2015 2nd International Conference on Geological and Civil Engineering
IPCBEE vol. 80 (2015) © (2015) IACSIT Press, Singapore
DOI: 10.7763/IPCBEE. 2015. V80. 10

Monitoring Corrosion Activity of Steel Reinforcement Using Acoustic Emission

Hisham Elfergani [1 +], Karen Holford [2] and Rhys Pullin [3]

[1] Faculty of Engineering, University of Benghazi, Benghazi, Libya

[2, 3] Cardiff School of Engineering, Cardiff University, Cardiff, UK

Abstract. Deterioration by corrosion of steel wire in reinforced and prestressed concrete is very serious and must be given special consideration because failure may result in the loss of life and a high financial cost. The main reason for the reinforced concrete damage is corrosion. The concrete pipes, of the Man-Made River Project in Libya, which transport water, are one such structure that has suffered from corrosion. Five catastrophic failures in pipes due to corrosion have occurred after ten years of operation. Detection of the corrosion in initial stages has been very important to avoid a failure of structure. Therefore, the big problem which faces the engineers is to find the best way to detect the very early stages of corrosion and prevent the structures from deteriorating.

This paper reports on the use of the Acoustic Emission (AE) technique to detect and locate the very early stages of corrosion prior to deterioration of the concrete structures.

Experimental results show that AE is capable of detecting the different stages of corrosion of steel in representative structures.

Keywords: Acoustic Emission, Monitoring, Corrosion, Steel Reinforcement, Reinforced Concrete.

1. Introduction

Corrosion is a significant problem in numerous structures. The cost due to corrosion is estimated at billions of dollars every year. The Department of Transport in the UK evaluated that the cost of repairing concrete structures damaged by corrosion problems is £755 million a year. [1] The risk of corrosion in this type of structure must be given special consideration because failure may result in the worst case a, loss of life, but at a minimum a financial loss. Most studies indicate that the main reason of the failure of bridges and concrete pipes is corrosion during the short period after they were constructed. However, the life of a concrete structure becomes even shorter due to steel corrosion, which may occur by aggressive ion attack from products of chloride or carbonation. [1], [2]

Detection of the corrosion in the initial stages has been very important to avoid other failures. Even though most of the non-destructive methods which are used are able to detect the very late of damage, they cannot detect the presence of corrosion. In this respect, AE has significant advantages compared with other NDT methods because the AE technique is able to reliably detect the very early stages of the corrosion process, before significant damage to the concrete has occurred. Furthermore, it can indicate the level of damage occurring to the concrete. [3]-[6]

1.1. Acoustic Emission Technique

Acoustic Emission (AE) is defined as the elastic energy released from materials which are undergoing deformation. The rapid release of elastic energy, the AE event, propagates through the structure to arrive at the structure surface where a piezoelectric transducer is mounted. These transducers detect the displacement

[+] Corresponding author. Tel.: +218913762270; fax: +218612229621
E-mail address: haf323@yahoo.com.

of the surface at different locations and convert it into a usable electric signal. By analysis of the resultant waveform in terms of feature data such as amplitude, energy and time of arrival, the severity and location of the AE source can be assessed. [6]

1.2. AE Parameter Analysis

AE parameter analysis is the fundamental method for identifying types of damage in a structure. It utilises features that describe the detected waveform. Typical parameters investigated include amplitude, energy, counts (number of threshold crossings), frequency, duration and rise time.

2. Experimental Procedure

The experimental program contains four key stages; wire preparation, concrete and mortar preparation, accelerated corrosion and AE monitoring.

2.1. Wire Preparation

The two working high strength steel wires samples (60 mm length and 4.88 mm diameter) were supplied from The Man-Made River Project manufacturing plant in Libya. The metallurgical composition and mechanical properties as certified by the wire manufactures is summarized as follows: Carbon steel (carbon 0.8-0.84%, 0.85-1.00%Mn, 0.030 %Max S, 0.035% Max P, 0.20-0.35% Si). The tensile strength of the wires is almost 1738 MPa. [7], [8]

2.2. Concrete and Mortar Preparation

A concrete specimen (400×400×50mm) was manufactured .The water to cement ratio used was 0.4 and the material proportions were 1:2:2.5:0.4 by weight of cement, sand, aggregate and water respectively and the concrete design strength was about 58 MPa strength at 28 days.

Three days later, after the concrete specimen had completely cured, two steel wires combined were placed on the upper surface of this specimen. The mortar 400×400mm and 20 mm thickness was coated on the upper surface of the concrete. The water to cement ratio used was 0.4 and the material proportions were 1:2:0.4 by weight of cement, sand and water respectively and the concrete design strength was about 56MPa strength at 28 days. The mortar should consist of one part cement to not more than three parts fine aggregate by weight. [6] The final construction is shown in Fig. 1.

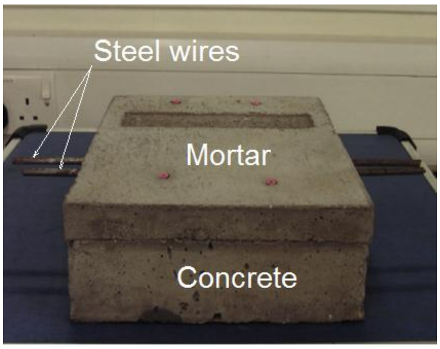

Fig. 1. Concrete and mortar specimen

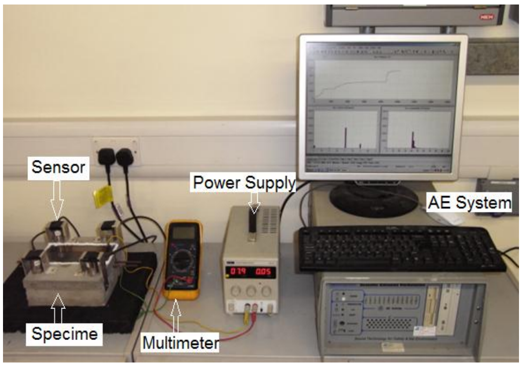

Fig. 2. Photograph of experimental set up

2.3. Accelerated Corrosion Technique

To study the effects of corrosion within a realistic time-scale, it is sometimes necessary to accelerate the initiation period and occasionally control the rate of corrosion during the propagation stage. To simulate the corrosion of reinforcement steel wires, the corrosion cell was induced by an impressed current ($100\,\mu A/cm^2$). This is reported as corresponding to the maximum corrosion rate for concrete in laboratory conditions and has been used by several researchers in the laboratory as discussed by Li and Zhang. [9], [10]

In this experimental work, the bar corrosion was induced by impressed current ($100\,\mu A/cm^2$). The wires were contacted in an electrical circuit with positive pole of power supplier and the negative pole connected with a stainless steel plate (30*300 mm) resting on the upper mortar. A 4% NaCl solution was poured on the surface of the mortar. Silicon sealant was used to pool the solution on the upper surface.

2.4. Acoustic Emission Set-Up

AE instrumentation typically consists of transducers, filters, amplifiers and analysis software. Four AE sensors (R3I – resonant frequency is 30 kHz) were mounted to surface of mortar as shown in Fig. 2. The four AE sensors were mounted using silicon sealant and were fixed on the upper surface of mortar with a U shaped plate. The plate was screwed to hold the sensors down and to ensure a good coupling. The threshold level for AE data acquisition was set up at 40 dB. Then the sensitivity of the sensors was checked by using the Hsu-Neilson source. [11], [12]

3. Results and Discussion

Upon completion of the test, the sample was visually examined for cracks, photographed and the mortar cover removed. Fig. 3 is a photograph of the top mortar surface after the end of the test (with sensor positions indicated) showing that no crack had occurred. The corrosion bars and corrosion product once the mortar had been removed is shown in Fig. 4. It is evident that significant corrosion occurred in the upper wire.

Fig. 3. Photo of top mortar surface

Fig. 4. Photograph of upper concrete surface and wires

All the detected and located signals with a minimum amplitude 45 dB detected by all sensors for almost 28 hr of continuous monitoring are shown in Fig. 5 as signal amplitude against time and Fig. 6 displays the cumulative hits against time. Fig. 7 displays the same data set but this time as energy against time. The detected hits and their energy are attributed to active corrosion, noise and separation of the mortar from the concrete.

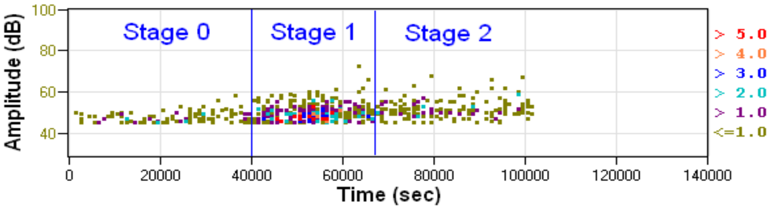

Fig. 5. Amplitude of detected signals for duration of investigation

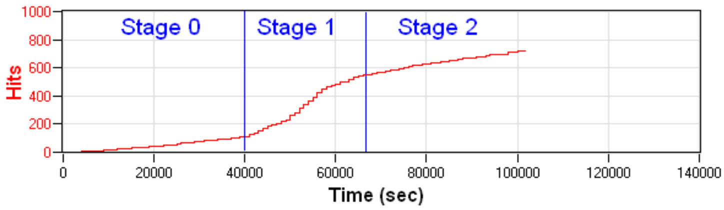

Fig. 6. Cumulative hits Vs time

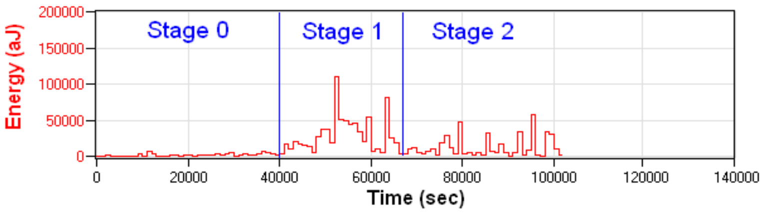

Fig. 7. Absolute energy of detected signals for duration of investigation

It can be noted that the whole time of the test can be divided into three significant stages, the first stage is stage 0 (0-40,000 sec) there are a small number of hits, low amplitude and with very low energy. The second stage (stage 1), which has an increase in the number of hits and higher energy emitted (peak of 12000 aJ) and is attributed to onset of corrosion and the build up of corrosion products on the corroding surface. The following decrease in the number of hits with smaller energy is attributed to a decrease in the rate of corrosion due to the corrosion products build up at stage 2. This behaviour is in remarkable agreement with the phases 1 and 2 of typical corrosion loss in the phenomenological model as illustrated in Fig. 8 [13].

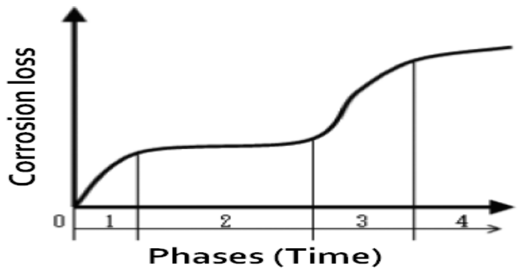

Fig. 8. Typical corrosion loss for steel in sea water immersion [13]

Fig. 8 illustrates a typical corrosion loss during the corrosion process. The corrosion is initiated at phase 1. The corrosion rate process is controlled by the rate of transport of oxygen. At phase 2, the corrosion rate loss decreases due to the corrosion product build up on the corroding surface of the steel material which inhibits oxygen transfer. Further corrosion loss increases due to anaerobic corrosion in phases 3 and 4. [13]

By comparing between stages in Fig. 6 and phases in Fig. 8 It can be seen that the stage 1 in Fig. 6 could correspond to phase 1 in Fig. 8 and the stage 2 corresponds to phase 2. It can be concluded that the onset of corrosion can be detected by determining the significant increase in AE activity and energy. Hence, the first increase of AE activity could be related to the onset of corrosion.

4. Conclusion

This paper examines the role of Acoustic Emission (AE) as a non-destructive testing (NDT) technique for reinforced concrete structures. The work focuses on the development of experimental techniques and data analysis methods for the detection, location and assessment of AE from reinforced concrete specimens. The results reveal that AE can be used to detect the onset of corrosion activity in wire in the interface between reinforced concrete and mortar as found in concrete pipes. Furthermore, the AE parameters analysis of correlation amplitude, hits and energy versus time plots were shown to be useful indicators of different corrosion stages.

5. Acknowledgements

The authors would like to thank to all technical staff of Cardiff School of Engineering, UK, who contribute in this work. Also, I thank Dr. Mark Eaton who provided technical assistance.

6. References

[1] Y. Ann, H. Ahn, S. Ryou . The importance of chloride content at the concrete surface in assessing the time to corrosion of steel in concrete structures. *Construction and Building Materials 23*. 2009, pp239–245.

[2] K. Singh. Corrosion Studies on Prestressing Steel Wire. *Ph.D. Thesis*, Imperial College, University of London,2000.

[3] M. Ing, S.Austin, R. Lyons. Cover zone properties influencing acoustic emission due to corrosion. *Cement and Concrete Research 35*. 2005, pp 284– 295.

[4] J. Hellier. *Handbook of Non-destructive Evaluation*. McGraw-Hill, USA, 2001.

[5] A.Carpinteri, G. Lacidogna , N. Pugno. Structural damage diagnosis and life-time assessment by acoustic emission monitoring. *Engineering Fracture Mechanics 74*. 2007, pp273–289.

[6] H. Elfergani, R. Pullin, K. Holford. Damage assessment of corrosion in prestressed concrete by acoustic emission,

Construction & Building Materials Journal. 2013 .

[7] Al NAHR CO. LTD. In Libya. *Technical Report*. July 1999.

[8] A. Kuwairi. Water mining: the Great Man-made River, Libya. *Proceedings of ICE Civil Engineering 159* .May 2006, pp 39-43.

[9] X. Li, and Y. Zhang Y. Analytical Study of piezoelectric Paint for Acoustic Emission-Based Fracture Monitoring. *Fatigue and Fracture of Engineering Materials and Structures 31*. 2008, pp 684-694.

[10] H. Elfergani, R. Pullin , K. Holford. Acoustic Emission Analysis of Prestressed Concrete Structures. *Journal of Physics: Conference Series 305*. 2011, 01207.

[11] K. Miller , K. Hill E, O. Moore. *Non-destructive Testing Handbook*, *Acoustic Emission Testing*. 2005, Volume 6, USA.

[12] N. Hsu, and R. Breckenridge. Characterization and Calibration of Acoustic Emission Sensor. *Materials Evaluation.*1981, **39** (1) : 60-68.

[13] E. Melchers. Modelling immersion corrosion of structural steels in natural fresh and brackish waters. *Corrosion Science*. 2006, V 48, Issue 12, pp. 4174–4201.