Scientific paper

Effectiveness Protection Performance of an Internal Blending Organic Corrosion Inhibitor for Carbon Steel in Chloride Contaminated Simulated Concrete Pore Solution

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Abstract

Application of corrosion inhibitors is considered as one of the most economical and effective solutions for the protection of reinforced concrete structures under severe environment. The aim of this paper is to investigate the protection performance and mechanism of an internal blending organic inhibitor for carbon steel in chloride contaminated simulated concrete pore solution. The influences of concentration of inhibitor, chloride content and pH value of the solutions on the protection efficiency were investigated. Both weight loss and electrochemical were used to evaluate the protection efficiency of the inhibitor. Scanning electron microscopy (SEM), X-ray photoelectron spectroscopy (XPS), and Fourier transform infrared spectroscopy (FTIR) analyses were performed to reveal the mechanism of corrosion resistance of the inhibitor. Results indicated that the corrosion of carbon steel in chloride contaminated simulated concrete pore solution was highly resisted in presence of inhibitor, the inhibition efficiency of 3.5% NaCl saturated Ca(OH)2 solution with 4% inhibitor reached 89%. With lower pH value, corrosion of steel will happen easier even with addition of inhibitor. However, inhibitor will still have effective even to protect carbon steel in fully carbonated concrete. The organic film with characteristics of aromatic groups can be detected on the carbon steel surface in presence of inhibitor, confirming the protection effects for steel.

1. Introduction

Corrosion occurring in reinforced concrete is an elec-

normally safe and environment friendly (Al-Amoudi et al. 2003).

Nowadays, organic inhibitors available in the market are mainly in the form of surface-applied corrosion inhibitors that can be applied onto the surface of concrete and then diffuse to the steel embedded in the concrete through capillary pores. However, surface-applied corrosion inhibitors may create many complications. For example, the loss of active components is large in the migration process and thereby long-term effect is poor (Elsener et al. 2000). It is usually difficult for the inhibitor to penetrate through the concrete matrix to the embedded reinforcement when the concrete is more compact (Xu et al. 2016). Researchers tried to solve this problem by mixing surface applied inhibitors into the concrete, but they found that the initial setting time of cement was delayed while the final setting time was accelerated (Li et al. 2014).

In this paper, a kind of internal blending organic corrosion inhibitor was chosen. The protection performance and mechanism of this organic inhibitor for carbon steel in chloride contaminated simulated concrete pore solution was investigated by weight loss tests, electrochemical tests, scanning electron microscopy, X-ray photoelectron spectroscopy, and Fourier transform infrared spectroscopy test. Results will be helpful for the practical application of this kind of inhibitor.

2. Experimental program

2.1 Materials

The internal blending organic corrosion inhibitor is a pale yellow, irritating, transparent liquid. All the working electrodes used in this research were Q235 carbon steel. The carbon steel was polished in sequence with a series of emery paper (grade from 180 to 2000), washed and degreased with acetone, cleaned in alcohol and distilled water by ultrasonic process. The working electrode with dimension of 10 mm × 10 mm × 10 mm was embedded in epoxy resin and poured into PVC pipe, exposing a working surface with a square shaped surface area of 100 mm² as shown in Fig. 1. Steel specimen with dimension of 50 mm × 25 mm × 5 mm was used for weight loss test. Steel plate with dimension of 10 mm × 10 mm × 2 mm was used for scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), X-ray photoelectron spectroscopy (XPS) and Fourier transform infrared spectroscopy (FTIR) test (Ormellese et al. 2009).

The formula for the preparation of the inhibitor is shown in Fig. 2. The main molecule structure of the inhibitor is the amino ketone molecule with strong molecular complexing ability. In the molecule structures, aromatic groups with rigid structure and rich electrons are introduced into the carbonyl side chain of amino ketones, which can be used as a barrier layer to isolate the corrosive media from the steel (Pearson 1973). By considering the repulsive forces between molecules, which formed steric resistance and thereby reduced the densification of the adsorbed membrane, polyhydroxyl groups were introduced into the inhibitor.

2.2 Preparation of chloride contaminated simulated concrete pore solution

The simulated concrete pore solution was prepared with analytical pure Ca(OH)₂ and distilled water. The chloride ions were then introduced by adding NaCl into the solution. The pH values of the solution were regulated by NaHCO₃. Four groups of exposure solutions were prepared to study the influence of inhibitor concentration, chloride contents and pH values on the protection efficiency of the inhibitor as shown in Table 1.

2.3 Weight loss tests

After pre-processing, the steel specimens were put into 3.5% NaCl saturated Ca(OH)₂ solution with different concentrations of inhibitor (0, 1%, 2%, 3%, and 4%) for 7 days. Then the specimens were taken out, rinsed with distilled water, washed by pickling solution (mixture of distilled water, HCl and C₆H₁₂N₄ with a ratio of 1:1:10 g/L), cleaned in alcohol, dried in desiccator and weighed accurately by analytical balance. The average weight loss of each group for three parallel specimens was obtained.

The corrosion rate and corrosion inhibition efficiency of the inhibitor can be calculated by Equations (1) and (2),

\[ R = \frac{W_0 - W}{A \times t} \times 100\% \]

\[ E = \frac{R_{0} - R}{R_{0}} \times 100\% \]

Fig. 1 The working electrode.

Fig. 2 Chemical reaction for the preparation of the inhibitor.
where “\( V \)” is the corrosion rate \([g/(m^2.h)]\), “\( W_0 \)” and “\( W_I \)” refer to the respective weights (g) of specimens before and after immersion in chloride contaminated simulated concrete pore solution, “\( s \)” is the surface area of the specimens (m\(^2\)), “\( t \)” is the immersion time (h), \( IE_W \) is the corrosion inhibition efficiency (%) and “\( v_0 \)” and “\( v_I \)” refer to the mean corrosion rates \([g/(m^2.h)]\) in the absence and in presence of inhibitor, respectively.

\[
V = \frac{W_0 - W_I}{s \times t} \quad (1)
\]

\[
IE_W = \frac{v_0 - v_I}{v_0} \times 100\% \quad (2)
\]

2.4 Electrochemical measurements

The electrochemical performance of working electrode under different exposed environment was measured by electrochemical workstation of Princeton Applied Research STAT 2273. The prepared working electrode was immersed in 3.5\% NaCl saturated Ca(OH)\(_2\) solution containing inhibitor as shown in Table 1 for 30 minutes. Then the working electrode was left at open-circuit potential (OCP) conditions until the potential achieved the stability (the change of potential was less than 2 mV within 300 s). After that, the electrochemical impedance spectroscopy (EIS) test was carried out with OCP of 10 mV peak-to-peak amplitude of the sinusoidal perturbation in the frequency range from 10 kHz to 10 MHz. In potentiodynamic polarization measurements, the potential was scanned from -250 mV to +250 mV (versus OCP) with a scan rate of 0.5 mV s\(^{-1}\). All the electrochemical data were collected and analyzed by PowerSuite and ZSimpWin software (Ma et al. 2015).

2.5 Surface analysis

To understand the protective mechanisms of the inhibitor on steel bar, the prepared carbon steel sample was put into 3.5\% NaCl saturated Ca(OH)\(_2\) solution with or without inhibitor. After 7 days, the steel samples were washed with deionized water. Then scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) were used to analyze the surface topography of carbon steel. X-ray photoelectron spectroscopy (XPS) was used to analyze the composition of elements of steel surface in different solutions. Fourier transform infrared spectroscopy (FTIR) was used to identify the functional groups in inhibitors that played a role in rust inhibition.

Table 1 Chloride contaminated simulated concrete pore solution.

| Number | Simulated concrete pore solution | Inhibitor concentration | Mass fraction of NaCl | pH values |
|--------|---------------------------------|-------------------------|-----------------------|-----------|
| 1      | Saturated Ca(OH)\(_2\) solution | 0\%, 1\%, 2\%, 3\%, 4\% | 3.5\%                 | 12.3      |
| 2      | Saturated Ca(OH)\(_2\) solution | 2\%                    | 0, 2\%, 3.5\%, 5\%    | 12.3      |
| 3      | Saturated Ca(OH)\(_2\) solution | 0\%                    | 0, 2\%, 3.5\%, 5\%    | 12.3      |
| 4      | Saturated Ca(OH)\(_2\) solution | 2\%                    | 3.5\%                 | 9.3, 10.3, 11.3, 12.4 |

Table 2 Corrosion rate and corrosion inhibition efficiency with different amount of inhibitor.

| Concentration | \( V \) [g/(m\(^2\).h)] | \( IE_W \) (%) |
|---------------|--------------------------|----------------|
| 0             | 0.0403                   |                |
| 1\%           | 0.0089                   | 77.73          |
| 2\%           | 0.0077                   | 80.85          |
| 3\%           | 0.0060                   | 84.91          |
| 4\%           | 0.0045                   | 88.73          |

3. Results and discussion

3.1 The corrosion rate and corrosion inhibition efficiency with different amount of inhibitor

The corrosion rate and corrosion inhibition efficiency with different amount of inhibitor are shown in Table 2. Results indicated that the corrosion rate of the steel decreased and the inhibition efficiency improved with the increase of inhibitor content. The corrosion rate of carbon steel with inhibitor was significantly lower than that without inhibitor. With the increase of inhibitor content, the corrosion rate decreased. When the amount of inhibitor is 4\%, the corrosion inhibition efficiency reaches a maximum value of 88.73\%. The reason could be that the inhibitor molecules had good water solubility, which might effectively be adsorbed on the surface of reinforcement and inhibited the corrosion of reinforcement. By increasing the concentration of inhibitor, the adsorbed film became denser and complete, thereby the corrosion of carbon steel turned to be more restrained.

3.2 Effect of inhibitor concentration on inhibition

Nyquist and Bode plots of carbon steel in 3.5\% NaCl saturated Ca(OH)\(_2\) solution with different concentrations of inhibitor are shown in Fig. 3. Obviously, all of the impedance spectra exhibit one single semicircle and the impedance arc radius increases with the increase of inhibitor concentration. That means addition of inhibitor increases the corrosion resistance of steel in the chloride contaminated simulated concrete pore solution, which can be explained by the promotion function while forming the passivating film on the surface of carbon steel.

Comparing the fitting results of different equivalent circuits in published papers (Królikowski et al. 2011; Ma et al. 2015; Nam et al. 2018), an equivalent circuit with the smallest error and closest to the actual system has been established, as shown in Fig. 4. In the equivalent circuit, \( R_s \) is the resistance of the solution, \( R_f \) is the resistance of the film formed on the steel surface, \( R_{ct} \) is the charge transfer resistance of electrode in simulated pore solution with inhibitor, \( C_f \) is composed of the membrane...
capacitance of the corrosion process and the deviation parameter, $C_2$ is composed of the double-layer capacitance and the deviation parameter.

Based on the fitting results of the EIS parameters, the protection efficiency of the inhibitor for steel can be calculated by Equation (3) (Królikowski et al. 2011; Miao et al. 2010):

$$\eta = \frac{R_c - R_0^c}{R_c} \times 100\%$$

where $\eta$ is the resistance efficiency and $R_0^c$ is the charge transfer resistance of electrode in simulated pore solution without inhibitor.

Table 3 lists the fitting results of the parameters for EIS data presented in Fig. 3. With increase of inhibitor concentration, both $R_s$ and $R_c$ increase, indicating that the addition of inhibitor effectively inhibited the corrosion of carbon steel. The reason could be that the formation of hydrophobic layer on the steel surface as the surface of the electrode was covered with amino ketone adsorption film. The decreases of constant phase elements $C_1$ and $C_2$ are related to the thickness of the double layer on the electrode surface and the dielectric constant of the adsorbed particles. The thicker double layer or the smaller dielectric constant of adsorbed particles resulted in smaller value of capacitance (Jamil et al. 2004). Compared with the water molecule and chlorine ions, the dielectric constant of amino ketone molecule was smaller. Hence, the adsorption of amino ketone molecule on the surface of steel bar led to the decrease of constant phase element.

When the inhibitor concentration increased from 1% to 4%, there was an increase of resistance efficiency from 79.47% to 89.08%. Higher concentration of inhibitor helped to increase the adsorption of extra amino ketone molecules on the surface of steel bar and formed a complete and compact adsorption film to improve the resistance to the chloride ions. In addition, the introduction of aromatic groups with electronegativity helped to form a hydrophobic layer, which effectively prevented the transport of the aggressive ions and the dissolution of passivating film on the steel surface.

The polarization curves of carbon steel electrode immersed in simulated pore solution with different concentrations of inhibitor are shown in Fig. 5. During the polarization test, small bubbles and green rust began to appear on the surface of the carbon steel electrode when the breakdown potential exceeded, and the corrosion was ongoing. From Fig. 5, it is obvious that the breakdown potential in all solution with inhibitor is higher than that in solution without inhibitor. With the increase of inhibitor concentration, the breakdown potential increased gradually. There was an obvious increase of the range of passivating region. However, the slope of passivating region decreased gradually. Therefore, the addition of
inhibitor could promote the formation of passivating film on the surface of steel. In this way, the resistance of carbon steel to the chloride erosion was enhanced.

3.3 Effect of chloride concentration on inhibition

The electrochemical impedance spectra of carbon steel immersed in saturated Ca(OH)$_2$ solution containing 2%, 3.5% and 5% NaCl with and without inhibitor are shown in Fig. 6. In the solution without inhibitor, the electrochemical impedance arc of carbon steel decreased with the increase of NaCl content, indicating that the corrosion become more severe. In the solution with 2% inhibitor, the impedance arc increased obviously, which indicated that corrosion of carbon steel was inhibited in presence of inhibitor. Furthermore, the inhibitor had good inhibition performance under different content of NaCl.

Table 4 lists the fitting parameters of the EIS data presented in Fig. 6. The inhibition efficiency of 2% NaCl saturated Ca(OH)$_2$ solution containing 2% inhibitor was 65.58%, the inhibition efficiency of 3.5% NaCl saturated Ca(OH)$_2$ solution containing 2% inhibitor was 79.99%, and the inhibition efficiency of 5% NaCl saturated Ca(OH)$_2$ solution containing 2% inhibitor was 66.30%. Clearly, with the addition of inhibitor, the corrosion of carbon steel is not obvious under the condition of low concentration of chloride. However, the impedance arc radius in the low frequency region decreased sharply when the mass fraction of NaCl is as high as 5%. This indicates that the adsorption of inhibitor molecules is weakened due to the increase of chloride concentration. As a result, the density and integrity of adsorption film on carbon steel surface was decreased, and the protective effect of inhibitor on steel was weakened.

The polarization curves of carbon steel electrode immersed in saturated Ca(OH)$_2$ solution containing different content of NaCl with and without inhibitor are illustrated in Fig. 7. With the increase of NaCl content, the slope of the passivating area decreases gradually, reflecting that the de-passivation of steel happened due to chloride attack. In presence of inhibitor, the range of passivating zone became enlarged. As a result, the breakdown potential shifted towards positive direction, and thereby decreases of both corrosion current density and dimension blunt current density occurred. The result indicates that the existence of inhibitor can decrease the surface activity of steel and effectively restrain the corrosion of carbon steel.

3.4 Effect of pH values on inhibition

Ca(OH)$_2$ is one of the major hydration products of cement, so pH value of normal concrete is about 12.5. However, pH value of concrete will decrease due to carbonation or acid attack. Carbonation of Ca(OH)$_2$ in
concrete can reduce the pH of concrete to value less than 9. When the pH value in vicinity of the rebar is lower than 11, initiation of active corrosion will happen even without chloride ions near rebar. If internal corrosion inhibitor can protect steel in concrete pore solution with lower pH value or not is very important for the application of this kind of inhibitor. Nyquist plots and inhibition efficiency in 3.5% NaCl saturated Ca(OH)₂ solution with inhibitor under different pH values are shown in Fig. 8. It can be found that the electrochemical impedance arc radius of the carbon steel electrode decreases with the decrease of pH value. That means with lower pH value, corrosion of steel will happen easier. However, the electrochemical impedance arc of carbon steel in 3.5% NaCl solution with pH value of 9.3 and with 2% of inhibitor is even bigger than that of carbon steel in 3.5% NaCl saturated Ca(OH)₂ but without inhibitor. Therefore, inhibitor will still have effective even to protect carbon steel in fully carbonated concrete. From (b) in Fig. 8, the inhibition efficiency is between 58.90% and 70.36% in 3.5% NaCl solution with pH value of 9.3 to 11.3. However, the inhibition efficiency is just 28.23% in 3.5% NaCl solution with pH value of 12.4. The reason is as follows: a compact and stable passive film forms on the surface of carbon steel in the highly alkaline concrete pore solutions. In this way, carbon steel will be not severely corroded even in the solution without inhibitor.

3.5 SEM and EDS analysis

Figures 9 and 10 present the magnified 5000 times surface morphology of carbon steel in solutions without inhibitor and with 4% inhibitor. There are significant differences between the two surface morphologies, as shown in Figs. 9 and 10. The surface of the sample without inhibitor is rough and has clear abrasion marks and pit corrosion. With the surface of specimen protected by inhibitor, no abrasion marks or corrosion can be found. The steel surface was covered with a dense, complete and uniform protective film. From Figs. 9(a) and 10(b), the content of C on the surface of carbon steel with inhibitor was higher than that without inhibitor, indicating that there were more organic substances on the surface of carbon steel immersed in 3.5% NaCl saturated Ca(OH)₂ solution with inhibitor. The organic protective film formed by adsorption of amino ketone molecules on the surface of carbon steel. The oxygen content of carbon steel with inhibitor was lower than that without inhibitor. The reason for this phenomenon is that corrosion of the carbon steel occurred without inhibitor, and iron oxide formed on the surface of the carbon steel, resulting in the increase of oxygen. The content of Ca and Na on the surface of carbon steel without inhibitor was much higher than that on the surface of carbon steel with inhibitor. The fluffy rust, which generated from the oxidation process, adsorbed the solution containing calcium.
and sodium ions. From the above results, we can conclude that the existence of the film forming component of the inhibitor. In addition, the film on the carbon steel surface can effectively isolate the chloride ions, and thus protect the steel bar from erosion.

3.6 XPS analysis

Figure 11 presents the XPS spectrum for steel surface immersed in 3.5% NaCl saturated Ca(OH)$_2$ solution without inhibitor and with inhibitor. Obviously, the elements on the surface of carbon steel are mainly Fe, O, Ca and C. When the surface of carbon steel immersed in 3.5% NaCl saturated Ca(OH)$_2$ solution without inhibitor [Fig. 11(a)], the contents of Fe, O, Ca, C and N were 10.36%, 46.93%, 7.4%, 33.03% and 2.28%, respectively. On the other hand, when the surface of carbon steel immersed in 3.5% NaCl saturated Ca(OH)$_2$ solution with inhibitor [Fig. 11(b)], the contents of Fe, O, Ca, C and N were 10.7%, 42.73%, 5.15%, 39.38% and 2.04%, respectively. Compared with carbon steel immersed in 3.5% NaCl saturated Ca(OH)$_2$ solution without inhibitor, the content of C element is higher and the content of O element is lower for carbon steel immersed in 3.5% NaCl saturated Ca(OH)$_2$ solution with inhibitor. The reason is as follows: The nitrogen atoms in the amino ketone inhibitor molecule and oxygen atoms in carbonyl group are both electronegative in nature, which can effectively be adsorbed along with oxide film on the surface of steel bar. Amino and carbonyl groups can form chelating rings with iron atoms on the surface of the oxide film (Rakanta et al. 2013), as shown in Fig. 12. The structure of chelating ring is very stable, which can enhance the adsorption of inhibitor on the surface of steel bar.

Figure 13 is the Fe 2p spectrum for steel surface immersed in 3.5% NaCl saturated Ca(OH)$_2$ solution with and without inhibitor. The Fe 2p spectra were fitted to two doublets peak profile and located at the site of binding energies (BE) of 711 eV approx. (Fe 2p3/2) and 725 eV approx. (Fe 2p1/2) together with an associated ghost structure (Watts et al. 2003; Outirite et al. 2010; Bouanis et al. 2009; Castro et al. 1995). Figure 13 also shows that the peak at BE 706.65 eV approx. in Fig. 13(a) was assigned to Fe$^{3+}$, which can be attributed to iron nitrides (Fe$_x$N) (Bouanis et al. 2009; Gontijo et al. 2004) due to the adsorption of N atoms on the surface of iron. The peak at BE 710.9 eV approx. in Fig. 13(b) and
BE 710.5 eV approx. in Fig. 13(a) were assigned to Fe$^{3+}$, which can be attributed to Fe$_2$O$_3$ and FeOOH (Bouanis et al. 2009; Pech-Canul et al. 2004; Fei et al. 2015; Oli-
vares et al. 2006). The two peaks at BE 713.43 eV approx. in Fig. 13(b) and at BE 712.65 eV approx. in Fig. 13(a) may be assigned to the satellite of Fe(II) (Outirite et al. 2010; Bouanis et al. 2009; Tandon et al. 1985). The peak values at BE 718.94 eV approx. in Fig. 13(b) and at BE 719.2 eV approx. in Fig. 13(a) may be credited to the satellites of the ferric compounds (Fe$^{3+}$) (Outirite et al. 2010; Bouanis et al. 2009; Castro et al. 1995).

The oxygen 1s spectrum for steel surface immersed in 3.5% NaCl saturated Ca(OH)$_2$ solution with and without inhibitor are presented in Fig. 14. The oxygen 1s spectra were fitted with three peaks. The peaks at BE 529.9 eV approx. in Fig. 14(b) and at BE 529.75 eV approx. in Fig. 14(a) are attributed to O$^{2-}$ (Temesghen et al. 2002; Bommersbach et al. 2006; Boumhara et al. 2015). The peaks at BE 531.5 eV approx. in Fig. 14(b) and at BE 531.15 eV approx. in Fig. 14(a) may be assigned to the oxygen double bonded to carbon (C=O), and to singly bonded oxygen (-O-) in C-O (Bhardava et al. 2007; Olla et al. 2006; Jaffer et al. 2009). The peak at BE 533.15 eV approx. in Fig. 14(b) and at BE 532.3 eV approx. in Fig. 14(a) are attributed to oxygen of adsorbed water (Boumhara et al. 2015; Babić-Samardžija et al. 2005).

The N 1s spectrum for steel surface immersed in 3.5% NaCl saturated Ca(OH)$_2$ solution with and without inhibitor are shown in Fig. 15. The N 1s spectra were fitted with three peaks. The peaks at BE 398.27 eV approx. in Fig. 15(b) and at BE 398.2 eV approx. in Fig. 15(a) are assigned to iron nitrides (Fe$_x$N) (Hong et al. 1995; Wang et al. 2003), which might be the adsorption of N atoms on the surface of iron. The peaks at BE 399.55 eV approx. in Fig. 15(b) and at BE 399.53 eV approx. in Fig. 15(a) are assigned to C–N bonding, and to the unprotonated N atoms (N-structure) (Jama et al. 1999; Kang et al. 1992; Lebrini et al. 2007). The peaks at BE 400.3 eV approx. in Fig. 15(b) and at BE 400.4 eV in Fig. 15(a) are assigned to the N–O bonding (Lebrini et al. 2007; Kieckow et al. 2006).

By using high-resolution peaks and the deconvolution of spectra, we can easily find the traces of C=O, iron nitrides, N-structure, etc. This confirms the obvious presence of rust inhibitor traces. The results of XPS analysis directly prove that the rust inhibitor is involved in the formation of passivating film on the surface of carbon steel.
3.7 FTIR analysis

FTIR spectrum of steel samples immersed in 3.5% NaCl saturated Ca(OH)₂ solution with and without 4% inhibitor was recorded and the data are shown in Fig. 16. Figure 15 showed that the surface of carbon steel immersed in solution with inhibitor had more complex interfacial structure and more functional groups. In Fig. 16(a), we found only one wide absorption peak at 3293.92 cm⁻¹, which could be the outcome of the vibration absorption of -OH group in the water adsorbed in rust (Wang et al. 1999; Petit 2018; Girard et al. 2011; Martin et al. 2010; Shenderova et al. 2011). The absorption peak near 1460.00 cm⁻¹ was found to be saturated C-H deformed vibration absorption peak. It was preliminarily determined that there were -CH₂ and -CH functional groups (Petit et al. 2017; Stehlik et al. 2015; Williams et al. 2010; Scholz et al. 2011; Wu et al. 2002). In the vicinity of 1009.42 cm⁻¹, the spectral information in this band was relatively rich, and it was mainly due to the C-O stretching vibrational absorption peak (Wu et al. 2002). In Fig. 16(b), the peak at 3278.19 cm⁻¹ represented the asymmetric N-H stretching absorption peak (Petit et al. 2017; Sotowa et al. 2004), and the peak at 3009.74 cm⁻¹ referred to the absorption peak of C-H.
stretches vibration from aromatic groups (Sotowa et al. 2004; Zhang et al. 2012; Jiang et al. 2007). The absorption peak at 1642.96 cm\(^{-1}\) and 1518.33 cm\(^{-1}\) referred to stretching vibration of C=O in aromatic group (Liang et al. 2009; Stehlík et al. 2015; Lin et al. 2014; Osswald et al. 2006). The 1337.40 cm\(^{-1}\) absorption peak was produced due to C=N symmetric stretching vibration (Tu et al. 2006; Korobov et al. 2013) while the absorption peak at 1231.73 cm\(^{-1}\) might be produced due to the C-N stretching vibration (Scholz et al. 2011; Wu et al. 2002; Zhang et al. 2012; Jiang et al. 2007; Lin et al. 2014; Lin et al. 1996). From the absorption peak in the wavelength range of 600 to 4000 cm\(^{-1}\), the characteristics of aromatic groups and chelate structures on the passivating film formed on the surface of carbon steel are obvious under the influence of rust inhibitor.

Carbon steel immersed in solution with internal blending organic corrosion inhibitor will form certain functional groups on the surface. These functional groups come from the active ingredients of rust inhibitor. In addition, by verifying the existence of these functional groups on the surface of carbon steel, it can be shown that the inhibitor has effect on the formation of protective film on the surface of carbon steel.

4. Conclusions

The protection efficiency and mechanisms of a new internal blending organic corrosion inhibitor for steel under different conditions were studied systematically by means of weight loss experiment, electrochemical measurements and surface microscopic analysis. The following conclusions can be achieved:

(1) The internal blending organic inhibitor can apply protection for steel in chloride containing simulated concrete pore solution. The protection efficiency of the inhibitor increases with the increase of concentration in solutions. When the content of the inhibitor was 4%, the maximum efficiency reached 89.07%.

(2) Under different concentrations of chlorine ions, the inhibitors showed fair performance of rust resistance, which increased first and then decreased. When the chloride ion concentration was 3.5%, the maximum inhibition efficiency was 80.06%.

(3) With lower pH value, corrosion of steel will happen easier even with addition of inhibitor. However, the electrochemical impedance arc of carbon steel in 3.5% NaCl solution with pH value of 9.3 and with 2% of inhibitor is even bigger than that of carbon steel in 3.5% NaCl saturated Ca(OH)\(_2\) but without inhibitor. Inhibitor will still have effective even to protect carbon steel in fully carbonated concrete.

(4) Organic protective inhibitor can form a dense protective film on the surface of carbon steel electrode. It also increases the breakdown potential of carbon steel electrode, enlarges the range of passivation zone, and increases the critical chloride concentration.

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