

Sami Masadeh

Al-Baha University, Faculty of Engineering, Mechanical Engineering Department, Al-Baha, Saudi Arabia, masadeh@bau.edu.jo

THE INFLUENCE OF ADDED INHIBITORS ON CORROSION OF STEEL IN CONCRETE EXPOSED TO CHLORIDE CONTAINING SOLUTIONS

ABSTRACT

Durability of concrete structures decrease due to corrosion in structures exposed to corrosive conditions. Several methods are adopted to minimize corrosion of steel in concrete; one of the methods is the use of inhibitors. In this work, the effect of inhibitor addition on corrosion of steel in concrete was investigated. Inhibitors added to concrete mix in different ratios, samples then immersed in 3.5% NaCl, and in Dead Sea Water for 15 months. Potential of steel reinforcement was measured by copper sulfate electrode according to ASTM C876. Results showed that an addition of 2% calcium nitrate or more was acceptable for adequate protection.

Keywords: *concrete, steel, inhibitors, Calcium nitrate*

INTRODUCTION

Concrete is the best building materials for all types of constructions. Steel reinforcement is used in combination with concrete to achieve high compressive and tensile strength. As corrosive species enters concrete and reaches concrete/steel interface, corrosion problems encounters yielding in deterioration of concrete due to higher volume of rust compared with parent metal. There are several methods used to minimize corrosion of steel in concrete, one of these is to use inhibitors. Among the available methods, the uses of corrosion inhibitors are cost-effective and easy to handle [1]. Inhibitors are added to fresh concrete while migrating inhibitors are usually proposed for concrete repair. Inhibitors, such as zinc oxide [2], molybdates and borates [3,4], carboxylate ions [5, 6], quaternary ammonium salts, and other organic compounds [7,8], were studied. Nitrite based inhibitors are considered as one of the most effective. Nitrite acts as a passivator due to its oxidizing properties, and its inhibitive effectiveness is related to the $[\text{NO}_2^-]/[\text{Cl}^-]$ molar ratio that should be higher than 0.8 to 1 to prevent corrosion [5,9]. Organic corrosion inhibitors act by adsorption on the metal surface forming an organic layer that may inhibit both the anodic and cathodic processes and they are considered as mixed inhibitors [10,11]. Amine and ester based admixed inhibitors have dual actions in concrete, as the amine compound acts as an inhibitor whereas the carboxylate ester compound acts as a pore-blocking agent which blocks the ingress of the chlorides ions [12–14]. Inhibitors in concrete are studied by many researchers to evaluate the effect of such admixtures in controlling corrosion of the reinforcement in concrete [15-18].

In this work the effect of added inhibitors on corrosion of the reinforcement is studied. Corrosion was determined with respect to steel potential.

EXPERIMENTAL

Twelve concrete samples with dimensions shown in Fig. 1 were made using ordinary Portland cement mixed with sand, and aggregates with mixing ratio 1:1.6:3 respectively, water-cement ratio was kept 0.55. Calcium nitrate was added to the mixing water at 1%, 2%, 3%, 4%, and 5% based on cement weight for 10 samples where two of the samples were cast with water containing no inhibitor. Dry materials were mixed thoroughly to obtain a uniform mixture into which water containing inhibitor was added. Prepared concrete mix was poured into molds containing steel rebar inserted in the center of the mold; the diameter of steel rebar used was 16 mm. After 48 hours, concrete samples were removed from molds and left in a curing room for 28 days, and then removed to tanks containing 3.5% NaCl solution, and in Dead Sea water. Dead Sea water containing 14.5% MgCl, 7.5% NaCl, 3.8% CaCl₂, 0.5% MgBr₂, 1.2% KCl. Potentials of the reinforcements were measured by copper sulfate electrode and according to ASTM C876. Potential monitoring was performed for 15 months for all samples.

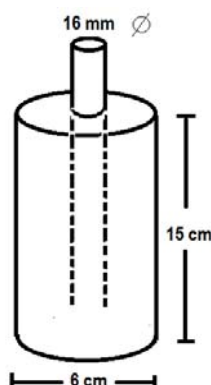


Fig. 1. Concrete specimen design

RESULTS AND DISCUSSION

The half-cell potential of steel reinforcement in concrete measured periodically according to copper-copper sulfate reference electrode and according to ASTM C876 is shown in Fig. (2-12). Fig. 2 and Fig. 3 show the potential of steel reinforcement recorded for 15 months while immersed in Dead Sea water and in 3.5% NaCl respectively, a comparison between these two potentials is shown in Fig. 4. It is noted that the potential of reinforcements in Dead Sea water is more negative than that in 3.5% NaCl solution, this is due to high chloride content and corrosivity of Dead Sea water. The effect of added inhibitors on potential of steel in concrete samples immersed in Dead Sea water is shown in Fig. 5. It is shown that the addition of 1%

inhibitor to concrete mix increased the potential of steel 100-150 mV but still the potential in active state, the addition of 1% was not enough to protect steel reinforcement against corrosive action of Dead Sea water. The addition of 2% of inhibitor or more kept steel reinforcement potential in a potential of acceptable range even after immersion in Dead Sea water for 15 months. Steel reinforcement having potentials greater than -200 mV (CSE) would have less than 10% probability of corrosion according to ASTM C876. So, an addition of 2% of calcium nitrate would be suitable for an acceptable decrease in corrosion probability.

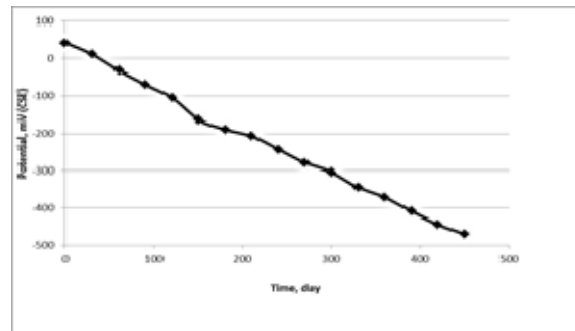


Fig. 2. Potential of steel reinforcement immersed in Dead Sea water with no inhibitor addition

Higher concentrations of calcium nitrate would give better performance of steel reinforcement in concrete subjected to Dead Sea water. 4% and 5% inhibitor kept potential values greater than -100 mV (CSE). The effect of inhibitor addition to concrete samples immersed in 3.5% NaCl solution was close to those immersed in Dead Sea water; the difference is that, potentials were greater in magnitude. See Fig. 6. 2% inhibitor addition or more (3%, 4%, and 5%) yielded in potentials greater than -200 mV (CSE), a noticeable increase in potential was observed for higher inhibitor addition, 4%, and 5%. These two inhibitor concentrations gave similar potentials for both immersion solutions. Recorded values were greater than -100 mV for both immersion solutions. A comparison between potential of steel with respect to inhibitor addition and immersion solution is shown in Fig. (7-12). In general, for all inhibitor additions, potential of steel reinforcement in samples immersed in Dead Sea water were less in value due to high corrosive ingredients in Dead Sea water compared to 3.5% NaCl.

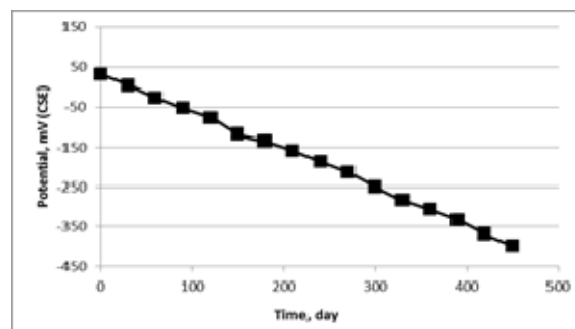


Fig. 3. Potential of steel reinforcement immersed in 3.5% NaCl solution with no inhibitor addition

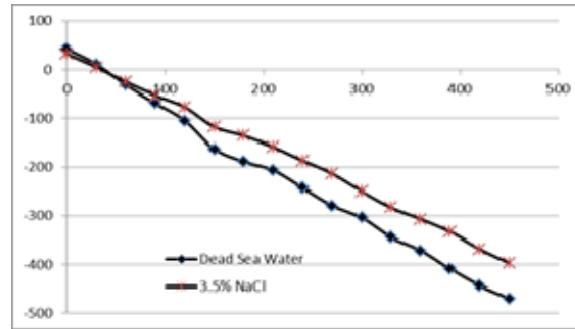


Fig. 4. Potentials of steel reinforcement immersed in 3.5% NaCl solution and Dead Sea water with no inhibitor addition

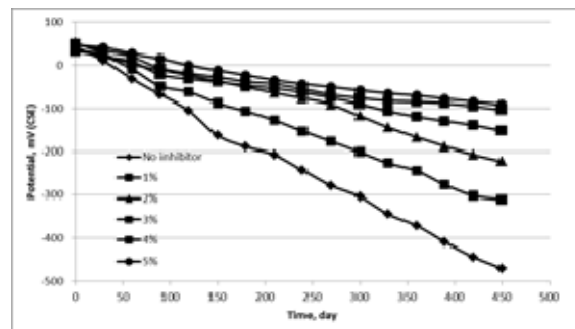


Fig. 5. Potentials of steel reinforcement immersed in Dead Sea water with different inhibitor additions

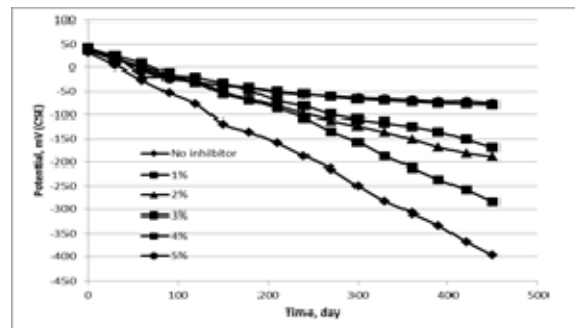


Fig. 6. Potentials of steel reinforcement immersed in 3.5% NaCl solution with different inhibitor additions

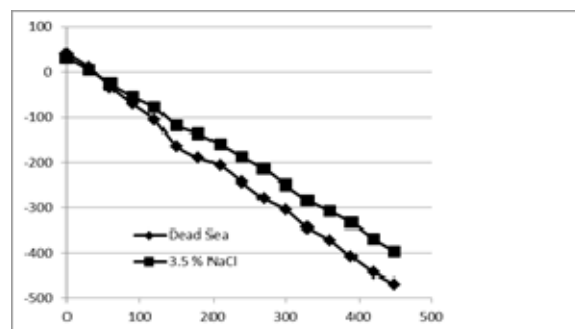


Fig. 7. Potentials of steel reinforcement immersed in 3.5% NaCl solution and Dead Sea water with 1% inhibitor addition

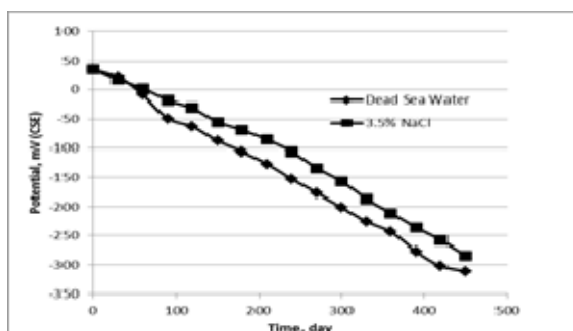


Fig. 8. Potentials of steel reinforcement immersed in 3.5% NaCl solution and Dead Sea water with 2% inhibitor addition

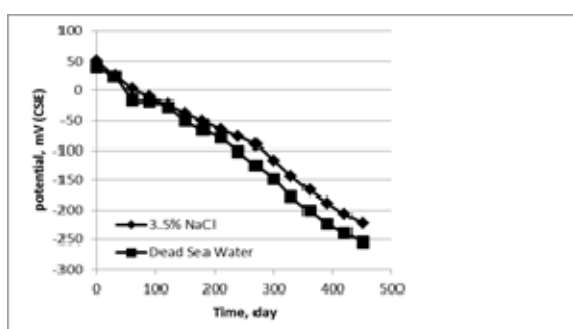


Fig. 9. Potentials of steel reinforcement immersed in 3.5% NaCl solution and Dead Sea water with 3% inhibitor addition

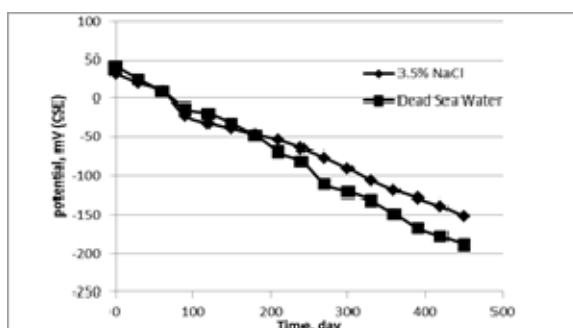


Fig. 10. Potentials of steel reinforcement immersed in 3.5% NaCl solution and Dead Sea water with 3% inhibitor addition

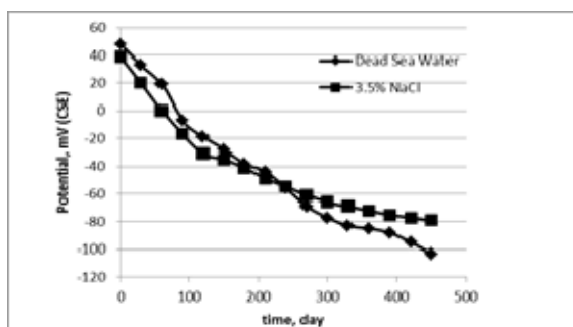


Fig. 11. Potentials of steel reinforcement immersed in 3.5% NaCl solution and Dead Sea water with 4% inhibitor addition

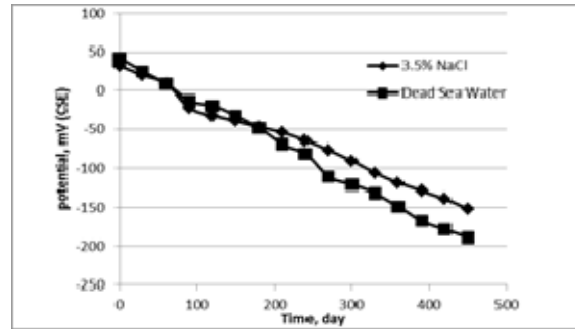


Fig. 12. Potentials of steel reinforcement immersed in 3.5% NaCl solution and Dead Sea water with 5% inhibitor addition

CONCLUSIONS

1. Potential of steel reinforcement immersed in Dead Sea water showed lower values compared to 3.5% NaCl.
2. Dead Sea water is more corrosive than 3.5% NaCl solution.
3. The addition of 1% calcium nitrate did not decrease the probability of steel reinforcement corrosion for both immersion environments.
4. Calcium nitrate concentrations of 2%-5% increased potentials above accepted values.
5. Inhibitor concentrations of 4% and 5% provided potentials greater than -100 mV (CSE).

REFERENCES

1. Elsener B.: Corrosion Inhibitors for Steel in Concrete - State of the Art Report. EFC Publications (2001).
2. Rincon de O. T., Perez O., E. Paredes, Caldera Y., Urdaneta C., Sandoval I.: Long-Term Performance of ZnO as a Rebar Corrosion Inhibitor. *Cem. Concr. Compos.* 24 (2002), 79–87.
3. Sagoe-Crentsil K. K., Yilmaz V. T., Glasser F. P.: Properties of Inorganic Corrosion Inhibiting Admixtures in Steel-Containing OPC Mortars: Chemical and Electrochemical Properties. *Adv. Cem. Res* 4 (1996), 91–102.
4. Gonzales J. A., Ramirez E., Bautista A.: Protection of Steel Embedded in Chloride -Containing Concrete by Means of Inhibitor. *Cem. Concr. Res.* 28 (1998), 577–589.
5. Sagoe-Crentsil K. K., Glasser F. P., Yilmaz V. T.: Corrosion Inhibitors for Mild Steel; Stannous Tin in Ordinary Portland Cement. *Cem. Concr. Res.* 24 (1994), 313–318.
6. Sagoe-Crentsil K. K., Yilmaz V. T., Glasser F. P.: Corrosion Inhibition of Steel in Concrete by Carboxylic Acids. *Cem. Concr. Res.* 23 (1993), 1380–1388.
7. Monticelli C., Frignani A., Trabanelli G.: A Study on Corrosion Inhibitors for Concrete Application. *Cem. Concr. Res.* 30 (2000), 635–642.

8. Saraswathy V., Muralidharan S., Kalyanasundaram R.M., Thangavel K., Srinivasan S.: Evaluation of a Composite Corrosion-Inhibiting Admixture and Its Performance in Concrete Under Macro Cell Corrosion Conditions. *Cem. Concr. Res.* 31 (2001), 789–794.
9. Ann K. Y., Song H. W.: Chloride Threshold Level for Corrosion of Steel in Concrete. *Corr. Sci.* 49 (2007), 4113–4133.
10. Bolzoni F., Fumagalli G., Lazzari L., Ormellese M., Pedferri M. P., Fontana F.: Inhibition Effect of Organic Molecules on Carbon Steel Corrosion in Alkaline Solution With Chlorides. *European Corrosion Congress Eurocorr*, Riva del Garda, Italy (2001).
11. Nmai C. K., Farrington S. A., Bobrowsky G. S.: Organic Based Corrosion Inhibiting Admixtures for Reinforced Concrete. *Concr. Int.* 14(4) (1992), 45–51.
12. Buffenbarger K., Miltenberger M. A., Miller B. D., Casal H. L.: Long-Term Performance of an Organic Corrosion Inhibiting: A Decade of Mechanism Study and Its Impact on Concrete Service Life. *International Congress on Advanced Materials, Their Processes and Applications*, Munich (2000).
13. Nmai C. K.: Multi-Functional Organic Corrosion Inhibitor. *Cem. Concr. Compos.* 26 (2004), 199–207.
14. Gaidis J. M.: Chemistry of Corrosion Inhibitors. *Cem. Concr. Compos.* 26 (2004), 181–189.
15. Saraswath, V., Ha-won Song.: Improving the durability of concrete by using inhibitors. *Building and Environment* 42 (2007), 464–472.
16. Zoltanetzky J.R., Gordon C., Parnes J.: New developments in corrosion inhibiting admixture systems for reinforced concrete. In: Page CL, Treadaway KWJ, Bamforth PB, editors. *Corrosion of reinforcement in concrete*. London: Elsevier (1990), 825–50.
17. Rozenfeld I.L.: *Corrosion inhibitors*. New York: McGraw-Hill Inc. (1981), 327.
18. Muller B., Fischer S.: Epoxy ester resins as corrosion inhibitors of aluminium and zinc pigments. *Corrosion Science* 48 (2006), 2406–2416.