

CORROSION PROTECTION EVALUATION OF REBARS AND REINFORCED CONCRETE COATED WITH EPOXY-ORGANO-BENTONITE NANOCOMPOSITES ADDED ZnO-ZrO₂ /Al₂O₃-ZrO₂ NANOPARTICLES IN SEAWATER

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Abstract— Corrosion of steel rebars in reinforced concrete constructions in marine environments is one of the major problems baffling the construction industry. To synthesis a suitable protective coating to rebars is necessary duty. In this study, two kinds of novel epoxy-based organobentonite nanocomposites with low-loading of ZnO-ZrO₂/ZnO-Al₂O₃ nanoparticles were prepared for protective coating on the surface of reinforced concrete and protective coating on the rebars embedded in concrete in 8 series of sample for exposure test into artificial seawater (ASW). In the same conditions, three series of bare rebars embedded in concrete were tested for comparison. After 112 days exposure to ASW, those two kinds of nanocomposites have proved performance well as good and durable coatings.

Index terms- Rebar, Epoxy-organobentonite composite coating, ZnO, ZrO₂, Al₂O₃ nanoparticles, Concrete, Corrosion protection, Artificial seawater.

I. INTRODUCTION

A large number of reinforced concrete structures such as harbors, docks, bridge decks, piers, floating offshore platforms and marine facilities are generally subjected to chloride ions and other chemical matters those come from seawater, salt spray in atmosphere. Reinforced concrete structures exposed to marine environments are subjected to the actions of a number of physical, chemical and electrochemical deterioration processes [1-3]. In those conditions, the durability performance of concrete structures has been causing great concern among researchers and designers all over the world. Among several degradation processes of reinforced concrete, the corrosion of steel reinforcements is of much greater importance. Embedded steel in concrete gets corroded through two reactions which are environmentally related, such as carbonation of concrete and chloride diffusion in concrete [4]. In the other way, attack on concrete due to any one of these causes tends to increase the

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

- ♦ improving the quality of concrete [5] and increasing its cover thickness,
- ♦ providing a protective coating on the surface of concrete [6],
- ♦ using corrosion inhibitors [7],
- ♦ implementing cathode protection of the surface [8] and,
- ♦ protecting the steel reinforcement in concrete [9].

For purpose of protective coating on the surface of concrete and protecting the steel reinforcement in concrete, organic coatings are generally adopted in most part of the world owing to their simplicity in application, flexibility, toughness, adhesion, chemical resistance and their durability. A stable organic coating serves as a barrier for isolating steel from moisture, chlorides and oxygen. Among different organic coatings such as coal tar epoxy, asphalt, chlorinated rubber, vinyl and epoxy coatings, the protection of rebar by epoxy coatings is the most prevalent [10,11].

In this study, two kind of epoxy-based organobentonite nanocomposites with low-loading of ZnO-ZrO₂/ZnO-Al₂O₃ nanoparticles were prepared for protective coating on the surface of reinforced concrete and protective coating on the rebar embedded in concrete in two systems of sample for exposure test. One system was exposed in condition which was the same as concrete structures in tide zone (type A); one system was exposed in condition which was the same as concrete structures in submerged zone (type B). In the same conditions, two systems of bare rebar embedded in concrete

were tested for comparison. All systems of sample have been examined for their corrosion protection effectiveness.

II. EXPERIMENTAL

A. Materials

This research used low-cost epoxy “GCC135” - a low viscosity liquid epoxy resin. The GCC135 is a bisphenol A type epoxy resin, ethylene glycol diglycidyl ether. Appearance of GCC135 epoxy resin: transparent liquid, no mechanical impurities; epoxy value: 0.54-0.6 (eq/100 g); viscosity: 700-1100 (mPas); density: 1.13 - 1.17 (g/cm³). The W93 type used as hardener - a low viscosity liquid hardener. The W93 is a modified isophorone amine; appearance of W93: colorless to pale yellow liquid; amine value (KOH/g): 550-600 mg; viscosity: 10-100 (mPas); epoxy resin and hardener will be purchased from G.C.Chem Co. Kunshan, China.

The TIXOGEL MP100 organobentonite (OB) was purchased from Shunde District of Foshan City, Qinghong Trade Co. Ltd. Performance of TIXOGEL MP100: density: about 1.4 g/cm³; bulk density: 370-510 g/l; moisture content: ≤ 3%; 90 microns sieve residue: < 15%; full basic state: 1-5 μm; thickness of organobentonite plate about 1.4 mm;

Nanosized ZnO/Al₂O₃ powder was purchased from Shanghai st-nano science and technology, China, with an average particle size of 20–60 nm. Nanosized ZrO₂ powder was purchased from Guangdong chemical raw materials Co. Ltd, China, with an average particle size of 30-50 nm. Metal oxides particle surfaces were modified by silane coupling agent, 3-aminopropyltriethoxy silane (KH550). The HRB400 steel (ribbed bars, used as rebars in concrete structures) was purchased from Lianyungang Xingxin Iron and Steel Co., Ltd, China. The chemical composition of HRB400 steel 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.

Table 1. Chemical composition of HRB400 steel (wt.%)

Element	C	Si	Mn	P	S	Ceq	Fe
Content	0.25	0.80	1.60	0.045	0.045	0.54	bal.

B. Composition epoxy-organobentonite nanocomposites added ZnO-ZrO₂/Al₂O₃ -ZrO₂ nanoparticles

In the present study, two different kinds of epoxy-organobentonite nanocomposites added metal oxides were prepared. The mixture proportions are shown in Table 2. The loading of every element was considered in “phr” - parts per hundred of total epoxy resin and hardener, the proportion of epoxy/hardener was 10/3 in weight.

Table 2. Compositions of epoxy based composites were synthesized in this study

Sample	Organobentonite concentration (phr)	ZrO ₂ nanoparticles concentration (phr)	ZnO nanoparticles concentration (phr)	Al ₂ O ₃ nanoparticles concentration (phr)
EBO1	1.5	0.75	0.75	-
EBO2	1.5	0.75	-	0.75

C. Concrete mixture

A concrete mixture with a maximum aggregate size of 16mm 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.

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

Materials	Mix proportions (kg/m ³)
Water	185
Cement	429
Sand	536
Stone	1250

D. Electrodes preparation

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 electrolyte for corrosion testing were sealed with a thick bulk E44 epoxy resin wrapped by PVC tube. After epoxy curing, the unsealed coupon surface was polished on silicon carbide (SiC) papers down to a grid size of 400. Then, the sample surface was rinsed with tap water, dried in air-flow of air-compressor machine.

E. Samples preparation

In this present study, 11 series of concrete samples were prepared. A table 4 gives the coating systems and exposure condition for all 11 series of samples was used in detailed. After the novel materials were obtained, the composite coatings were applied by wire-beam film applicator on steel electrodes. Dry film thicknesses of the coatings were about 55±2 μm (Those typical films were detached from substrate and measured by QF dual-plate thickness testing instrument). All samples were cured in ambient condition at 18 h before being placed on concrete samples (SEBO series). A three series of concrete samples with bare HRB400 steel were prepared too for making comparison (BHA and BHB series). For preparation of CEBO series, firstly, a series of concrete samples with bare HRB400 steel electrode inside were casted. After 28 days of moist-curing, all 6 surfaces of concrete blocks were polished by silicon carbide (SiC) papers down to a grid size of 240, cleaned in air-flow of air-compressor machine. Then, 5 surfaces of concrete blocks were painted 2 layers of E44 epoxy resin by brush, 2 layers of yellow color paint by paint spray gun. The total thickness of E44 epoxy resin layers is about 2 mm; total thickness of paint layers is about 0.3 mm. Finally, the EBO composite coatings were applied by wire-beam film applicator on last surface of concrete samples, dry film thicknesses of the EBO coatings were about 55±2 μm too. All CEBO samples were cured in ambient condition at 18 h before being exposed in ASW solution. The structure of concrete sample was shown in Fig.1.

Table 4. Nomenclature for samples systems

Denote	Preparation	Exposure condition
BHA1	Concrete sample with bare HRB400 steel electrode inside – type A	A1
BHA2	Concrete sample with bare HRB400 steel electrode inside – type A	A2
BHB	Concrete sample with bare HRB400 steel electrode inside – type B	B
SEBO1A	Concrete sample with EBO1 coating on HRB400 steel electrode inside – type A	A1
SEBO1B	Concrete sample with EBO1 coating on HRB400 steel electrode inside – type B	B
SEBO2A	Concrete sample with EBO2 coating on HRB400 steel electrode inside – type A	A1
SEBO2B	Concrete sample with EBO2 coating on HRB400 steel electrode inside – type B	B
CEBO1A	Bare HRB400 steel electrode was placed inside concrete sample which was covered by EBO1 – type A	A2
CEBO1B	Bare HRB400 steel electrode was placed inside concrete sample which was covered by EBO1 – type B	B
CEBO2A	Bare HRB400 steel electrode was placed inside concrete sample which was covered by EBO2 – type A	A2
CEBO2B	Bare HRB400 steel electrode was placed inside concrete sample which was covered by EBO2 – type B	B

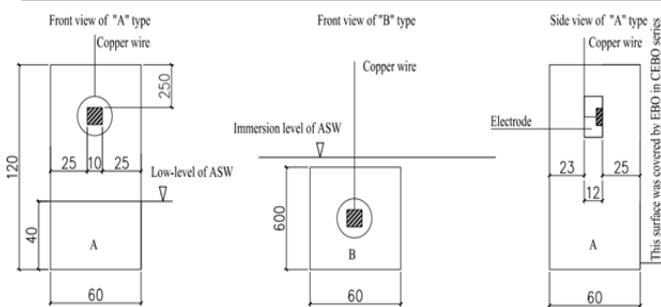


Figure 1. Schematic of the structure of concrete sample

F. Synthesis of artificial sea water

According to the Lyman and Fleming formula for artificial seawater [12], the artificial seawater with salinity 3.50% is prepared. This solution was used for corrosive media to exposure samples.

G. Exposure condition

The tidal zone and submerged zone of marine concrete structures were subjected to frequent application of corrosion-inducing solution which was simulated in the laboratory. The working and casting situations of reinforcement concrete structures in marine environment were simulated by 3 procedures which are listed under here in detailed.

A1 exposure condition: concrete samples were casted in formwork. After casting 6 h, sample was immersed in glass cup at low-level of ASW (Fig1-Fig.3), at the same time, ASW solution was dropped by dropping funnel to sample's surface. After next 6 h, sample was fully immersed in ASW and holding in this condition for next 12 h. Then, exposure cycle was started. In exposure cycle, the sample was immersed in glass cup at low-level of ASW in 9 h, followed by 3 h of ASW solution dropping, finally, the sample was fully immersed into ASW for next 12 h. All samples were detached out of

formwork after 36 h of casting. This condition was subjected to cast-in-situ concrete structure in tidal zone.

A2 exposure condition: 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, exposure cycle was started. In exposure cycle, the sample was immersed in glass cup at low-level of ASW in 9 h, followed by 3 h of ASW solution dropping, finally, the sample was fully immersed into ASW for next 12 h. This condition was subjected to precast concrete structure in tidal zone.

B exposure condition: 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. This condition was subjected to precast concrete structure in submerged zone.

All procedures were carried out in room condition with temperature $T=25 \pm 2^{\circ}\text{C}$, relative humidity $\text{RH}=55 \pm 5\%$.

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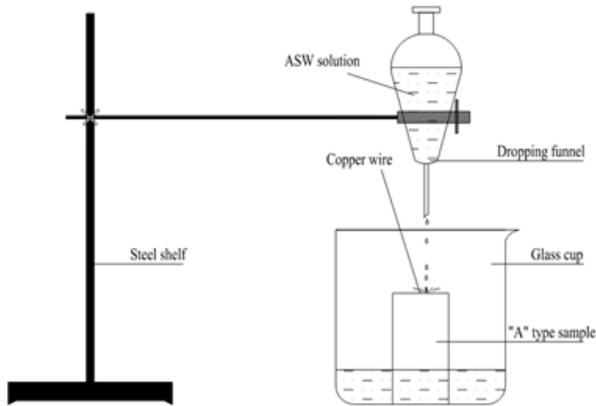


Figure 2. Modeling samples in tidal zone by ASW dropping funnel

J. Evaluations of corrosion of rebars in concrete

Electrochemical measurements were conducted using a three-electrode system. The epoxy-coated steel samples served as the working electrode, while the counter electrode and the reference electrode used were a platinum grid and a saturated calomel electrode (SCE) respectively. The coatings evaluated in the electrochemical measurements had similar thickness as those used in the morphological study since they were prepared following the same procedures. The corrosive solutions tested were artificial seawater (ASW). Two methods were used to test the anticorrosive performance of these nanocomposite coatings: electrochemical impedance spectroscopy (EIS) and potentiodynamic weak polarization (Tafel plots). From 56 days up to 112 days exposing of the samples in ASW, the EIS measurements were carried out periodically using a CHI660C electrochemical workstation. The steel was polarized at ± 10 mV around its open circuit potential (OCP) by an alternating current (AC) signal with its frequency ranging from 10 kHz to 10 mHz (12 points per decade). The polarization scans were conducted at 10 mV/s, and the scan range generally started at nearly -250 mV cathodic of the open circuit potential and terminated at nearly 250 mV noble of the open circuit potential. Corrosion current (I_{corr}), corrosion rate (CR) and corrosion potential (E_{corr}) were calculated automatically by CHI ver. 8.03 software.



Figure 3. Samples were exposed in ASW (digital images were taken by Canon IXUS 75)

III. RESULTS AND DISCUSSION

The electrochemical impedance spectroscopy has been widely employed as a method for the interpretation of the electrode

reaction, the estimation of the corrosion-resisting property of metals, and the monitoring of corrosion. Recently it is used to investigate anticorrosive properties of the coated metal. Among various methods for evaluation of anticorrosive properties of the coated metal, this method is known to give most quantitative information on anticorrosive properties of the coated metal. Moreover it can provide comprehensive information on the reaction taking place on the film metal interface [13].

In this study, corrosion behavior of 11 series of samples was investigated by means of AC impedance method. The HRB400 steel electrodes were covered by concrete layer (BHA1, BHA2 samples) or both concrete layer and EBO epoxy-based organobentonite nanocomposite coating (SEBO and CEBO samples). According to the literature [13~15], the impedance modulus at 0.01 Hz ($|Z|_{0.01\text{Hz}}$) is an appropriate parameter for characterization of the protective properties of the coatings. EIS plots for all samples are presented in the Bode plot format as a function of exposure time. The impedance modulus at the low frequency ($|Z|_{0.01\text{Hz}}$) is used as an useful parameter to characterize the corrosion protection of coatings [13, 15]. In this work, the long-term anticorrosion behaviour of coatings on HRB400 rebar was focused on, therefore, electrochemical analyses was carried out after 56 days of exposure in ASW. The Bode impedance plots obtained for SEBO and CEBO samples during exposure in ASW are shown in Fig. 4 and Fig. 5. The Bode impedance plots obtained for BHA and BHB sample are shown in Fig. 6.

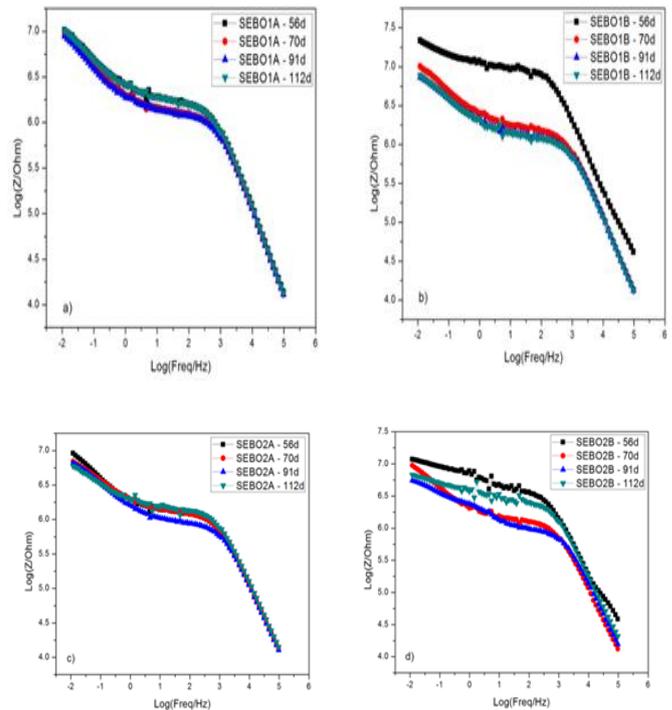


Figure 4. Bode plots at different exposure time in ASW for SEBO samples: a) SEBO1A sample, b) SEBO1B sample, c) SEBO2A sample and d) SEBO2B sample

As were shown in Fig. 4, the $|Z|_{0.01\text{Hz}}$ for SEBO1A sample was $1.023 \times 10^7 \Omega\text{cm}^2$ after 56 days of exposure, then decreased gradually to $9.268 \times 10^6 \Omega\text{cm}^2$ at 70 days, to $8.895 \times 10^6 \Omega\text{cm}^2$ at 91 days and regained to $1.019 \times 10^7 \Omega\text{cm}^2$ at the end of 112

days. The $|Z|_{0.01\text{Hz}}$ for SEBO1B sample was $2.161 \times 10^7 \Omega\text{cm}^2$ after 56 days of exposure, then decreased rapidly to $1.008 \times 10^7 \Omega\text{cm}^2$ at 70 days, to $7.401 \times 10^6 \Omega\text{cm}^2$ at 91 days and regained to $7.643 \times 10^6 \Omega\text{cm}^2$ at the end of 112 days. The $|Z|_{0.01\text{Hz}}$ for SEBO2A sample was $9.1 \times 10^6 \Omega\text{cm}^2$ after 56 days of exposure, then decreased gradually to $6.9 \times 10^6 \Omega\text{cm}^2$ at 70 days, to $6.579 \times 10^6 \Omega\text{cm}^2$ at 91 days and still maintaining to $5.907 \times 10^6 \Omega\text{cm}^2$ at the end of 112 days. The $|Z|_{0.01\text{Hz}}$ for SEBO2B sample was $1.175 \times 10^7 \Omega\text{cm}^2$ after 56 days of exposure, then decreased gradually to $9.456 \times 10^6 \Omega\text{cm}^2$ at 70 days, to $5.519 \times 10^6 \Omega\text{cm}^2$ at 91 days and still maintaining to $6.76 \times 10^6 \Omega\text{cm}^2$ at the end of 112 days.

$5.646 \times 10^7 \Omega\text{cm}^2$ at 91 days and still maintaining to $1.505 \times 10^7 \Omega\text{cm}^2$ at the end of 112 days. The $|Z|_{0.01\text{Hz}}$ for CEBO2A sample was $1.525 \times 10^7 \Omega\text{cm}^2$ after 56 days of exposure, then decreased gradually to $9.283 \times 10^6 \Omega\text{cm}^2$ at 70 days, to $6.904 \times 10^6 \Omega\text{cm}^2$ at 91 days and still maintaining to $6.533 \times 10^6 \Omega\text{cm}^2$ at the end of 112 days. The $|Z|_{0.01\text{Hz}}$ for CEBO2B sample was $1.446 \times 10^7 \Omega\text{cm}^2$ after 56 days of exposure, then decreased gradually to $9.642 \times 10^6 \Omega\text{cm}^2$ at 70 days, to $8.718 \times 10^6 \Omega\text{cm}^2$ at 91 days and still maintaining to $6.014 \times 10^6 \Omega\text{cm}^2$ at the end of 112 days.

For SEBO series, in initial period of testing, the rebars with coatings of SEBO1A and SEBO2A samples were placed in wet concrete and exposed in ASW after 6 h of casting. The coatings were affected by the processing of compacting concrete samples, chemical matter in concrete, other small molecules, ions... in corrosive solution. With B exposure condition, the coatings of rebars in SEBO1B and SEBO2B were affected by the processing of compacting concrete samples, chemical matter in concrete only. The exposure process was carried out after concrete samples having full designed compressive strength and after 56 days of exposure, the $|Z|_{0.01\text{Hz}}$ for SEBO type B bigger than the $|Z|_{0.01\text{Hz}}$ for SEBO type A. When exposure time increased, those decreases of the $|Z|_{0.01\text{Hz}}$ resulted from penetration of small molecules (water and oxygen), corrosive ions in solution. In the same condition of exposure, the final results of study on long-term anticorrosion behaviour have proved that SEBO1 samples had much better barrier property to corrosive ions than SEBO2 samples. On the other way, the EBO1 coating showed better anticorrosion performance than the EBO2 coating. But beside that, both types had indicated efficient protection of coatings.

For CEBO series, there was a little of difference between CEBO type A and type B. After 112 days of exposure in ASW, the $|Z|_{0.01\text{Hz}}$ for both CEBO1A and CEBO1B around $1.5 \times 10^7 \Omega\text{cm}^2$, it once again revealed that EBO1 has good anti-corrosion properties. The $|Z|_{0.01\text{Hz}}$ for both CEBO2A and CEBO2B around $6 \times 10^6 \Omega\text{cm}^2$ at 112 days of exposure, it revealed that EBO2 has acceptable anti-corrosion properties. It also means that when EBO epoxy-based organobentonite nanocomposites added fillers were used as coatings on concrete samples, the difference of impedance with time for exposed in A2 condition and B condition (tide and submerged zone) in long-term is not much. Because the CEBO series were coated after having full designed compressive strength in room condition so the $|Z|_{0.01\text{Hz}}$ for CEBO samples maintained high values after till 56 days of exposure.

As were shown in Fig. 6, the $|Z|_{0.01\text{Hz}}$ for BHA1 sample was $9.292 \times 10^3 \Omega\text{cm}^2$ at 112 days, for BHA2 sample was $2.11 \times 10^4 \Omega\text{cm}^2$ and for BHB sample was $6.604 \times 10^3 \Omega\text{cm}^2$ at 112 days. Those results proved that with 2.5 cm of thickness, the concrete protection layer had very weak anticorrosion properties. Beside that, in the present work, by using this indoor testing method, those results also were similar to field testing [16, 17].

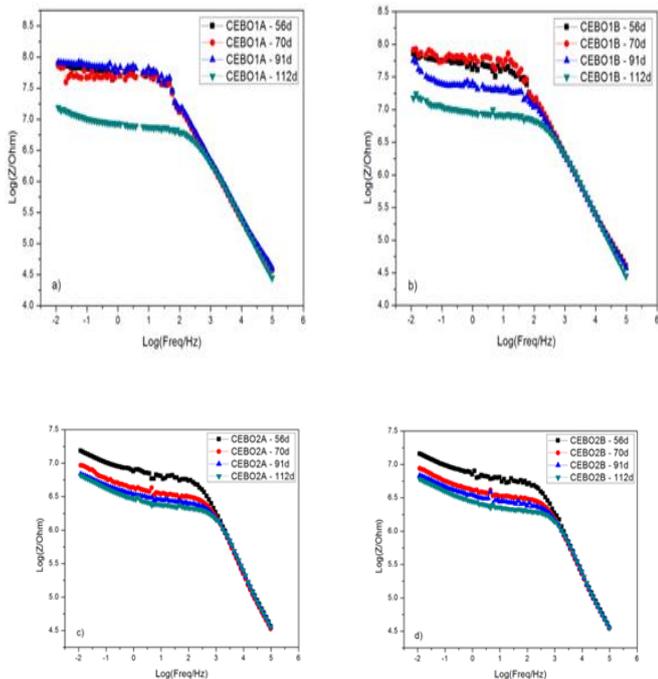


Figure 5. Bode plots at different exposure time in ASW for CEBO samples: a) CEBO1A sample, b) CEBO1B sample, c) CEBO2A sample and d) CEBO2B sample

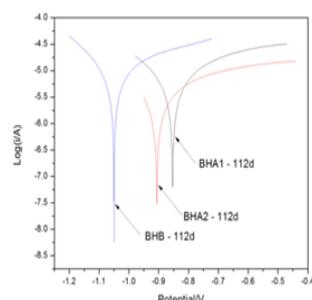
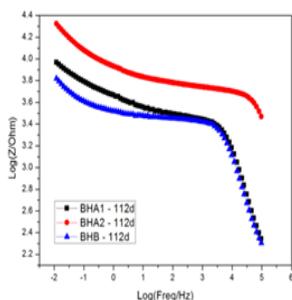


Figure 6. Bode plots at 112 days exposure in ASW for BHA and BHB samples
Figure 7. Tafel plots of BHA and BHB samples after 112 days of exposure in ASW.

As were shown in Fig. 5, the $|Z|_{0.01\text{Hz}}$ for CEBO1A sample was $7.627 \times 10^7 \Omega\text{cm}^2$ after 56 days of exposure, then decreased gradually to $7.247 \times 10^7 \Omega\text{cm}^2$ at 70 days, regained to $8.24 \times 10^7 \Omega\text{cm}^2$ at 91 days and decreased to $1.539 \times 10^7 \Omega\text{cm}^2$ at the end of 112 days. The $|Z|_{0.01\text{Hz}}$ for CEBO1B sample was $7.189 \times 10^7 \Omega\text{cm}^2$ after 56 days of exposure, and then increased to $8.225 \times 10^7 \Omega\text{cm}^2$ at 70 days, then decreased gradually to

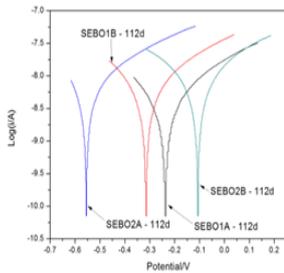


Figure 8. Tafel plots of SEBO samples after 112 days of exposure in ASW.

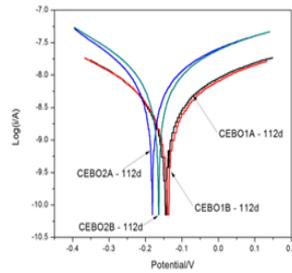


Figure 9. Tafel plots of CEBO samples after 112 days of exposure in ASW.

From Tafel polarization curves (Fig. 7 ~ Fig. 9), it can be observed that the anticorrosion properties of different samples were further revealed clearly and directly. The corrosion current is one among the important factors to characterize the anticorrosion performance [15].

Table 5. Fitting values of Tafel curve of different samples after 112d of exposure into ASW

Samples	E_{corr} (V)	I_{corr} (10^{-6} A/cm 2)	CR (10^{-3} mm/year)
BHA1	-0.853	5.680	65.964
BHA2	-0.906	2.813	32.664
BHB	-1.051	8.395	97.485
SEBO1A	-0.238	2.805×10^{-3}	32.563×10^{-3}
SEBO1B	-0.315	4.199×10^{-3}	48.768×10^{-3}
SEBO2A	-0.555	5.266×10^{-3}	61.138×10^{-3}
SEBO2B	-0.107	6.014×10^{-3}	69.825×10^{-3}
CEBO1A	-0.140	2.739×10^{-3}	31.801×10^{-3}
CEBO1B	-0.146	2.840×10^{-3}	32.969×10^{-3}
CEBO2A	-0.181	6.408×10^{-3}	74.397×10^{-3}
CEBO2B	-0.165	6.729×10^{-3}	78.130×10^{-3}

For SEBO series, as values were shown in table 5, the SEBO1A sample indicated the corrosion potential which was higher than the corrosion potential of SEBO2A sample ($E_{corr} = -0.238$ V with -0.555 V), the corrosion current of the SEBO1A sample was lower than the corrosion current of the SEBO2A sample ($I_{corr} = 2.805 \times 10^{-9}$ A/cm 2 with 5.266×10^{-9} A/cm 2). The SEBO1B sample indicated the corrosion potential which was lower than the corrosion potential of SEBO2B sample ($E_{corr} = -0.315$ V with -0.107 V). However, the corrosion current was just opposite. The corrosion current of the SEBO1B sample was lower than the corrosion current of the SEBO2B sample ($I_{corr} = 4.199 \times 10^{-9}$ A/cm 2 with 6.014×10^{-9} A/cm 2). For evaluating effective protection of novel EBO epoxy-based organobentonite nanocomposites coatings, CR was used. The BHA and BHB series were used as references. In A1 exposure condition, using EBO1 coating reduced the CR of bare rebar embedded in concrete by 2026 times, using EBO2 coating reduced the CR of bare rebar embedded in concrete by 1079 times, after 112 days exposure in ASW. In B exposure condition, using EBO1 coating reduced the CR of bare rebar embedded in concrete by 1999 times, using EBO2 coating reduced the CR of bare rebar embedded in concrete by 1396 times, after 112 days exposure in ASW. Hence, in those conditions, their anticorrosion performance can be rated as SEBO1A>SEBO2A and SEBO1B > SEBO2B

For CEBO series, as values were shown in table 5, the CEBO1A sample indicated the corrosion potential which was higher than the corrosion potential of CEBO2A sample ($E_{corr} = -0.140$ V with -0.181 V), the corrosion current of the CEBO1A sample was lower than the corrosion current of the CEBO2A sample ($I_{corr} = 2.739 \times 10^{-9}$ A/cm 2 with 6.408×10^{-9} A/cm 2). The

CEBO1B sample indicated the corrosion potential which was higher than the corrosion potential of CEBO2B sample ($E_{corr} = -0.146$ V with -0.165 V), and the corrosion current of the CEBO1B sample was lower than the corrosion current of the CEBO2B sample ($I_{corr} = 2.84 \times 10^{-9}$ A/cm 2 with 6.729×10^{-9} A/cm 2). To evaluated effective protection by CR. In A2 exposure condition, using EBO1 coating reduced the CR of bare rebar embedded in concrete by 1027 times, using EBO2 coating reduced the CR of bare rebar embedded in concrete by 437 times, after 112 days exposure in ASW. In B exposure condition, using EBO1 coating reduced the CR of bare rebar embedded in concrete by 2957 times, using EBO2 coating reduced the CR of bare rebar embedded in concrete by 1248 times, after 112 days exposure in ASW. Hence, in those conditions, their anticorrosion performance can be rated as CEBO1A>CEBO2A and CEBO1B > CEBO2B

Based on those results, the potentiodynamic polarization test once again revealed that the EBO1 coating showed better anticorrosion performance than the EBO2 coating.

IV. CONCLUSIONS

In term of 112 days performance in artificial seawater, the novel coating systems had shown appreciable corrosion protection properties at 55 ± 2 μ m thickness. The electrochemical testing indicated that when the two types of new material coatings are applied to the reinforcing steel or concrete surfaces which provides the effective protection and should extend the service life of reinforced concrete significantly as compared to when normal uncoated reinforcement is used. In detailed:

- (i) For protection of a cast-in-situ concrete structure in tidal zone, the EBO1 coating can reduce the CR of bare rebar embedded in concrete by 2026 times, the EBO2 coating reduced the CR of bare rebar embedded in concrete by 1079 times.
- (ii) For protection of a precast concrete structure in tidal zone, coating on concrete surface, the EBO1 coating can reduce the CR of bare rebar embedded in concrete by 1027 times, the EBO2 coating reduced the CR of bare rebar embedded in concrete by 437 times.
- (iii) For protection of a precast concrete structure in submerged zone, coating on rebar, the EBO1 coating can reduce the CR of bare rebar embedded in concrete by 1999 times, the EBO2 coating reduced the CR of bare rebar embedded in concrete by 1369 times.
- (iv) For protection of a precast concrete structure in submerged zone, coating on concrete surface, the EBO1 coating can reduce the CR of bare rebar embedded in concrete by 2957 times, the EBO2 coating reduced the CR of bare rebar embedded in concrete by 1248 times.

The anti-corrosion performance of EBO1 epoxy-based organobentonite nanocomposite coating was more effective than EBO2 epoxy-based organobentonite nanocomposite coating. It can be rated as EBO1>EBO2

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