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Acoustic emission vis-à-vis electrochemical techniques for corrosion monitoring of reinforced concrete element

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HIGHLIGHTS

- We evaluated corrosion activity in RC element using three non-destructive techniques.
- Perfect correlation between all techniques is obtained.
- Two stages in corrosion activity found using AE technique.
- AE technique identified both corrosion of rebar and cracking of concrete.
- CSS parameter of AE showed a specific trend indicating active corrosion.

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ABSTRACT

Corrosion of steel reinforcement and subsequent cracking of concrete is a major cause for deterioration of reinforced concrete (RC) structures. For safety of structures early detection of deterioration by means of non-destructive testing is the need of the day. Comparative study of acoustic emission (AE) and electrochemical techniques for an experimental investigation of corrosion of steel embedded in concrete is presented here. The results show two stages of corrosion process and also indicate that, cumulative signal strength can be used as a promising parameter of AE technique to monitor progress of damage in RC due to corrosion.

1. Introduction

Corrosion of rebar in concrete is an electrochemical process [1,2] and it has been widely studied using various electrochemical methods. Corrosion monitoring using half-cell potential (HCP) is the most common method used for indicating probability of corrosion in RC structures [3]. The quantitative techniques for corrosion assessment mainly involve determination of corrosion rate which is an important parameter for predicting the service life of RC structure [4]. Linear polarisation resistance (LPR) method, AC impedance spectroscopy and Tafel plot techniques are most widely used non-destructive techniques for this purpose. In all above mentioned methods electrical or physical contact with steel embedded in concrete is required.

The corrosion process of rebar can also be studied using acoustic emission (AE) technique. AE is not an electrochemical method, but by utilising the sensitivity of the technique to the initiation and growth of micro-cracks, AE is able to identify corrosion by detecting micro-cracking induced to concrete as a consequence of the corrosion reaction [5,6]. It has been reported that, AE technique is suitable for health monitoring of bridges and RC structures [7–9] and for failure monitoring of RC retrofitted with FRP [10,11]. It is recently reported that the onset of corrosion can also be detected by acoustic emission measurement [12,13].

According to a phenomenological model of steel in marine environments [14], a typical corrosion loss during the corrosion process is illustrated in Fig. 1. At phase 1, the onset of corrosion occurs. As the corrosion products build up on the corroding surface of rebar, the flow of oxygen is eventually inhibited. Thus, the rate of corrosion loss decreases and is stabilized at phase 2. The corrosion

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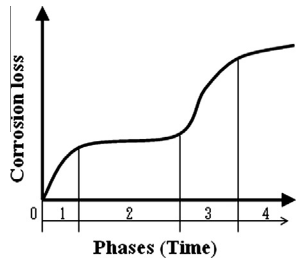

Fig. 1. Typical corrosion loss for steel in seawater immersion.

process advances further, and the corrosion loss again increases as phases 3 and 4, due to anaerobic corrosion, where the corrosion penetrates inside the rebar and the expansion of corrosion products occurs. Thus, two-step corrosion losses are modelled.

The researchers also compared the total number of AE hits with phenomenological model of steel embedded in concrete subjected to marine environments and showed that the two curves are in remarkable agreement [15]. Many researchers compared HCP results with AE results and indicated that the technique can give an early warning of corrosion than the established electrochemical technique [12,13,16]. The researchers also studied the process of corrosion accelerated by imposed potentials followed by AE coupled with electrochemical techniques and showed a perfect correlation between the evolution of AE hits and the corrosion current density [6]. They also underlined that AE activity depends on porosity of mortar. Some researchers [17] studied the effectiveness of AE using different parameters like cumulative signal strength (CSS), average signal level and absolute energy, in detecting and characterising the initiation of corrosion process coupled with electrochemical techniques for pre-cracked RC beam specimens. But, the corrosion monitoring was limited only during initiation period focusing the study related to onset of corrosion only. Thus, very little research on the continuous monitoring of RC specimen subjected to corrosion progressing from onset up to development of visible crack on concrete surface by AE technique using CSS parameter in comparison with well-established electrochemical techniques was found. With the progress in corrosion, the electrochemistry of steel surface and consequently the cracking pattern of concrete changes. As electrochemical measurements are carried out having direct contact with steel rebar and AE measurements are taken on concrete surface, the results obtained by these techniques differ from each other. Hence proper interpretation of the results obtained using AE in comparison with electrochemical techniques is necessary. Hence, the focus of this paper is to study whether AE can offer direct information about damage due to corrosion in comparison with the results obtained using electrochemical techniques.

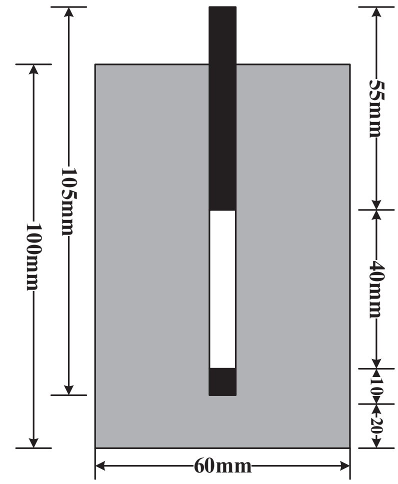

Fig. 2. Cylindrical reinforced concrete specimen.

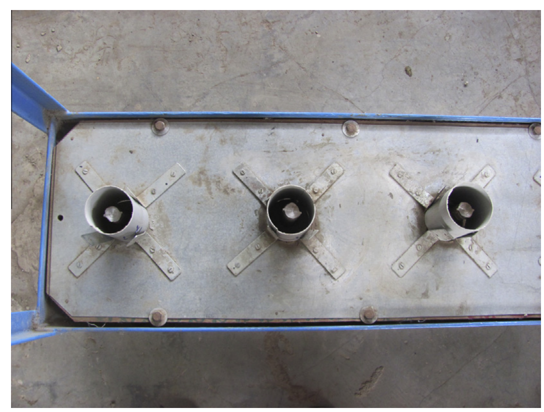

Fig. 3. Special moulding system.

2. Experimental procedure

2.1. Materials and specimen preparation

Cylindrical RC specimen as shown in Fig. 2 with concentric steel bar were cast.

The experimental procedure comprised of studying the corrosion activity on the RC cylindrical specimens made with 12 mm diameter steel rebar with three replicates (12 SP-1, 12 SP-2 and 12 SP-3) having bottom cover of 20 mm and transverse cover of 24 mm. For casting of specimens, a special moulding system was fabricated as shown in Fig. 3. The specimens were cast in inverted position to maintain the bottom cover and concentric position of rebar. Due to smaller dimensions and inverted casting procedure, some specimens showed honeycombing. Such samples were deliberately used for testing to create real life situation.

Along with cylinders 6 concrete cubes having dimensions 150 mm × 150 mm × 150 mm were also cast and tested after 7 days and 28 days curing for finding compressive strength of concrete as per IS 516 – 1959 [18].

For all the specimens, M20 grade of concrete was prepared. Ordinary Portland cement of nominal strength 53 MPa was used for preparation of concrete mixes. Natural river sand confirming to zone I as per IS 383-1970 [19] was used as fine aggregates and crushed stone of nominal size 10 mm was used as coarse aggregates. The concrete mix was designed as per IS 10262:2009 [20] and the mix proportion obtained was 1:2.78:2.73 with water–cement ratio of 0.5. Average 7-days and 28-days compressive strength obtained for all specimens were 20 MPa and 32 MPa respectively.

A standard reinforcing bar of 105 mm length of TMT 500 grade was used as a concentric reinforcement in the cylindrical specimens. Before casting, the steel bar was drilled and threaded at one end to accommodate the threaded copper screw for electrical connections. Then the bar was wire brushed to remove any surface scale. Epoxy resin was then applied for the length of 55 mm from top and 10 mm form bottom in order to protect this portion from the corrosion activity. The remaining middle portion of 40 mm was subjected to accelerated corrosion process. The epoxy resin was allowed to harden for 24 h and then the weight of reinforcing bar was recorded to an accuracy of 0.01 g.

The cylinders were cast in the special moulding system and were removed from the moulds after 24 h of casting and kept for curing for the period of 7-days at a room temperature and relative humidity of 100%. On 8th day the specimens were immersed in 5% NaCl solution, approximately double the salinity of seawater, at a room temperature for 24 h to ensure full saturation of the test specimen. From ninth day constant potential was applied to the specimen to accelerate the corrosion process using impressed current technique.

2.2. Accelerated corrosion set-up

In the present study, the specimens were subjected to accelerated corrosion using impressed current technique. The objective of inducing corrosion to the bar is to simulate the corrosion-damaged concrete. The commonly used methods of inducing corrosion in RC specimens are salt spray, Chloride diffusion [1,12,21], alternate drying and wetting in salt water [13] and impressing anodic current [6,22–24]. Previous studies have shown that, the salt spray technique is not suitable considering the time constraint. Method of adding chlorides artificially to the concrete during casting is an effective method of inducing corrosion, but practically no concrete is deliberately cast using salt. Alternate immersion into NaCl solution and