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ACOUSTIC EMISSION for CORROSION DETECTION

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ABSTRACT

Corrosion is the major cause of structural degradation; the process of corrosion itself usually causes acoustic emission as a result of the fracture and disbonding of expansive corrosion products. This means that the method may be used for corrosion detection and quantification of corrosion rate. This paper describes the use of acoustic emission for corrosion detection in storage tanks, reinforced concrete structures, and process equipment.

ACOUSTIC EMISSION from CORROSION

Acoustic emission energy is released when a crack propagates, in the normal corrosion of carbon steel the corrosion of 1 mm of steel results in up to 12 mm of the hydrated iron oxide. It is during this expansive process that there are multiple micro-fractures and de-laminations of the oxide that cause acoustic emission. The emission from corrosion usually releases much less energy than emission from crack growth, and so is more difficult to detect in the field environment. The sensor frequencies used to detect these signals are determined more on the basis of the environmental noise under test conditions than on the frequency spectrum of the emission. In low noise environments the signals from corrosion may be detected at distances of tens of metres by using monitoring frequencies down to ten kilohertz, however, in live process plant it may be necessary to use several hundred kilohertz to get above process noise, in this case detection distance may be limited to less than half a metre.

Since acoustic emission only occurs when the corrosion scale fractures or de-bonds, the corrosion needs to be active, however the presence of inactive corrosion may be found by causing the scale to fracture or de-bond by changing the strain sufficiently on the base material. One of the most common indications found during acoustic emission monitoring of pressure testing is activity resulting from spalling of corrosion scale.

Quantification of emission from corrosion is not so straightforward, and is largely a matter of experience with particular monitoring instrumentation and test procedures.

CORROSION of CARBON STEEL STORAGE TANKS

Corrosion of storage tanks causes acoustic emission, a fact which is used widely to help maintenance planning. The costs of removing a tank from service and cleaning it just to inspect the floor are wasted if the floor is then found to be in good condition, by listening first for active corrosion it is possible to decide if inspection and repair are really necessary. Conversely, tanks that are in an advanced state of corrosion may be removed from service before a costly failure. There are many published papers on this method[1]; the most established procedure is TANKPAC™ from Physical Acoustics, which has been used on more than 8000 tanks, and has been verified by third party internal inspection on more than 1000 tanks[2-5]. The use of TANKPAC™ is corporate policy for a number of companies, and is widely approved by authorities and professional organisations. Emission from corrosion of the floor can be confused with emission from other sources such as internal sacrificial zinc anodes, or corrosion of the shell under insulation, experience is required to differentiate between these different sources, as well as from non relevant noise sources such as condensation and noise from the environment. Figure 1 shows an example of emission from a storage tank floors and internal damage, figure 2 emission from corroding sacrificial zinc anodes, and figure 3 shows emission from corrosion of a tank shell under the insulation. The sensors used for storage tank testing can be low frequency since noise levels are low in storage facilities, this means that a large sensor spacing can be used, if high frequency sensors were used the sensor spacing would need to be significantly less. Location by triangulation shows the source of the higher amplitude emissions, it must be remembered that these represent typically 5-25% of the total emission from the tank.

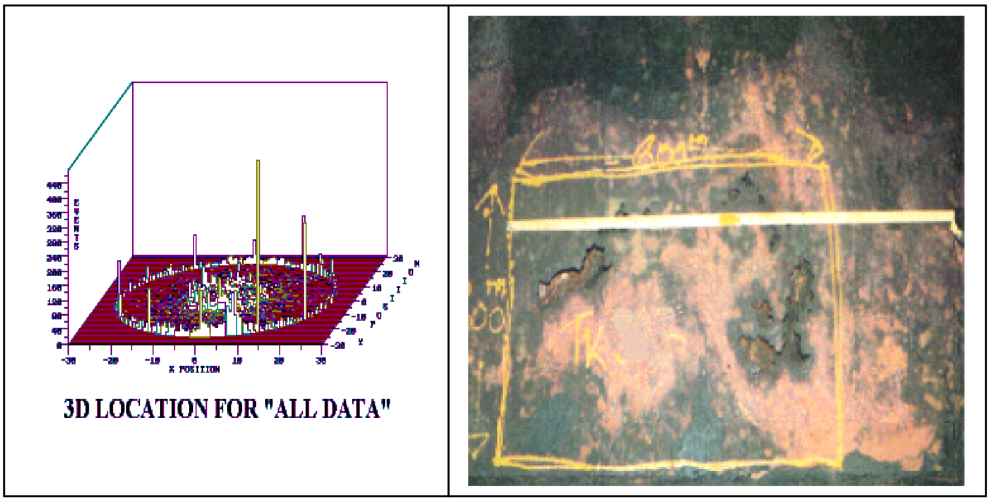

Figure 1: 3D Location analysis from a tank floor test using acoustic emission, and internal damage.

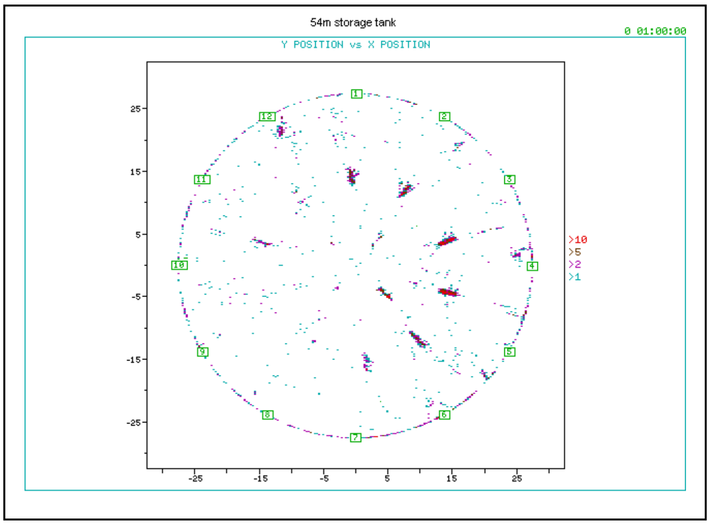

Figure 2: 2D Location analysis from a tank floor test showing emission from sacrificial zinc anodes (red).

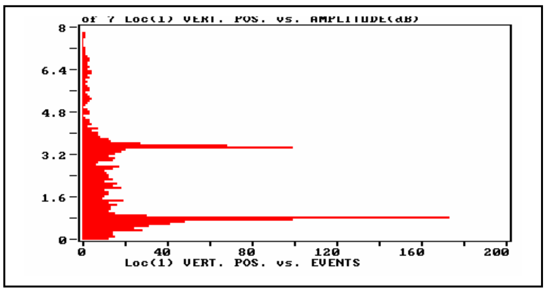

Figure 3: Vertical distribution of emission from a tank shell, concentrations are at insulation support rings.

EMISSION FROM CORROSION OF REINFORCING BAR IN CONCRETE

Corrosion of reinforcing steel in reinforced concrete structures is a major serviceability problem in the UK and worldwide, costing the UK an estimated £615m annually. Over the past 25 years a number of methods for assessing the state of corrosion of reinforcing steel have been under development but a need still exists. AeCORR[6] is a novel non-destructive technique for detecting corrosion of rebar. The AeCORR system detects microscopic damage occurring within the concrete due the formation of corrosion at the steel/concrete interface.
As corrosion initiates, the expansive products generate micro-cracks in the concrete, detectable on the surface by piezoelectric acoustic emission transducers.
The collection, interpretation and analysis of these emissions form the basis of the AeCORR technique.
The development of AeCORR required the investigation of the influential parameters. These were broadly split into three groups.

- Environmental factors.
- Electrochemical factors.
- Material Factors.

The success of AeCORR to detect and monitor reinforcement corrosion relies upon an appreciation of these variables, which are then incorporated into a Risk Based Investigation Protocol (RBI) to enable a full assessment of a structure's condition to be made.
The corrosion rate of steel in concrete is dependent upon factors such as temperature, internal moisture content, resistivity and the availability of oxygen. In reality, these factors are inter-dependent and are constantly evolving with time.
The temperature constantly changes influencing the corrosion rate. The time of year and time of day may affect the accuracy of the results. AeCORR research has investigated these effects and has fed the results into the RBI procedure.
Corrosion rate also is strongly dependent on the electrical resistivity of concrete, which is influenced by temperature and relative humidity (RH). The rate of corrosion can change dramatically between 80-90% RH. These factors are shown in figure 4.
The rate and type of corrosion (e.g. chloride or carbonation induced) may influence the magnitude and rate of emissions as different corrosion products are formed.
Finally, increasing material properties such as strength of the concrete result in an increase in the energy expelled per gram of steel loss. Consequently, it is important to know the material properties of the concrete being tested to enable normalisation of the results within the procedure.
The key benefit of this procedure when applied appropriately is that it gives a definitive answer to the question "is there unseen incipient damage in the structure?". Other methods such as half cell tell you that there is the potential for corrosion based on conditions, but not that it has actually initiated.

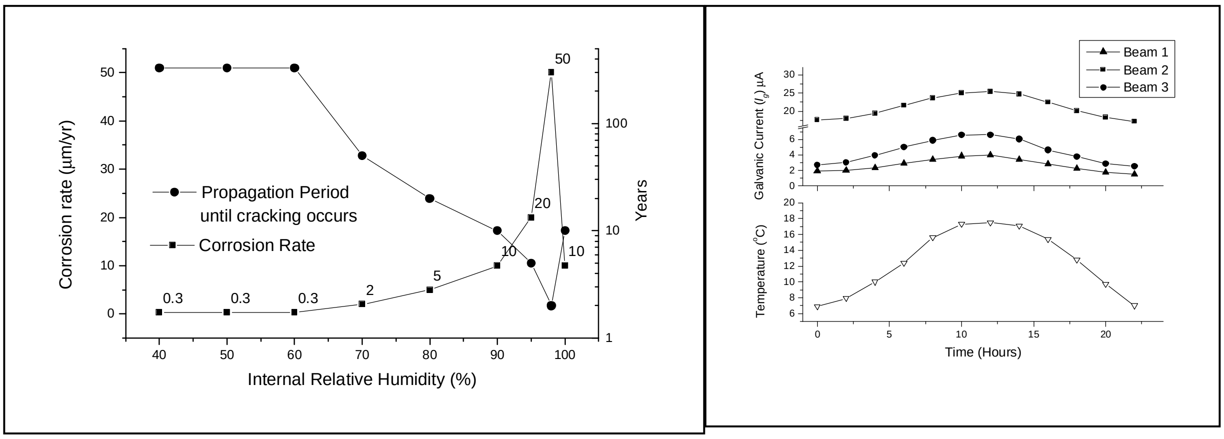

Figure 4: Effect of internal humidity and temperature on corrosion rate.

Emission from corrosion of re-bar is shown in figure 5, during the initiation phase the conditions for corrosion may be present, but the passivation layer on the re-bar has not yet been breached. Once the passivation layer is breached then propagation occurs, and emission starts. In this case the extent of corrosion corresponding to this amount of emission was established by break out of the re-bar.

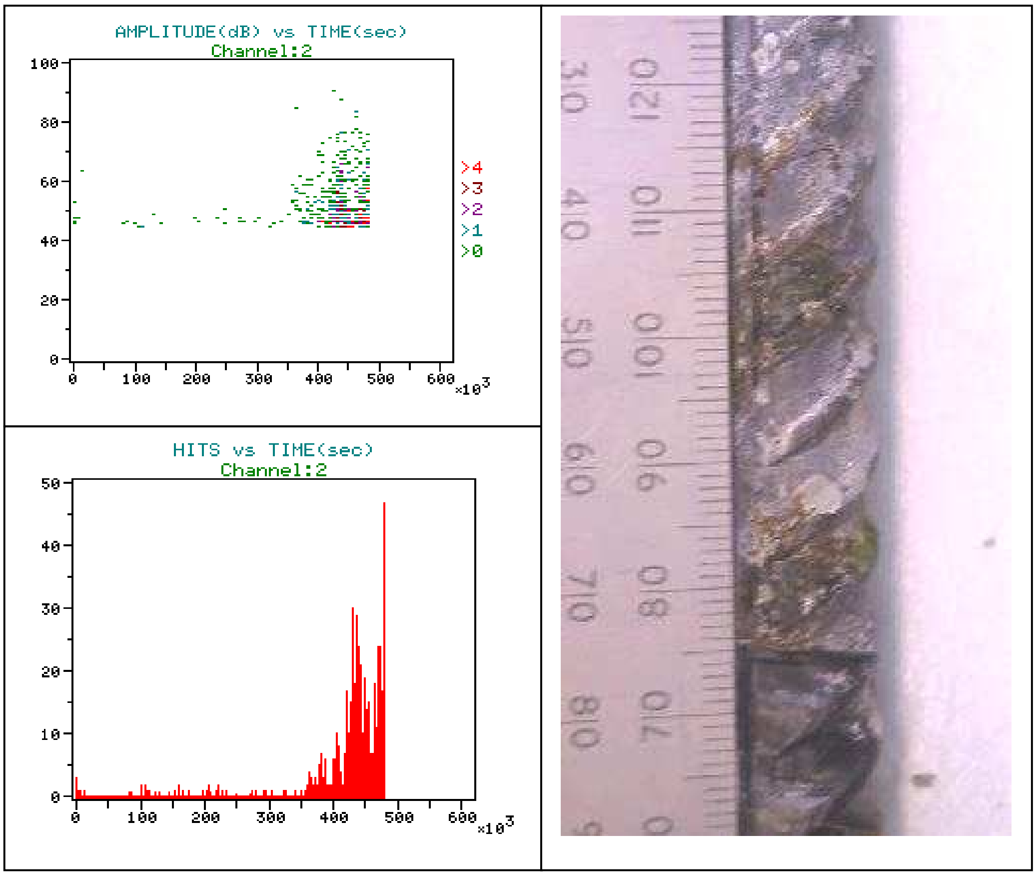

Figure 5: Onset of propagation detected by AE monitoring, and corresponding damage after break-out.

Quantification of corrosion rate and residual life predictions direct from the acoustic emission data is theoretically possible, but does depend upon an understanding and careful quantification of the variables involved, so is an expert task.
Figure 6 shows how acoustic emission energy varies with corrosion current density, the major factor in structural degradation, together with an example of AE located from a severely degrading structure where passivation has long given way to corrosion propagation and structural degradation.

One major use of this new procedure is in helping “due diligence” during major asset purchases, there may be no evidence of corrosion damage on the surface, but if corrosion is active then within a few years cracks and spalling will be visible, AECorr can give the advanced warning that a hidden problem may exist.

The main practical difficulty in applying the procedure is environmental noise, this makes it difficult to apply on major road bridges unless periods exist where traffic density is low (e.g. night time) and noise from individual vehicle loadings can be filtered from the data set whilst still leaving sufficient time for detection of corrosion activity.

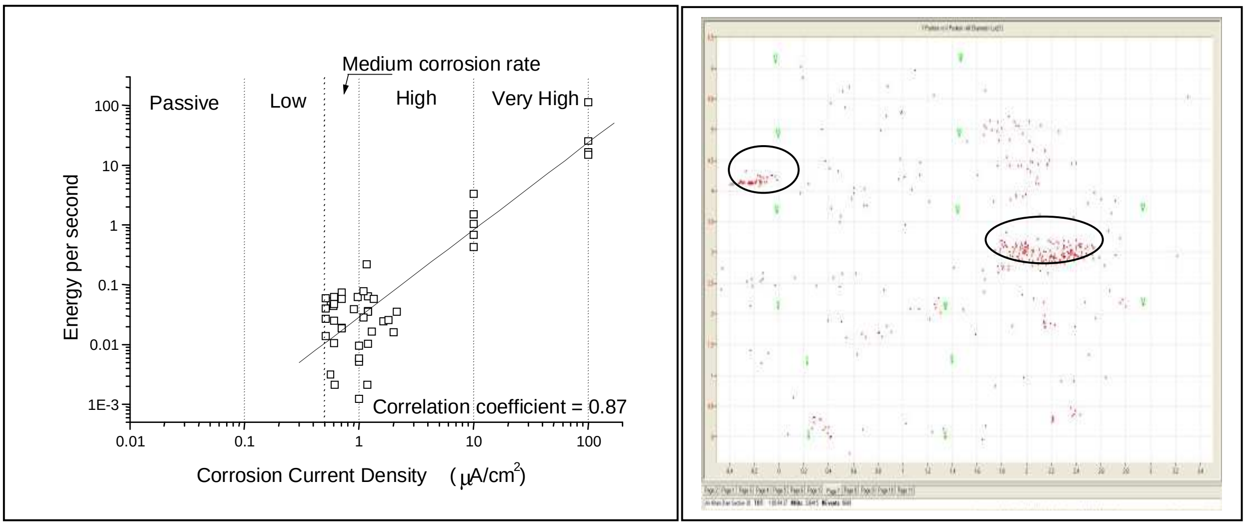

Figure 6: Corrosion current density versus emission energy rate, damage located in a concrete structure.

CORROSION OF PROCESS EQUIPMENT

Active corrosion of process equipment, whether carbon or stainless steel, may be detected provided the amplitude of the process noise is less than the amplitude of the emission at the monitoring frequency in use. In practice the frequencies used for tank monitoring are rarely suitable, and frequencies 5-10x higher need to be used in the process environment. One consequence of the higher monitoring frequency is that the distance at which corrosion can be detected is limited to typically one metre or less from the sensor. Nevertheless the ability to identify when corrosion is active can be very useful, and in chemical plants the method is used to help corrosion control, inhibitors are added when corrosion is active. In one case the addition of inhibitors to a vessel reduced emission/corrosion rate from more than 100,000 emissions per hour to less than 200. Rhone Poulenc and several other chemical companies in co-operation with Physical Acoustics helped to develop the CORPAC technology and system for plant corrosion monitoring, this "expert" system checks background noise, runs the test for a one hour duration, and then advises the operator if corrosion pitting or stress corrosion cracking is present or not. Some examples of applications are shown in figure 7.

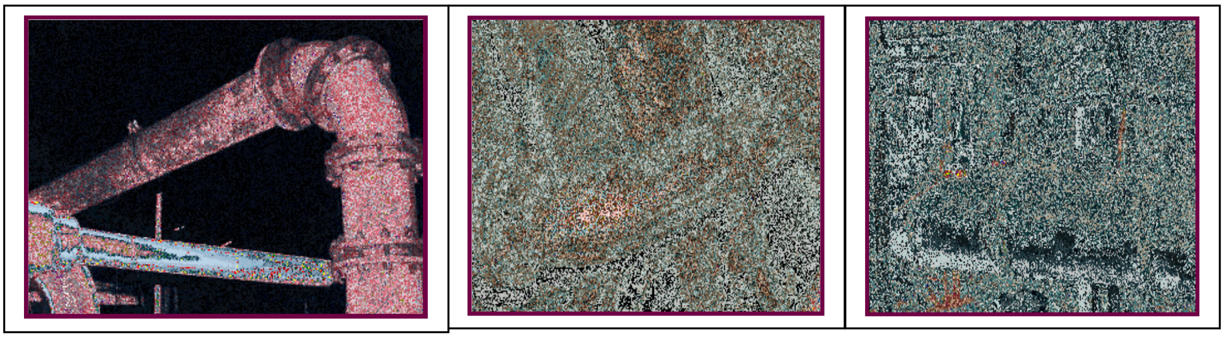

Figure 7: Corrosion monitoring applications:
Stainless pipe 106 deg.C: Corrosion pitting. 316 Stainless 80deg.C: SCC. Nickel Steel pipe 100deg.C: SCC

Figure 8 shows a “Mark 1” CORPAC system in use, a new PDA based unit is currently in development. Where it is desired to monitor a larger area, or many areas at the same time, multi-channel AE systems are used to acquire the data and an expert system used for analysis.

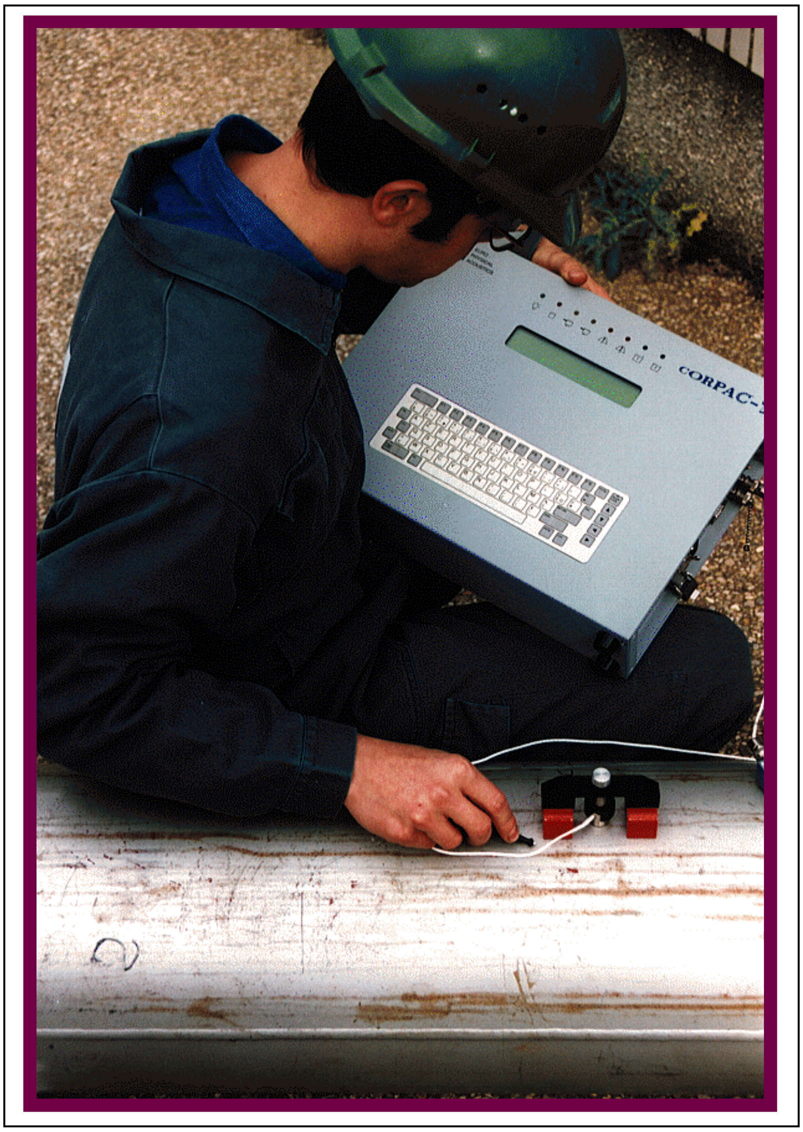

Figure 8: Corrosion monitoring using the Mark 1 CORPAC system.

CONCLUSIONS

Detection of corrosion by acoustic emission is not a new phenomenon, the first papers being published in the early 80’s. However, years of experience and continuing development have helped to make the use of the method practical and in some cases even quantitative. Recognising and eliminating noise is still the main challenge due to the small size of the signals in the presence of potential process noise. Modern instrumentation and pattern recognition helps, but operator training and procedures still play a major part in achieving meaningful measurements.

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