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APPLICATION OF ACOUSTIC EMISSION TO PREDICT CORROSION

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ABSTRACT

Non-destructive testing (NDT) techniques used for petroleum pipelines and offshore wind-turbines can only detect corrosion after it has occurred. Therefore, intrusive inspections are required regularly, potentially causing disruption to operation and production. Acoustic Emission (AE) is a non-destructive testing (NDT) sensor based technique which measures the detection and the conversion of high frequency (between 100 kHz to 1 MHz) elastic waves generated by the rapid release of energy to electrical signals. AE is released when crack propagates in the specimens during corrosion. This presentation will summarise AE sensor based technique for monitoring corrosion and offer examples of practical applications. Samples tested include aluminium and steel thin plates (rectangular shape) in different corrosive environments. AE from corrosion usually releases much less energy than emission from crack growth, and so is more difficult to detect in the field environment. However, the results present an exponential curve showing a trend between the concentration of the corrosive environment and the energy of the acoustic emission signal.

Key words: Acoustic Emission (AE), Corrosion, Non-destructive testing (NDT).

1.   Introduction

Corrosion is a natural phenomenon which can be defined as the degradation of material due to a reaction with its environment. From an environmental perspective, corrosion is a natural occurrence which aims to return metals to their more stable states such as oxides and sulphides; as they were originally found in their ores. However, from an engineering perspective the corrosion process is destructive, causing a significant loss in material, which in turn leads to losses in integrity, productivity and finances [1]. The cost of corrosion in the USA alone was estimated to be $135 billion in 2001 [2]. If corrosion is not identified and acted upon accordingly, it can undermine any asset's integrity and eventually lead to a failure with severe consequences. Corrosion occurs in every aspect of modern life, however it is not always possible to witness the process taking place and this is why it is necessary to periodically inspect and monitor assets for corrosion. Singh et al [1] have categorised the effects of corrosion in three main areas; economics, safety and the environment. There are several economic impacts caused by corrosion (e.g. costs involved with the repair and maintenance of corroded materials, whilst considering the extra costs of using materials or protection methods to extend asset's life). In severe cases structures can eventually fail if no action is taken, thereby causing a number of severe repercussions. The environmental concerns involved with corrosion can stem of number

of hazardous materials transported or contained in structures susceptible to corrosion and it has been seen from past corrosion related failures, that they often have a great effect on the environment and require costly mitigation methods.

Corrosion monitoring systems are an essential part of an integrity management system. However, the multivariate forms of corrosion, environment factors affecting corrosion are all contributing factors to the complexity of selecting an appropriate corrosion control system. Despite the fact the corrosion monitoring process is complex in nature; the advantages proffered by the implementation of a monitoring system, far outweigh the complexities involved.

Generally, corrosion monitoring techniques are divided into intrusive and non-intrusive methods. Direct intrusive methods such as mass loss coupons, electrical or inductive resistance probes, and electrochemical techniques are used to directly monitor corrosion by installing in situ monitors, which measure the variance in the physical properties of associated flow process. However, most of these methods are often limited due to their operational requirements for obtaining accurate corrosion data.

Non-intrusive techniques involve monitoring corrosion without inserting a retrievable probe; through an access fitting, into the flow process. AE testing is well recognised as a NDT technique that provides key benefits over other methods such ultra-sonic and radiography. One essential benefit of the AE system is that it can be used to locate damaged areas, with a relatively minimal number of sensors; also its equipment can be setup in a relatively short time. Meanwhile, radiography and ultrasonic testing will require the inspection of entire area, which equates to more sensors and longer setup time. Such advantage has positioned AE, as a more economical tool which is used to pinpoint the approximate damaged area prior to the implementation of more expensive techniques for precise fault location [3]. The acoustic emission (AE) technique involves the use of highly sensitive piezoelectric sensors, which are used to measure the elastic waves generated by the distortions produced in the corrosion process. There are numerous literature and practices related to corrosion monitoring using AE sensor, and nearly all presented equivalent conclusion that such sensors can detect corrosion efficiently. A variety of corrosion types including uniform corrosion, pitting corrosion, crevice corrosion, stress corrosion cracking, abrasion corrosion and erosion corrosion, has been studied and found to be correlated with AE [4]. Mazille et al [5] have established a linear relationship between the AE count rate and the evolution of hydrogen while monitoring corrosion in an aluminium wire placed in a saline solution following 15 hour stabilisation period at open circuit potential followed by a 7 hour polarisation period. However, large fluctuations in the plots of the number of AE events against the weight loss were observed. They concluded that pitting rate bears a linear relationship with the AE activity and also the applied current density. Kim et al [6] have used different AE parameters such as amplitude, counts number, hits, duration, corrosion potential and cumulative energy of AE signals, to characterise crevice corrosion in stainless steel. Ferrer et al [7] used AE techniques to interrogate the synergistic abrasion-corrosion phenomena in the presence of multivariate factors. Plots of corrosion current, RMS, weight loss and AE energy, revealed quantities of large magnitude, that are strongly correlated to high degradation caused by the abrasion-corrosion process.

In this study, an AE technique has been implemented to monitor corrosion of several metal samples under different corrosive environments, and to establish a correlation between corrosion rate and AE parameter with a view to provide a guide that can be used in monitoring and predicting corrosion of different materials in service.

2. Experimental procedures

This section details the processes carried out to complete the experimental part of the project. This includes describing the specimen design, the fabrication of the specimens and the details about the placement of the sensor. The procedures conducted for both the calibration of the AE sensor and for the experiment on the specimens will be explained.

2.1 Specimen design

Four aluminium rectangular specimen are tested in this study. The rectangular design was chosen for its simplicity, ease of application of the sensor and it would be long enough to keep equipment away from the corrosive environments. All specimens were cut in-house from the same long length bar using a guillotine. The dimensions of the specimens are shown in Fig. 1. The edges of each specimen were them smoothed down using a grinding wheel to remove any sharp edges before 8mm hole was drilled in each specimen to provide an area where a bolt of a different metal can be inserted. As the specimens are all cut from the same long length bar it can be assumed that the material has uniform properties throughout.
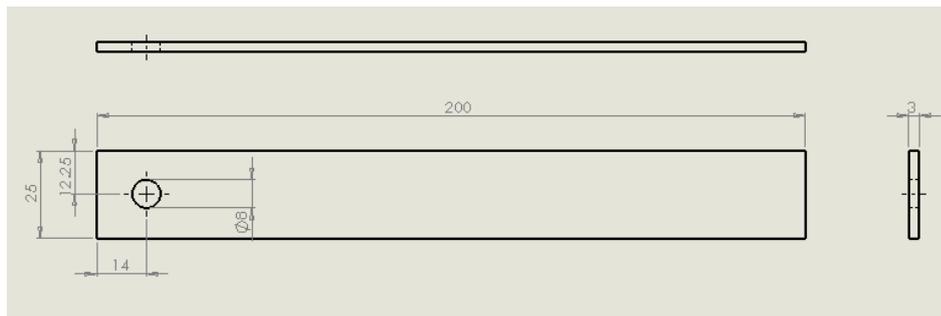
Fig. 1: Schematic view of the experimental specimen

Steel bolts were used and one was inserted into the hole of each specimen. A steel nut was used to secure the bolt in place in order to increase the rate of the corrosion with the addition of galvanic corrosion with final specimen design is shown in Fig. 2.

Fig. 2: Aluminium sample with steel bolt and nut

2.2 Acoustic emission

A Micro-80D differential AE sensor manufactured by Physical Acoustics Ltd was used throughout the investigation. The sensor has a useful frequency response over the region of 100 – 1000 kHz and features electrical isolation between the sensing element and the cavity in order to increase the sensors ability in applications featuring high background noise. The frequency at which the AE sensor most efficiently converts energy, the resonance frequency, was determined to be 340 kHz. Silicone grease was applied to the sensor before attaching to the specimen surface using electrical tape. The silicone grease was applied in order to improve the transmission of the AE signal between the specimen surface and the AE sensor; hence the imperfect connection caused by air gaps between the sensor and the specimens' microscopic surface roughness was minimised.

The AE acquisition set-up (shown in Fig. 3) consists of the AE sensor was connected to a pre-amplifier that was utilised to amplify the acquired signals gain and could be varied between 20, 40 and 60 dB. The pre-amplifier was connected to an in-house-built 4-channel signal conditioning unit (SCU) that was coupled with a gain programmer in order to supply 28V of power, coupled with adjustable gain control. The SCU transmits the adjusted signal to a National Instruments (NI) BNC-2120 shielded connector block in order to complete the systems signal

transmission to the data acquisition card (DAQ). The signals were interpreted through a computer using a NI PCI-6115 DAQ in order to obtain the raw signal data and convert it to a binary file within the LabVIEW software for further analysis using Matlab.
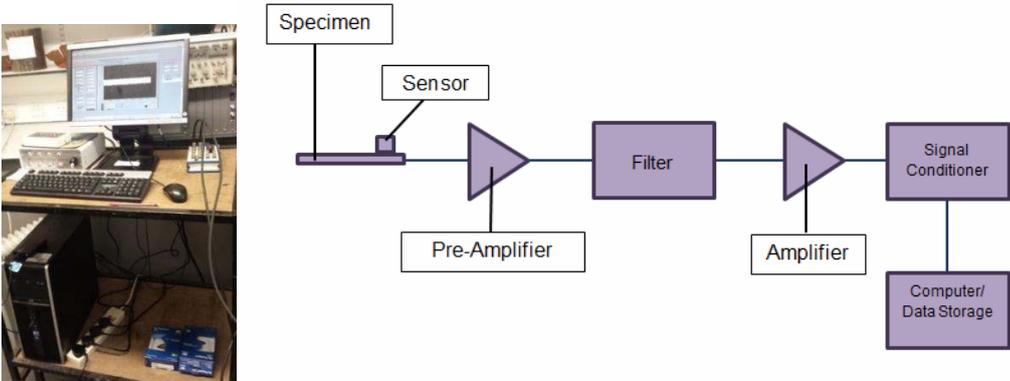
Fig. 3: Acoustic emission system

In order to obtain accurate and reliable results throughout the experiment, the AE sensor was positioned in the same location for each test. This location was chosen in order to keep a reasonable distance between the sensor and corrosive environment to prevent any damage being done to the acoustic emission equipment.

2.3   Test procedures

In order to test the aluminium specimens, it was important to know what type of environment would be able to corrode the specimens in a short time period to provide adequate results. "Aluminium finds most application in corrosive environments at a pH level between 5 and 7, and undergoes rapid corrosion under either highly acidic or highly alkaline conditions." (Byars 1999 p. 81). Therefore. Hydrochloric acid (pH between 1 and 2) was chosen to induce corrosion. Furthermore, to increase the rate of corrosion on the aluminium specimen further, a steel bolt is used to induce galvanic corrosion.

To establish a trend between the amount of corrosion taking place and the acoustic emissions recorded, four different corrosive environments were used. Table 1 shows the four solutions used in the experiment (The dilutions and their volumetric make up of solution and deionised water). To carry out the experiment the setup shown in Fig. 4 is used. The set up comprises of a 250 millilitre glass beaker, 100 millilitres of the hydrochloric acid solution, the specimen being tested and the sensor. This part of the apparatus will always be inside a fumigation hood.

Table 1: Test solution percentages and volumes

Percentage of Hydrochloric Acid Solution	Volume of Distilled Water (ml)	Volume of 37% Hydrochloric Acid Solution (ml)	Volume of Final Solution (ml)
No Solution	0	0	0
3.7 % Solution	90	10	100
18.5% Solution	50	50	100
37% Solution	0	100	100
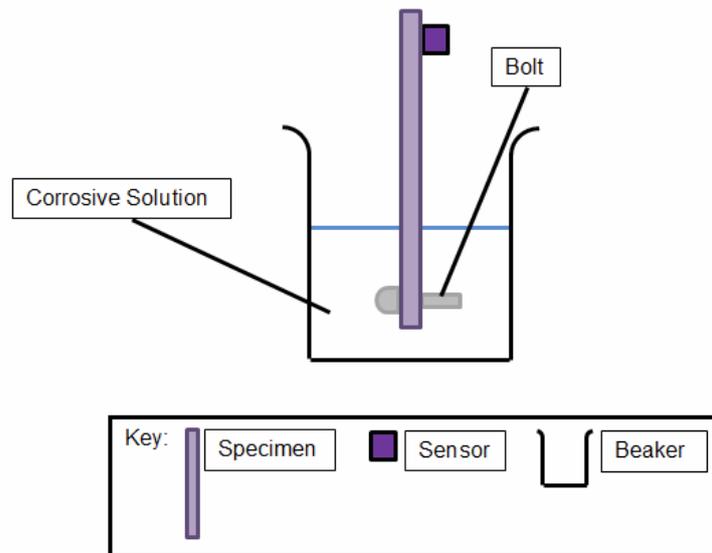
Fig. 4: Experimental set-up of specimen in its corrosive environment

3.   Results

3.1   Visual results
For 3.7% solution, a small fizz of bubbles surrounding the bolt-specimen area was observed. The activity of these bubbles being produced/ bursting remained relatively constant throughout the tests. When the specimen was removed from the hydrochloric solution the specimen was covered by a very small amount of grey residue, and the hydrochloric acid remained clear and transparent. For 18.5% solution, tests were relatively reactive, with the activity of the bubbles quickly began to increase with time and the solution began to turn a dirty colour. On removal from the experiment set-up, there was a grey residue surrounding the bottom of the specimen, this was the area of specimen placed in the corrosive environment. For 37% solution, the mixture began to froth violently producing large bubbles that would then burst. The solution itself turned from being clear and transparent to a dirty yellow colour while releasing a strong egg-like odour. When the tests were complete and the specimen was removed from the corrosive solution, it could be seen that there were blister like marks on the aluminium.

To ensure that corrosion has actually taken place for all samples, all specimens were weighed before and after the tests. Table 2 provides values of the specimens before and after they were subject to a corrosive environment.

Table 2: specimen initial and final weights

Specimen Type	Initial Weight (kg)	Final Weight (kg)	Weight Difference (kg)
Test 1 - No Corrosion	63.1	63.1	0.0
Test 2 - 3.7% Solution	62.9	62.8	0.1
Test 3 - 18.5% Solution	62.7	62.4	0.3
Test 4 - 37% Solution	62.9	61.8	1.1

3.2   AE results

Fig.5 displays the AE signal for test A for no corrosion. It can be seen that a continuous signal is recorded with the amplitude sitting generally about 0.5×10^{-5} volts. This would be expected as any background noise picked up would be constant through all experiments and there are no corrosion reactions taking place to generate any changes in signal.
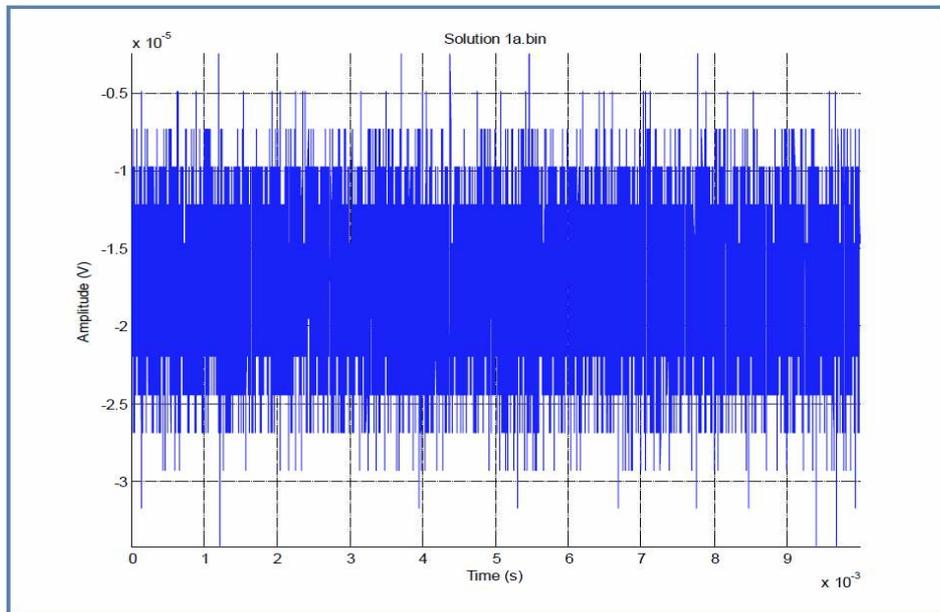
Fig. 5: Typical time domain AE signal for the specimen immersed in water

Fig. 6 shows a typical AE signal for the weakest hydrochloric acid solutions where some peaks associated with higher amplitude (1.5×10^{-4} Volts) in the record are evident, suggesting a sort of activities has taken place.
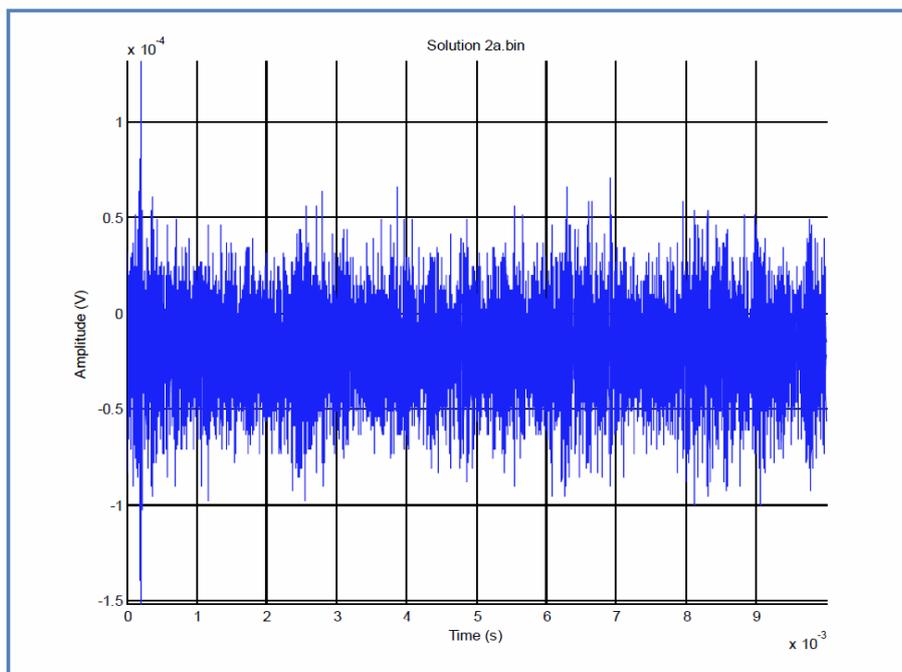
Fig. 6: Typical time domain AE signal for the specimen immersed in 3.7% solution

Similar peaks were observed for18.5% solution (Fig.7) but this time with more activities during the AE record, suggesting that using AE amplitude only to characterise the signal is not sufficient.
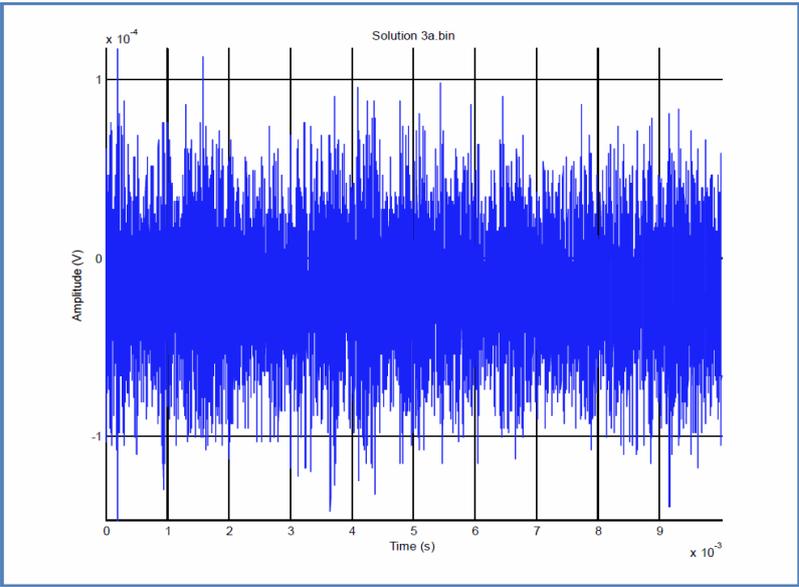
Fig. 7: Typical time domain AE signal for the specimen immersed in 18.5% solution

Fig. 8 shows a typical AE signal for the most corrosive environment. It is clear that AE activities are higher in amplitude (4 x 10^{-4} Volts) and intensity.
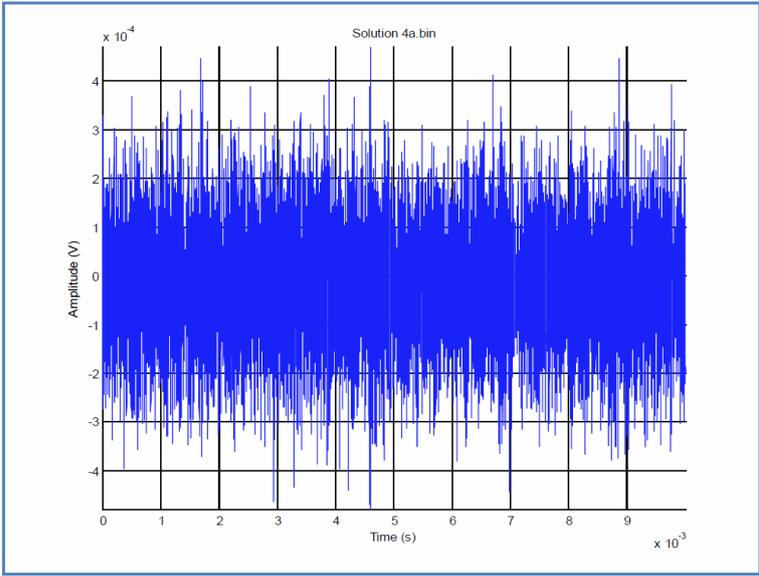
Fig. 8: Typical time domain AE signal for the specimen immersed in 37% solution

Figure 9 shows a clear relationship (exponential) between average AE energy values of all tests and their corresponding corrosive environment. An exponential trend means that at each point of the graph the energy increase becomes greater and greater. The higher AE energy observed from test 4 can be attributed to material blistering/cracking; it was presumed that a crack in a metal material caused greater acoustic emissions than a bubble rupture. Hence, if the cracks in the material were more frequent and growing at a more rapid rate the acoustic energy would be far greater than the values obtained in this experiment.

Average Acoustic Emission Energy against Concentration of Hydrochloric Acid Solution

$y = 4E\text{-}07e^{0.1739x}$
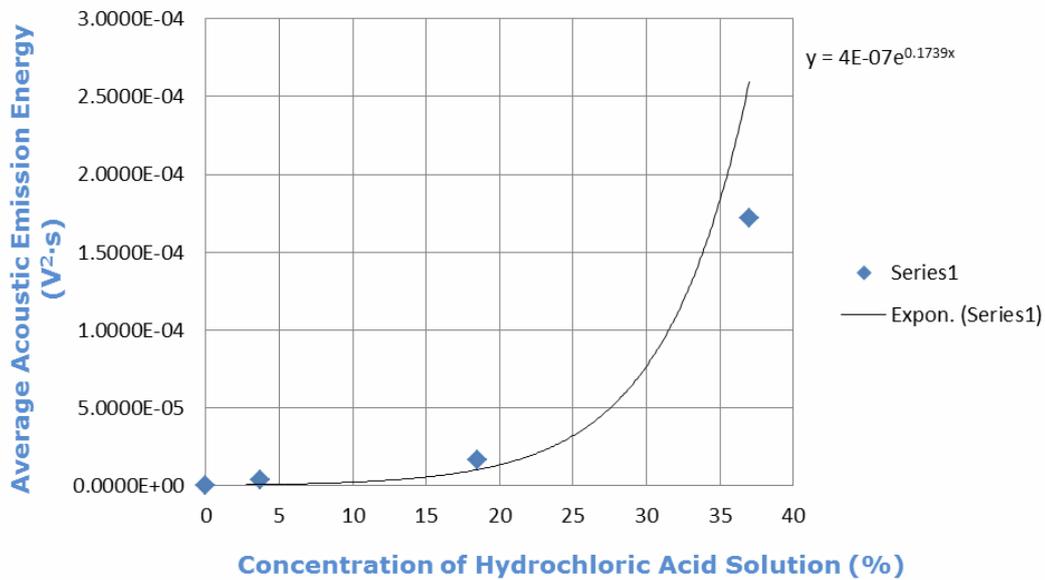
Fig. 9: Average acoustic emission energy versus acid concentration for all tests

4.   Conclusion

AE method has been used to monitor corrosion activities on aluminium specimens under four different corrosive environments with the broad conclusions;

- Corrosion caused by a means of bubbles rupturing on the surface of a material or by cracking generates adequate acoustic emissions.
- Increasing the concentration of the hydrochloric acid solution will result in higher AE signal amplitude and more intensive activities.
- An exponential relationship has been developed between AE energy and acid concentration, suggesting the feasibility of using AE as promising technique to monitor corrosion.

5.   References

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