Effects of $NaNO_3$ and Na_2CO_3 on Corrosion Failure of Low Alloyed Steel Concrete Reinforcement

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ABSTRACT

Concrete structures such as bridges and buildings normally contain steel reinforcement. To forestall damage to concrete steel an investigation was conducted on steel used in concrete reinforcement. The general corrosion performance of the steel in a simulated laboratory environment containing various concentration of inhibited and activated solutions was evaluated by measuring electrochemical potential of steel samples in the media and by weight loss due to corrosive action on completely immersed specimens. Observations revealed that corrosion effect on the reinforcement even though negligible is enough to initiate a conclusion that both inhibitors and activators can contribute to failure of steel reinforcement in service. To be useful in reinforced concrete, corrosion-inhibiting admixture must not only control the corrosion, but must also be compatible with the concrete.

Keywords: Concrete, Corrosion, Reinforcement.

INTRODUCTION

Concrete structures such as bridges and buildings normally contain steel reinforcement and the main benefit for using steel reinforcement is the economical increase of safe load-carrying capacity and ductility. (Shreir, 1983). Also, thermal coefficients of expansion for steel and concrete are well matched. In addition, we have known for almost a hundred years that the alkaline nature of the surrounding concrete assures protection of the steel from corrosion. However, reinforced concrete is prone to corrosive attack of CO_2 from atmosphere, which react with saturated $Ca(OH)_2$ in pure water forming saturated carbonate. Deliberate efforts are therefore required to enhance the service life of these components if their usage is to be sustained, (Macdonald et al, 1991). Corrosion inhibitors have been applied for corrosion prevention. The breakdown of passivity will lead to localised corrosion and when this is sufficient

to cause formation of large volume of corrosion products, some forms of concrete failure occur. The corrosion of steel in concrete is generally initiated by a chemical reaction related to the composition of the constituent parts and the influence of one or more of the following parts: chloride concentration, carbonation penetration, oxygen concentration, bacteria action, degree of moisture ingress, and other acid radicals, (Moskim, 1983). Variations in chemical composition can slowly build up localised corrosion and affect the steel concrete interface and the surrounding environment (concrete) permits an electron movement from one part of the metallic surface to another. This current flow starts to dissolve the metal in areas where it flows off the steel thereby initiating corrosion. Because of these two motivating processes the overall phenomenon becomes an electrochemical degradation process. In the U.S., the major impetus for large-scale use of corrosion inhibitors in concrete arose from premature failures of reinforced concrete bridges on the interstate highway system, (Weinermair et al, 1996). Use of corrosion inhibitors in concrete structures is quite common, based on the successful performance of these products. The corrosion process in concrete requires water, oxygen from air carbon dioxide and a catalyst such as chloride ions. Structural steel won't corrode in dry reinforced concrete, even if salt is present, nor will it in wet concrete, even in the presence of chloride ions, which are in salt solutions, if oxygen is essentially unavailable, for instance, at great depths under the ocean surface. Damage caused by corrosion of reinforcement in concrete results from oxidation due to an electrochemical process. In this process, water is the solvent medium, which allows transportation of ions. Oxygen is the reactant, which takes electrons from iron atoms, causing iron to go into solution. In reinforced concrete, a catalyst, like chloride ion from salt that has diffused into concrete, is the critical component in the corrosion process. This accelerates the deterioration and keeps it going. Mechanistic details are difficult to pin down, but the chloride ion is able to penetrate and weaken the thin film of iron oxides coating the reinforcing steel. This covering is normally passive in concrete. Chloride ions are also uniquely able to react with ferrous ions (iron in solution) after they are liberated from the rebar, allowing them to travel some distance before precipitating as iron hydroxide. When the ferrous ions are finally deposited, they oxidize further by reaction with oxygen and become very insoluble hydrated ferric oxides, with a volume much larger than that of the original iron in the rebar. The chloride ions are then released to return to the rebar and continue the corrosion cycle. Generally, steel is chemically passive in concrete

because of concrete's alkalinity, but it isn't immune to corrosion. That is, the rate of corrosion can be so low that normally we can neglect it for all practical purposes. But if conditions change, the corrosion rate could increase to problematic proportions. The process of carbonation converts carbonate in the cement to carbonic acid:

$$Ca^{2+} + CO_3^{2-} + 2H^+ + 2OH^- = 2H^+ + 2HCO_3^{2-} + Ca^{2+} + O^{2-}$$

Carbonation results in failure of the structure with its attendant economic losses and danger to human life. The presence of acidic environment further aggravates corrosion reactions on the reinforcing rods. The original oxide layer on the reinforcing materials may suffer structural damage by scaling. The region provides easy path for chloride ions onto the surface of the bar. The aim of this paper therefore is to study the effects of nitrites and carbonates on the corrosion rate of the steel used in concrete reinforcement.

Experimental Methods

The samples were prepared from hot rolled low alloy steel rod. The chemical analysis is as shown in Table 1. The samples were cut into small cylindrical parts of 8mm diameter and 40mm long. The samples were machined to standard tensile specimens, grounded on 240mm grade emery paper to standardize the surface profile and then cleaned in alcohol to remove adherent grease and stop corrosive action of water. The "corrosive" media used for this study consist of an alkaline media ($Ca(OH)_2$). The pH of this media was stabilized between 7.5 to 8.0 and various concentrations (0.1, 0.2, 0.3, 0.4, 0.5 and 0.6M) of inhibitors and activators were added into the solutions. Sodium nitrite was added as inhibitors and Sodium Carbonate as activator. All investigations were carried out at room temperature under normal atmospheric pressure and with complete immersion of the specimens into the media. The pH measurement was done using Crison Micro processor this makes it possible to monitor and ascertain the tendency of various samples under study to corrode. The potential measurement was taken with a multimeter and Ag/AgCl reference electrode. The specimens were suspended in the solution. The rate of corrosion was determined by measuring the weight loss, which was evaluated, by measuring the difference in weight every five days for 60 days.

Results and Discussion

The results of changes in weight loss with exposure day, potentials with exposure days and variation of the pH with exposure days for various samples immersed in $Ca(OH)_2$ solutions containing $NaNO_3$ and Na_2CO_3 respectively are

presented in Figures 1 to 6. In Figure 1, in the solutions containing $NaNO_3$, the weight loss increases with increase in concentrations, varying from 0.01 and 0.09mg. In all the concentrations, there was gradual increase within the first 15 days and continues till 30 days. After 30 days the weight loss increase even though at a very slow rate. In Figure 2, in the solutions containing Na_2CO_3, the weight loss decreases with increase in concentrations. The weight loss varies from 0.02 to 0.17mg gradually increasing with increase in days of exposure. The rate of corrosion attack on the samples immersed in sodium carbonate solution increased with exposure time however slowly. In the sodium nitrite a slower rate was observed. At 60 days of exposure it is found that the weight loss reduces with increase in the concentration of sodium nitrite and sodium carbonate. Variations in concentration can slowly build up localised corrosion and affect the steel concrete interface. Surrounding environment (concrete) permits an electron movement from one part of the metallic surface to another. This current flow starts to dissolve the metal in areas where it flows off the steel thereby initiating corrosion. Because of these two motivating processes the overall phenomenon becomes an electrochemical degradation process. To be useful in reinforced concrete, a corrosion-inhibiting admixture must not only control the corrosion, but must also be compatible with the concrete. From Figures 1 and 2, it could be seen that both admixtures show tendency to corrode as revealed in the increase in weight loss with exposure of days and changes in concentrations, even though the corrosion rate is low. In Figures 3 and 4, the potential measurements for both admixtures were negative. The fact that the solutions respond to changes in potentials testifies to the possibility of corrosion in the steel reinforcement occurring and the need to monitor concrete structures effectively to avoid failures. Detection and monitoring of corrosion of reinforcement using potential measurements is based on the change in potential that occurs when steel reinforcement changes from the passive to the active state. Corrosion rate is low judging from the potential measurements, which varies from 10 to -84MV in solutions containing $NaNO_3$ and from -45 to -133MV in solutions containing $NaCO_3$. Within the initial 30 to 40 days, owing to the passivity induced by the highly alkaline nature of the solution the corrosion rate was virtually constant, however after 40 days, this passivity is broken due to the effect of atmospheric CO_2 reacting with concrete constituents. In Figure 5, the pH of solution containing $NaNO_3$ appeared stabilised for 40 days and thereafter there is gradual reduction till 50 days and after 50 days there is gradual increase. Also in Figure 6, the pH of solution containing Na_2CO_3 followed identical

pattern. Increase or reduction in pH allows corrosion of reinforced steel in the concrete, however low.

Conclusion.

To be useful in reinforced concrete, a corrosion-inhibiting admixture must not only control the corrosion, but must also be compatible with the concrete. Sodium nitrite appears unstable as an inhibitor. Variations in concentration slowly build up localised corrosion, which can affect the steel concrete interface. Reinforced concrete is prone to corrosive attack of CO_2 from atmosphere, which react with saturated $Ca(OH)_2$ forming saturated carbonate. Changes in pH and potentials allow corrosion of reinforced steel in concrete.

References:

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Table 1. Chemical analysis of as received sample.

Element	C	Si	S	P	Mn	Ni	Cr	Cu	Sn	Pb	Fe
Wt. %	0.153	0.0698	0.0698	0.62	0.58	0.131	0.299	0.265	0.0141	0.0003	96.798

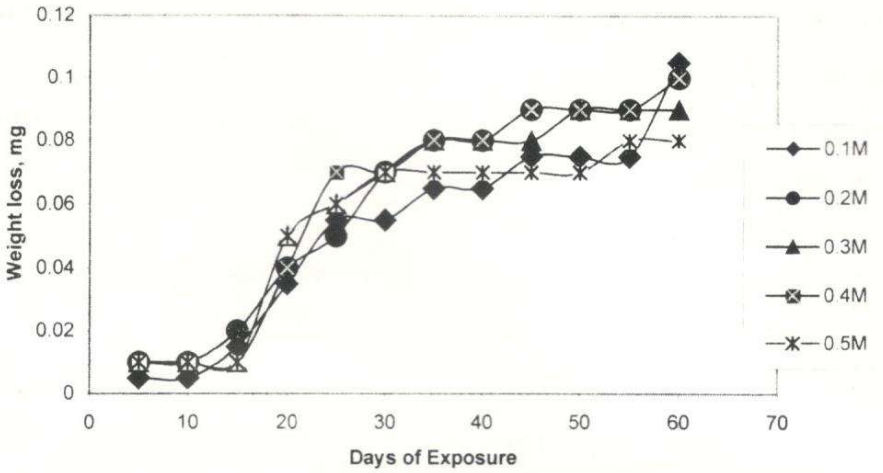

Figure 1. Weight loss with Days of Exposure for Samples in Ca(OH)2 Containing Various Concentrations of NaNO3

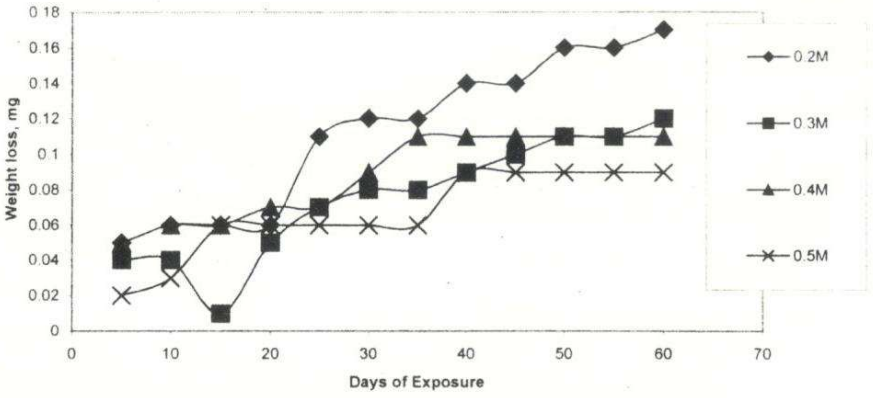

Figure 2. Weight loss with Days of Exposure of Samples in Ca(OH) Containing various concentrations of Na2 CO3

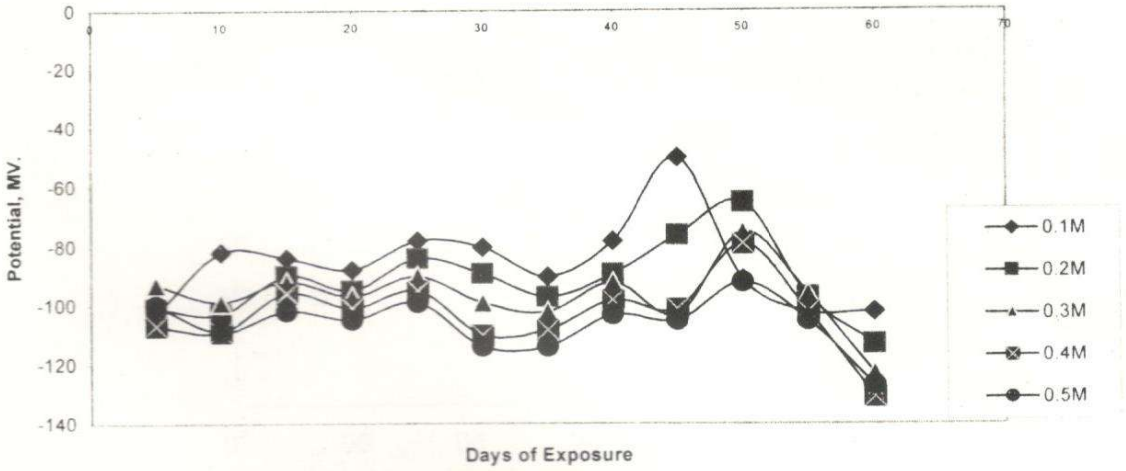

Figure 4. Potential Measuremnet for Samples Immersed in Ca(OH)2 containing Various Concentrations of Na2 CO3

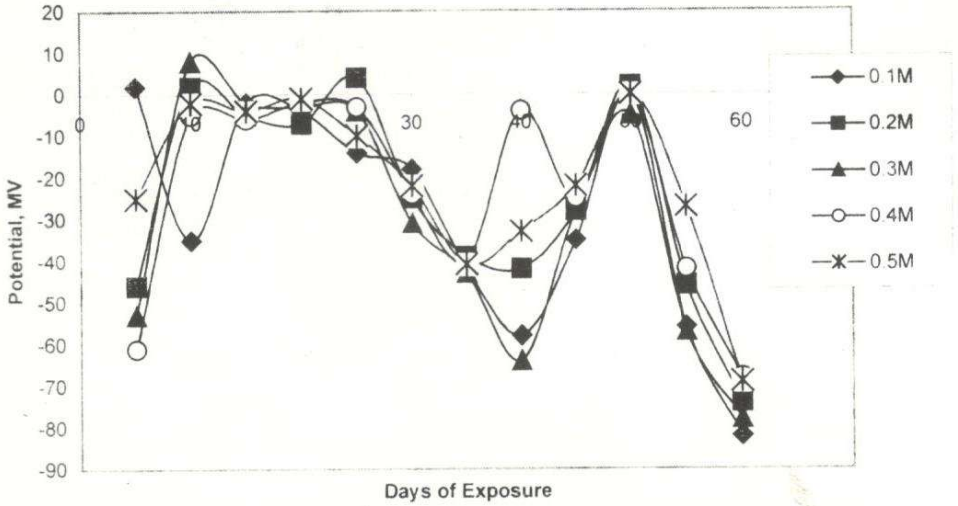

Figure 3. Potential Measurement for Samples in Ca(OH)2 Containing Various Concentrations of NaNO3.

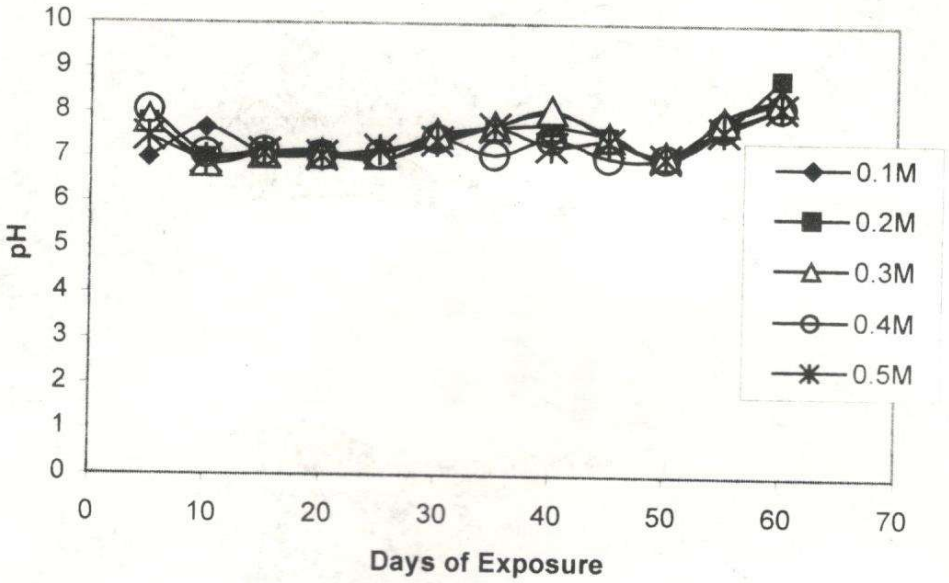

Figure 5. pH variation with Days of Exposure for Samples in Ca(OH)2 Containing Various Concentrations of NaNO3.

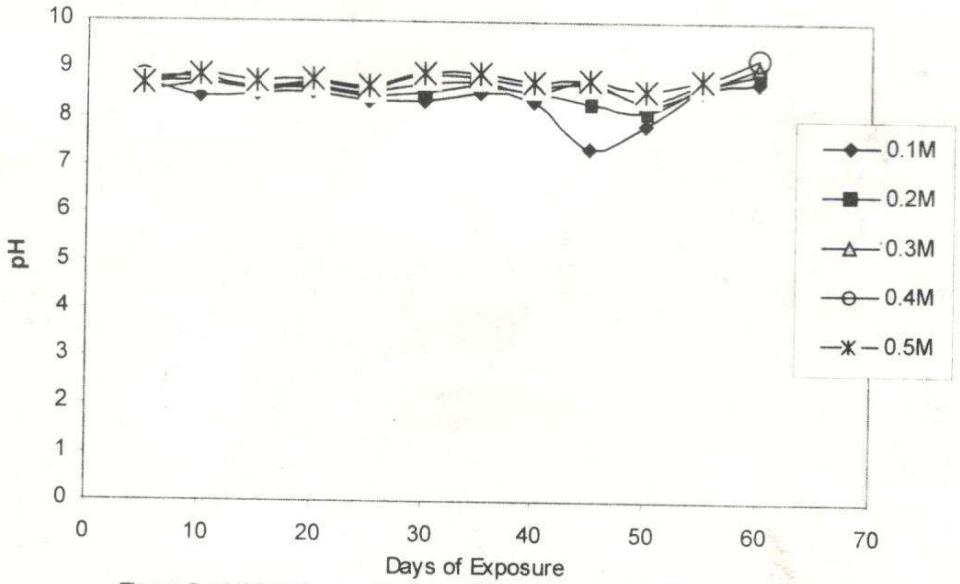

Figure 6. pH Variations with Days of Exposure of Samples in Ca(OH)2 Containing Various Concentrations of NaNO3