Effects of surface modification with amino branched polydimethylsiloxane (ABP) on the corrosion protection of epoxy coating

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Abstract

An epoxy coating was designed to give a hydrophobic property on its surface by modifying it with three types of amino branched polydimethylsiloxane (ABP), and then effects of the modification on the structure, surface hydrophobic tendency, water transport behavior and hence corrosion protection of the modified epoxy coating were examined using FT-IR spectroscopy, hygrothermal cyclic test, and impedance test. The surface of epoxy coating was changed from hydrophilic to hydrophobic property due primarily to a phase separation tendency between epoxy and modifier by the modification. The phase separation tendency is more appreciable when modified by ABP with higher molecular weight ABP at higher content. Water transport behavior of the modified epoxy coating decreased more in that with higher hydrophobic surface property. The resistance to localized corrosion of the modified epoxy coated carbon steel was well agreed with its water transport behavior and hydrophobic tendency.

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1. Introduction

Epoxy is one of the most common coating materials used in severe corrosion environments including marine environment [1,2]. Due to the hydrophilic chemical groups of cured epoxy structure such as hydroxyl group (−OH), carboxyl group (C=O) and amino group (N–H) that have unpaired electron, epoxy has exhibited the hydrophilic properties by attracting water from the environment [3–6] to which it is exposed, resulting in a decrease in its protectiveness for metal underneath. Accordingly, there have been a lot of efforts to improve the protectiveness of epoxy coats, considering their material cost and applications, etc. Hydrophobic coating materials such as fluorine [7] and silicon polymer were introduced for special purposes requiring high corrosion protection, especially as a top coating in heavy duty environments or an anti-fouling coating in shipbuilding industry. However, the applications of these polymers have been limited due to their bad workability during painting work, poor adhesion and expensive material cost.

A blending technology combining hydrophilic polymer with hydrophobic polymer may produce an attractive coating system having both high corrosion protection and good adhesion. In fact, a reactive blending of poly[(3-aminopropyl)methylsiloxane] (PAMS) and epoxy has been attempted to improve the impact resistance of composite materials and adhesives by separating PAMS from the epoxy phase as a spherical shape [8–10]. In other approach, Cabanelas et al. made an epoxy system by adding PAMS as a curing agent rather than as a modifier [10], and confirmed that the water absorption of the epoxy was significantly decreased due to the change from hydrophilic to hydrophobic properties of epoxy coating. However, the introduction and application of amino substituted polydimethylsiloxane as a surface modifier for epoxy coating was rarely reported in the literatures. Kasemura et al. examined the surface modification of epoxy from hydrophilic to hydrophobic by blending amino-propyl terminated polydimethylsiloxane with epoxy [11,12]. However, the effects of the surface modifications on the corrosion protection of epoxy have rarely been investigated.

The research objective of present work is to develop an epoxy coat system by modifying its surface with amino branched polydimethylsiloxane that is hydrophobic and immiscible with epoxy, and then to examine the effects of the surface modification on the corrosion protection of the modified epoxy coatings.

2. Experimental

2.1. Materials

Diglycidyl ether bisphenol-A (DGEBA) and polyamide epoxy adduct (PAEA) were used as epoxy curing agents. Three types of amino branched polydimethyl siloxane (ABP) with different number of average molecular weight of 2200 g/mol (ABP1), 6700 g/mol (ABP2) and 25,800 g/mol (ABP3), respectively, were used as surface modifiers. Toluene was used as a solvent of the coatings. The molecular structures of epoxy resin, curing agent and ABP were shown in Figs. 1 and 2.
2.2. Preparation of modified epoxy specimens

Modified epoxy coatings were prepared by mixing DGEBA, PAEA and ABP1, ABP2 and ABP3 according to the designed ratio as specified in Table 1. The mixtures were vigorously stirred and degassed for 10 min during blending. The modified epoxy coats were sprayed on polypropylene plate to 100 ± 10 µm thick by an air spray method, and then cured at 25 °C for 4 days followed by post-curing for 4 h at 80 °C. After the curing, the films were removed for further tests such as measurements of contact angle and FT-IR.
Carbon steel sheet (15 mm × 15 mm × 3 mm thick) connected with copper wire was embedded in epoxy mold, cured, and used as a working electrode. Surface of the working electrode was pretreated by blasting of aluminum oxide grit, degreased by ethyl alcohol in ultrasonic bath for 10 min, and then dried in a convection oven. The average surface roughness of carbon steel was measured to be about 1 μm. The modified epoxy coating were sprayed on the surface of the carbon steel working electrode to 100 ± 10 μm thick by the air spray method. The coated specimens were then cured in an oven for 4 days at 25 °C, and then post cured for 4 h at 80 °C.

2.3. Analysis of surface modification

FT-IR spectroscopy scanning was conducted from 4000 to 650 cm⁻¹ on the top and bottom parts of the epoxy coating modified with different contents of ABP1, ABP2 and ABP3. ATR (attenuated total reflection) method was applied at 45 ° of IR beam, with the penetration depth of beam into the coating layer being about 1.47 μm at 1000 cm⁻¹. Distribution of the modifier (ABP) in the modified epoxy coating was analyzed by measuring the Si peak intensity by ATR mode of FT-IR (JASCO 680 plus, USA) since Si is contained only in ABP. Fig. 3 shows IR spectrum of pure ABP in which the peak

![Image](image-url)

Fig. 3. IR spectrum of ABP in which functional peaks marked are as follows: (1) * CH₃ symmetric deformation of Si–CH₃: 1260 cm⁻¹, (2) * Si–O–Si stretching vibration: 1010 cm⁻¹, and (3) * Si–C stretching and rocking: 800 cm⁻¹.

Table 1
Composition (wt%) of epoxy coating systems modified ABP1, ABP2, and ABP3 at different contents

<table>
<thead>
<tr>
<th>Modified epoxy system</th>
<th>ABP1 (wt%)</th>
<th>Modified epoxy system</th>
<th>ABP2 (wt%)</th>
<th>Modified epoxy system</th>
<th>ABP3 (wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ES1-1</td>
<td>0.5</td>
<td>ES2-1</td>
<td>0.5</td>
<td>ES3-1</td>
<td>0.5</td>
</tr>
<tr>
<td>ES1-2</td>
<td>2.5</td>
<td>ES2-2</td>
<td>2.5</td>
<td>ES3-2</td>
<td>2.5</td>
</tr>
<tr>
<td>ES1-3</td>
<td>5.0</td>
<td>ES2-3</td>
<td>5.0</td>
<td>ES3-3</td>
<td>5.0</td>
</tr>
<tr>
<td>ES1-4</td>
<td>7.5</td>
<td>ES2-4</td>
<td>7.5</td>
<td>ES3-4</td>
<td>7.5</td>
</tr>
</tbody>
</table>
at 1010 cm\(^{-1}\), at 800 cm\(^{-1}\), and at 1260 cm\(^{-1}\), respectively, are those for Si–O–Si stretching vibration, Si–C stretching and rocking, and CH\(_3\) symmetric deformation of Si–CH\(_3\), respectively. All of these peaks were used to characterize the distribution of the modifier. The change in the surface properties of the modified epoxy system depending on the type and content of the modifier was evaluated by measuring the contact angle using a contact angle meter GSA10 (KRÜSS Co. Ltd.) according to the Sessile drop method. The contact angle was measured at 10 s after dropping the distilled water.

2.4. Electrochemical cell and EIS combined with hygrothermal cyclic test

Hygrothermal cyclic tests were conducted to accelerate the cumulative effects of electrolyte on the coating/metal interface through the diffusion of electrolyte into the coating. The thermal cycle employed in the test was shown in Fig. 4 in which the cooling of specimen from the maximum temperature occurred naturally. Three electrode electrochemical cell consisted of the epoxy coated carbon steel as a working electrode, a saturated calomel reference electrode, and a platinum counter electrode was used to conduct electrochemical impedance spectroscopy (EIS) test at corrosion potential in 5 wt% NaCl solution. The impedance and capacitance of the modified epoxy coated carbon steel electrode was measured by EIS method. The data were obtained by applying a sine wave of 100 mV amplitude as a function of frequency ranged from 100 kHz to 100 mHz.

3. Results and discussion

3.1. Modifier distribution and surface modification

3.1.1. FT-IR analysis

Fig. 5a and b shows IR spectra measured on top and bottom, respectively, of the epoxy coatings modified with ABP1 as a function of ABP1 content. Peaks 1, 2, and 3 marked in Fig. 5 are those characterizing the epoxy without modifier such as ABP1, ABP2 and
ABP3; the aliphatic C–O stretching vibration at 1040 cm$^{-1}$, hydrogen atoms of para-disubstituted aromatic bending at 820 cm$^{-1}$, and phenyl–O– stretching vibration at 1250 cm$^{-1}$. These three peaks were used as those of reference to identify the distribution of modifier in the modified epoxy coatings. It is evident from Fig. 5a and b that IR spectra of the epoxy coatings modified with ABP1 are almost similar each other, irrespective of the ABP1 content, suggesting that the modifier ABP1 is uniformly distributed from the bottom to the top of the coatings.

Fig. 5. IR spectra of epoxy coatings modified with various contents of ABP1 ($M_w$: 2200 g/mol) on the top layer (a) and in the bottom layer (b) of the coatings. Functional peaks marked in the IR spectra are as follows: (1) phenyl–O– stretching: 1250 cm$^{-1}$; (2) aliphatic C–O stretching vibration: 1040 cm$^{-1}$; (3) bending of two adjacent hydrogens of para-disubstituted aromatic: 820 cm$^{-1}$.

ABP3; the aliphatic C–O stretching vibration at 1040 cm$^{-1}$, hydrogen atoms of para-disubstituted aromatic bending at 820 cm$^{-1}$, and phenyl–O– stretching vibration at 1250 cm$^{-1}$. These three peaks were used as those of reference to identify the distribution of modifier in the modified epoxy coatings. It is evident from Fig. 5a and b that IR spectra of the epoxy coatings modified with ABP1 are almost similar each other, irrespective of the ABP1 content, suggesting that the modifier ABP1 is uniformly distributed from the bottom to the top of the coatings.

Fig. 6a and b shows IR spectra measured on the top and bottom layers as a function of ABP2 content, respectively, for the epoxy coatings modified with ABP2. In addition to the reference peaks 1, 2, and 3, new peaks marked 1*, 2* and 3*, characterizing the presence of Si in the modifier, were appeared in the IR spectrum; Si–O–Si stretching vibration at 1010 cm$^{-1}$, Si–C stretching and rocking at 800 cm$^{-1}$, and CH$_3$ symmetric deformation
of Si–CH\(_3\) at 1260 cm\(^{-1}\). It is evident from the IR spectra for the top layer shown in Fig. 6a that the peaks 1, 2, and 3 were shifted to the peaks 1\(^*\), 2\(^*\) and 3\(^*\), respectively, at ABP2 content higher than 2.5 wt% with their intensity being increased with ABP content. On the other hand, peaks 1\(^*\), 2\(^*\), and 3\(^*\) were appeared in the bottom layer at ABP content higher than 7.5 wt%, as confirmed in Fig. 6b. These results clearly demonstrated that the modifier ABP2 is distributed more in the top layer than in the bottom layer of the modified epoxy coatings, due primarily to an increase in phase separation tendency between epoxy and ABP2 with an increase in the molecular weight of modifier. The phase separation tendency between epoxy and modifier is more appreciable in the epoxy coatings modified with higher molecular weight such as ABP3 as confirmed in Fig. 7a and b. Evidently, the shift of peaks 1, 2, 3 to peaks 1\(^*\), 2\(^*\) and 3\(^*\) occurred at the ABP3 content greater than 2.5 wt% on the top layer of the coating, whereas peaks 1\(^*\), 2\(^*\) and 3\(^*\) were not appeared in the bottom layer, indicating that the modifier ABP3 is distributed dominantly on the top layer of the coating.

Fig. 6. IR spectra of epoxy coatings modified with various contents of ABP2 (\(M_n: 6700\) g/mol) on the top layer (a) and in the bottom layer (b) of the coatings.
3.1.2. Contact angle measurement

The surface energy of the modified epoxy coating was calculated by measuring its contact angle, and then put it into the Good–Girifalco equation as shown in Eq. (1) [13–15]:

\[
\gamma_S = \frac{\gamma_{LV} (1 + \cos \theta)^2}{4\phi^2}
\]  

(1)

A static contact angle was measured on a pure epoxy coating and also on the epoxy coatings modified by ABP1, ABP2 and ABP3, respectively, and the results were presented in Fig. 8. Evidently, the contact angle was dramatically increased by the addition of modifier with 0.5 wt% irrespective of the type of modifier, and thereafter reached almost a constant value. The contact angles on the epoxy coatings modified with ABP3 showed slightly higher than those on the epoxy coatings modified with ABP1 and ABP2. These results clearly indicates that the surface of pure epoxy coating was changed from hydrophilic to hydrophobic due to the modification, and the hydrophobic tendency of the coating...
surface is more appreciable when the modification was done by a modifier with high molecular weight such as ABP3, as confirmed in Fig. 8.

3.2. Effects of modifier for water transport behaviors

To investigate the diffusion of water through the modified epoxy coatings, the volume fraction of water uptake and the diffusion coefficient of water through the coating were calculated by measuring the capacitance of the coating. Brasher and Kinsbury [16–19] suggested an empirical expression that relates the capacitance of a coating to the volume fraction of water absorbed into the coating, which was expressed by

$$V_t = \frac{100 \log(C_t/C_0)}{\log \varepsilon_{\text{H}_2\text{O}}}$$

(2)

Fig. 8. Effects of modifier content on the contact angle of epoxy coatings modified with different modifier (ABP1: 2200 g/mol, ABP2: 6700 g/mol, ABP3: 25,800 g/mol) at different contents (0, 0.5, 2.5, 5.0 and 7.5 wt%).

Fig. 9. ln $C_t/\sqrt{t}$ curve for unmodified epoxy coating measured in 0.5 wt% NaCl solution.
where $V_t$ is volume fraction of absorbed water at time $t$, $C_0$, $C_t$ are the capacitances of an organic coating at time $t = 0$ and at time $= t$, respectively and $\varepsilon_{\text{H}_2\text{O}}$ is the dielectric constant of water (80 at $T = 20 \, ^\circ\text{C}$). Further, the diffusion coefficient of water into an organic coating can be calculated by Eq. (3) in which [slope] is that at the initial stage of $\ln C - \sqrt{t}$ plot, called “the initial slope method” [20,21],

$$D = \frac{L^2 \pi}{4} [\text{slope}]^3,$$

where $C_\infty$ is the capacitance of the organic coating at a saturated state, and $L$ is thickness of the coating. The capacitance of a coating at the frequency of 1 kHz was selected for the

![Graph](image)

Fig. 10. $\ln C - \sqrt{t}$ curve for epoxy coatings modified with various contents of ABP1, measured in 0.5 wt\% NaCl solution.

![Graph](image)

Fig. 11. $\ln C - \sqrt{t}$ curve for epoxy coatings modified with various contents of ABP2, measured in 0.5 wt\% NaCl solution.
calculation of diffusion coefficient of water through the coating in this work. The \( \ln C_C - \sqrt{t} \) curve of an organic coating can be divided into two typical stages. At the first stage, the capacitance of a coating increases linearly with immersion time, indicating that the water may permeate into the coating through pores formed by a solvent evaporation, free volume or space between cross-linked chains formed by a curing reaction. At the second stage or after a certain time of immersion, the capacitance of the coating reaches a constant value, indicating that the water uptake into the coating has been saturated.

Fig. 9 shows \( \ln C_C - \sqrt{t} \) curve of the epoxy coating without any modification. Diffusion coefficient of water into an epoxy coating was calculated from the slope of \( \ln C_C - \sqrt{t} \) curve using Eq. (3), and volume fraction of water uptake was calculated by Eq. (2). The capacitance of dry coating, \( C_0 \), was determined by extrapolation of \( \ln C_C - \sqrt{t} \) curves at \( t = 0 \). The diffusion coefficient of water and the water uptake for the pure epoxy coating were calculated to be \( 9.94 \times 10^{-7} \) cm\(^2\)/s and 6.15 vol.% at 25°C, respectively. Fig. 10 shows

<table>
<thead>
<tr>
<th>Blending system</th>
<th>Diffusion coefficient (( \times 10^{-8}, \text{cm}^2/\text{s} ))</th>
<th>Volume fraction of water uptake (vol.%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy</td>
<td>99.4</td>
<td>6.15</td>
</tr>
<tr>
<td>ES1-1</td>
<td>53.3</td>
<td>4.30</td>
</tr>
<tr>
<td>ES1-2</td>
<td>25.9</td>
<td>3.67</td>
</tr>
<tr>
<td>ES1-3</td>
<td>23.5</td>
<td>2.92</td>
</tr>
<tr>
<td>ES1-4</td>
<td>13.2</td>
<td>2.88</td>
</tr>
<tr>
<td>ES2-1</td>
<td>48.6</td>
<td>4.48</td>
</tr>
<tr>
<td>ES2-2</td>
<td>23.3</td>
<td>3.55</td>
</tr>
<tr>
<td>ES2-3</td>
<td>15.7</td>
<td>3.22</td>
</tr>
<tr>
<td>ES2-4</td>
<td>12.2</td>
<td>2.67</td>
</tr>
<tr>
<td>ES3-1</td>
<td>49.0</td>
<td>3.70</td>
</tr>
<tr>
<td>ES3-2</td>
<td>22.4</td>
<td>3.11</td>
</tr>
<tr>
<td>ES3-3</td>
<td>21.0</td>
<td>3.04</td>
</tr>
<tr>
<td>ES3-4</td>
<td>8.2</td>
<td>1.83</td>
</tr>
</tbody>
</table>
In $C_C-\sqrt{t}$ curves for the epoxy coatings modified with ABP1. The calculated diffusion coefficient of water in the modified epoxy coatings were decreased from $5.33 \times 10^{-7}$ to

![Fig. 13. EIS spectra in Bode plot for epoxy coating without modification with hygrothermal cycle.](image)

![Fig. 14. EIS spectra in Bode plot for epoxy coating modified with various contents of ABP1 as a function of hygrothermal cycle: (a) ES1-1, 0.5 wt%; (b) ES1-2, 2.5 wt%; (c) ES1-3, 5.0 wt%; and (d) ES1-4, 7.5 wt%.](image)
1.32 \times 10^{-7} \text{ cm}^2/\text{s} with an increase in the modifier content, and the water uptake into the coatings were decreased from 4.3 vol.% to 2.88 vol.% at 25 ^\circ\text{C} with an increase in the modifier content.

Fig. 11 shows $\ln C – \sqrt{t}$ curves for the epoxy coatings modified with ABP2. The diffusion coefficients of water in the modified epoxy coatings were calculated to be in the range of $4.86 \times 10^{-7}–1.22 \times 10^{-7} \text{ cm}^2/\text{s}$, depending on the modifier content, and the water uptake in the coating decreased from 4.5 vol.% to 2.67 vol.% at 25 ^\circ\text{C} with an increase in the modifier content. Fig. 12 shows $\ln C – \sqrt{t}$ curves for the epoxy coatings modified with ABP3. The calculated diffusion coefficient of water in the modified coatings reduced to $8.19 \times 10^{-8} \text{ cm}^2/\text{s}$ from $4.9 \times 10^{-7} \text{ cm}^2/\text{s}$ and the water uptake into the coating decreased from 3.7 to 1.83 vol.% at 25 ^\circ\text{C}, with increasing the ABP3 from 0.5% to 7.5%. The calculated values of water diffusion coefficient and water uptake were given in Table 2. These results clearly demonstrate that the water diffusion coefficients in the epoxy coatings modified with either ABP1 or ABP2 or ABP3 are much lower than that of the pure epoxy coating, and hence the water uptake into the modified coatings is much less than that into the pure epoxy coating. The effects of modification on the retardation of water transport is more appreciable in the coating modified with greater molecular weight such as ABP3 at higher modifier content.

![Fig. 15. EIS spectra in Bode plot for epoxy coating modified with various contents of ABP2 as a function of hygrothermal cycle: (a) ES2-1, 0.5 wt%; (b) ES2-2, 2.5 wt%; (c) ES2-3, 5.0 wt%; and (d) ES2-4, 7.5 wt%.](image-url)
3.3. Effects of modifier on corrosion protectiveness from the EIS results

The corrosion protection of the modified epoxy coated steel was examined by EIS combined with hygrothermal cycling test [22–26]. Fig. 13 shows EIS spectrum measured for the unmodified epoxy coated on steel as a function of cycle in the hygrothermal test. Impedance modulus of log $|Z|$ at 0.1 Hz decreased even after one cycle of the hygrothermal test, and then continues to reduce with cycling, which was associated with an occurrence of corrosion at carbon steel, as will be shown shortly.

Fig. 14 shows the EIS spectrum as a function of cycle in the hygrothermal test for carbon steel coated with the epoxy modified with ABP1. Evidently, the impedance modulus $|Z|$ of ES1-1 (0.5 wt% of ABP1) at 0.1 Hz was dropped to a low value after 30 cycles. However, ES1-2 (2.5 wt% of ABP1), ES1-3 (5.0 wt% of ABP1) and ES1-4 (7.5 wt% of ABP1) showed the constant impedance modulus at 0.1 Hz even after 45 cycles. Fig. 15 shows the EIS spectrum as a function of cycle in the hygrothermal test for carbon steel coated with the epoxy modified with ABP2. The impedance modulus for ES2-1 (0.5 wt% of ABP2) at 0.1 Hz was decreased dramatically to a low value after 30 cycles. However, ES2-2 (2.5 wt% of ABP2), ES2-3 (5.0 wt% of ABP2) and ES2-4 (7.5 wt% of ABP2) showed the constant impedance modulus at 0.1 Hz after 45 cycles, suggesting that corrosion did not occur on the coated carbon steel.

Fig. 16. EIS spectra in Bode plot for epoxy coating modified with various contents of ABP3 as a function of hygrothermal cycle: (a) ES3-1, 0.5 wt%; (b) ES3-2, 2.5 wt%; (c) ES3-3, 5.0 wt%; and (d) ES3-4, 7.5 wt%.
Fig. 16 shows EIS spectrum as a function of cycle in the hygrothermal test for carbon steel coated with the epoxy modified with ABP3. The impedance modulus of ES3-1 (0.5 wt% of ABP3) at 0.1 Hz decreased to a low value after 30 cycles. However, ES3-2 (2.5 wt% of ABP3), ES3-3 (5.0 wt% of ABP3) and ES3-4 (7.5 wt% of ABP3) showed the constant impedance modulus at 0.1 Hz after 45 cycles.

Fig. 17 shows effects of modifier type and its content on the corrosion morphology on the carbon steel coated with or without modifier. Evidently, localized corrosion occurred by an electrochemical reaction of carbon steel with water that had been transported to steel surface by diffusion through the coating layer during the hygrothermal test. The severity of localized corrosion was evaluated by the size of corrosion spot and its occurrence density in Fig. 7. For the carbon steel coated with the epoxy without modifier, size of corrosion spots appears to be most coarse with the maximum occurrence density. For the modified epoxy coated carbon steel, the size of corrosion spot and its occurrence density, generally, decreased either with an increase in the molecular weight of modifier or...
with an increase in the modifier content at the specific modifier. When compared the results in Fig. 17 and water transport behaviors through the modified or the unmodified coatings in Table 2, it is evident that the modified epoxy coating with lower diffusion coefficient or lower water uptake caused less corrosion attack on carbon steel. Further, the decrease in the impedance modulus $|Z|$ at low frequency region with cycling in hygrothermal test for the pure or the modified epoxy coatings, shown in Figs. 13–16, associated with initiation and growth of localized corrosion on carbon steel as well as the increase in water uptake into the coating.

4. Conclusions

Conclusions drawn from the work are as follows:

1. The phase separation tendency between epoxy and modifier in the modified epoxy coating is more appreciable in the epoxy coatings modified with higher molecular weight such as ABP3, confirming that the modifier ABP3 is distributed dominantly on the top layer of the coating.

2. The surface properties of pure epoxy coating was changed from hydrophilic to hydrophobic by the modification, and the hydrophobic tendency of the coating surface is more appreciable when the modification was done by a modifier with high molecular weight such as ABP3.

3. Water diffusivity and water uptake into the epoxy coatings modified with ABP were much lower than those into the pure epoxy coating. The effects of modification on the retardation of water transport are more appreciable in the coating modified with greater molecular weight such as ABP3 at higher modifier content.

4. The decrease in the impedance modulus $|Z|$ at low frequency region with cycling in hygrothermal test for epoxy coatings was associated with the initiation and growth of localized corrosion on carbon steel. The size of corrosion spot and its occurrence density of the modified epoxy coated carbon steel generally decreased either with an increase in the molecular weight of modifier or with an increase in the modifier content, confirming that corrosion protectiveness of the modified epoxy coating is well agree with its water transport behavior.

References