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Initiation and Propagation of Crack Due to Corrosion of Reinforcement - An Experimental Investigation

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Abstract:*In the field of fracture mechanics of concrete as well as for health risk assessment of reinforced concrete structures in marine environment, the initiation and propagation of cracks due to corrosion of reinforcement plays a vital role. In the present study, the location of crack initiation is evaluated experimentally. The thicknesses of rust layer around the reinforcement and width of crack due to this rust formation were also investigated. Accelerated corrosion test were used to furnish the experiment. It was found that the major crack was initiated from the outer surface of the cover concrete and propagated towards the steel reinforcement interface. Corrosion induced crack of width 0.225 mm was caused by a thickness of rust layer of 0.358 mm.*
Keywords: *Initiation location of crack, propagation of crack, thicknesses of rust layer, width of crack.*

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I. Introduction

Concrete is the most versatile material used worldwide to construct various structures like buildings, bridges, highway pavement and marine structures. Chloride ions present in the marine environment does not affect the concrete but the reinforcement. They diffuse into the concrete through the pore spaces and when the amount of chloride ions exceeds a threshold value, it breaks the layer of passivation [1]. This passive layer is formed around the steel bars due to high alkalinity of the pore solutions [1]. After depassivation of steel, corrosion occurs spontaneously. Corrosion is an electrochemical process in which the steel is oxidized to various stable iron oxides. The volume occupied by the corrosion products are as much as six times the volume of parent metal[2]. Initially few amounts of corrosion products fill the porous zone of concrete surrounding the reinforcement. So, no stress will develop when free expansion occurs. However when the products volume exceeds that of the porous zone, expansive stress is developed in cover concrete.

Cracking in concrete is an important factor for evaluating the structures when it is time for repair or replacement. Many researcher says that the limiting point is reached when the cover concrete has just cracked [3,2,4]. The width of crack at the initiation is considered as 0.05 mm and this happens in a very short period from the starting of corrosion. So, if this criteria is considered, the cost of repair will increase significantly. This limiting state is effectively defined as the formation of crack having a width of 0.3 mm[5]. The location of initiation of crack is a great concern to define mechanism of crack propagation as well as the interpretation of limiting state for repair work. When the stress developed due to external force exceeds the strength of concrete, crack initiates whether it stands in compression or tension. Circumferential stress induced due to expansive corrosion products on the cover concrete is tensile in nature and the cracks initiated when this circumferential stress exceeds tensile strength of concrete. This consequences begins cracking at the steel–concrete interface and propagates outwards [6,7,8,1,9]. However, the experimental study on initiation of cover cracking as well as the propagation path induced by corrosion of reinforcement is still very limited.

In the present study, the location of crack initiation is evaluated experimentally. The location of crack initiation will provide an essential information in fracture mechanics of concrete. This will also help in continuous health risk assessment of structures exposed to marine environment.

II. Experimental Procedures

Impressed current technique was used to accelerate the test procedure. High resolution video camera was used to track the location of crack initiation. The thickness of corrosion product was measured by image analysis by capturing image of the top surface of the specimen using USB digital microscope at different time intervals.

2.1 Material Properties:

Normal weight concrete was used in this study. Proportion of concrete mix was designed in accordance with ACI 211.1 and the proportion is shown in Table 1. A w/c of 0.45 was used to implement the codalrequirements for exposure condition of concrete in saline environment. ASTM Type-I (Ordinary Portland Cement), 19 mm downgrade stone chips and river sand with fineness modulus of 2.8 were used as binding material, coarse aggregate and fine aggregate in concrete respectively. The tap water used in this study have a chloride ion concentration of 1200 mg/L. The compressive strength and tensile strength of concrete were tested according to ASTM C39 and ASTM C426 respectively. The studied average compressive strength and tensile strength of concrete were found as 30 $\pm$ 2 MPa and 2.9 $\pm$ 0.2 MPa respectively. Two types of steel reinforcement were used in this research. 12 mm diameter Grade 60 MS plain bar was used to represent as anode and 4 mm diameter wire as cathode.

Table 1: Mix proportions for the concrete

Materials (kg/m^3)					w/c ratio
Water	Cement	Fine Aggregate	Coarse Aggregate	Fresh density	
190	422	725	1008	2345	0.45

2.2 Specimen Fabrication:

A 12 mm diameter Grade 60 MS plain bar was used to represent as anode and three 4 mm diameter wire were used as cathode. Length of each bar was 75 mm. The anode and cathode bars were embedded in a cubical concrete specimen of 100 mm x 100 mm in section and 50 mm in thickness. Schematic sketch of the test specimen is shown in Figure 1. The 12 mm diameter bar (anode) was placed in such a manner that a clear cover of 35 mm had accomplished and three 4 mm diameter wires (cathode) were placed equidistant from each other as well as from central anode bar. It was assumed that all the current are consumed to oxidize the steel in accelerated corrosion test. So that a certain amount of chloride ions is needed in the concrete. Before conducting the accelerated corrosion test, the specimens were cured in 3.5% NaCl solution by weight. The accelerated corrosion test was started when the age of concrete specimen became 28 days.

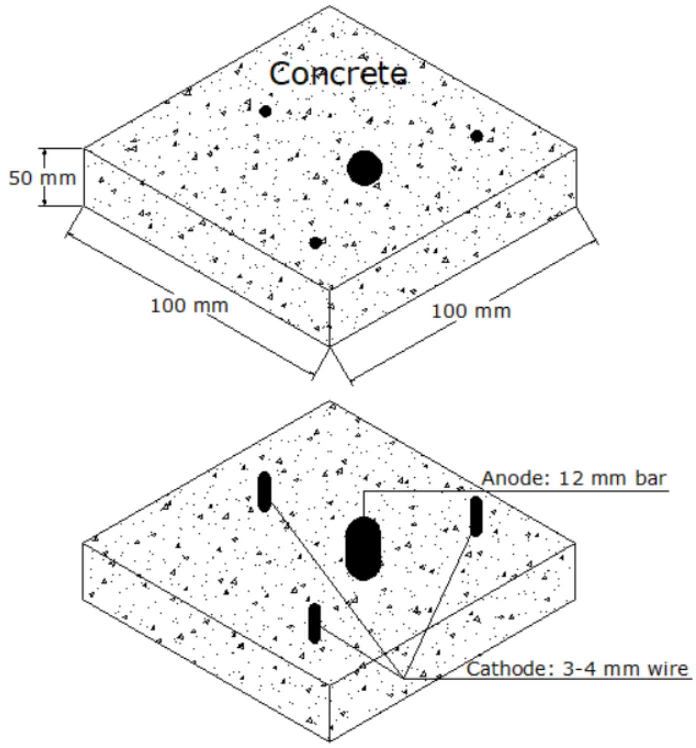
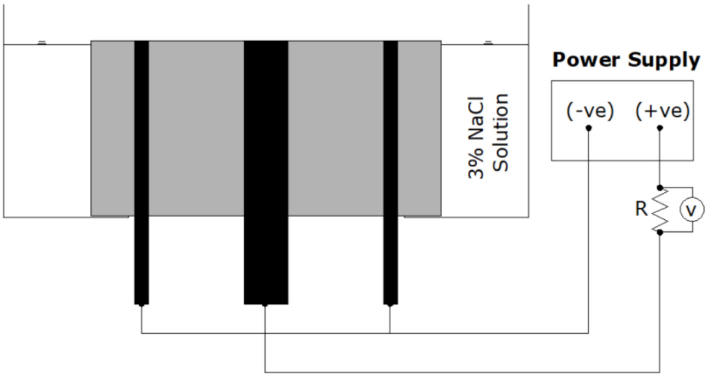


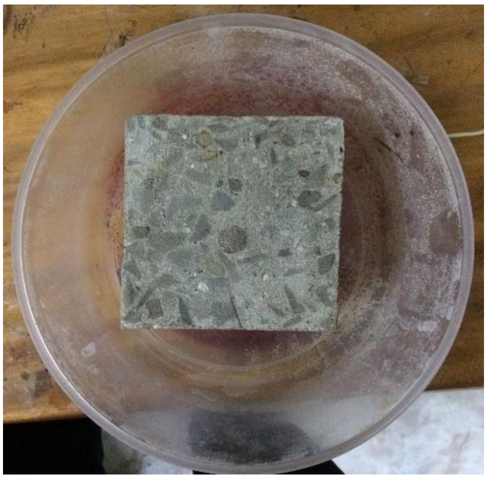
Figure 1: Schematic diagram of specimen (top and bottom view respectively)

2.3 Test Setup and Test Procedure

To accelerate the corrosion, direct current was impressed on the steel reinforcing bars by means of DC power supplies. The test setup is shown in Figure 2. A power supply of 30 V, 1 A was used. A constant voltage of 30 V was applied across the anode and cathode and the voltage drop across a fixed resistor of 1Ω was measured. From which the current passed through the circuit was calculated by Ohm's law (I = V/R). The top surface of the specimens was polished and smoothened with grade 400 sand paper and then cleaned with air blower and duster cloth. The bottom side of the specimen was sealed with paint before immersed it in 3% NaCl solution in a manner that the chloride ions penetrate only through the side surface. A video camera was fixed at the top of the setup for capturing video until the major crack had formed. The video was then analyzed to observe the location of initiation point of crack. The thickness of corrosion product layer and crack width were observed by a magnifying USB digital Microscope. The corrosion product layer and the cracks were clearly distinguished in color images. The top surface of the specimens was dried and cleaned again before taking each photograph.



(a)



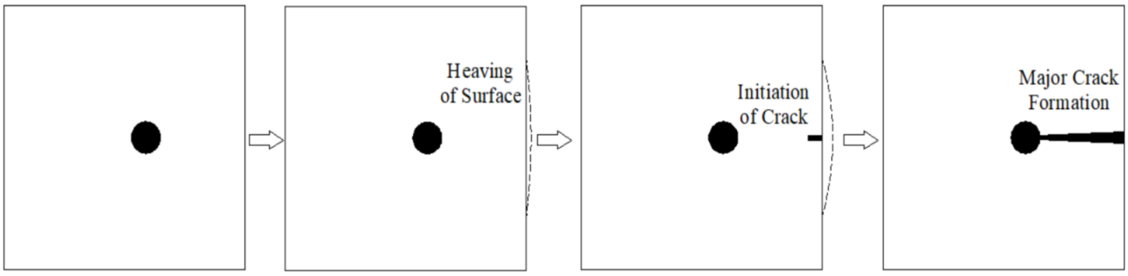
(b)

Figure 2: Experimental Setup (a) accelerated corrosion test (b) system of ponding

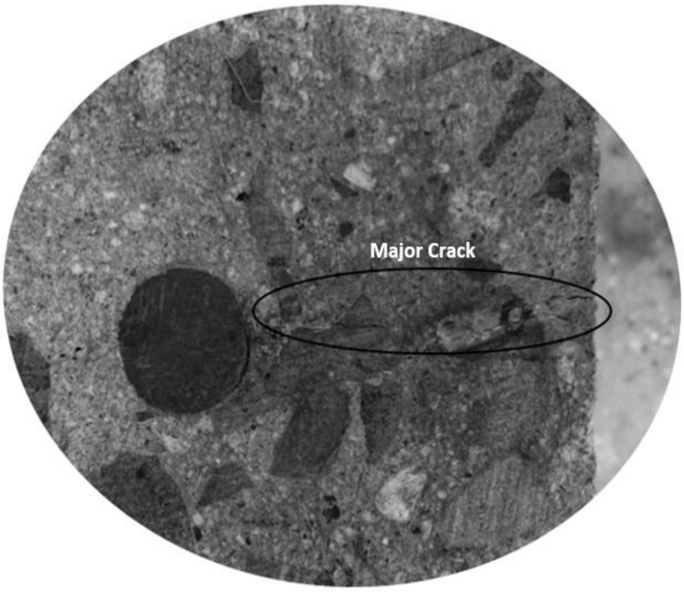
III. Resultsand Discussion

3.1 Crack Initiation

Classical theory says that, crack initiates when the stress induced due to expansive corrosion products exceeds the tensile strength of concrete. Tensile stress can be happened either by circumferentially or bending of cover concrete. In this experiment, it was found that the crack initiated at the shortest outer surface of the cover and propagate towards the steel concrete interface. The phenomenon is illustrated in Figure 3. Figure 3(a) describes the initiation and propagation of major crack and Figure 3(b) shows the pictorial view of the cracked specimen. A possible explanation for this phenomenon is that there is a heaving of cover concrete occurred due to the expansive corrosion products. For this reason, a local bending stress had induced. After the bending stress had reached the tensile strength of concrete, a crack initiated. Within a short period of time the initiated crack was propagated and reached to the steel concrete interface. Tran et al. [10] reported that there were minor cracks formed initially around the reinforcing steel but in this study there were no observations about the minor cracks found.



(a)

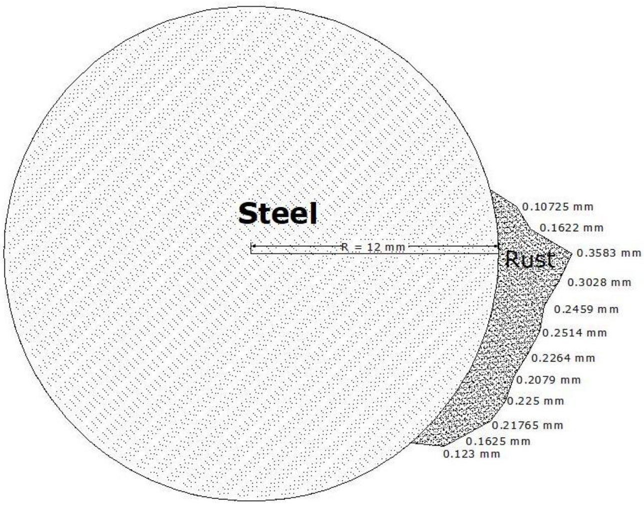


(b)

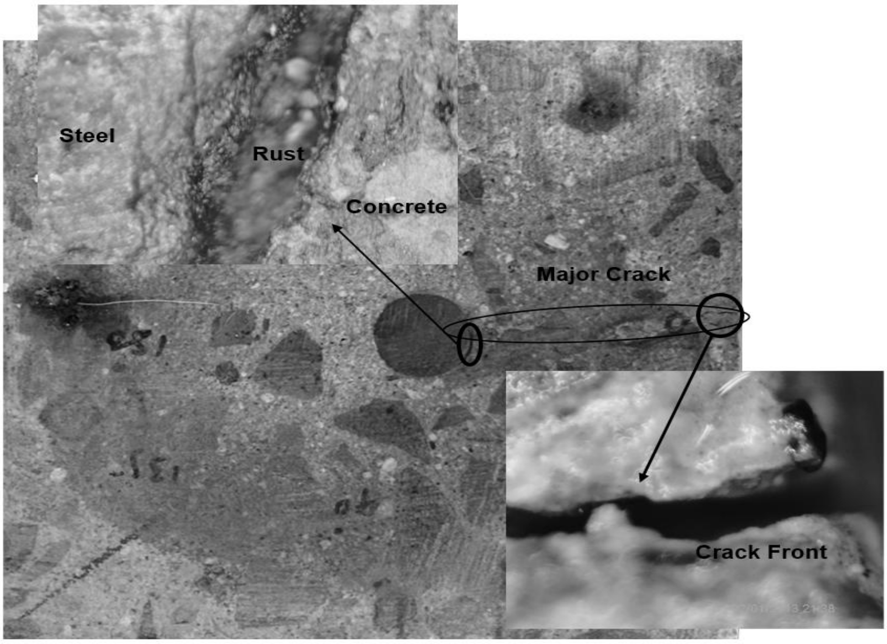
Figure 3: Initiation and formation of major crack (a) schematic diagram (b) cracked specimen

3.2 Thickness of Corrosion Products

Color photographs, taken by the magnifying USB digital Microscope, could clearly illustrate the layer of corrosion products and the cracks formed due to expansive nature of corrosion products. The thickness of corrosion products around the rebar was plotted against polar coordinates of the bar and is shown in Figure 4. Figure 4(b) shows the specimen after the completion of the test. It was continued for about 7 hours 45 minutes and the major crack was formed after 6 hours. The rust layer around the bar was highly non uniform which is shown in Figure 4(a). The magnified view of rust layer and the crack front is shown in figure 4(b). The thickness of rust layer is plotted in polar coordinate and the thickness of 0.358 mm causes a crack of width 0.225 mm. From Figure 4 it can be seen that the crack was formed at the weakest plane which is the shortest clear cover.



(a)



(b)

Figure 4:(a) Thickness of corrosion product around the perimeter of rebar in polar co-ordinate for a crack width of 0.225 mm(b) Specimen showing the magnified view of rust layer and the major crack front.

IV. Conclusions

In the field of fracture mechanics of concrete as well as for health risk assessment of reinforced concrete structures in marine environment, the initiation and propagation of cracks due to corrosion of reinforcement plays a vital role. In the present study, the location of crack initiation is evaluated experimentally. The major crack was initiated from the outer surface of the cover concrete and propagated towards the interface of steel and concrete. There were no minor cracks were observed adjacent to the steel concrete interface. The width of crack is an important parameter for the corrosion level as well as prediction of the time for repair. Corrosion induced crack of width 0.225 mm was caused by a thickness of rust layer of 0.358 mm.

References

[1]. Bazant, Z. P. Physical Model for Steel Corrosion in Concrete Sea Structures - Theory. J. Struct. Div.**105,** 1137–1153 (1979).

[2]. Liu, Y. & Weyers, R. E. Modeling the Time-to-Corrosion Cracking in Chloride Contaminated Reinforced Concrete Structures. ACI Mater. J.**95,** 675–680 (1998).

[3]. Magne Maage, Steinar Helland, Ervin Poulsen, Øystein Vennesland, and J. E. C. Service Life Prediction of Existing Concrete Structures Exposed to Marine Environment. ACI Mater. J.**93,** (1996).

[4]. Torres-Acosta, A. A. & Martnez-Madrid, M. Residual Life of Corroding Reinforced Concrete Structures in Marine Environment. J. Mater. Civ. Eng.**15,** 344–353 (2003).

[5]. Andrade, C., Alonso, C. & Molina, F. J. Cover cracking as a function of bar corrosion: Part I-Experimental test. Mater. Struct.**26,** 453–464 (1993).

[6]. Val, D. V., Chernin, L. & Stewart, M. G. Experimental and Numerical Investigation of Corrosion-Induced Cover Cracking in Reinforced Concrete Structures. J. Struct. Eng.**135,** 376–385 (2009).

[7]. Bhargava, K., Ghosh, A. K., Mori, Y. & Ramanujam, S. Model for cover cracking due to rebar corrosion in RC structures. Eng. Struct.**28,** 1093–1109 (2006).

[8]. Pantazopoulou, S. J. & Papoulia, K. D. Modeling Cover-Cracking due to Reinforcement Corrosion in RC Structures. J. Eng. Mech.**127,** 342–351 (2001).

[9]. Hansen, E. J. & Saouma, V. E. Numerical Simulation of Reinforced Concrete Deterioration : Part II — Steel Corrosion and Concrete Cracking. (2000).

[10]. Tran, K. K., Nakamura, H., Kawamura, K. & Kunieda, M. Analysis of crack propagation due to rebar corrosion using RBSM. Cem. Concr. Compos.**33,** 906–917 (2011).

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