STUDY ON AMPLIFICATION OF ACOUSTIC EMISSION SIGNALS DURING TENSILE DEFORMATION OF ALUMINIUM


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Abstract

Acoustic emission (AE) technique is useful for detection of growing defects and for characterization of materials e.g. plastic deformation of metallic materials. AE signals generated during tensile deformation are weak in nature and may be masked by background noise (except near yield and at fracture). It is possible to amplify these weak AE signals significantly through superimposing acoustic waves. External injection of acoustic waves activates some of the potentially subcritical AE sources and contributes to increase in AE energy. This paper discusses the results of the experimental studies carried out on Aluminium specimens and compares the ranges of average amplification factors obtained for different strain ranges with that reported in the literature for austenitic stainless steel.

Keywords: Acoustic emission, tensile deformation, transfer function, amplification, aluminium

1. Introduction

Acoustic Emission (AE) is defined as a class of phenomenon whereby transient elastic waves are generated by a rapid release of energy from localised sources in a material [1, 2]. AE technique is widely used for materials research. Example applications of AE technique include study of deformation behaviour of materials, phase transformation, crack growth, corrosion etc. [3]. The source of acoustic emissions in metals is closely associated with the dislocation movement accompanying plastic deformation and with the initiation and growth of cracks in a structure under stress.

AE signals generated during tensile test are weak in nature and may be masked by background noise (except near yield and at fracture). Vary and Smith [4] reported that spontaneous stress (elastic) waves emitted by various nucleation (microfracture) events interact with other potential nucleation sites, and tend to promote fracturing of these sites. Swift and Richardson [5] reported that plastic deformation can be produced by injecting waves of very large strain amplitude. It is also known from Kerkhof [6] that imposition of ultrasonic waves will deflect a running crack in a predictable manner. Valsakumar et al. [7] studied mathematically a material’s response due to the effect of external fluctuations using
Gaussian decoupling and Monte Carlo simulation techniques. Baldev Raj et al [8] reported that it is possible to amplify weak AE signals significantly through injection of acoustic waves of suitable frequency (obtained from specimen’s transfer function) and amplitude during tensile deformation of solution annealed AISI type 316 stainless steel. Thus, it can be expected that externally injected acoustic waves will interact with potentially (energetically) nearly subcritical or hibernating AE sources and would give rise to enhanced emission which otherwise would not have been released at that stress level.

However, detailed study on amplification of AE signals in other materials is scarce. It is therefore of interest to conduct similar experiments on other materials to confirm and investigate the applicability of amplification studies already carried out. With the aim of amplification of acoustic emission signals, the present study is conducted on solution annealed aluminium specimens during tensile deformation. A comparative analysis of the present results with previously conducted experiments on stainless steel is also carried out [3, 8].

2. Experimental Conditions:

Flat specimens of solution annealed aluminium, having dimension 200 mm x 55 mm x 3 mm (gauge length: 100 mm) were used for the experiments. Chemical composition (weight %) of aluminium used: Iron (Fe): 0.3%, Tungsten (W): 0.16%, Lead (Pb): 0.1%, Aluminium (Al): Balance (99.43%). Figure 1 shows the photomicrograph of aluminium, obtained after etching with HF.

![Photomicrograph of aluminium specimen](image)

As can be seen, no inclusions are found. Thus, formation of dislocation pinning sources is significantly reduced in the present study. The typical experimental setup used for this study is given in Figure 2. Tensile tests were carried out on the specimens using Mytidyne 910, Universal Testing Machine (UTM), at a strain rate of $1.45 \times 10^{-5}$ s$^{-1}$. Continuous sinusoidal acoustic waves of suitable frequency and amplitude (0.5V peak to peak amplitude) were injected using a UT transducer (NDT V101, Band Width: 200 – 800 kHz). Transmitted acoustic signals from the specimen were picked up by a broadband AE sensor (WDI-AST BZ18, Band Width: 100 kHz to 1 MHz).
Acoustic emission signals were recorded using AE win software (32 bit Windows based data acquisition and replay program by Mistras, Physical Acoustic Corporation). The recorded data were analysed using MATLAB 7.0 and Origin 6.1. The signals received were digitized at a sampling rate of $10^7$ samples per second. Data length of each ASCII file was set at 15 kilobytes.

3. Experimental Procedure:

The experimental procedure followed for studying the amplification of AE signals includes simultaneous injection of acoustic waves and AE generation due to tensile deformation of specimen.

Acoustic waves having suitable frequency (obtained from the transfer function of the specimen) were injected. Since the AE signals were not produced continuously during material deformation, the AE acquisition software was always kept in acquisition mode to catch AE generated alone. As soon as an AE signal (without injection) was obtained, acoustic waves were injected into the specimen and injected signal with AE was obtained. After this, the UTM was held for approximately 10 seconds till relaxation of AE signals occurred. After 10 seconds of holding, acoustic waves were injected into the specimen and injected signal without AE was acquired.

Acquisition of data for the above three steps corresponds to 1 set of data. 41 such data sets were recorded for the overall strain range of 0 to 10%. Power spectra of the acquired time signals were obtained using MATLAB 7.0 and the areas under the power spectra plots were computed for studying the AE energy content.
The power spectra shows prominent peak at the injected frequency, amplitude of which is always fluctuating. In order to study AE amplification, effect of this peak due to injected acoustic waves was removed. Also in the present study, peaks at higher order frequencies of the injected waves were obtained. Therefore the study for amplification of AE signals has been performed for the two frequency bands: 50–300 kHz and 450–650 kHz. These bands are free from any effect due to peaks at injected frequency and higher harmonics. A representative result of the bands chosen is given in Figure 3. As it is expected to find stimulated emission from subcritical AE sources under the influence of injected acoustic waves, the net acoustic energy is plotted with respect to % yield strain using Equation (1):

\[
\text{Net Acoustic Energy }_{\text{(Injected)}} = \text{Acoustic Energy }_{\text{(Injected with AE)}} - \text{Acoustic Energy }_{\text{(Injected without AE)}} \tag{1}
\]

Amplification factors are calculated for 4 different ranges of strain: 0–75%, 75–150%, 150–250% and > 250% of yield strain, using Equation (2):

\[
\text{Amplification Factor} = \frac{\text{Net Acoustic Energy }_{\text{(Injected)}}}{\text{AE Energy }_{\text{(Non Injected)}}} \tag{2}
\]

These ranges have been chosen for analysing amplification before yield, during and beyond yield region.
4. Results:

Figure 4 shows typical time domain AE signal and corresponding power spectrum for non-injected and injected conditions for aluminium specimen at 0.4% strain. The power spectrum of signals corresponding to the injected condition shows a strong peak at the injected frequency. In addition, peaks at some new frequencies (e.g., 280 kHz, 468 kHz, 560 kHz, etc. for 0.4% strain) were observed. The net acoustic energy of signals determined using Equation 2 was higher as compared to the energy content of only AE signal (without injection) for frequency ranges 50 – 300 kHz and 450 – 650 kHz respectively. Amplification factors (Equation (2)), at the start of loading (0% to 75% yield strain) were observed to be significant.

![Figure 4: Typical time signal and power spectrum for a continuous type AE signal (at 0.4 % Strain).](image)

Tables 1 and 2 show maximum as well as average amplification factors for different strain ranges for 50-300 kHz and 450-650 kHz, respectively. Figure 5 shows a comparative chart of maximum as well as average amplification factors for different strain ranges in 50-300 kHz and 450-650 kHz bands. Amplification factor is found to increase with increase in strain levels till around yielding. It is then found to decrease gradually with increasing strain. Amplification factor for both the frequency bands of 50 kHz to 300 kHz and 450 kHz to 650 kHz is found to be maximum during the yield region (spanning approximately from 75% to 150% the yield strain).
Figure 5: Comparison of maximum and average amplification factors for 50 – 300 kHz and 450 – 650 kHz

<table>
<thead>
<tr>
<th>% Yield Strain</th>
<th>Amplification Factor (Maximum)</th>
<th>Amplification Factor (Average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 75%</td>
<td>8.3</td>
<td>4.9</td>
</tr>
<tr>
<td>75 – 150%</td>
<td>13.5</td>
<td>7.8</td>
</tr>
<tr>
<td>150 – 250%</td>
<td>4.7</td>
<td>2.4</td>
</tr>
<tr>
<td>&gt; 250%</td>
<td>4.2</td>
<td>3.2</td>
</tr>
</tbody>
</table>

Table 1: Amplification factors for different strain ranges for frequency band 50 – 300 kHz.

<table>
<thead>
<tr>
<th>% Yield Strain</th>
<th>Amplification Factor (Maximum)</th>
<th>Amplification Factor (Average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 75%</td>
<td>2.1</td>
<td>2.1</td>
</tr>
<tr>
<td>75 – 150%</td>
<td>12</td>
<td>8.9</td>
</tr>
<tr>
<td>150 – 250%</td>
<td>7.6</td>
<td>5.3</td>
</tr>
<tr>
<td>&gt; 250%</td>
<td>5.4</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Table 2: Amplification factors for different strain ranges for frequency band 450 – 650 kHz.
5. Discussion

It is seen that net acoustic energy is higher in the yield region as compared to the other strain levels and decreases after yielding. It has been observed that the amplification factor increases till yield and decreases gradually thereafter for higher strain levels (Figure 5). This can be explained on the basis of variation of AE power which is maximum at yield strain due to rapid expansion of (groups of) dislocations [9] or sudden stoppage at obstacles or due to breakaway of dislocations from obstacles [10]. AE power decreases rapidly thereafter, due to material hardening [10].

From the histograms shown in Figure 5, the amplification factors for 450 – 650 kHz range is seen higher than that of 50 – 300 kHz range except at the beginning when strain is below 75% yield strain. This may be due to external noise content in the region of 50 – 300 kHz being more, as is evident from Figure 4.

The spectrum of the signals corresponding to injected condition shows a strong peak at the injected frequency in addition to some new frequencies as observed under the influence of injected acoustic waves. For the case of 0.4% strain, as shown in Figure 4 several new frequencies, eg. 280 kHz, 468 kHz, 560 kHz, etc. are observed. The strain levels of the spectra before and after remains the same; therefore the new frequencies must be the result of injected waves. However, it must be noted that emission of new frequencies is not typical for all strains.

6. Conclusion:

The maximum amplification factor noted for aluminium is 13.5 and this is for the yield region.

The range of average amplification factors obtained for aluminium is 2.1 to 8.9 times as compared to 3.3 to 4.5 times (for input of 0.5V peak to peak amplitude) obtained for stainless steel by Baldev Raj et al. [8]. Thus, amplification of AE signals is more pronounced in aluminium.

In addition to a strong peak at injected frequency, some new frequencies were observed under the influence of injected acoustic waves, e.g., 280 kHz, 468 kHz, 560 kHz, etc. This is attributed to be due to the combined effect of constructive interference and unpinning of AE sources.

Amplification around yield region is found to be more than other regions. Amplification factors are found to be random in nature. However, they show a broad pattern of continuous increase till yielding after which they decrease gradually. Significant amplification factors at the start of material deformation (in the elastic region) have been found (maximum 8.3 times). This study, therefore, points towards the possibility of extending these findings to AE testing of civil structures, e.g. metallic bridges and other large structures, which operate within the elastic region for early detection of small cracks in large installed structures.

7. Future work:

High amplification factors indicate possibility of application to practical situations. As of now, amplification studies have been carried out for aluminium (in present study) and AISI
316 stainless steel [8]. It would thus be interesting to study the behaviour of materials with other crystal structure and microstructural features. Studies on other materials with elaborate yield point can also be taken up for understanding the interaction mechanism near yield and to develop mathematical models. In order to develop a mathematical model explaining the observed results, experiments on single crystal specimens will also be beneficial and necessary.

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References: