signal; the signal acquires for higher loads, indicate the dominant frequency of 120kHz i.e. around 20000N of loading, the material exhibits more of burst emission, indicating there by the occurrence of localized cracking associated distressing the material.

Observation on characteristics of raw signal acquired. Typical illustrations on the acoustic emission signal acquired with different applied load are presented in fig 5. With applied load of 250 the acoustic emission signal comprises many different frequency components, with the dominant around 120KHz. As the load is increased to 5000N, only few frequency components were observed with a shift in the dominant frequency towards a lower magnitude. This indicates the occurrence of a relatively more continuous emission (also indicated by occurrence of higher r.m.s value). A summary of observations is indicated below.

7500	Higher power, high amplitude over 75 KHz frequencies, continuous mode, mixed mode of emission-associated with localized burst emission.
10000N	Similar trend continued.
12500N	Occurrence of dominant low frequency, continuous mode of emission has indicated by raise in rms value.
15000N	Reduced power-mixed mode of emission
17500N	Increased power (75KHz, 110-120kHz), mixed mode of emission.
20000N	Mixed mode, increased mode of signal emission.
22500N	Reduction in power, light shift in peak frequency, mixed mode of emission.
25000N	Reduction in power, light shift in peak frequency, mixed mode of emission.
27000N	Increased power, shift in peak frequency, increasing order of rms
26000N	Reduced power, failure.

Summing up; the continuous monitoring of AE has illustrated the deformation of the material, occurrence of local fissures during early phase of loading and continuous deformation as illustrated by higher r.m.s value; further, barring few load stage, the monitored AE signal contains a dominant frequency around 100-120kH. This can be the typical frequency of acoustic emission for titanium alloy tested.

Fractured surfaces of test samples were observed through JEOL make Scanning Electron Microscope. The typical Scanning Electron Microscope of fractured surface is shown in Fig.5.16 (a-h). The higher ductility of titanium alloy is clearly illustrated through a textured macrograph, with elongated grains and occurrence of dimpled zones. Further, the flow of material around the dimples indicated that the material has undergone viscous yielding during tensile loading. Closer observation of localized regimes indicate possibility of failure initiation around spherical, second phase particles. Observations also indicate the occurrence of the cracking of the material prior to failure.



(a) (b) (c)

Figure 4: (a) Load Extension Characteristic (b) Variation of the R.M.S value with the load (c) Variation of the Dominating frequency with the load

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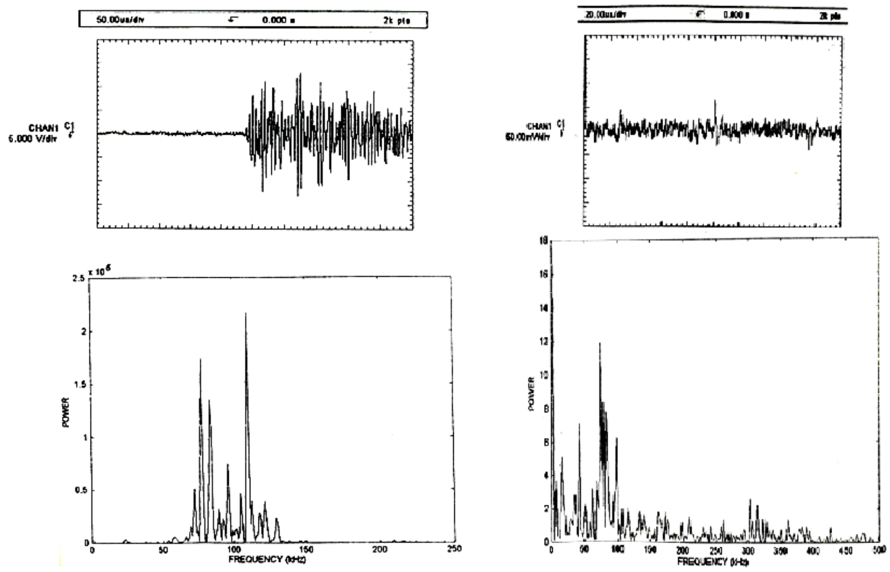

(a) (b)

Figure 5: (a) FFT Spectra for power vs. frequency at 15000 N Applied load for ambient Condition and (b) (a) FFT Spectra for power vs. frequency at 15000 N Applied load for Cryogenic Condition

6.0 CONCLUSION

Study on AE response of titanium alloy, has been carried out with a view to develop an integrity evaluation methodology applicable to aerospace material. Necessary criteria has been evolved and applied to aerospace related application for real time integrity monitoring. The following are the significant conclusions emerging from the studies.
Observation on the tensile specimens bearing possible surface defects indicated that the AE response of titanium alloy subjected to tensile under ambient condition. The acoustic emission acquisition data indicated mixed mode of signal emission ambient condition. This might be due to occurrence of local fissure during early phase of loading and continuous deformation illustrated by high r.m.s value. Further barring few load stages, the monitored AE signal contains a dominating frequency around 100-120 kHz. This can be a typical frequency of acoustic emission of the titanium alloy tested.

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