

Corrosion Prevention of Steel Reinforcement in 7.5% NaCl Solution using Pure Magnesium Anode

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Abstract. The current work investigates the performance of pure Magnesium on corrosion prevention of steel reinforcements by way of sacrificial anoding. Two set of six steel reinforcements were tested for half-cell potential, weight loss, anode efficiency and tensile strength for each of the sacrificial anodes in a high chloride atmosphere of 7.5% NaCl in tap water. Significant reduction in weight of anode was observed during the initial 12 days. The reduction in weight of steel reinforcements tied with anodes was found to be negligible, while that of reinforcements without anodes was significantly higher. Five distinct zones of corrosion were observed during the test. The tensile strength of steel cathodically protected by Mg alloy anodes was found less affected. It could be concluded that pure Mg anode provides an effective way of corrosion mitigation.

1. Introduction

The high compressive strength, durability, ease of working and easy availability of raw materials of concrete has made it the basic building material for almost any type of construction all over the world. But poor performance of concrete in tension has made structural steel an inseparable ingredient of concrete structures leading to what is known as reinforced cement concrete (RCC). Such structures are known for their high strength characteristics. The structural performance of steel depends largely on the exposure conditions [1]. The presence of chlorides, carbonates, sulfates and ionic materials is reported to be detrimental leading to reduced structural performance due to advent of corrosion [2-4]. The ingress of such components in concrete leads to reduction in pH of concrete by formation of acids such as HCl, H₂CO₃ and H₂SO₄, which results in depassivation of protective layer of reinforcement [4]. The removal of protective layer can lead to active corrosion site. As the corrosion advances, the corrosion products increase in volume, thereby causing spalling of concrete and further exposes the steel to the environment thereby causing structural deterioration. Fig. 1 enlists various factors which can lead to the deterioration of reinforced cement concrete structures. It is to be emphasized only the predominant factors are mentioned here and the list is not exhaustive.

There are several ways to prevent the corrosion of reinforcement in concrete such as, providing protective coatings of epoxy, inhibitor [5] or providing coatings of metals which are electrochemically more active than steel [6], or by way of corrosion resistant steel re-bars, the more recent and elegant technique being the cathodic protection of reinforcements [7,8].



The primary objective of this paper is to experimentally investigate the effectiveness of pure Magnesium anode in electro-chemically protecting reinforcement in severe Chloride atmosphere.

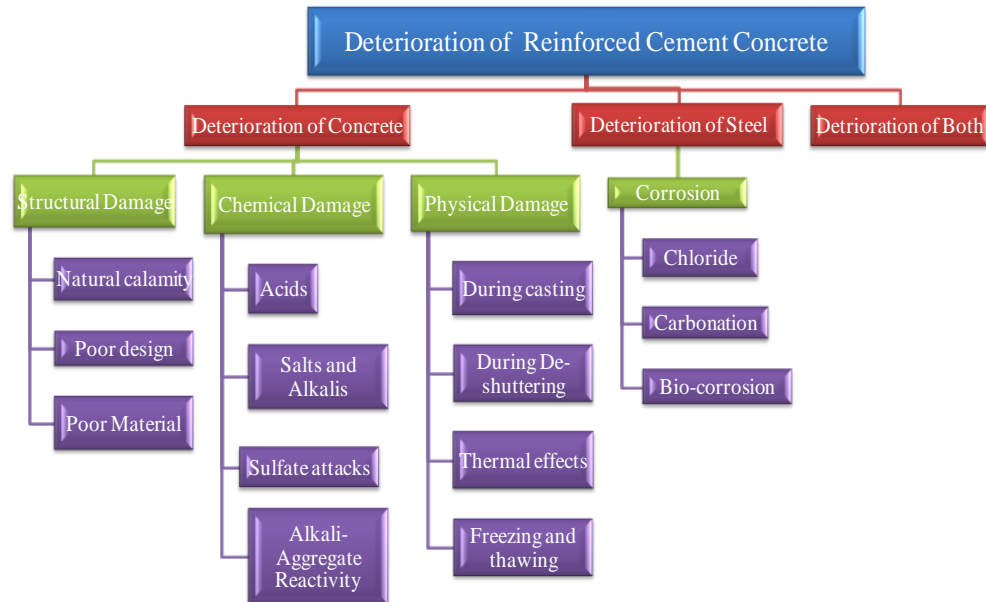


Figure 1. Predominant factors of deterioration of Reinforced Cement Concrete.

2. Experimental Set-Up

The experimental set-up for the work is as shown in Fig.2 consisted of two containers each containing six steel reinforcements 16mm diameter 950mm long. In the first container, rods were tied using steel wires to 22mm diameter 250mm long pure Magnesium anode in the middle, while bare steel reinforcements were tied and placed in second container. All the samples were kept under controlled laboratory conditions. The specification of water used in these containers is presented in Table 1.

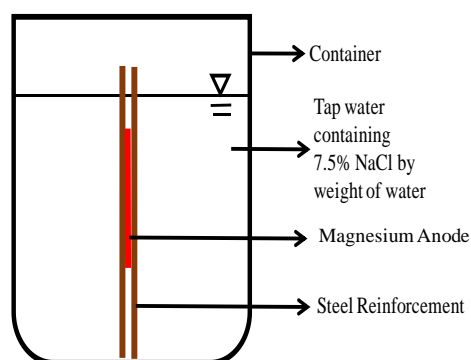


Figure.2. Experimental set-up for testing in Chloride atmosphere.

In order to simulate severe chloride atmosphere, 7.5% NaCl was mixed in the water used. The reinforcements were regularly untied and weighed accurately up to three decimal places.

TABLE 1: Tap water characteristics confirming IS: 10500:2012

S.No.	Parameter	Value
1	Chloride	168mg/l
2	pH	7.6
3	Fluoride	0.4mg/l
4	Dissolved Oxygen	10.15mg/l
5	Chemical Oxygen Demand	0
6	Biological Oxygen Demand	0
7	Free Residual Chlorine	0.1mg/l

3. Results and Discussions

Anode weight loss: The reduction in weight of anode with time is shown in Fig.3. It is seen that drastic weight reduction is observed in the initial 12 days after which weight reduction rate is reduced. During these 12 days, nearly 27% reduction of anode weight is observed. This could be attributed to the fact that the free chloride ions are consumed rapidly during the initial days, react with the Magnesium matrix of the alloy, forming $MgCl_2$.

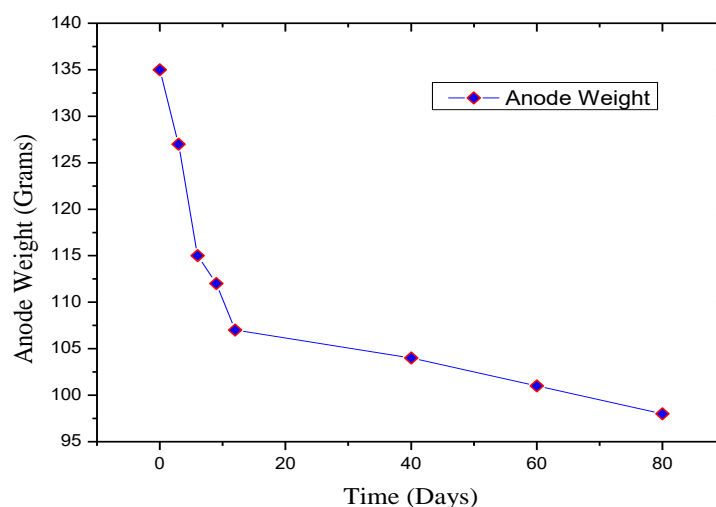


Figure.3. Weight reduction of pure Magnesium anode with respect to time.

Weight Reduction of steel reinforcements: Fig.4. graphically depicts the variation of weights of reinforcement with and without anode. It is evident from Fig.4. that reinforcement bars tied with anodes show negligible changes in weight even at the end of 80 days. This means that pure Magnesium, being at higher electro-chemical potential, acts as anode and is hence consumed forming $MgCl_2$ thereby preventing the free chloride ions to attack the reinforcements. Whereas, the reinforcement bars without anode are vulnerable to chloride attack and this is evident by the drastic reduction in weights of reinforcements.

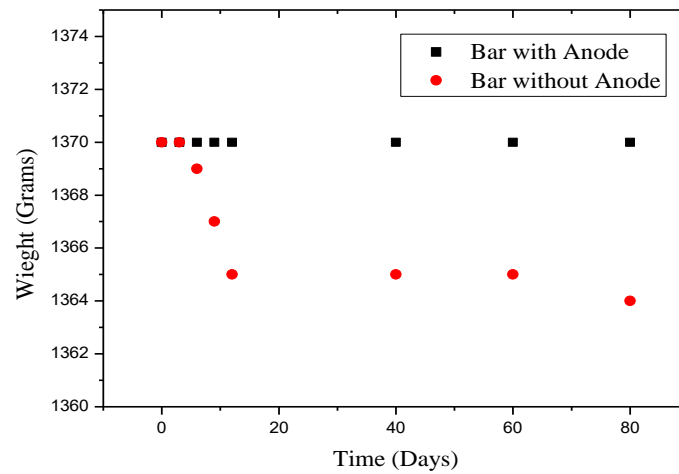


Figure 4. Weight of reinforcement with respect to time.

Corrosion Zones: Five distinct zones of corrosion were observed for the bars having no cathodic protection as shown in Fig. 5. (a-f) with increasing order of magnification of every zone.

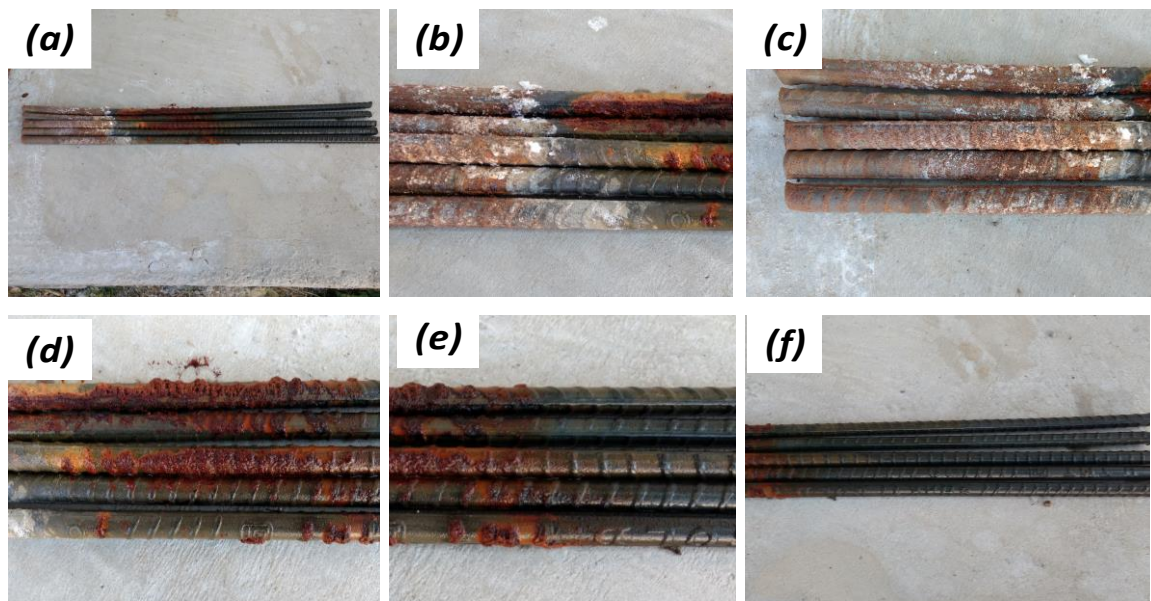


Figure.5 (a-f) Increasing Magnification of corrosion zones in steel reinforcements without anode.



Figure. 6. Magnified image of all corrosion zones in reinforcement.

All the zones present in corroded reinforcement are clearly depicted in Fig.6. The zone I is a region exposed to atmosphere and is corroded along with deposits of salts at the junction of steel with water. This region is supplied with abundant free chloride ions, moisture and oxygen, and thus provides a favorable atmosphere for corrosion. Zone II is a narrow region of negligible corrosion not visible to naked eyes. In zone III, there is rust deposit, while zone IV is a small transition zone from rusting to markedly reduced corrosion. It is worth mentioning that zone V, which is characterized by negligible corrosion, was submerged deeper in the NaCl solution. The results of water used for dipping the rods in NaCl solution shows that the amount of dissolved oxygen present is negligible. The oxygen so present is consumed in formation of rust towards the water surface as corrosion initiates from the surface. Thus, even in the presence of free chloride ions the corrosion in this region is reportedly negligible. It could be expected that in significant course of time, the rusting would propagate towards zone V.

4. Conclusion

The performance of pure Magnesium anode is evaluated systematically by subjecting bare reinforcements and reinforcements tied with anode in extreme chloride ion atmosphere. It is concluded that pure Magnesium being electro-chemically active compared to reinforcements, acts as anode, while reinforcements are rendered cathode. Hence, reinforcements are protected from corrosion. Further, the weight loss in anode supplements the conclusion drawn. The weight loss for bare reinforcements is reported to be drastic during the initial 12 days while that of reinforcements tied with pure Magnesium is found to be negligible even up to 80 days. Five distinct zones of corrosion are identified in bare reinforcement. Zone V is identified as corrosion free zone, which in due course of time is expected to be prone to rusting and later corrosion. From the results, it is well-established that pure Magnesium anodes are effective means of cathodic protection of steel reinforcements.

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