

# Improving the Anti-Corrosion Properties of Portland Cement Concrete by using Inhibitors

Dr. Bui Quoc Binh<sup>1</sup>, Dr. Zhong Qingdong<sup>2</sup>

<sup>1</sup>Faculty of Civil Engineering - Vietnam Maritime University, SRV

<sup>2</sup>Electrochemical Laboratory, Department of Materials Engineering, SHU, Shanghai, China

**Abstract:- Corrosion of reinforcement steel bars (rebar) in concrete is one of the principal causes of untimely degradation of reinforced concrete structures, leading to structural failure. Various procedures are being used to enhance the anti-corrosion properties of reinforced concrete structures, which include surface coatings (both of concrete and rebar surface), cathodic protection, chloride eliminated and corrosion inhibitors.**

Among those procedures, the using of corrosion inhibitors is proved the effective manners to control corrosion of rebar. Some attempts have been carried out to investigate the performance of the vary kinds of inhibitors such as: anodic inhibitors, cathodic inhibitors and mixed inhibitors to control reinforcement steel bars corrosion. Compressive strength test and electrochemical test were conducted by series of inhibitors and varying the proportion of inhibitors. In portland cement concrete the additives not only increased or not effected in the compressive strength of the concrete samples but also enhanced the anti-corrosion properties.

This paper presents the results of experimental for 9 series of sample for exposure test (one series of pure concrete) into artificial seawater (ASW).

**Keywords:** Anti-corrosion, Portland cement concrete, Inhibitor.

## I. INTRODUCTION

A large in amount of reinforced concrete structures such as harbours, dry-docks, bridge beam and decks, piers, floating offshore platforms and marine facilities are generally exposed to chloride ions and other chemical substances those come from saltwater, salt spray in atmosphere. Reinforced concrete structures exposed to marine or river mouth environments are subjected to the actions of a number of physical, chemical and electrochemical degradation processes. In those conditions, the endurance performance of concrete structures has been causing great anxiety among researchers and designers around the world. Among several deterioration processes of reinforced concrete, the corrosion of steel rebar is of much greater significance. Embedded steel rebar in concrete gets corroded through two reactions which are environmentally concerned, such as carbonation of concrete and chloride diffusion in concrete. In the other way, attack on concrete due to any one of these causes having a tendency to increase the

permeability; not only would this make the material increasingly more susceptible to further action by the same devastating agent but also to other types of attack. Thus mazes of interlace chemical as well as physical causes of degradation are found at work when a concrete structure exposed to seawater is in an advanced stage of deterioration. The basic procedures that have so far been applied to prevent corrosion of reinforced concrete are as follows:

- enhancing the quality of concrete and increasing its cover thickness,
- covering the surface of concrete by protective coatings,
- adding corrosion inhibitors,
- using cathode protection of the surface and,
- protecting the steel reinforcement in concrete [1].

The addition of inhibitors in concrete is an alternative option for staving off the corrosion of steel in concrete in the chloride ions environment [2,3]. Corrosion inhibitors can be divided into three types: anodic, cathodic and mixed depending on whether they interfere with the corrosion preferentially at the anodic or cathodic sites or whether both are involved [4]. The use of corrosion inhibitors in concrete has been reviewed by Treadaway and Russel [5], Craig and Wood [6], Griffin [7],Slater [8] and most recently by Berke [9].

In this study, the present investigation anodic inhibitor, cathodic inhibitor and the combination of two inhibitors were evaluated for their anti-corrosion properties by taking in various electrochemical techniques.

## II. EXPERIMENTAL

### A. Material

All inhibitors powder was purchased from Shanghai st-nano science and technology, China. The HRB400 steel (ribbed bars, used as rebar in concrete structures) was purchased from Lianyungang Xingxin Iron and Steel Co., Ltd, China. Those chemical type of inhibitors which were used is shown in table 1. For making concrete samples, an ordinary portland cement (GB 175-2007) was used. That Conch Brand P.C 32.5 Portland cement was purchased from Shanghai Conch Cement Ltd.

No.	Chemical formula	Type of inhibitor		
		Anodic inhibitor	Cathodic inhibitor	Mixed inhibitor
1	NaNO <sub>2</sub>	✓		
2	Zn(H <sub>2</sub> PO <sub>4</sub> ) <sub>2</sub>			✓
3	Na <sub>2</sub> SiO <sub>3</sub> .9H <sub>2</sub> O			✓
4	Na <sub>2</sub> PO <sub>4</sub> .12H <sub>2</sub> O		✓	
5	ZnSO <sub>4</sub> .7H <sub>2</sub> O		✓	
6	Na <sub>2</sub> MO <sub>4</sub> .2H <sub>2</sub> O	✓		
7	ZnO		✓	
8	Na <sub>2</sub> WO <sub>4</sub> .2H <sub>2</sub> O	✓		

Table 1. Inhibitors used

According to the Lyman and Fleming formula for preparation of artificial seawater [10], the artificial seawater with salinity 3.50% was prepared. This solution was used for corrosive media to exposure samples.

The chemical composition of ASW is shown in table 2. All of chemical elements of ASW solution were AR types and were purchased from Sinopharm Chemical Reagent Co. Ltd. The corrosive solution was synthesized in large glass cups by magnetic stirrer.

Element	Content (g/ kG of solution)
NaCl	23.926
Na <sub>2</sub> SO <sub>4</sub>	4.008
KCl	0.677
NaHCO <sub>3</sub>	0.196
KBr	0.098
H <sub>3</sub> BO <sub>3</sub>	0.026
NaF	0.003
MaCl <sub>2</sub> .6H <sub>2</sub> O	10.831
CaCl <sub>2</sub> .2H <sub>2</sub> O	1.519
SrCl <sub>2</sub> .6H <sub>2</sub> O	0.024
Distilled water	bal.

Table 2. Formula for 1 kG of ASW with salinity 3.50%

**B. Concrete mixture**

In this work, concrete were mixed from natural coarse aggregate and fine aggregate. A coarse aggregate was stone with average diameter of 16 mm. A fine aggregate was dark yellow river sand. All aggregates were purchased from Hosen Building Materials Store, Haiphong, SRV.

A concrete mixture with those aggregate and slump 100-140 mm was used. The 28-days compressive strength of this normal concrete, as measured on 150 mm cubes, was 30 MPa, respectively. The mixture proportions are shown in Table 3, it conforms to JGJ55-2000.

Materials	Mix proportions (kG/m <sup>3</sup> )
Water	185
Cement	429
Sand	536
Stone	1.250

Table 3. The mixture proportions for concrete (water/cement = 0.43)

**C. Samples preparation**

Electrodes: a copper wire was electrically connected to one surface of each 10mmx10mmx0.5mm HRB400 steel piece, and then this surface and all the other surfaces except the one exposed to corrosive solution for corrosion testing were sealed with a thick bulk E44 epoxy resin wrapped by PVC tube. After epoxy curing in laboratory condition, the unsealed coupon surface was burnished on silicon carbide (SiC) papers down to a grid size of 400. Then, the electrode surface was rinsed with tap water, dried in air-flow of air-compressor machine (Fig.1).

After having prepared, all electrodes were cured in ambient condition at 18 h before being placed on concrete samples (Fig. 2). In this present study, 9 series of concrete samples were prepared. A table 4 gives the inhibitors proportion in detailed.

After 28 days of moist-curing for concrete sample, beside taking compressive strength test for 150mm cubic samples, all other concrete samples being exposed in artificial sea water (ASW) solution. Concrete samples were casted in formwork. After casting 36 h, the sample was detached out of formwork and moist-curing for next 26.5 days. Then, the sample was fully immersed into ASW for 60days. This condition was subjected to precast concrete structure in submerged zone (Fig. 4).

All procedures were carried out in room condition with temperature T=25±2<sup>0</sup>C, relative humidity RH=55 ± 5%.

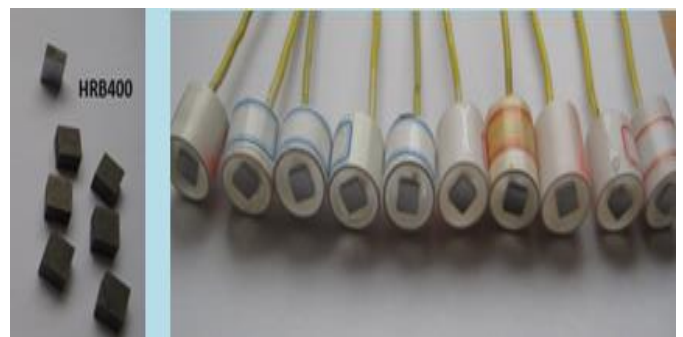


Fig 1:- HRB400 steel pieces and Electrodes

No	Denote samples	Inhibitor proportion
1	BC	Blank sample
2	IH1	$\text{Na}_2\text{SiO}_3 \cdot 9\text{H}_2\text{O} \sim 9.2\text{g/L}$
3	IH2	$\text{Zn}(\text{H}_2\text{PO}_4)_2 \sim 9.2\text{g/L}$
4	IH3	$\text{Na}_2\text{PO}_4 \cdot 12\text{H}_2\text{O} \sim 9.2\text{g/L}$
5	MIH1	$\text{NaNO}_2 \sim 4.6\text{g/L}$ & $\text{ZnO} \sim 4.6\text{g/L}$
6	MIH2	$\text{Na}_2\text{WO}_4 \cdot 2\text{H}_2\text{O} \sim 4.6\text{g/L}$ & $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O} \sim 4.6\text{g/L}$
7	MIH3	$\text{Na}_2\text{MO}_4 \cdot 2\text{H}_2\text{O} \sim 4.6\text{g/L}$ & $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O} \sim 4.6\text{g/L}$
8	MIH4	$\text{Na}_2\text{WO}_4 \cdot 2\text{H}_2\text{O} \sim 4.6\text{g/L}$ & $\text{ZnO} \sim 4.6\text{g/L}$
9	MIH5	$\text{Na}_2\text{MO}_4 \cdot 2\text{H}_2\text{O} \sim 4.6\text{g/L}$ & $\text{ZnO} \sim 4.6\text{g/L}$

Table 4. The inhibitor proportions for concrete samples



Fig 2:- Schematic of the structure of concrete sample

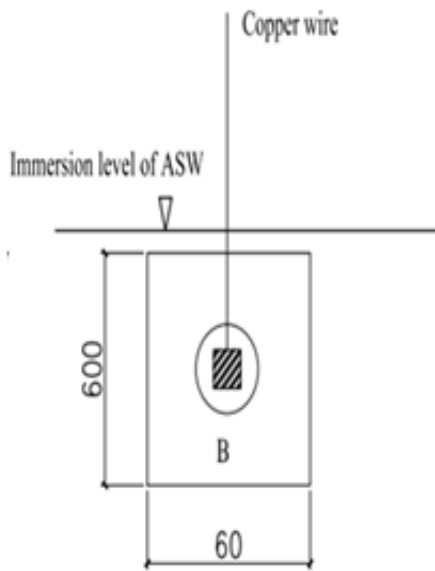


Fig 3:- Concrete samples

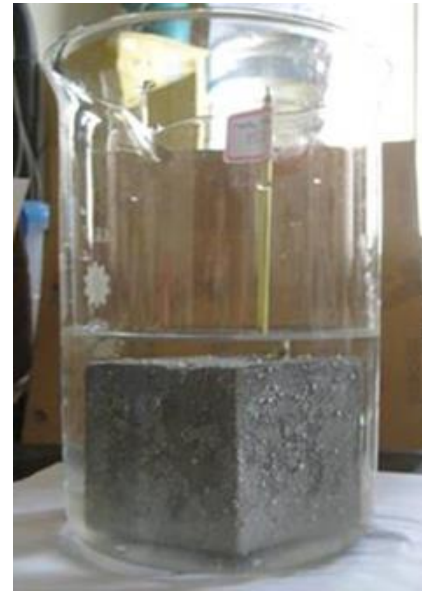


Fig 4:- Samples were exposed in artificial sea water (ASW)

### III. RESULTS AND DISCUSSION

#### A. Compressive strength test

After 28 days of moist-curing, the resistance of a concrete sample to breaking under compression was taken by MTU -100 testing machine. Table 5 shows the average compressive strength results of different inhibitor added concrete.

No.	Samples	Average compressive strength (kG/cm <sup>2</sup> )
1	BC	315
2	IH1	312
3	IH2	322
4	IH3	326
5	MIH1	7.2 (broken after having load)
6	MIH2	318
7	MIH3	319
8	MIH4	306
9	MIH5	309

Table 5. The inhibitor proportions for concrete samples

From table 5 it is observed that mixing of  $\text{NaNO}_2$  and  $\text{ZnO}$  (MIH1) is not suitable for inhibitor of cement concrete. Electrochemical measurements were not conducted for this sample series. The other samples proved that inhibitor additions were not effected to compressive strength of concrete samples. Indeed, sulfate and phosphate inhibitors could increase compressive strength of concrete samples slightly.

#### B. Evaluations of corrosion of rebars in concrete

In this study, corrosion behavior of 8 series of samples

(BC, IH1-3, MIH2-5) was investigated by means of AC impedance method. The impedance modulus at the low frequency ( $|Z|_{0.01\text{Hz}}$  - getting from Bode plots by CHI660C Electrochemical Workstation - Fig.5) is used as an useful parameter to characterize the anti-corrosion properties. The results were shown in table 5.

From table 5 it is observed that based on impedance value in comparison with blank sample BC, IH1, IH3, MIH4 and MIH5 had no effective inhibition. But mixed inhibitors such as IH2 and MIH3 had tremendous in inhibition of anticorrosion. A mixing of both cathodic and anodic inhibitor such as MIH3 gained biggest impedance.

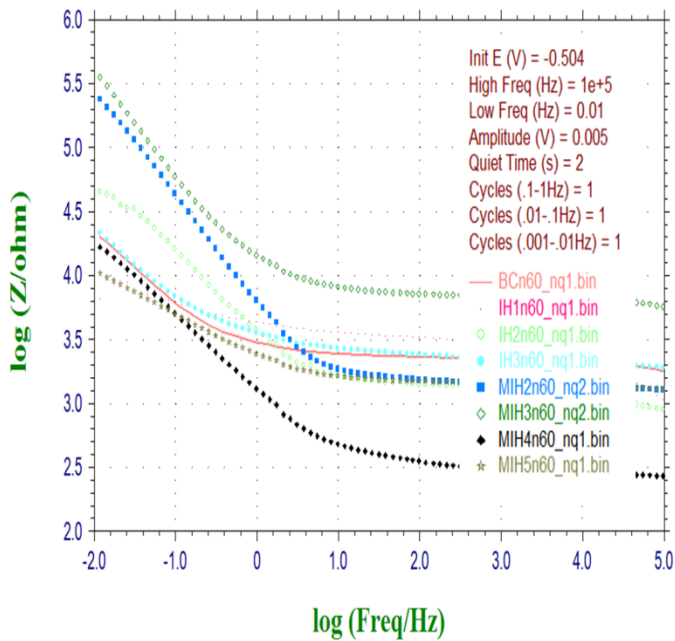


Fig 5:- Bode plots at 60 days exposure in ASW of 8 samples

No.	Samples	$ Z $ at 0.01Hz (Ohm)
1	BC	2.05E+4
2	IH1	9.279E+3
3	IH2	8.964E+4
4	IH3	2.162E+4
5	MIH2	2.388E+5
6	MIH3	3.571E+5
7	MIH4	1.695E+4
8	MIH5	1.039E+4

Table 5. The impedance modulus at the low frequency ( $|Z|_{0.01\text{Hz}}$ )

#### IV. CONCLUSION

Based on the above results, some following conclusions can be drawn:

Compressive strength measurements revealed that, the  $\text{NaNO}_2$  and  $\text{ZnO}$  inhibitor can effect compressive strength of

concrete, not suitable for inhibition corrosion of cement concrete. Compressive strength of concrete sample was not affected by the other addition of inhibitors.

In this study, excepted  $\text{NaNO}_2$  and  $\text{ZnO}$  inhibitor, the others proved that which are suitable for anticorrosion additives of cement concrete.

#### REFERENCES

- [1]. Quocbinh Bui, Qingdong Zhong, International Journal of Technical Research and Applications e-ISSN: 2320-8163, Vol.4, Issue 3 (May-June, 2016), pp. 371-377.
- [2]. Roseberg A.M., Gaidis J.M., Materials Performance, Vol.18, Nov. 1979, pp. 45-48.
- [3]. Gaidis, J.M., Chemistry of corrosion inhibitors. Cement and Concrete Composites, Vol. 26, 2004, pp.181–189.
- [4]. Ramachandran V.S., Concrete Admixtures Hand book: Properties, Science and Technology. Park Ridge, NJ, USA: Noyes Publications, 1984, pp. 540–545.
- [5]. Treadaway K.W.J., Russel A.D., Inhibition of the corrosion of steel in concrete. Highways Public Works, Vol.36, Aug. 1969, pp.40–41.
- [6]. Craig R.J., Wood L.E., Effectiveness of Corrosion Inhibitors and Their Influence on the Physical Properties of Portland Cement Mortars. Transportation Research record, No. 328, 1970, pp. 77–80.
- [7]. Griffin D.F., Corrosion Inhibitors for Reinforced Concret. ACI SP-49, American Concrete Institute, Detroit, 1975, pp. 95–102.
- [8]. Slater J.E., Corrosion of Metals in Association with Concrete ASTM STP-818, American Society for Testing and materials, Philadelphia, 1983. pp. 53.
- [9]. Berke N.S., Corrosion Inhibitors in Concrete, Paper No.445, Corrosion 89, National Association of Corrosion Engineers, Houston, 1989.
- [10]. Culkin F., The Major Constituents, Chapter 4, Chemical Oceanography, Vol. 1, 1st Ed., J. P. Riley and G. Skirrow, Academic Press, New York, 1965, pp.121-161.