ROBERT GORDON UNIVERSITY ABERDEEN

31st January 2017 (6.30-7.30 pm)
Palm Court Hotel, Aberdeen, ICorr Aberdeen Technical Evening Events

Acoustic Emission Techniques in Corrosion Monitoring

Nadimul Faisal, Ghazi Droubi, Iain Steel
School of Engineering, Robert Gordon University, Garthdee Road, Aberdeen

Presentation Scheme

1. Introduction (Research Group: Condition Monitori
2. Acoustic Emission
3. Corrosion
4. Why corrosion monitoring?
5. Corrosion measurement techniques
6. Literature: Corrosion monitoring using AE
7. ASTM Standards
8. Corrosion testing facilities at RGU
    a. Acoustic Emission (AE) technique
    b. Electro-chemical Impedance Spectroscopy (EIS) technique
9. Examples (Corrosion monitoring using AE)
10. Signal processing
11. Ground penetrating radar technique

Introduction: Condition Monitoring Group

Principal Group Members

- **Dr Nadimul Faisal** [Acoustic Emission, Vibration Dynamics, Mechanics of Materials, Instrumented Mechanical Testing, Simulations]
- **Prof Iain Steel** [Acoustic Emission, Condition Monitoring]
- **Dr Ghazi Droubi** [Acoustic Emission, Erosion and corrosion management, multiphase modelling]
- **Dr Ketan Pancholi** [Materials, Vibrations]
- **Dr Sha Jihan** [Acoustic Emission, Ultrasonic Testing]


Iain Steel

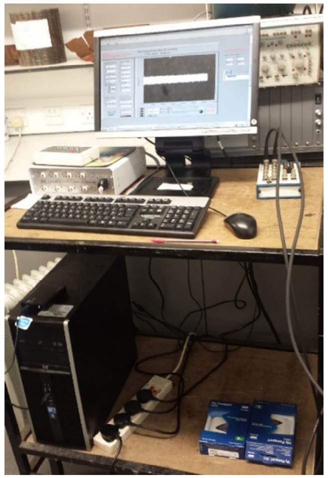

Ghazi Droubi


Sha Jihan

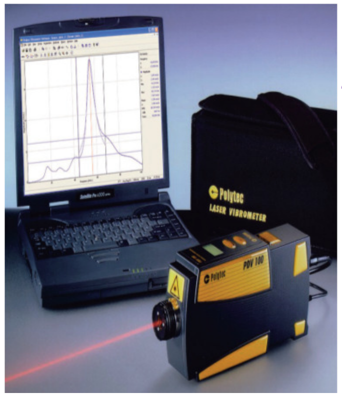

Nadimul Faisal


Ketan Pancholi

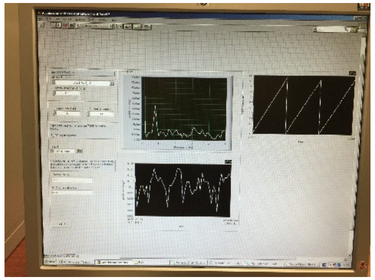
Acoustic Emission



Laser Vibrometer



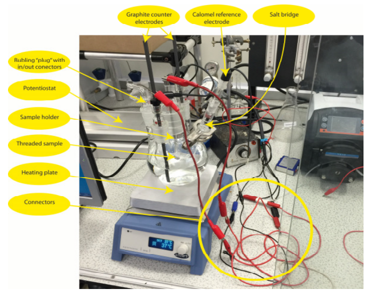
Tri-axial accelerometer



Ultrasonic

Eddy Current

EIS



Acoustic Emission technique

- **Acoustic Emission (AE)** refers to the generation of transient elastic waves produced by a sudden redistribution of stress in a material.
- **AE testing** simply listens for the energy released by the object.
- **AE tests** are often performed on structures while in operation, as this provides adequate loading for propagating defects and triggering acoustic emissions.
- **AE systems** can qualitatively/quantitatively gauge how much damage is contained in a structure.

Corrosion & Mechanism

Anode reaction : $2\,M \rightarrow 2\,M^{2+} + 4e^-$

Cathode reaction : $O_2 + 2\,H_2O + 4e^- \rightarrow 4OH^-$

- **Corrosion** is defined as "the deterioration of a material, usually a metal, by a chemical or electrochemical reaction with its environment" (Byars p.1, 1999).
- **Mechanism:** Anodic reaction is the dissolution of metallic ions through the passive film, and the cathodic reaction involves dissolved oxygen.
- **Stress corrosion cracking (SCC)** is caused by the "synergistic" action of corrosion and applied tensile stress; that is, the combined effect of the two is greater than the sum of the single effects.
- **Galvanic corrosion:** Byars (1999) states that "When two different metals are placed in contact in an electrolyte containing an oxidizing agent, the more reactive one will corrode and the other will not. This coupling of dissimilar metals is referred to as a bimetallic couple. It can be extremely destructive, drastically accelerating the corrosion rate of the more reactive metal."

Why corrosion monitoring using sensors?

- **Remote diagnostics (if possible)**
- **Early warning and control**
- **Reduction in maintenance and operational cost**
- **Minimize construction and installation costs**
- **Extend the lifetime of offshore structures**

Corrosion measurement techniques

- **Direct intrusive corrosion monitoring techniques**
  - Corrosion coupons (metallography): Facility/Expertise at RGU
  - Electrical resistance (ER): Commercial product available/wireless corrosion monitoring
  - Inductance resistance probes
  - Linear polarization resistance (LPR): Commercial product available/wireless corrosion monitoring
  - Electro-chemical impedance spectroscopy (EIS): Facility/Expertise at RGU
  - Electro-chemical frequency modulation
  - Harmonic analysis
  - Electro-chemical noise
  - Zero resistance ammetry
  - Potentiodynamic polarization
  - Thin layer activation

- **Direct non-intrusive techniques**
  - Gamma radiography
  - Electrical field signature method (FSM): Commercial product available/wireless corrosion monitoring
  - Acoustic emission (AE) method: Facility/Expertise at RGU
  - Ground penetrating radar (GPR) method: Commercial product available/wireless corrosion monitoring/Concrete
  - Ultrasonic method (thickness measurement): Commercial product available/wireless corrosion monitoring

- **Indirect non-intrusive techniques**
  - Corrosion potential
  - Hydrogen flux monitoring

Advantage of using AE technique

- AE is unique
  - as it detects flaws and leaks,
  - used for on-line, real time monitoring of structural integrity without interruption of operation, cleaning or product evacuation.
- Evaluation of flaw propagation rate.
- Differentiating between developing and non-developing flaws.

Contribution: Jordan Davidson, RGU (2016/17)

Literature Examples (Corrosion monitoring using AE)…

AE Techniques in Corrosion Monitoring – Reference List [1984-2016]

[1] Luigi Calabrese, Massimiliano Galeano, Edoardo Proverbio, Domenico Di Pietro, Filippo Cappuccini, Angelo Donato, **Monitoring of 13% Cr martensitic stainless steel corrosion in chloride solution in presence of thiosulphate by acoustic emission technique**, Corrosion Science, Volume 111, October 2016, Pages 151-161

[2] Fabienne Delaunois, Alexis Tshimombo, Victor Stanciu, Véronique Vitry, **Monitoring of chloride stress corrosion cracking of austenitic stainless steel: identification of the phases of the corrosion process and use of a modified accelerated test**, Corrosion Science, Volume 110, September 2016, Pages 273-283

[3] Kaige Wu, Woo-Sang Jung, Jai-Won Byeon, **In-situ monitoring of pitting corrosion on vertically positioned 304 stainless steel by analyzing acoustic-emission energy parameter**, Corrosion Science, Volume 105, April 2016, Pages 8-16

[4] N. Morizet, N. Godin, J. Tang, E. Maillet, M. Fregonese, B. Normand, **Classification of acoustic emission signals using wavelets and Random Forests : Application to localized corrosion**, Mechanical Systems and Signal Processing, Volumes 70–71, March 2016, Pages 1026-1037

[5] José Luis López, José Bonastre, Jorge Gabriel Segura, José María Gadea, Ernesto Juliá, Francisco Cases, **Correlations between acoustic and electrochemical measurements for metallic corrosion on steel strings used in guitars**, Engineering Failure Analysis, Volume 57, November 2015, Pages 270-281

[6] Luigi Calabrese, Lucio Bonaccorsi, Massimiliano Galeano, Edoardo Proverbio, Domenico Di Pietro, Filippo Cappuccini, **Identification of damage evolution during SCC on 17-4 PH stainless steel by combining electrochemical noise and acoustic emission techniques**, Corrosion Science, Volume 98, September 2015, Pages 573-584

[7] Jaka Kovač, Andraž Legat, Bojan Zajec, Tadeja Kosec, Edvard Govekar, **Detection and characterization of stainless steel SCC by the analysis of crack related acoustic emission**, Ultrasonics, Volume 62, September 2015, Pages 312-322

[8] Woonggi Hwang, Seunggi Bae, Jaeseong Kim, Sungsik Kang, Nogwon Kwag, Boyoung Lee, **Acoustic emission characteristics of stress corrosion cracks in a type 304 stainless steel tube**, Nuclear Engineering and Technology, Volume 47, Issue 4, June 2015, Pages 454-460

[9] Lamine Djeddi1, Rabia Khelif , Salim Benmedakhene and Jérôme Favergeon, **Reliability of Acoustic Emission as a Technique to Detect Corrosion and Stress Corrosion Cracking on Prestressing Steel Strands**, Int. J. Electrochem. Sci., 8 (2013) 8356 – 8370

[10] M.G. Alvarez, P. Lapitz, J. Ruzzante, **Analysis of acoustic emission signals generated from SCC propagation**, Corrosion Science, Volume 55, February 2012, Pages 5-9

[11] G. Du, J. Li, W.K. Wang, C. Jiang, S.Z. Song, **Detection and characterization of stress-corrosion cracking on 304 stainless steel by electrochemical noise and acoustic emission techniques**, Corrosion Science, Volume 53, Issue 9, September 2011, Pages 2918-2926

[12] G. Van Dijck, M.M. Van Hulle, **Genetic algorithm for informative basis function selection from the wavelet packet decomposition with application to corrosion identification using acoustic emission**, Chemometrics and Intelligent Laboratory Systems, Volume 107, Issue 2, July 2011, Pages 318-332

[13] Jian Xu, Xinqiang Wu, En-Hou Han, **Acoustic emission during pitting corrosion of 304 stainless steel**, Corrosion Science, Volume 53, Issue 4, April 2011, Pages 1537-1546

Contribution: Jordan Davidson, RGU (2016/17)

…Literature Examples (Corrosion monitoring using AE)

[14] Dong-Hwan Kang, Jong-Kwan Lee, Tae-Won Kim, **Corrosion fatigue crack propagation in a heat affected zone of high-performance steel in an underwater sea environment**, Engineering Failure Analysis, Volume 18, Issue 2, March 2011, Pages 557-563

[15] C. Jirarungsatian, A. Prateepasen, **Pitting and uniform corrosion source recognition using acoustic emission parameters**, Corrosion Science, Volume 52, Issue 1, January 2010, Pages 187-197

[16] Jaka Kovac, Carole Alaux, T. James Marrow, Edvard Govekar, Andraz Legat, **Correlations of electrochemical noise, acoustic emission and complementary monitoring techniques during intergranular stress-corrosion cracking of austenitic stainless steel**, Corrosion Science, Volume 52, Issue 6, June 2010, Pages 2015-2025

[17] Krakowiak, S. & Darowicki, K. J **Electrochemical and acoustic emission studies of aluminum pitting corrosion**, Solid State Electrochem (2009) 13: 1653.

[18] C. Jomdecha, A. Prateepasen, P. Kaewtrakulpong, **Study on source location using an acoustic emission system for various corrosion types**, NDT & E International, Volume 40, Issue 8, December 2007, Pages 584-593,

[19] Rongsheng Geng, **Modern acoustic emission technique and its application in aviation industry**, Ultrasonics, Volume 44, Supplement, 22 December 2006, Pages e1025-e1029

[20] H. Chang, E. Han, J. Q. Wang, **Acoustic emission study of corrosion fatigue crack propagation mechanism for LY12CZ and 7075-T6 aluminum alloys**, Journal of Materials Science, 2005, Volume 40, Number 21, Page 5669

[21] F Bellenger, H Mazille, H Idrissi, **Use of acoustic emission technique for the early detection of aluminum alloys exfoliation corrosion**, NDT & E International, Volume 35, Issue 6, September 2002, Pages 385-392

[22] Ferrer, F., Schille, E., Verardo, D. et al. **Sensitivity of acoustic emission for the detection of stress corrosion cracking during static U-bend tests on a 316L stainless steel in hot concentrated magnesium chloride media**, Journal of Materials Science (2002) 37 pp 2707–2712

[23] Z.F. Wang, Z. Zhu, W. Ke, **Behaviour of acoustic emission for low strength structural steel during fatigue and corrosion fatigue,** Metallurgical Transactions, 22A (1991), pp. 2677–2680

[24] D.J. Buttle, C.B. Scruby, **Acoustic emission monitoring of a fatigue crack in 50D steel in a sea-water environment**, NDT International, Volume 22, Issue 2, 1989, Pages 81-96

[25] C. Thaulow, T. Berge, **Acoustic emission monitoring of corrosion fatigue crack growth in offshore steel**, NDT International, Volume 17, Issue 3, 1984, Pages 147-153

Literature Examples (Corrosion monitoring using AE)

A. Study on source location using an acoustic emission system for various corrosion types

- Four main types of corrosion: uniform, pitting, crevice and stress corrosion cracking (SCC) found in the petrochemical industry, were characterized and identified by AE using their locations and extracted AE parameters.
- Specimens: austenitic stainless-steel SS304.
- AE signals from each type of corrosion was plotted using their location and correlation.
- Correlations of AE parameters including amplitude, counts, hits and time were used to identify different types of corrosion.
- Characteristics of the corrosion process for each type were explained using AE signals obtained corresponding to the source locations, together with experimental observation.

NDT&E International 40 (2007) 584–593

Literature Examples (Corrosion monitoring using AE)

A. Study on source location using an acoustic emission system for various corrosion types

$$R = \frac{1}{2}\frac{D_2^2 - Dt_1^2 V^2}{Dt_1 V + D_2 \cos(\theta_2 - \theta)}$$

$$R = \frac{1}{2}\frac{D_3^2 Dt_2^2 V^2}{Dt_2 V + D_3 \cos(\theta - \theta_3)},$$

where Dt_1 and Dt_2 are the time differences between sensors 1 and 2 and 1 and 3, respectively

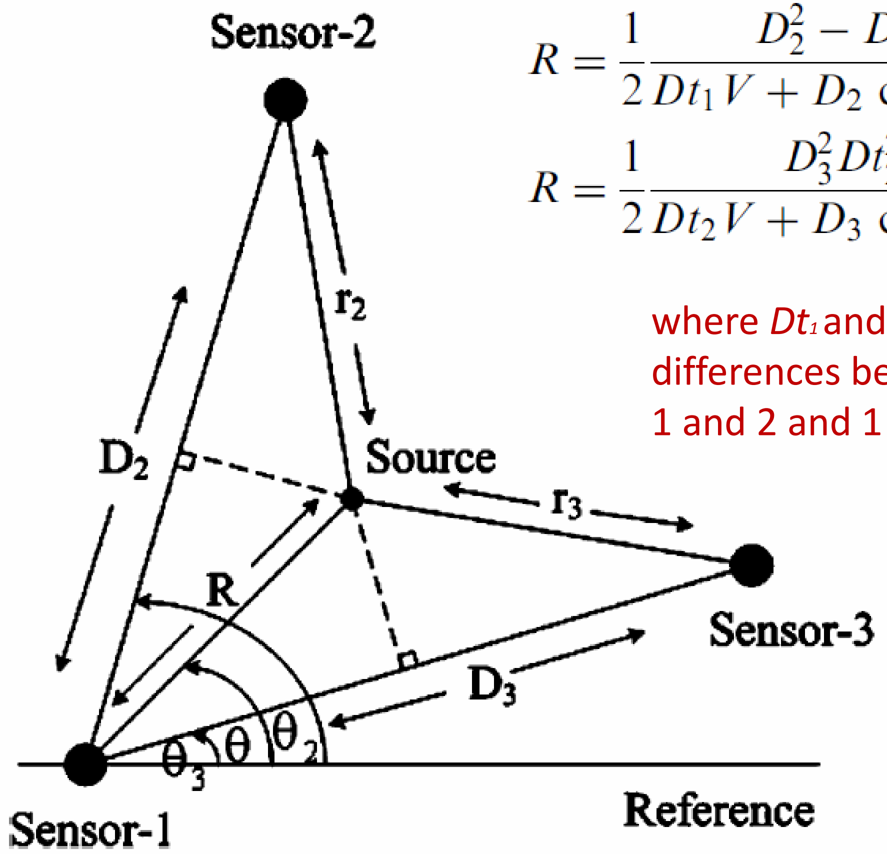


Fig. 2. Three sensors of source-location technique.

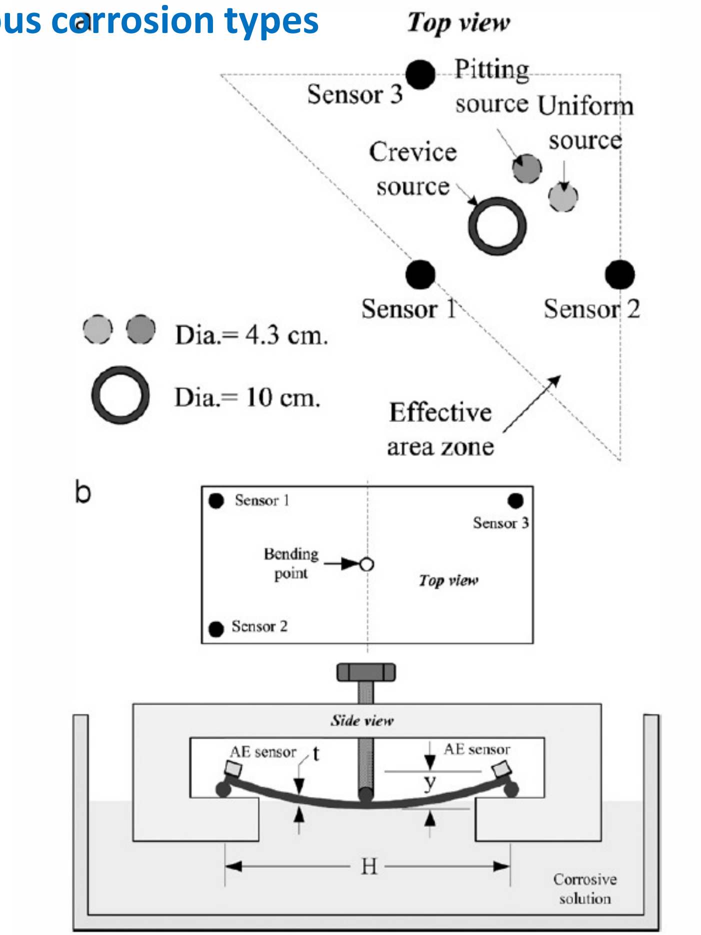
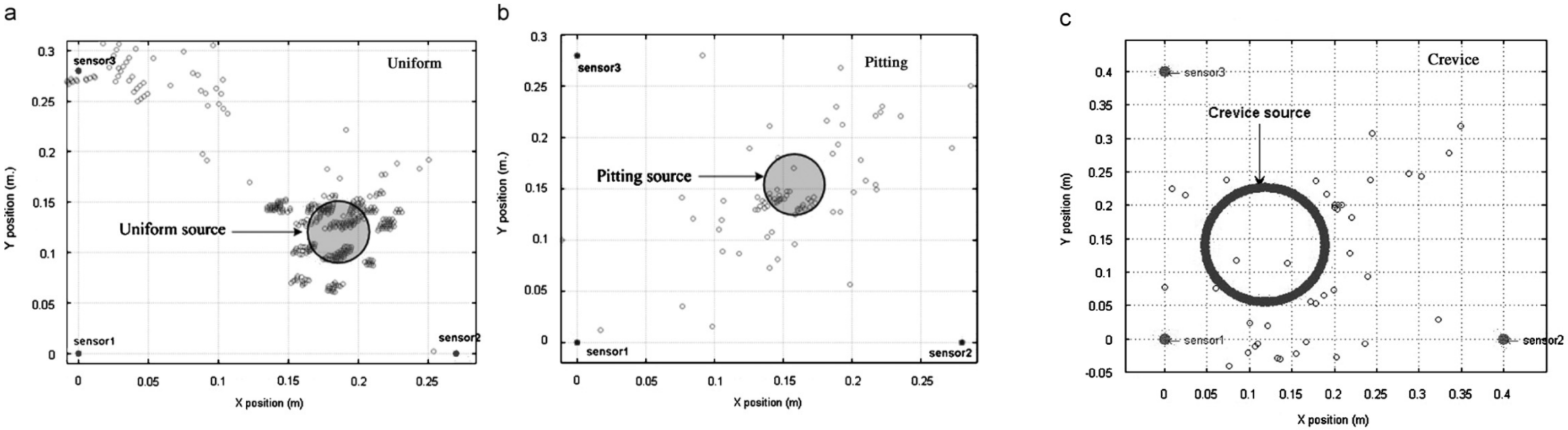


Fig. 3. Set up for producing (a) uniform, pitting and crevice corrosion; (b) stress corrosion cracking.

NDT&E International 40 (2007) 584–593

Literature Examples (Corrosion monitoring using AE)

A. Study on source location using an acoustic emission system for various corrosion types



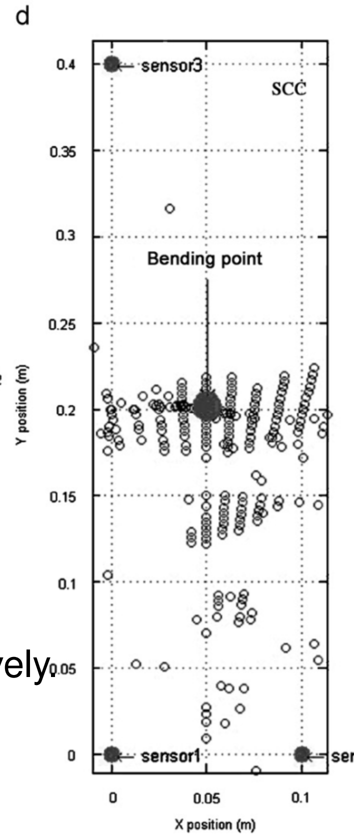


Fig 7. Location results and their characteristics for uniform, pitting, crevice corrosion and SCC, respectively.

NDT&E International 40 (2007) 584–593

Contribution: Jordan Davidson, RGU (2016/17)

Literature Examples (Corrosion monitoring using AE)

B. Monitoring of 13% Cr Martensitic Stainless Steel Corrosion in Chloride Solution in Presence of Thiosulphate by Acoustic Emission Technique

- Studied a martensitic stainless steel in a chloride solution.
- The pit growth mechanism was observed to change during time.
- AE source localisation along the specimen length allowed for the identification of different damage mechanisms.
- AE technique allowed for the identification of specific parameter values for the different damage mechanisms.
- NACE TM077 method A
- Test solution was continuously deaerated by nitrogen gas bubbling until AE recording started, whereby the test cell was then sealed to avoid air inlet.
- Several experiments were intentionally stopped after 200–250 h in order to evaluate the extension of corrosion damage at an intermediate stage.

Corrosion Science, 111, 2016, p. 151-161

Contribution: Jordan Davidson, RGU (2016/17)

Literature Examples (Corrosion monitoring using AE)

B. Monitoring of 13% Cr Martensitic Stainless Steel Corrosion in Chloride Solution in Presence of Thiosulphate by Acoustic Emission Technique

- All specimens failed in a time range between 300 h and 400 h.
- Pitting corrosion was observed on the stainless steel sample under tensile load.
- As pit size increased, stress concentrations effects became significant.
- AE monitoring allowed to distinguish different damage mechanisms characterized by specific AE parameters.
- Hit duration, hit rise time, burst average frequency, crack index and hit energy were identified as the most relevant parameters in damage mechanism identification.
- FeS scale build up and hydrogen evolutions were the most energetic AE sources during the first stage of corrosion test.
- Localization of AE events along specimen length vs time. Position values were calculated starting from the top AE sensor.
- Bubble diameters and bubble colour code refer to: (a) hit energy normalized values; (b) hit rise-time normalized values; (c) hit duration normalized values.

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List of relevant standards: AE based corrosion monitoring

BSI

- BS EN 15856 Non-Destructive Testing. Acoustic Emission. General Principles of AE Testing For the Detection of Corrosion within Metallic Surrounding Filled With Liquid. [MOST RELEVANT]
- BS EN 14584 Non-Destructive Testing. Acoustic Emission. Examination of Metallic Pressure Equipment during Proof Testing. Planar Location of AE Sources.
- BS EN 15495 2007 Non-Destructive Testing. Acoustic Emission. Examination of Metallic Pressure Equipment during Proof Testing. Zone Location of AE Sources.

ASTM

- ASTM E 1930 Standard Practice for Examination of Liquid-Filled Atmospheric and Low-Pressure Metal Storage Tanks Using Acoustic Emission.
- ASTM E 1211 Standard Practice for Leak Detection and Location Using Surface-Mounted Acoustic Emission Sensors.
- ASTM E 569 Standard Practice for Acoustic Emission Monitoring Of Structures during Controlled Stimulation.
- ASTM E 650 Guide for Mounting Piezoelectric Acoustic Emission Sensors.
- ASTM E 750 Standard Practice for Characterizing AE Instrumentation.
- ASTM E 976 Guide for Determining the Reproducibility of Acoustic Emission Sensor Response.
- ASTM E 1316 Terminology for Non-destructive Examinations.
- ASTM E 2374 Guide for Acoustic Emission System Performance Verification.
- ASME Standard: Section V, Article 12, Boiler & Pressure Vessel Code, Acoustic Emission Examination of Metallic Vessels during Pressure Testing.
- ASME Standard: Section V, Article 13, Boiler & Pressure Vessel Code, Continuous Acoustic Emission Monitoring.

ASTM documents: AE based corrosion monitoring

STP908

Acoustic Emission Capabilities and Applications in Monitoring Corrosion

Published: Jan 1986

Format	Pages	Price	
PDF (180K)	13	$25	ADD TO CART
Complete Source PDF (9.2M)	520	$70	ADD TO CART

STP908

Monitoring Stress-Corrosion Cracking by Acoustic Emission

Published: Jan 1986

Format	Pages	Price	
PDF (220K)	14	$25	ADD TO CART
Complete Source PDF (9.2M)	520	$70	ADD TO CART

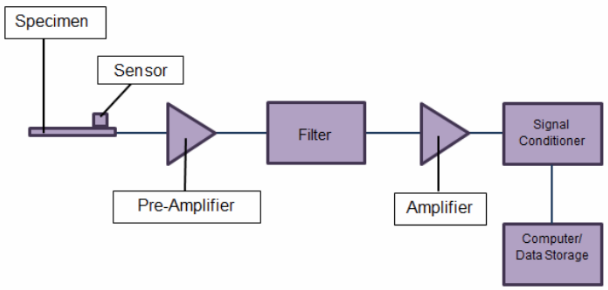
STP908

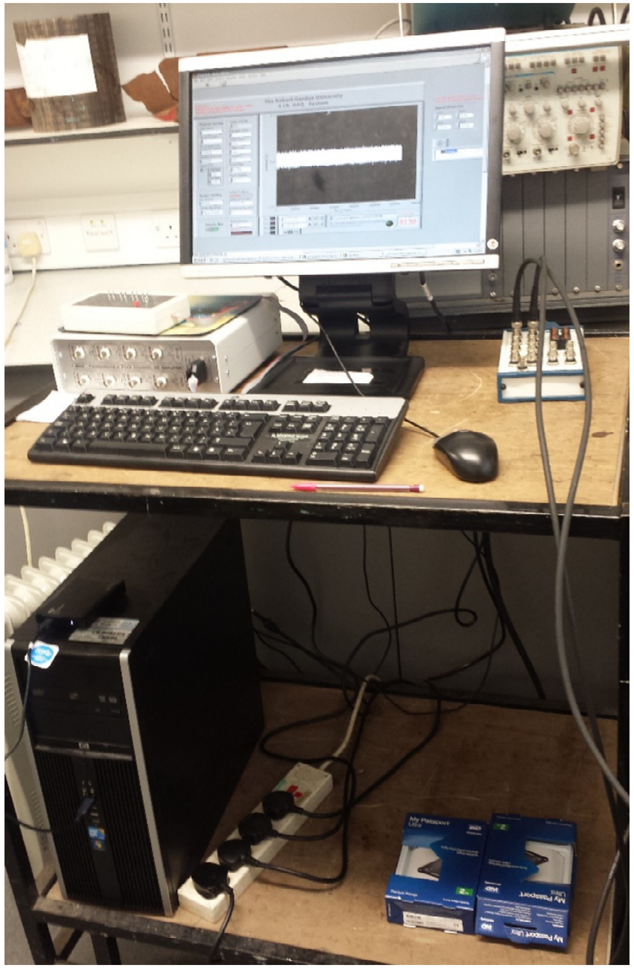
Fundamental Aspects of Acoustic Emission Applications to the Problems Caused by Corrosion

Published: Jan 1986

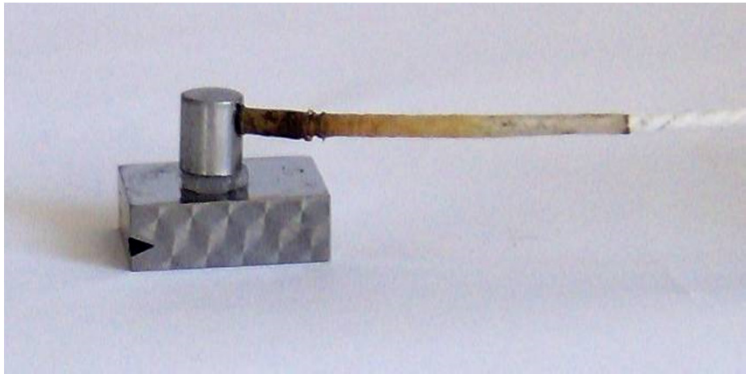
Format	Pages	Price	
PDF (524K)	32	$25	ADD TO CART
Complete Source PDF (9.2M)	520	$70	ADD TO CART

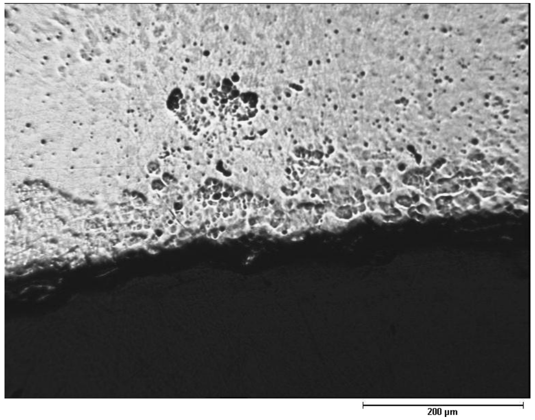
Corrosion testing facilities at RGU





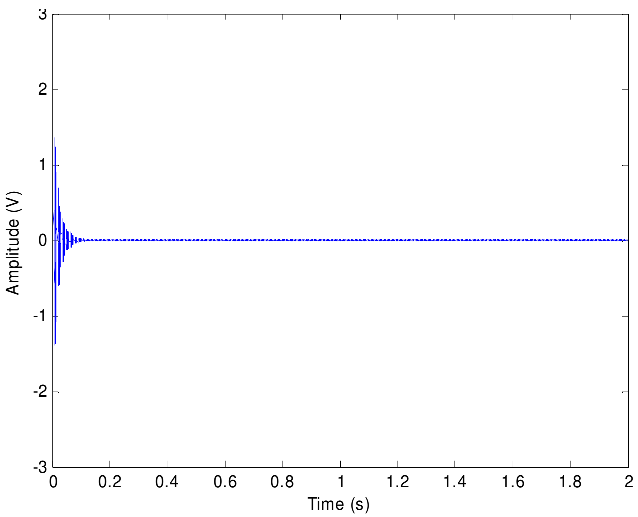
- Data acquisition (NI-6115, 4 channel, 10 MS/s)
- AE PZT sensors (Micro-80D)
- PAC Pre-amplifiers (1220A) [0.1-1 MHz]
- 4-channel signal conditioning unit (SCU)
- Connector Block (BNC-2120)
- LabVIEW codes (records data in *.txt, *.bin, *.sgl file formats)
- Can record data until the hard drive is full or can be recorded on portable hard drive (e.g. corrosion monitoring of carbon steel or nitinol wires, runs for several days continuously)

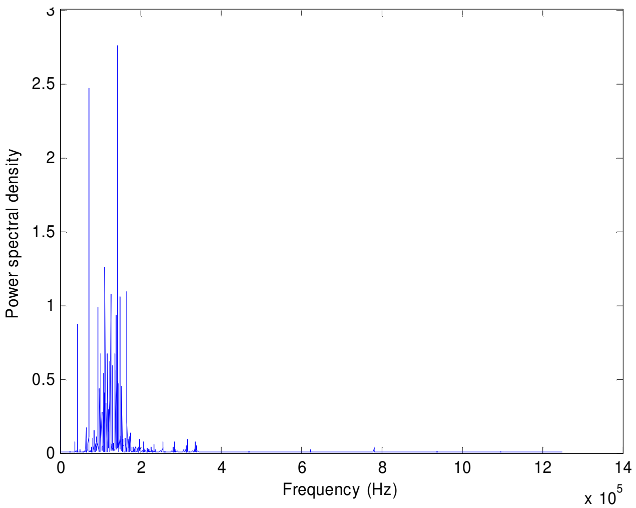


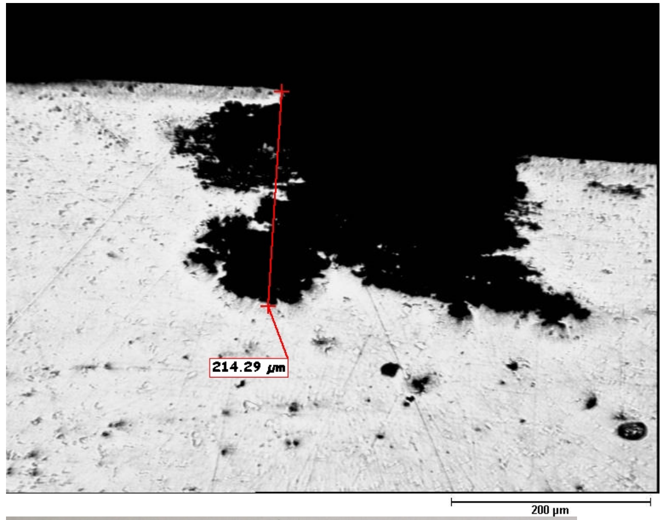


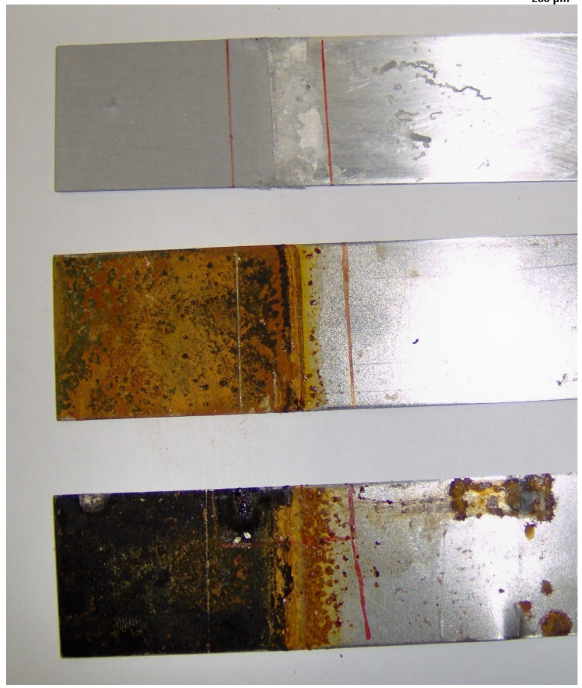
Method 1

Corrosion testing facilities at RGU



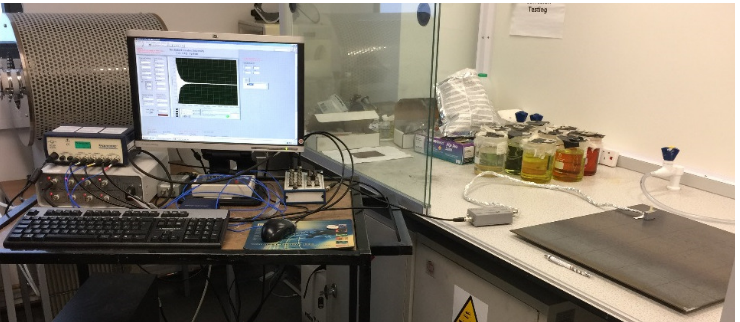


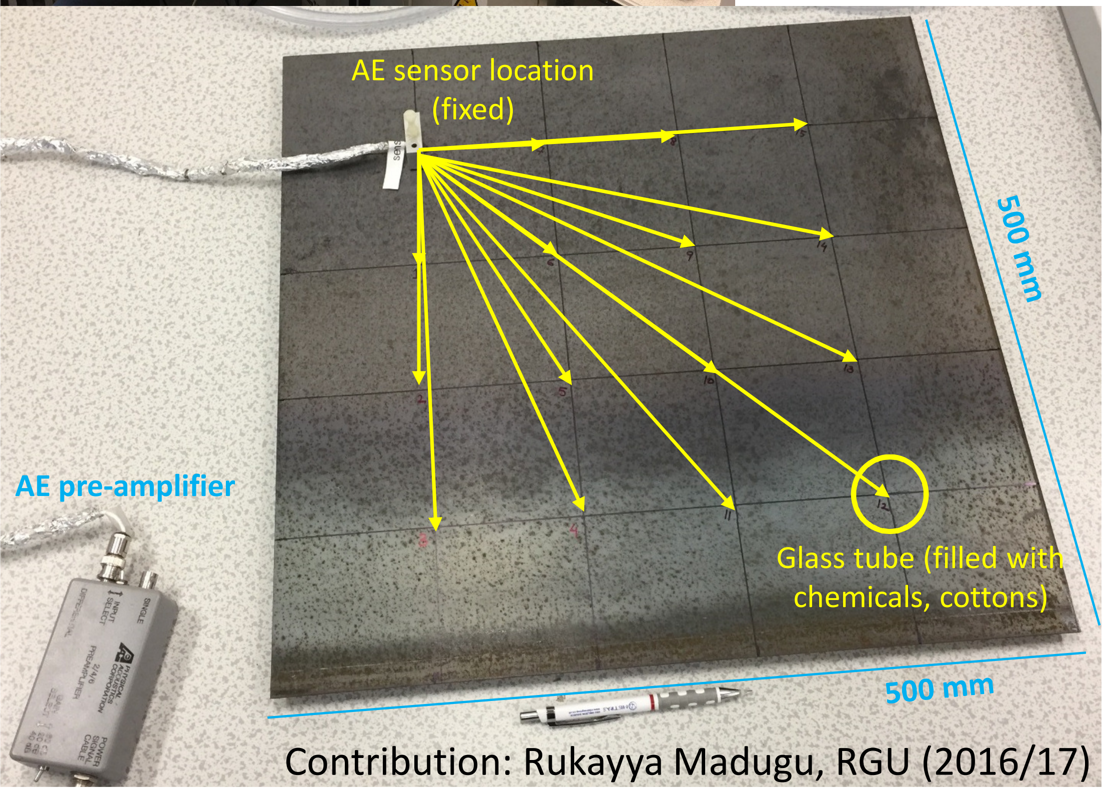


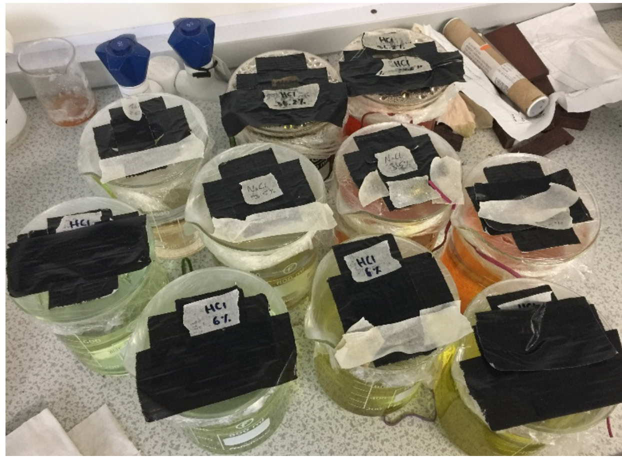


Method 3

Corrosion testing facilities at RGU







Work in progress

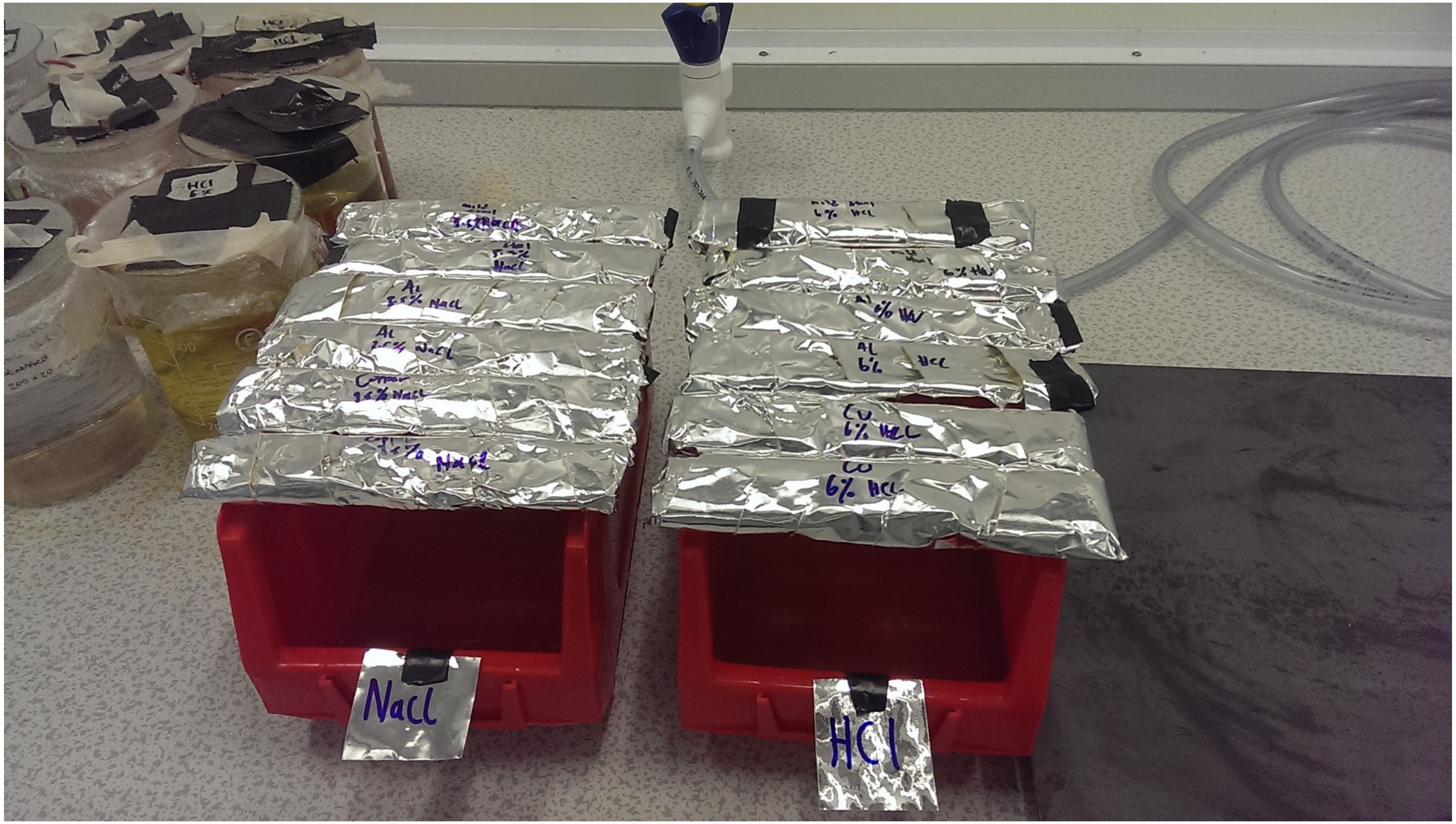
AE study on carbon steel plate (0.5 m x 0.5 m)

- Corrosion source location
- Quantification (time & frequency domain signals)
- Carry out pencil lead break (PLB) test on metal plate
- Submergence of metal in sea water
- Submergence of metal in 3.5%HCL
- Exposure of metal to corrosion via insulation using sea water.
- Exposure of metal to corrosion via insulation using 3.5%HCL.

Method 4

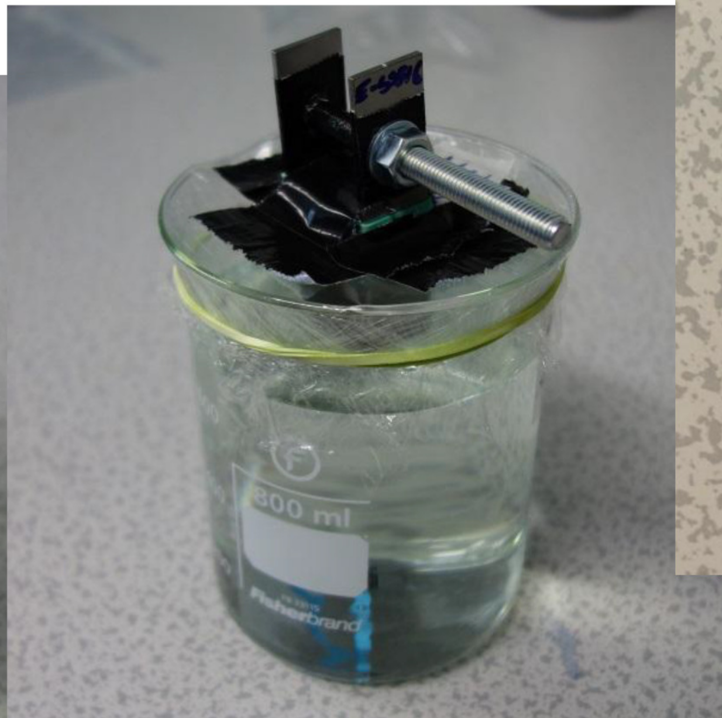
Contribution: Murali Thanasegaran, RGU (2016/17)

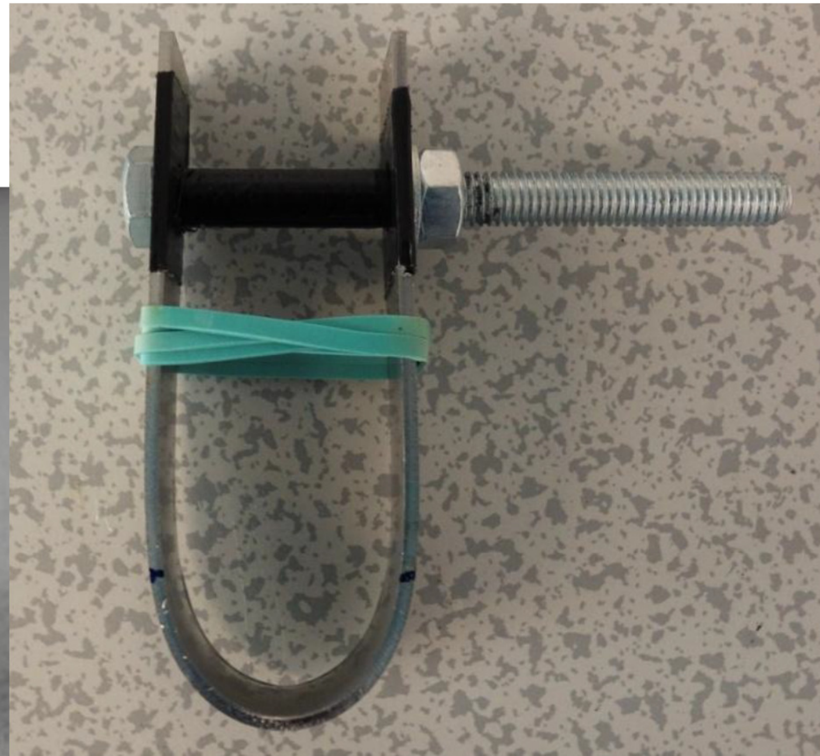
Corrosion Under Insulation (CUI) and AE monitoring during bending fatigue of pipes/tubes



Method 3

Corrosion testing facilities at RGU (Immersion testing)



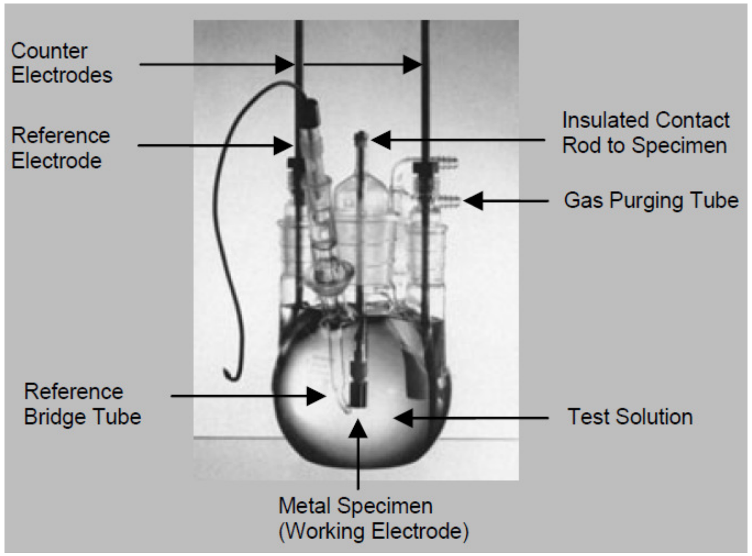


Contribution: Niall Rafferty, RGU (2016)

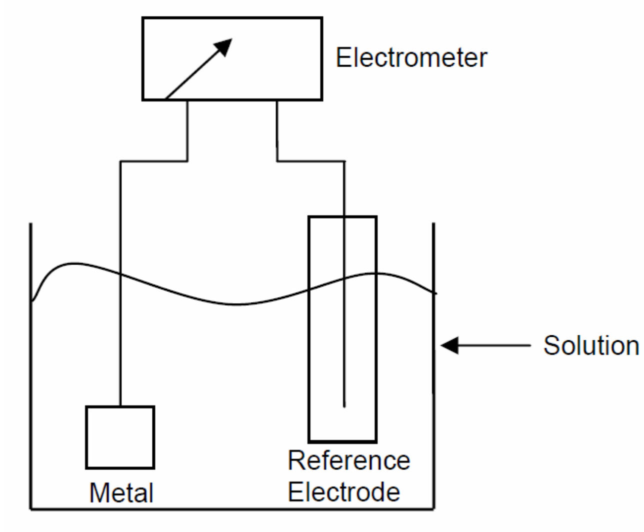
Method 5

Corrosion testing facilities at RGU

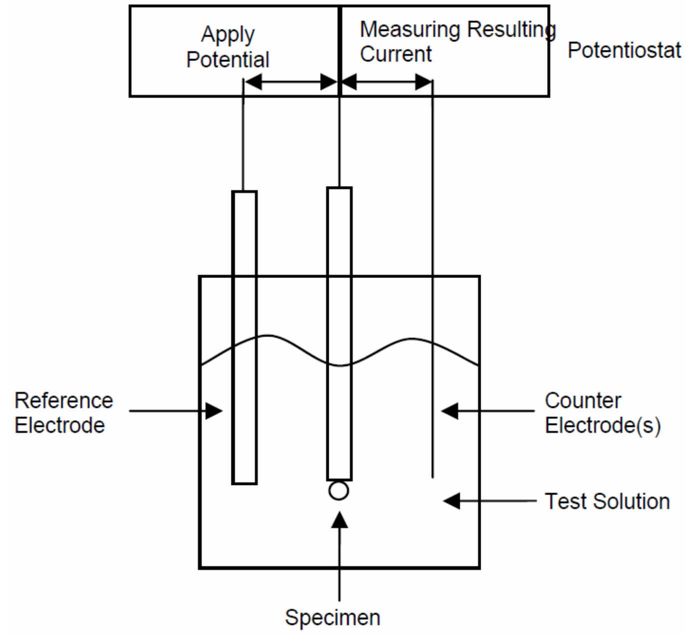
Electro-chemical Impedance Spectroscopy (EIS) technique



2 electrode system



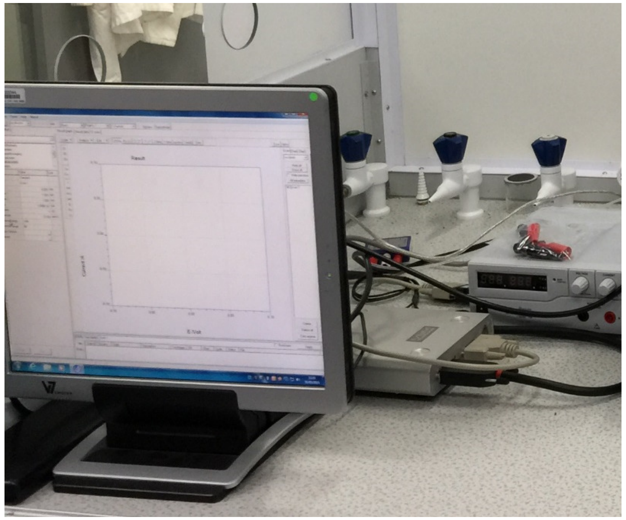
3 electrode system

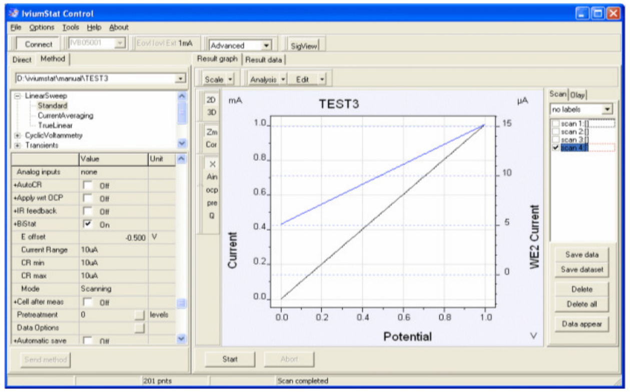


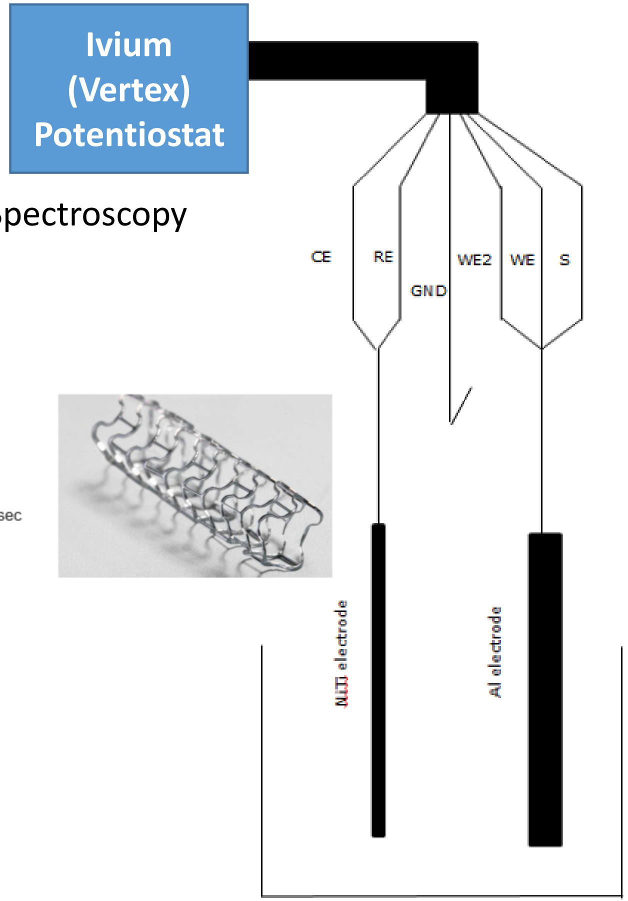
Method 5

Corrosion testing facilities at RGU

Electro-chemical Impedance Spectroscopy (EIS) technique







- Ivium Vertex 5 Amp Electrochemical Impedance Spectroscopy
- High temperature furnace (*Kittec, DE* ; 1320°*C*)

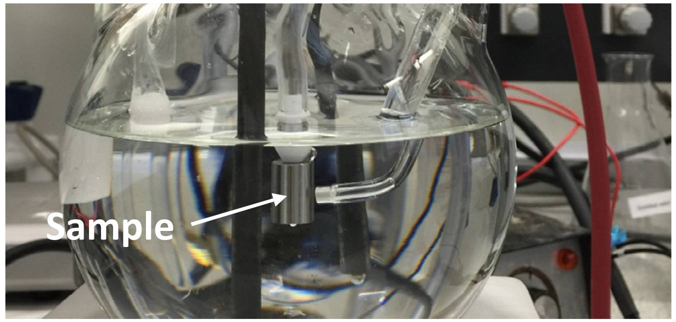
Standard model

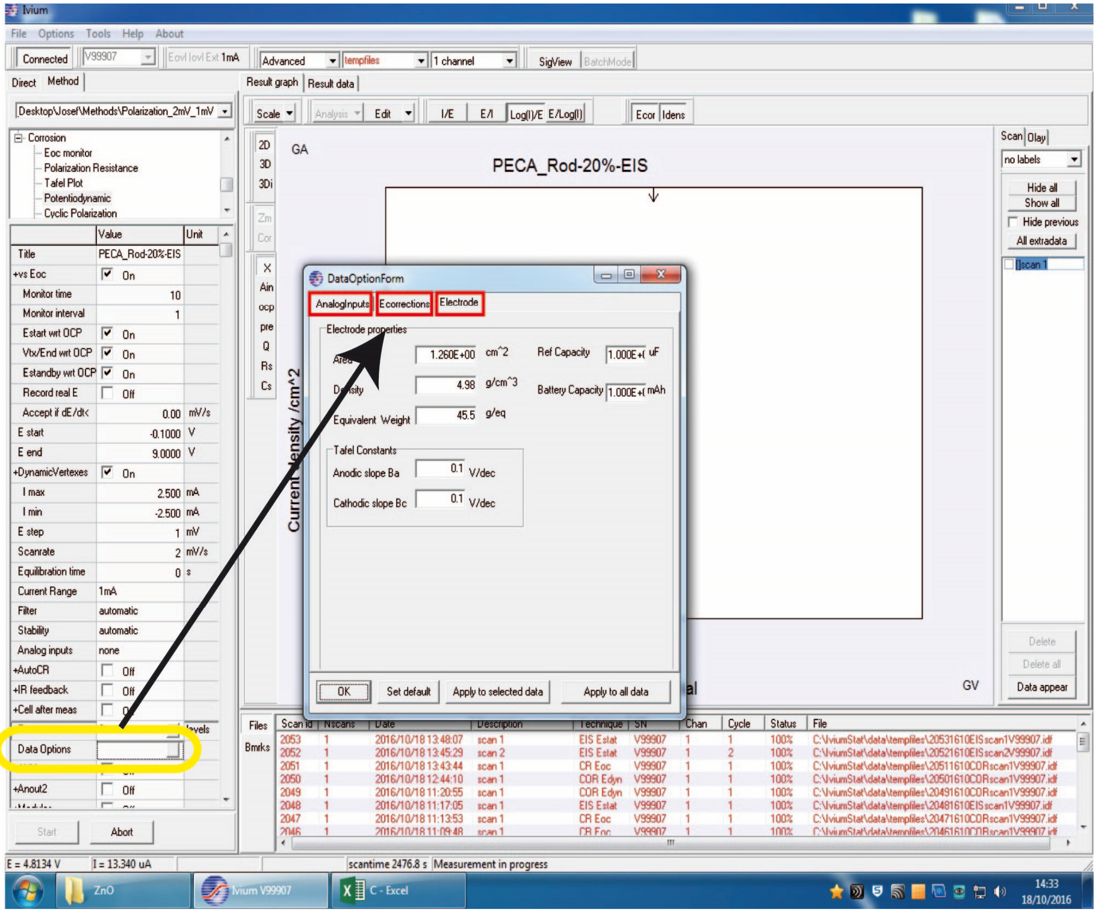
System Performance:	**Standard (100mA/10V)**
Current compliance	±100 mA
Maximum output Voltage	±10 V
Potentiostat Bandwidth	>500 kHz
Stability settings	High Speed, Standard, and High Stability
Programmable response filter	1 MHz , 100 kHz , 10 kHz , 1 kHz , 10 Hz
Signal acquisition	dual channel 16 bit ADC, 100.000 samples/sec
Potentiostat:	
Applied potential range	±10 V, at 0.333mV resolution
Applied potential accuracy	0.2%, or 2 mV
Current ranges	±10 nA to ±100 mA (±1A, ±10A)
Measured current resolution	0.015% of current range, minimum 15pA
Measured current accuracy	0.2%
Galvanostat	
Applied current resolution	0.033% of applied current range
Applied current accuracy	0.2%
Potential ranges	±10 mV, ±100 mV, ±1 V, ±10 V (±20V)
Measured potential resolution	0.004% of potential range, minimum 0.4µV
Measured potential accuracy	0.2%, or 2mV
Impedance Analyser (optional)	
Frequency range	10µHz to 1MHz
Amplitude	0.015mV to 1.0V, or 0.03% to 100% of current range
DC offset	16 bit dc offset subtraction, and 2 dc decoupling filters

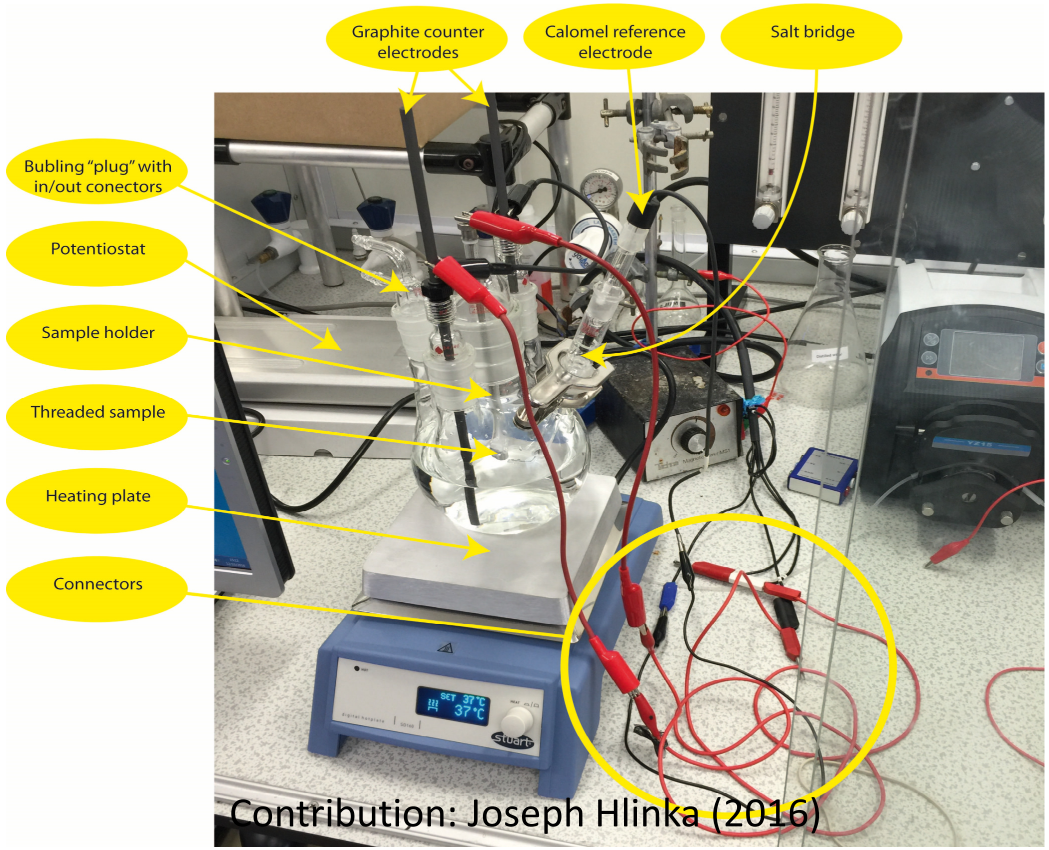
Method 5

Corrosion testing facilities at RGU

Electro-chemical Impedance Spectroscopy (EIS) technique

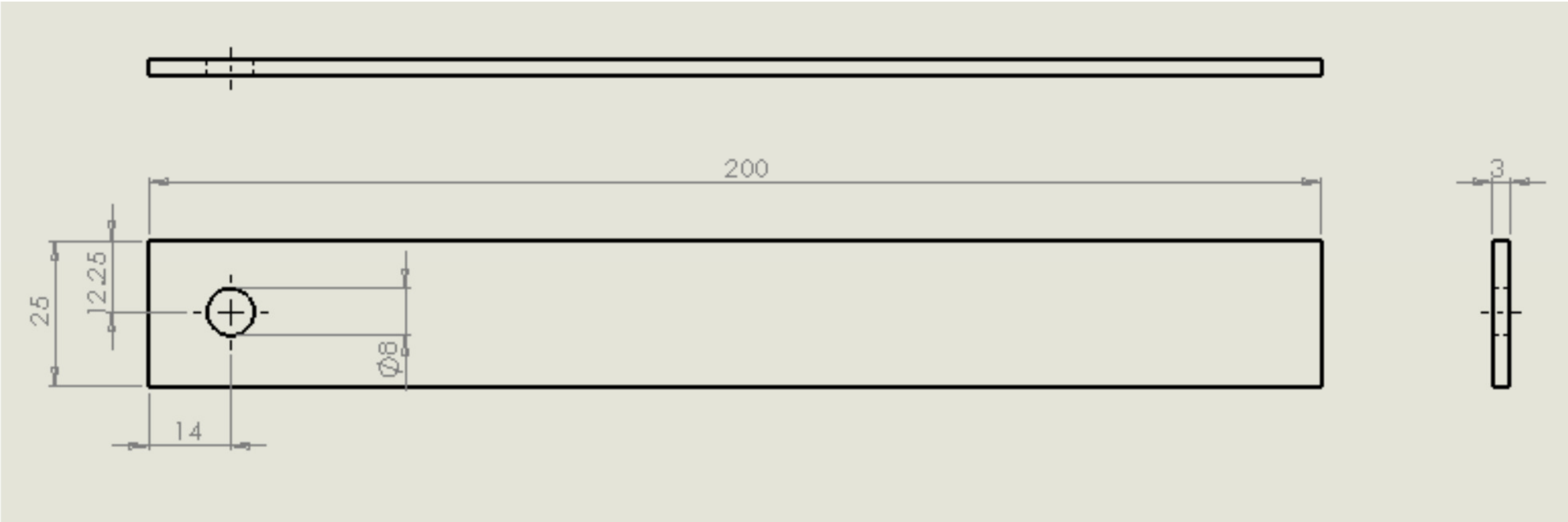






Method 1 (Example 1): Laurene Hay, 2016 (RGU)

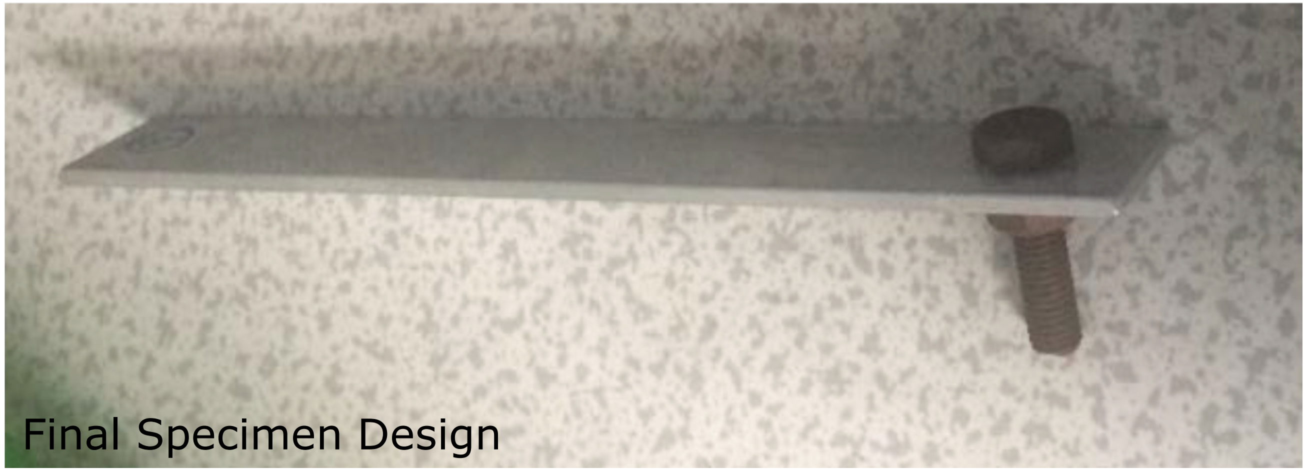
AE monitoring during corrosion (Calibration)



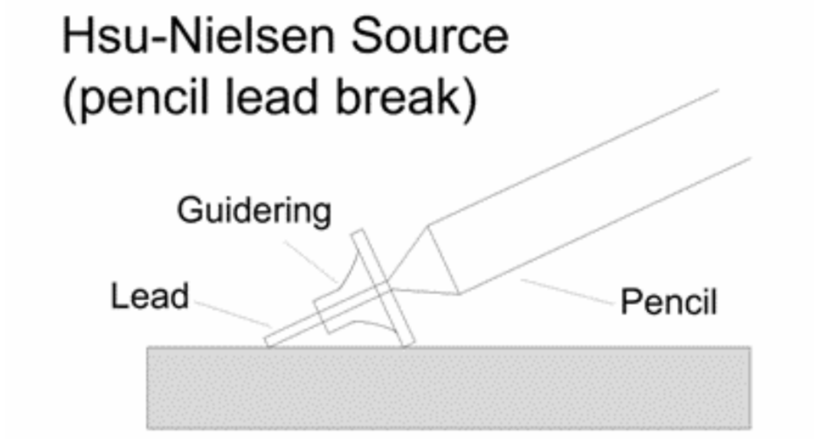
- Experiments carried on four rectangular specimens of aluminium.
- Rectangular design was chosen for its simplicity, ease of application of the sensor and it would be long enough to keep equipment away from the corrosive environments.
- The edges of each specimen were them smoothed down using a grinding wheel to remove any sharp edges.
- An 8 mm hole was drilled in each specimen to provide an area where a bolt of a different metal can be inserted in to.

Example 1…continue

AE signal transmission (Sample calibration)



Final Specimen Design



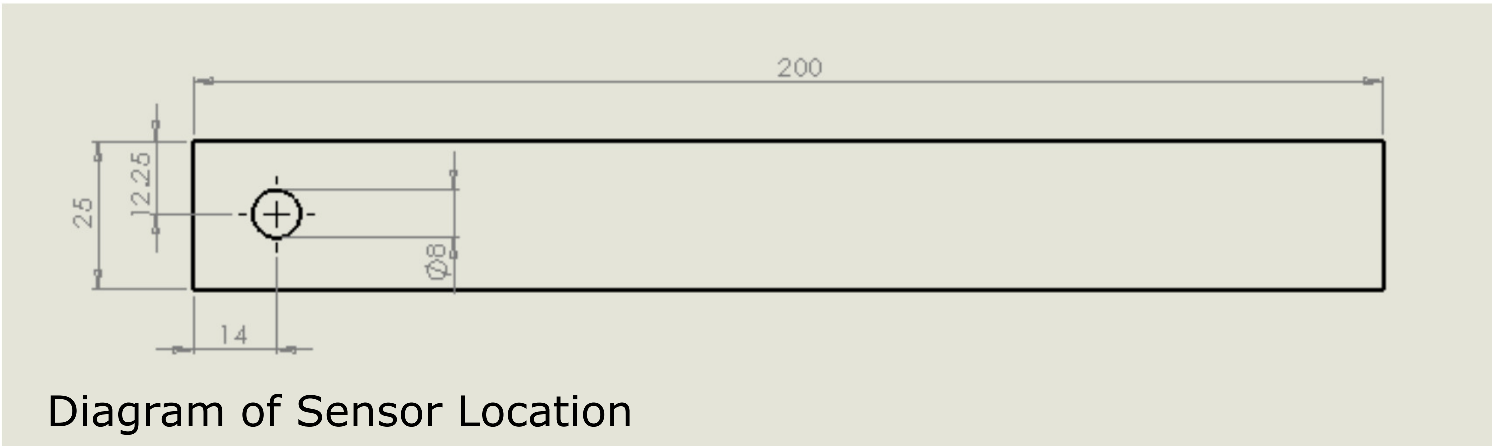


Diagram of Sensor Location

Example 1…continue

AE monitoring during corrosion

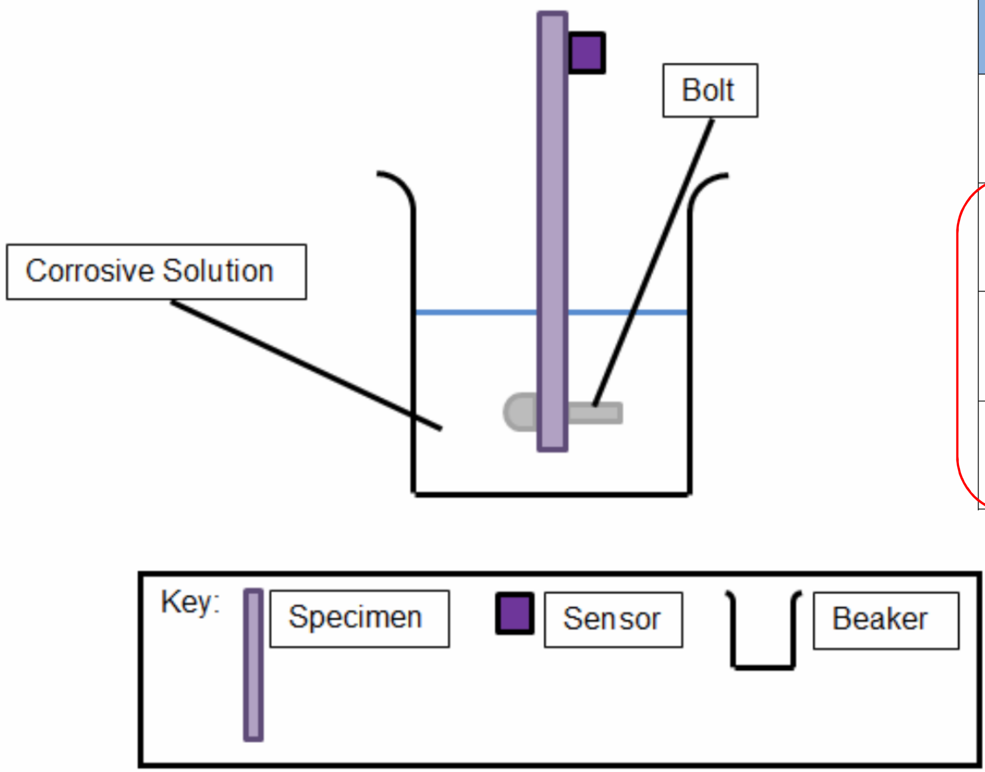
Test Solution Percentages and Volumes

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

Example 1...continue

AE monitoring during corrosion

Experimental Set-up of Specimen in its corrosive environment



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

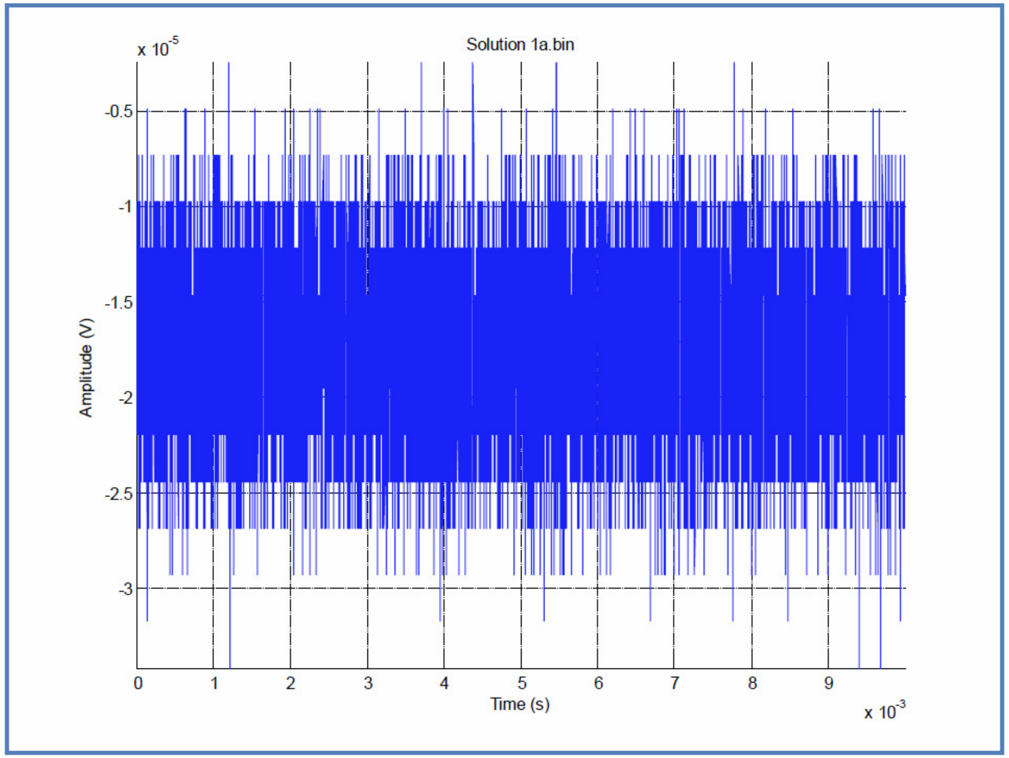
Specimen Initial and Final Weights

Example 1…continue

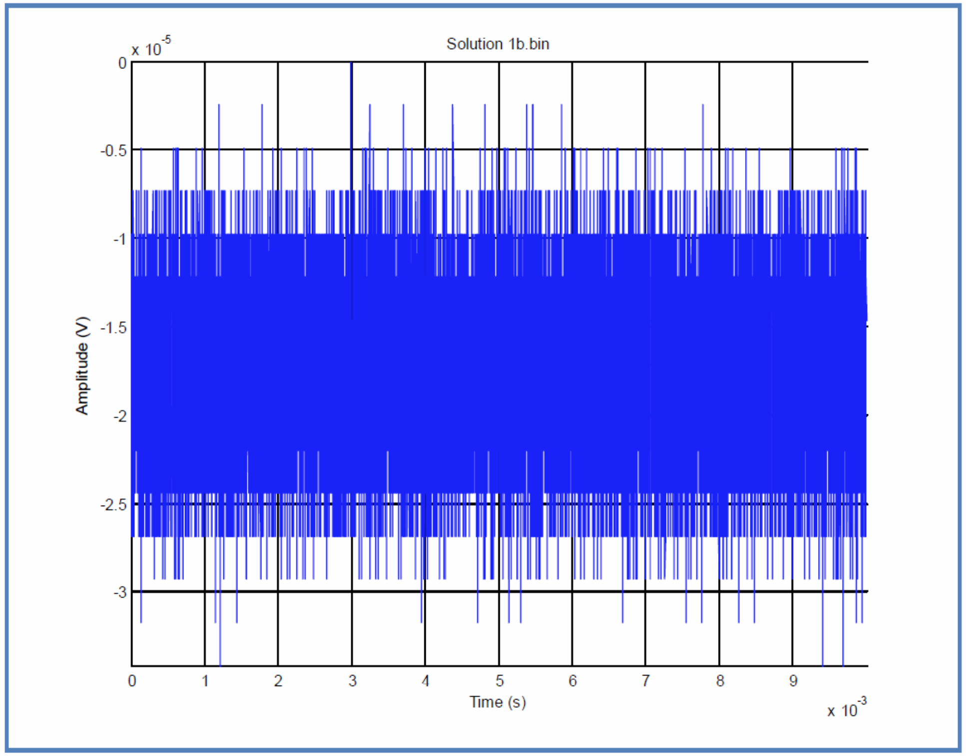
Test 1 – No Corrosion

AE monitoring during corrosion (time domain signals)

Electronic/background noise



Test 1a Acoustic Emission Signal

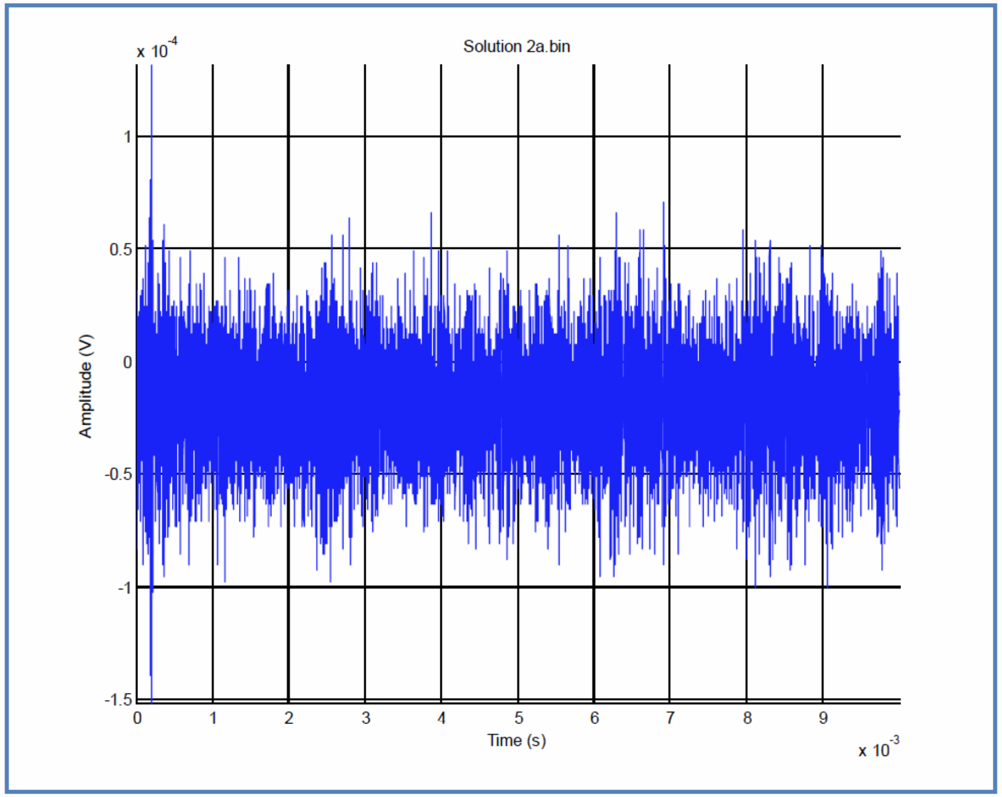


Test 1b Acoustic Emission Signal

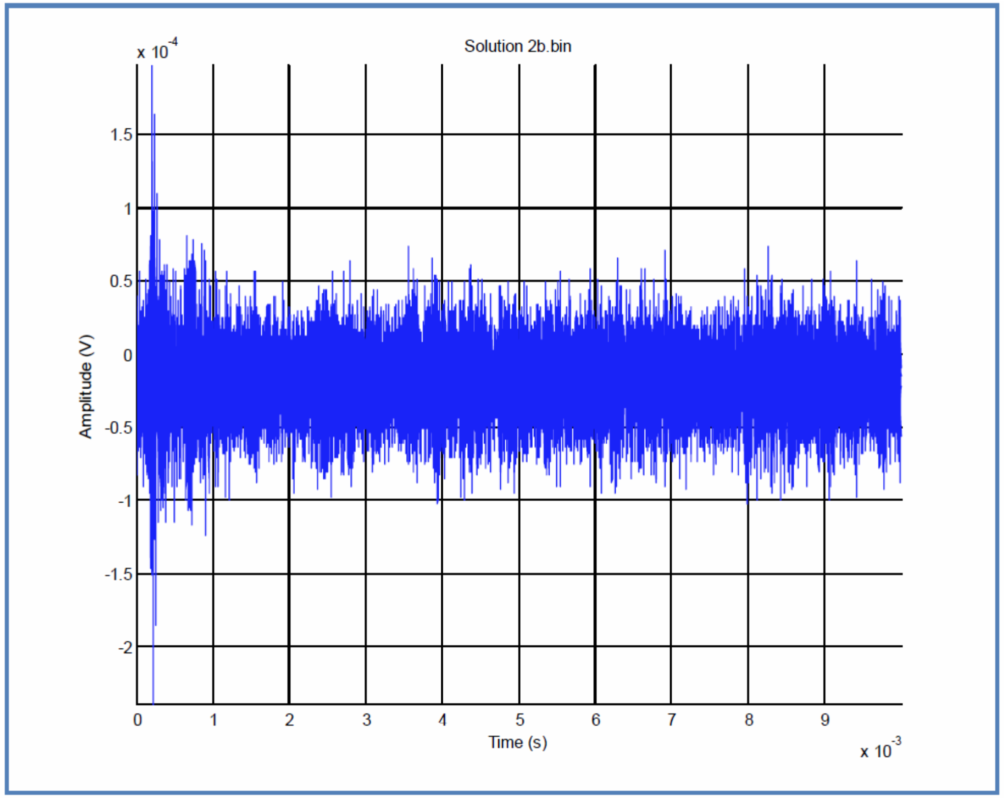
Example 1…continue

Test 2 – 3.7% Solution

AE monitoring during corrosion (time domain signals)



Test 2a Acoustic Emission Signal

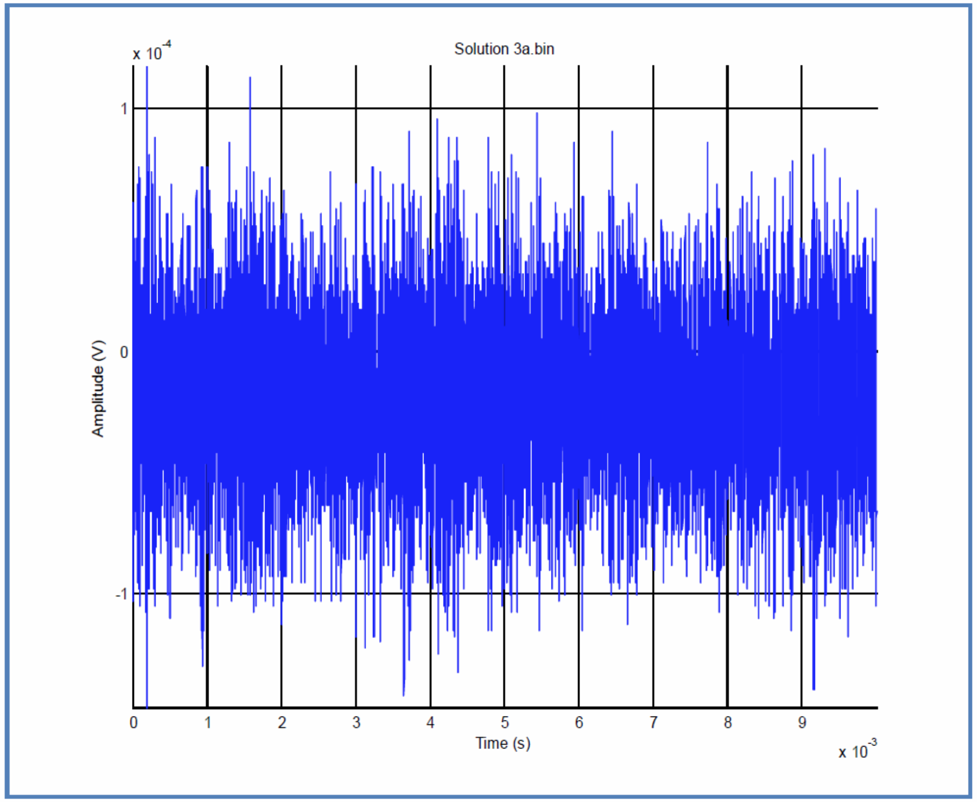


Test 2b Acoustic Emission Signal

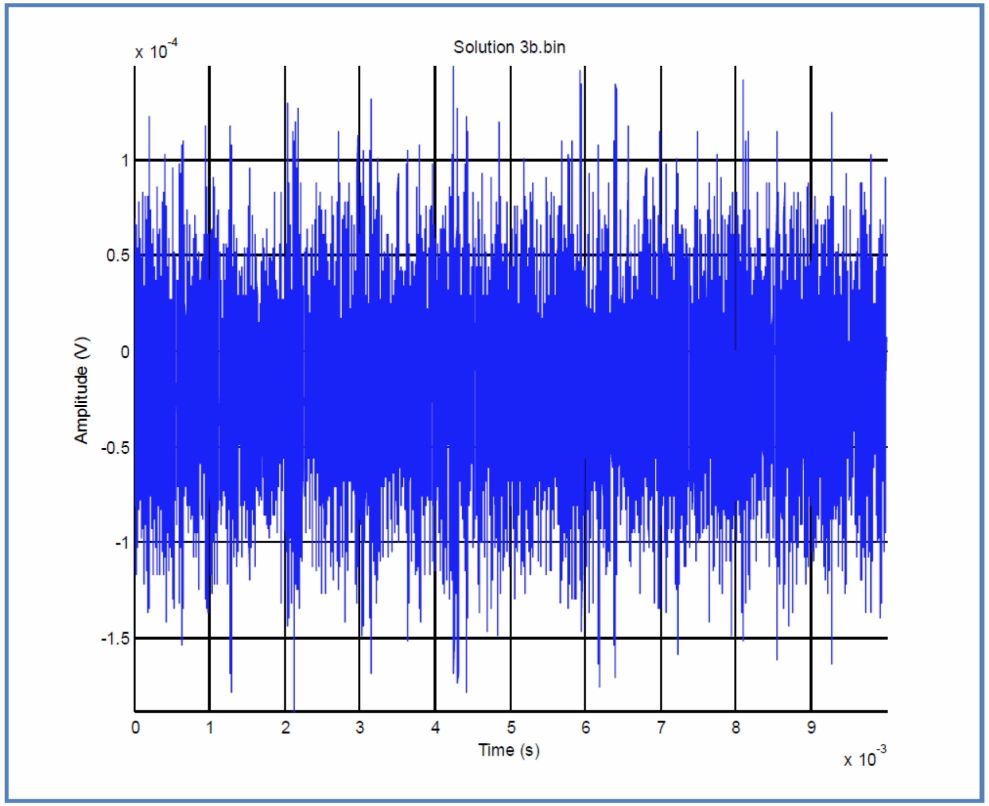
Example 1...continue

Test 3 – 18.5% Solution

AE monitoring during corrosion (time domain signals)



Test 3a Acoustic Emission Signal

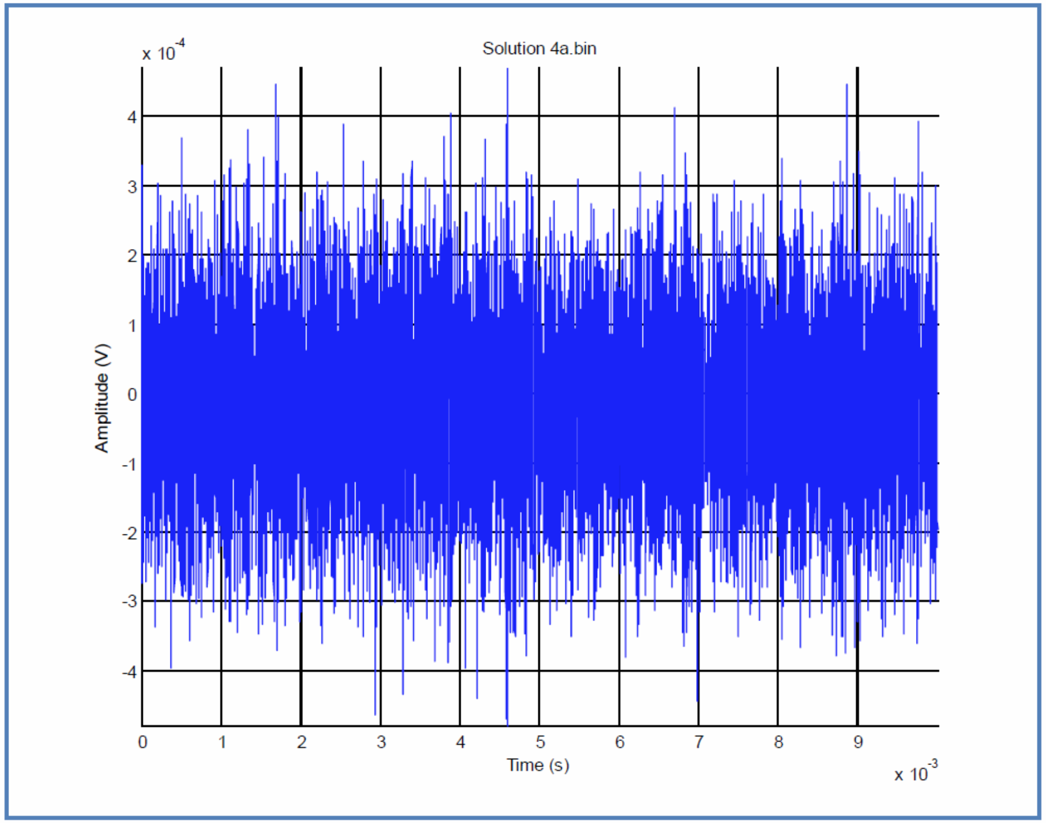


Test 3b Acoustic Emission Signal

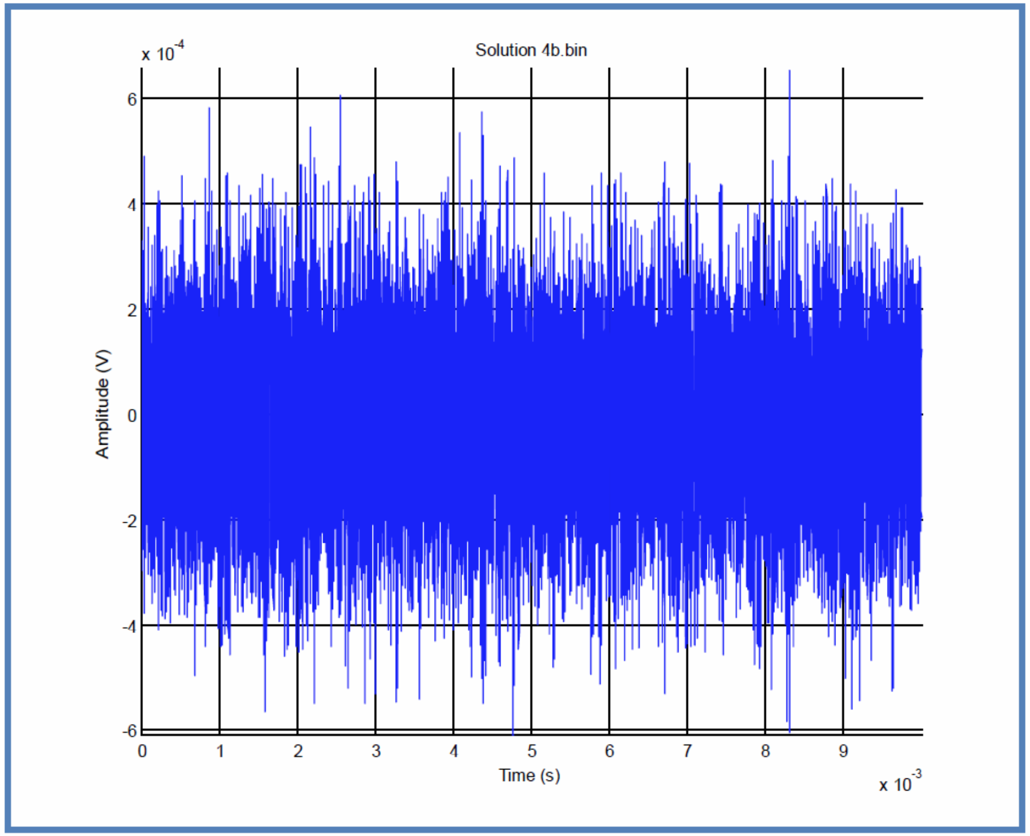
Example 1…continue

Test 4 – 37% Solution

AE monitoring during corrosion (time domain signals)



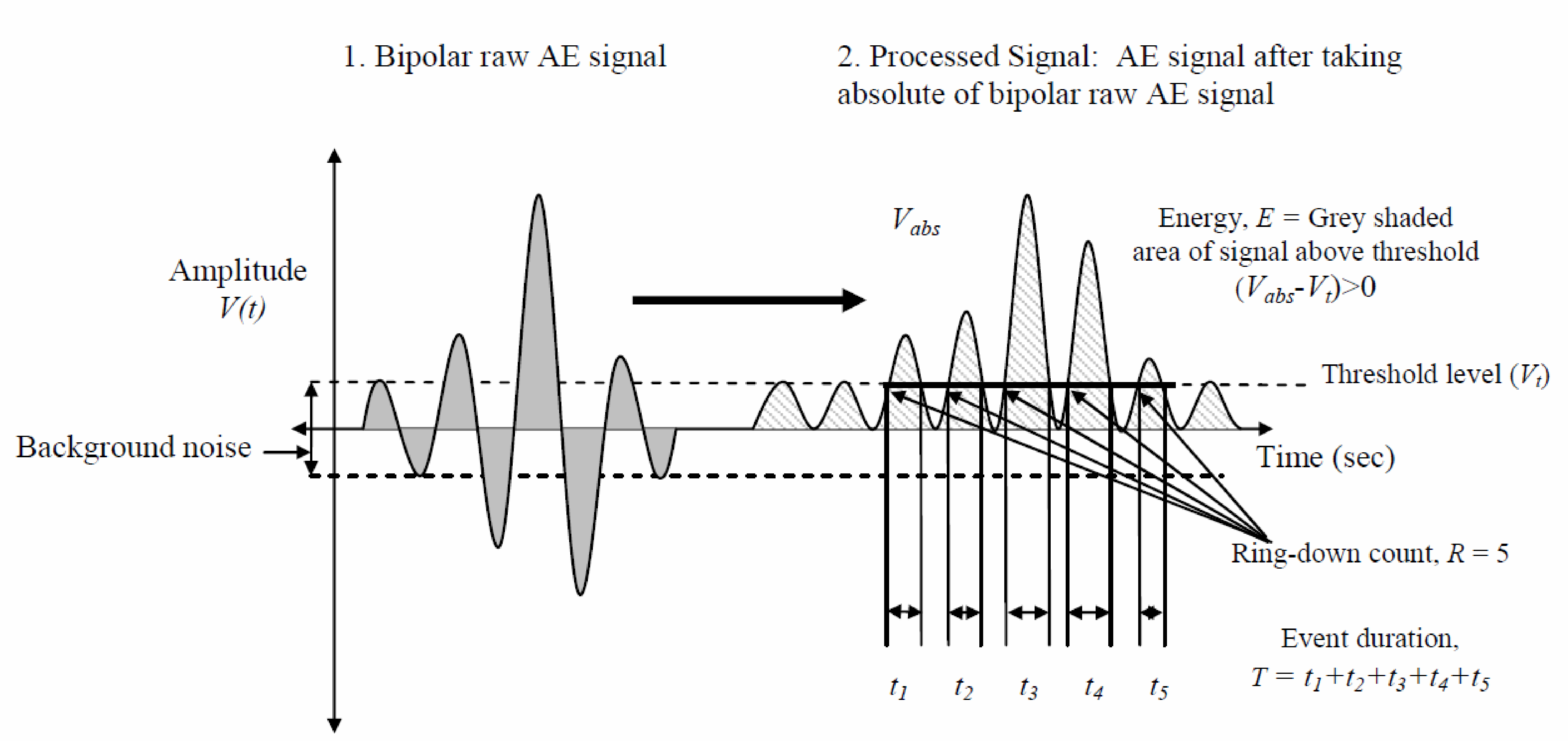
Test 4a Acoustic Emission Signal



Test 4b Acoustic Emission Signal

Ghazi Droubi

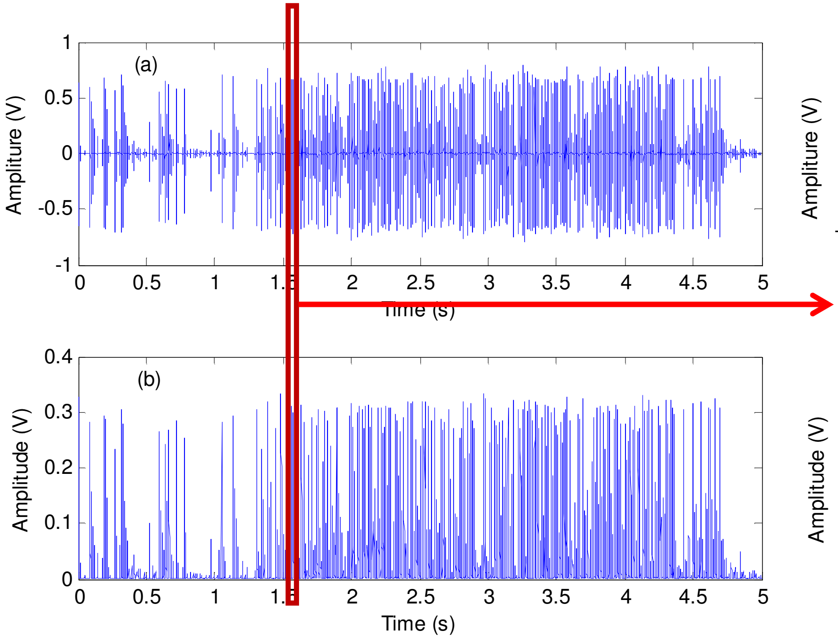
AE signal processing (MATLAB)



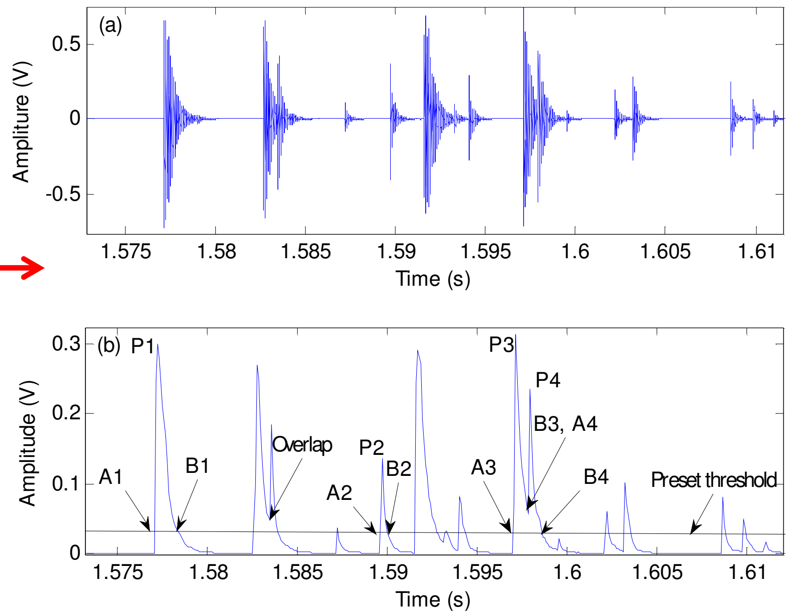
N. H. Faisal, PhD thesis, Heriot-Watt University, 2010

Ghazi Droubi

Examples of AE signal processing (MATLAB)

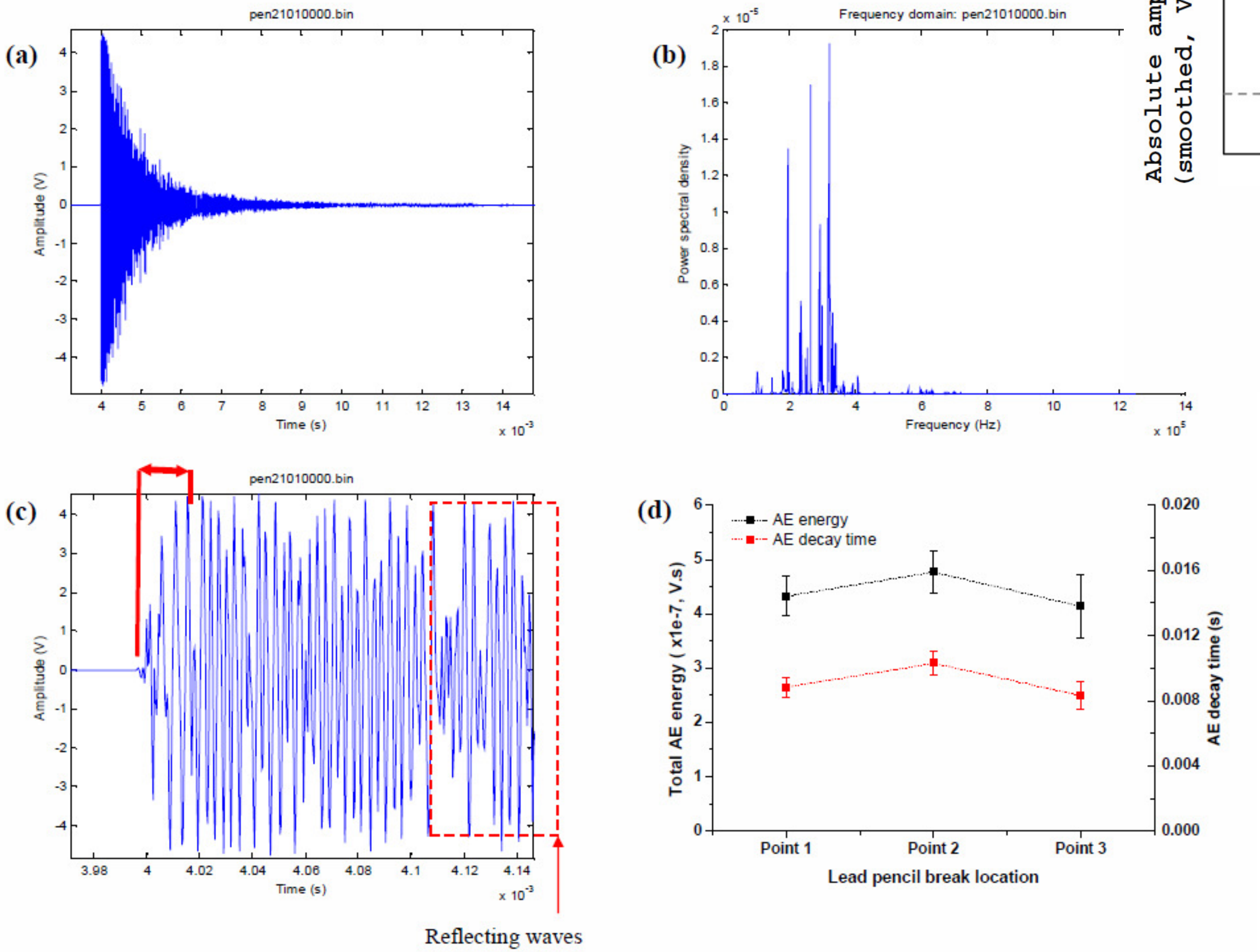


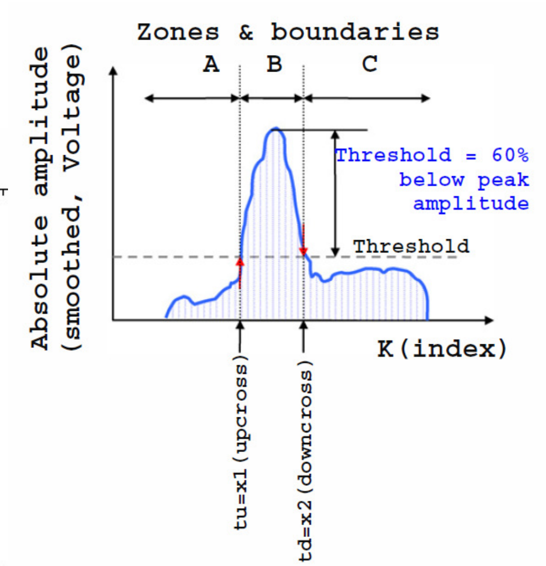
Typical 5-second record for corrosion activities: (a) raw AE signal, (b) *RMS* AE signal.

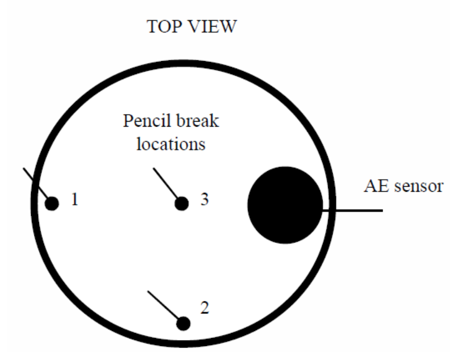


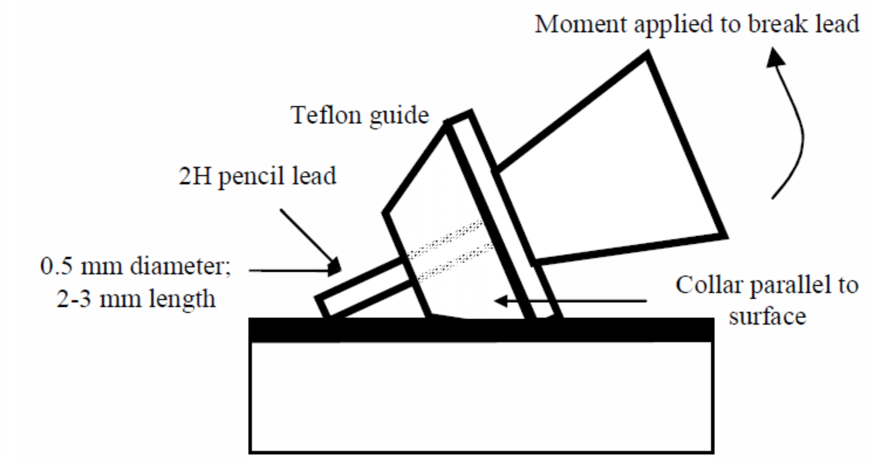
Magnified view of (a) raw and (b) *RMS* AE signal, illustrating distribution of multiple sources.

AE signal processing (MATLAB)









N. H. Faisal, PhD thesis, Heriot-Watt University, 2010

Example 1...continue

AE signal processing (MATLAB)

Automated and continuous analysis of corrosion data files

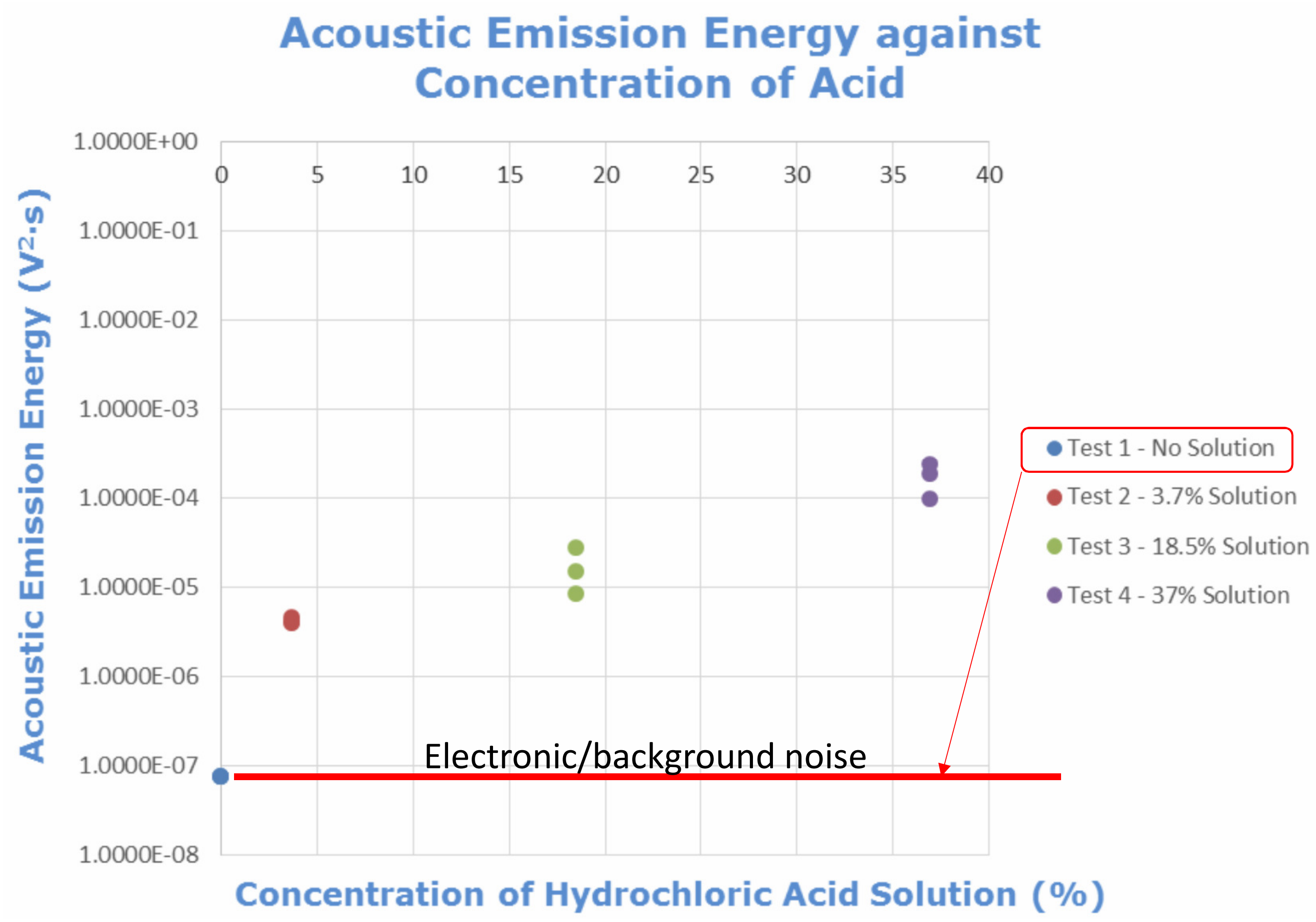
```
if length(names) == 0;
    disp ('No .sgl files found in this directory');
else
    disp(['Number of .sgl files in selected directory: ' num2str(length(names))]);
end


for fl = 1:length(names);
    disp([names{fl} '.  File ' num2str(fl) ' of ' num2str(length(names)) '.'])
 clear x header energy;
    [x,y,fs,starttime,header] = fnlvsgltime([pname names{fl}]);

    y1=y(:,1);    <- Sensor 1
    %y2=y(:,2);   <- Sensor 2
```

Method 1 (Example 1): Laurene Hay, 2016 (RGU)

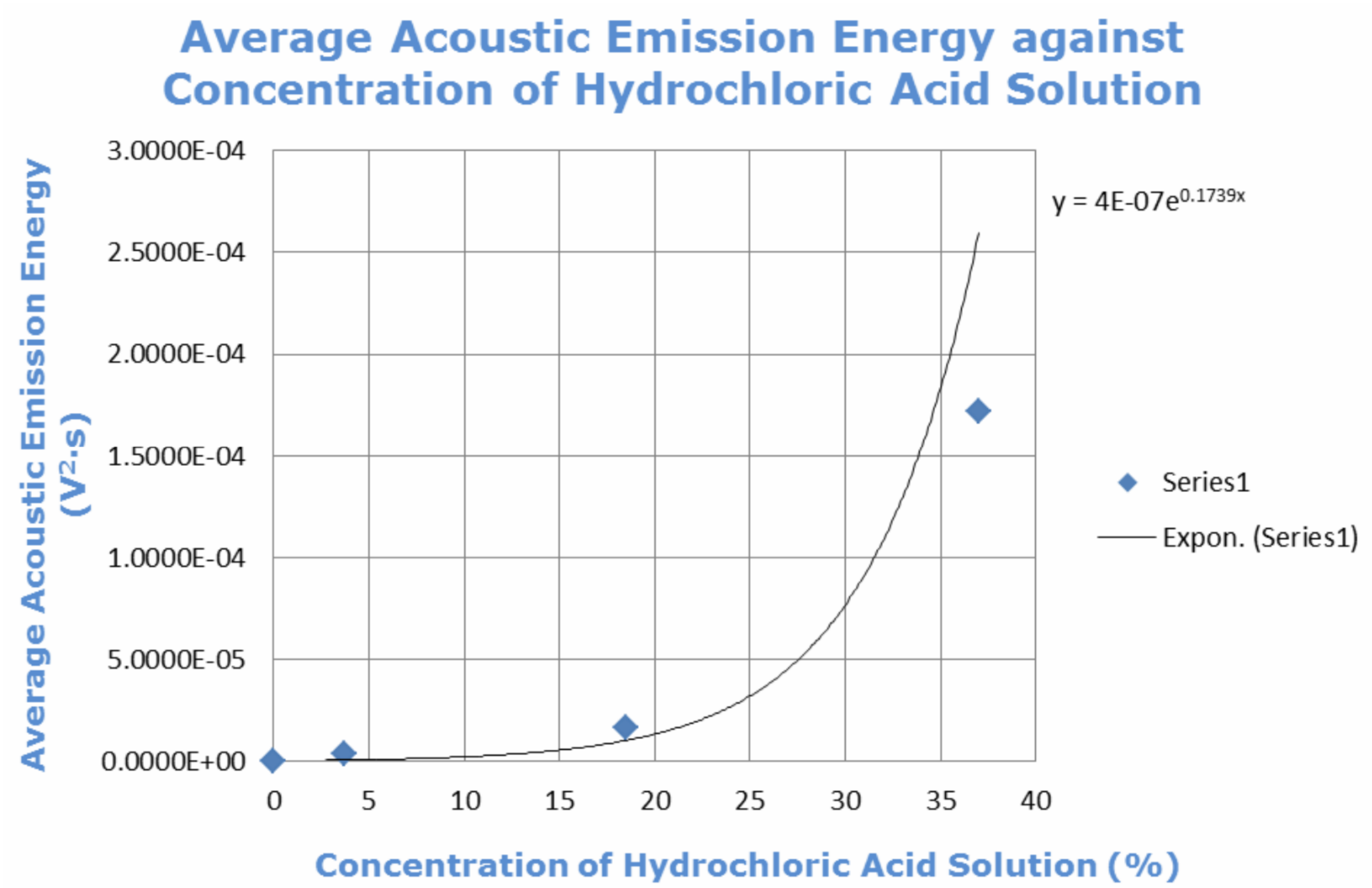
AE monitoring during corrosion



Acoustic Emission Energy against Acid Concentration

Example 1…continue

AE monitoring during corrosion



Average Acoustic Emission Energy for Experimental Tests

Example 2 [CALUM WEST, DANIEL MASSIE AND AYUBA JONATHAN (RGU, 2015)]

AE monitoring during corrosion

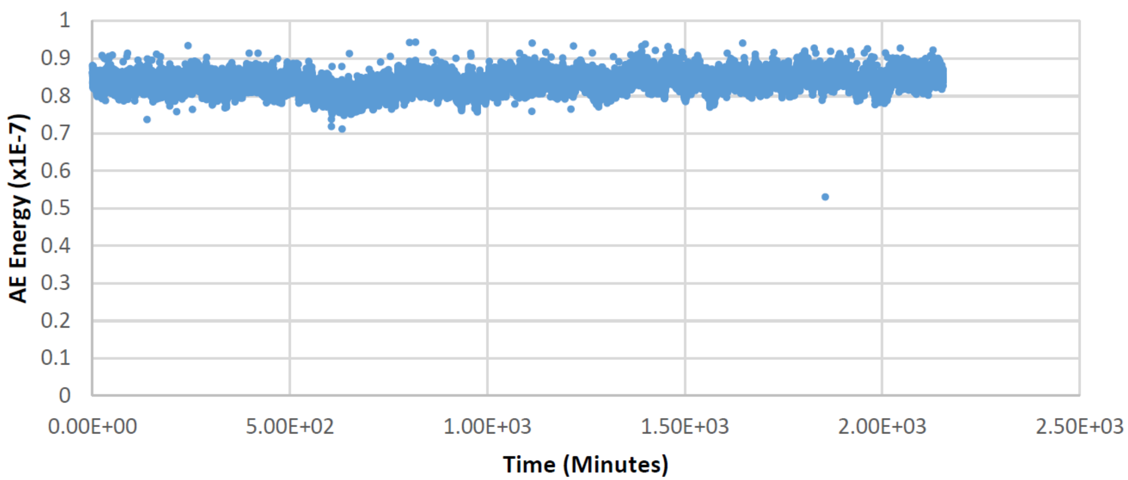
Calibration block (Steel) **Sensor top (Carbon steel)** **Sensor bottom (Carbon steel)**

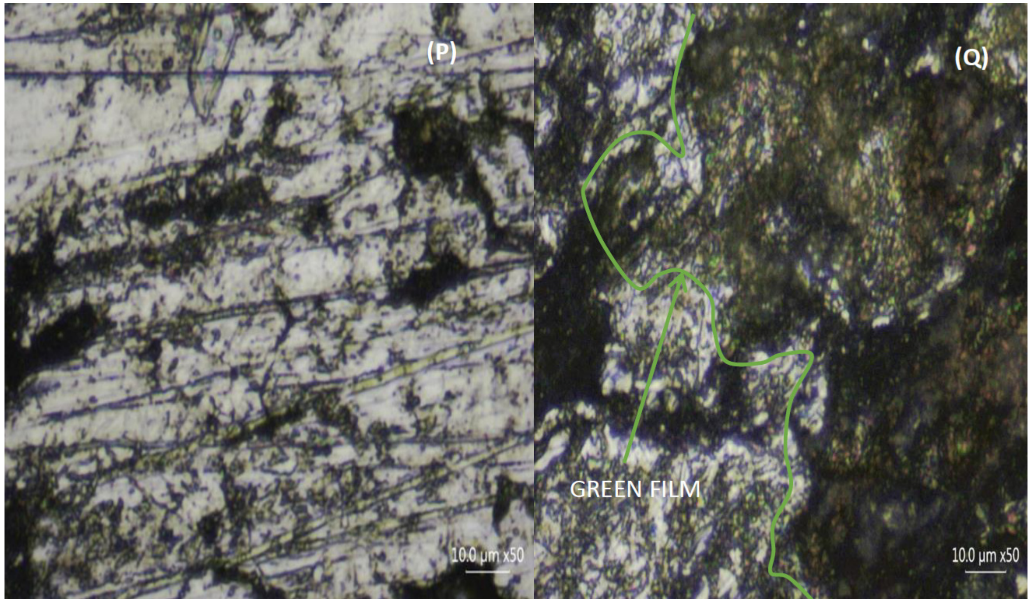
Signal transmission and calibration

Example 2…continue

AE monitoring during corrosion

Specimen A (Carbon steel): The specimen analysed was submerged in 300 ml of seawater for 6 hours, 36 hours.





CORRODED (Q) AND UNCORRODED (P) MICROGRAPHS OF SPECIMEN A

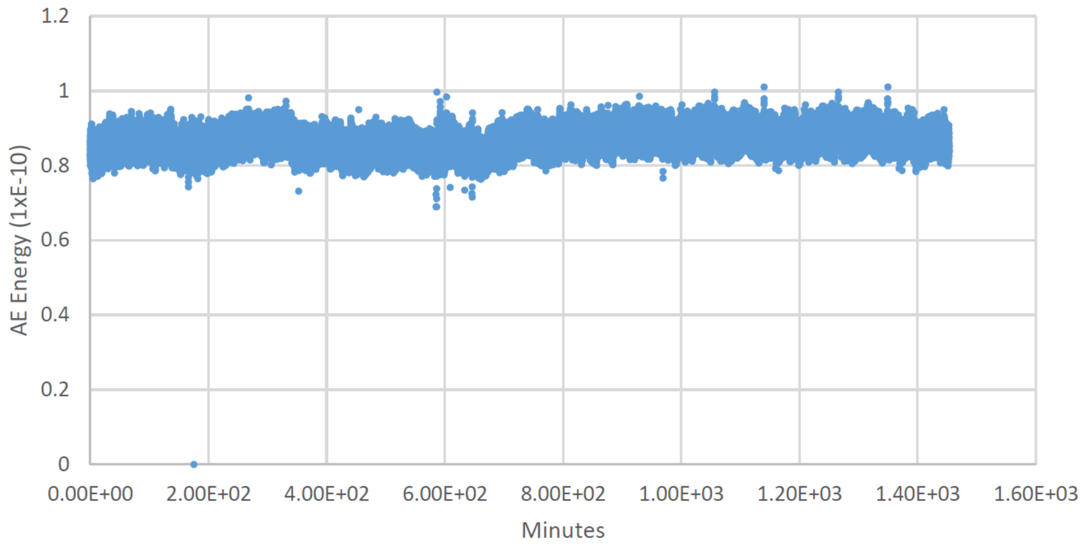
Time Period	Average AE Energy	No. of values above first 12 hour average
0-9 Hours	8.357×10^{-8}	5045
9-18 Hours	8.245×10^{-8}	3052
18-27 Hours	8.452×10^{-8}	6383
27-36 Hours	8.497×10^{-8}	7064

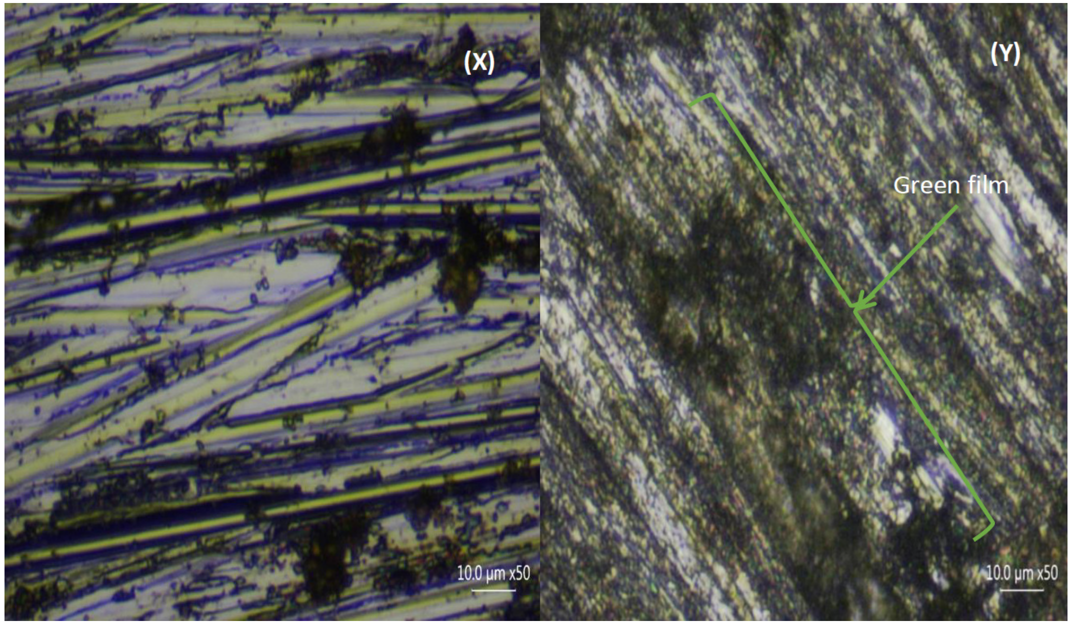
A rough surface finish leading to a long period of slow localised corrosion.

Example 2...continue

AE monitoring during corrosion

Specimen B (Carbon steel): : The second specimen was polished using decreasing grit sizes of emery cloth to achieve a more even surface finish and allow for microstructure analysis prior to being tested under the same conditions as specimen A for a period of 2 hours, 24 hours.





CORRODED (Y) AND CORROSION FREE (X) MICROGRAPHS OF SPECIMEN B

Time Period	Average AE Energy	No of values above first 12 hour average
0-12 hours	8.54382×10^{-10}	50754
12-24 hours	875678×10^{-10}	88268

Laurene Hay, 2016 (RGU)

AE monitoring during corrosion

NDT Comparison Table

NDT Method	Accessibility	Real Time	Detect exact location of corrosion	Standardised Method
Visual Inspection	Difficult if under ground/sea	Not Possible	Yes	Yes
Liquid Penetrant	Pipe has to be above ground.	Not Possible	Yes	Yes
Radiography	Full surrounds of pipe need to be accessible.	Possible	Yes	Yes
Ultrasonic	Intelligent ultrasonic pigs can collect data from difficult areas of pipeline (underground, submerged in water, tight bends)	Not Possible	Yes	Yes
Acoustic Emission	If sensor attached, can detect emissions for up to 25 metres.	Possible	Yes	No

Can wireless AE technique can be used for corrosion monitoring?

It has been used for other reasons:

- http://www.mistrasgroup.com/services/company/publications/AE_Wireless_Monitoring_Systems.pdf
- Christian U. GROSSE, Markus KRÜGER, Steven D. GLASER, Wireless Acoustic Emission Sensor Networks for Structural Health Monitoring in Civil Engineering, ECNDT 2006 - Tu.1.7.3,
- Open access: http://www.ndt.net/article/ecndt2006/doc/Tu.1.7.3.pdf

Further development: AE based corrosion monitoring

Method for

- Wireless
- Corrosion in air may be important
- Corrosion from the splash zone
- Internal and external corrosion to be considered.
- For fully submerged members
- During fatigue loading
- Painted structure

Literature data on the recent advancement in wireless sensor (e.g. using ground penetrating radar, GPR) based monitoring of subsurface structural corrosion, a method which can be useful for monitoring corrosion in extreme environmental conditions.

Ground Penetrating Radar technique

Ground Penetrating Radar (GPR) methods has been found to be useful in evaluating the corrosion damage in the concrete structures.

Ground Penetrating Radar technique

Ground Penetrating Radar (GPR) image can be difficult to be interpreted because it requires image processing technique.

Note:

- Radar uses radio waves in the microwave frequency range, or approximately 1 cm in wavelength.
- This wavelength range is used because it is easier to direct the waves with small antennas in narrow beams.
- Unfortunately, microwaves are strongly absorbed by sea water within feet of their transmission.
- This renders radar unusable underwater.

Literature

- Ahmad Zaki, Shahid Kabir, Radar-based Quantification of Corrosion Damage in Concrete Structures, PIERS Proceedings, Marrakesh, MOROCCO, March 20-23, 2011, p. 794-798.
- David Eisenmann, Frank Margetan, Chien-Ping T. Chiou, Ron Roberts, Scott Wendt, Ground penetrating radar applied to rebar corrosion inspection, AIP Conf. Proc. 1511, 1341 (2013)

Thank you

ROBERT GORDON UNIVERSITY ABERDEEN

Any Questions, Comments or Suggestions!!!

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