Friendly to Environment Heterocyclic Adducts as Corrosion Inhibitors for Steel in Water-Borne Paints

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ABSTRACT: Two groups of emulsion paints were formulated to evaluate the efficiency of emulsified heterocyclic adducts: 2-mercaptothiazoline (2-MT), 2-mercaptobenzothiazole (2-MBT), 2-mercapto-5-methyl-1,3,4-thiadiazole (2-MMT), and 3-mercapto-4-methyl-4H-1,2,4-triazole (3-MMT). Different concentrations of 2-MT adduct, which has the simplest structure were added in water-borne paint formulations based on urabrid AC 100 emulsion resin to detect the optimum concentration range of the adduct as corrosion inhibitor. The efficiency of all the emulsified adducts has been studied at constant concentration within the optimum range in order to arrange them according to their efficiency as corrosion inhibitor for mild steel. Chemical, mechanical, corrosion resistance and water up-take tests of paint films were measured. Weight loss measurements (mg/cm^2), for steel panels under paint films and the steel corrosion inhibition efficiency of adduct has been determined. It was found that the prepared water-borne adducts could protect steel from corrosion and their efficiencies as corrosion inhibitors could be arranged in descending order: 3-MMT > 2-MMT > 2-MBT > 2-MT adducts. © 2010 Wiley Periodicals, Inc. J Appl Polym Sci 117: 1270–1278, 2010

Key words: coatings; resists; orientation; heteroatom-containing polymers; adsorption

INTRODUCTION

Over the recent years, water-based paints have been extendedly produced, under increasing environmental restrictions. These coatings are widely recognized as the environmentally friendly paints due to their water-based resin composition and low level of volatile organic compounds (VOC). Stricter environmental laws in 1950s have intensified researches on water-based paints, leading to a gradual substitution of solvent-based counterparts since 1970s.[1–3] Less volatility, more safety, especially against fire risk, and better hygienic conditions during production and application are the main advantages of using water-based paints.[4] In addition, more safe organic corrosion inhibitors can be introduced in paint formulations, in additives level, instead of toxic anticorrosive pigments. Organic corrosion inhibitors provide metal protection by various mechanisms. The compound's functional groups play an important role in their activity. Among the more important types of functional groups are amines, hydroxyls, mercaptans, sulfonates, and nitrogen in heterocyclic compounds.[5–9] Heteroatom-containing polymers such as nitrogen and sulfur are of particular importance. They often provide excellent inhibition compared with compounds containing only nitrogen or sulfur.[10] The corrosion inhibiting property of these compounds is attributed to their molecular structure. The planarity (π) and lone pair of electrons present on heteroatoms are the important structured features that determine the adsorption of these molecules on the metal surface.[11] Mechanism of action of organic inhibitors is function by physical adsorption (Van der Waal's forces), chemisorptions, or by π-bond orbital adsorption. The variation of electron density at the reactive center can affect the chemisorptions bond strength between the inhibitor and the metal.[12–16] The aim of this work is to evaluate the prepared and emulsified 2-mercaptothiazoline (2-MT), 2-mercaptobenzothiazole (2-MBT), 2-mercapto-5-methyl-1,3,4-thiadiazole (2-MMT), and 3-mercapto-4-methyl-4H-1,2,4-triazole (3-MMT) adducts as corrosion inhibitors for mild steel in water-borne paints.

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MATERIALS AND TECHNIQUES

In this study, the used materials were collected in Table I.

The test methods were summarized in Table II.

RESULTS AND DISCUSSION

Epoxydized soybean oil was allowed to react with 2-mercaptothiazoline (2-MT), 2-mercaptobenzothiazole

TABLE I
Materials

Ingredient	Property	Source
Epoxidized soybean oil	Oxirane content 6.5%	Hobum company, Germany
2-Mercaptothiazoline	M. wt. 119.19 and m.p. 105–107°C	Sigma-Aldrich
2-Mercaptobenzothiazole	M. wt. 167. 25 and m.p. 179°C	Sigma-Aldrich
2-Mercapto-5-methyl-1,3,4-thiadiazole	M. wt. 132.198 and m.p. 182−186°C	Sigma-Aldrich
3-Mercapto-4-methyl-4H-1, 2, 4-triazole	M. wt. 115.16 and m.p. 167–173°C	Sigma-Aldrich
Urabrid AC 100 emulsion resin	A hybrid, alkyd emulsion and polymer dispersion. Its solid content 42–44	DSM Company
Talc	60–63% silica, 30–32% magnesium oxide, <1.0% iron oxide, <1.5% calcium oxide, and <1.5% aluminum oxide	El-Nasr Phosphate Company, Cairo
Titanium dioxide (Rutile R-902)	91% Titanium dioxide, 4.5% aluminum oxide, 2% silicon oxide, and 2% additives	Du-pont Company
Butyl glycol (Dowanal EB)	Fast-evaporation coalescing agent. Evaporation rate (*n*-butyl acetate = 1) is 0.079	DOW Company
Texanol	Evaporation rate (*n*-butyl acetate = 1) is 0.002	Eastman Chemical Company
Iso-propanol	Evaporation rate (*n*-butyl acetate = 1) is 2.88	TCI Company
Dispersing and wetting agent (EDAPLAN 482)	Solution of acrylic polymer	Münzing Chemie, Germany
Anti-foaming agent (AGITAN 731)	Blend of modified organo polysiloxanes with nonionic alkoxylated compounds, pH 7	Münzing Chemie, Germany
Drier (Dapro 7007)	Chelating catalyst designed to replace cobalt driers	Daniel Products Company, USA
Biocide (MERGAL K6N)	Nonionic	Troy Chemie GmbH, Germany
Flash rust inhibitor	Ammonium benzoate ($C_7H_9O_2N$)	Fluka Company, Germany
pH stabilizer	Ethanolamine (C_2H_7NO)	Fluka Company, Germany
Thickening agent (TAFIGEL PUR 60)	Nonionic polyurethane in butyltriglycol/water, pH 7	Münzing Chemie, Germany

All solvents and chemical reagents were of pure grade.

(2-MBT), 2-mercapto-5-methyl-1,3,4-thiadiathole (2-MMT), and 3-mercapto-4-methyl-4H-1,2,4-triazole (3-MMT) for 4–6 h at temperature 110–190°C according to melting point of each reactant. Both reactants and products were characterized physically and by infra-red spectroscopy (IR). The prepared adducts, Figure 1, have been emulsified using T20, span 20, and span 80, in order to disperse the prepared adduct (oil phase) in water.[22]

In this research, two groups of water-borne paints have been formulated to evaluate the emulsified 2-mercaptothiazoline (2-MT), 2-mercaptobenzothiazole (2-MBT), 2-mercapto-5-methyl-1,3,4-thiadiazole (2-MMT), and 3-mercapto-4-methyl-4H-1,2,4-triazole (3-MMT) adducts as corrosion inhibitors for mild steel. Figure 1 represents the chemical structure of the mentioned adducts.

Group I: 2-MT adduct as corrosion inhibitor

This group comprises 11 formulations based on urabrid AC 100 resin. One formula (B1) is a blank, free from corrosion inhibitor and 10 formulations (B2–B11) contain different concentrations (0.05%, 0.06%, 0.07%, 0.08%, 0.09%, 0.10%, 0.11%, 0.12%, 0.13%, 0.14%, and 0.15% as solid) of the emulsified

TABLE II
Test Methods

Property	Test method	Property	Test method
Preparation of emulsion paint formulations	Refs. 17 and 18	Fineness of grind	ASTM D 1210-96
Solid content	ASTM D 2369-01	Preparation of steel panel surface	Ref. 19
Film application	ASTM D 823-95 (2001)	Dry film hardness	ASTM D3363-92
Adhesion test	DIN 53151	Bending test	ASTM D522-93a (2001)
Preparation of artificial sea water	Ref. 20	Corrosion scratch test	ASTM D 1654-92 (2000)
Alkali and acid resistance test	DIN 53168	Blistering resistance test	ASTM D 714-87 (2000)
Weight loss measurements	ASTM D 2688-94 (1999)	Water up-take measurements	Ref. 21

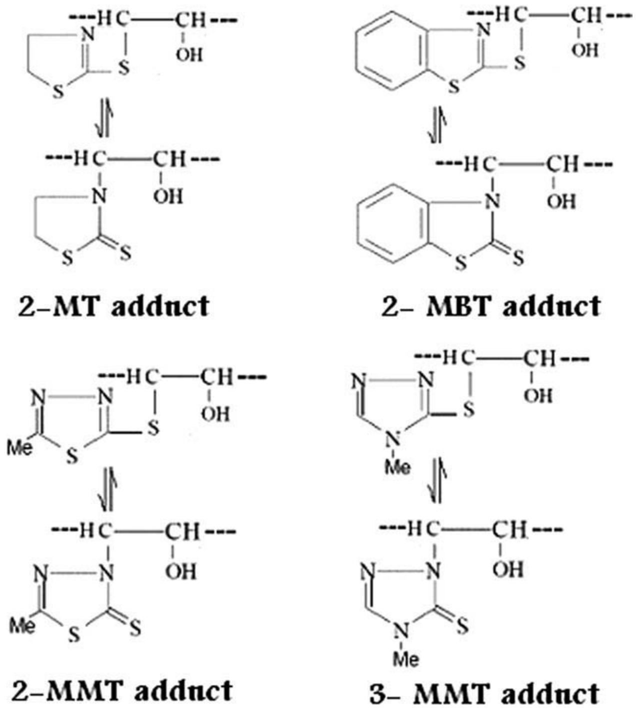


Figure 1 Chemical structure of the prepared adducts.

2-mercaptothiazoline (2-MT) adduct, which has the simplest chemical structure.

The aim of this group was to optimize the best concentration of the prepared (2-MT) adduct, as corrosion inhibitor in water-borne paint formulations based on urabrid AC 100 emulsion.

The prepared paints were listed in Table III. All concentrations of thiol adduct in the paint formulations were based on the weight of solid adducts added to 100 gm of liquid emulsion paint. Flash rusting inhibitor (ammonium benzoate) was added to all formulations in this group to prevent the corrosion phenomenon known as flash rusting, which occurs in water-borne coatings due to the direct contact of water to ferrous metal surface during drying.

Physical, chemical and mechanical tests of all paint formulations of group (I) are listed in Table IV. The collected results showed that, the addition of different concentrations of the emulsified 2-MT adduct had more or less, no effect before corrosion tests. All films of the investigated formulations showed high adhesion to steel panels, and excellent flexibility (bending and ductility). All coated glass samples were not affect when immersed in acids, alkali and water, this proving a distinguished chemical resistance of paint films. Results of other mechanical properties such as hardness were reasonable for all paint formulations.

The influence of emulsified 2-MT adduct on water up-take percentage of paint film of Group (I) up to 30 days had intensively studied, the obtained results were given in Table V and plotted in Figure 2. It was clear that, the minimum water up-take had been obtained with Formula B7, after 30 days immersion in distilled water, whereas the maximum water up-take was observed at Formula B12. These results were revealing that the water absorption of water-borne coatings was affected by amount and nature of polar groups in dry paint film.

The results of corrosion resistance tests were given in Table VI. The painted metal plates of this group were detected for blistering resistance of coating films, failure around the scribe and degree of rusting of metal surface under paint films, after immersion of plates in artificial seawater for 28 days. The results showed that 2-MT adduct resists metal corrosion and the best corrosion resistance was obtained

TABLE III
Emulsion Paint Formulations of Group I

Composition	Formula no.											
	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
Mill base (I)	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1
Urabrid AC100	39.54	39.54	39.54	39.54	39.54	39.54	39.54	39.54	39.54	39.54	39.54	39.54
Texanol	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Flash rust inhibitors	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Butyl glycol	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Ethanol amine	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2-MT	–	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15
Defoamer	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Biocide	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Drier	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Water	8.16	8.11	8.10	8.09	8.08	8.07	8.06	8.05	8.04	8.03	8.02	8.01
Thickener	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Total weight	100	100	100	100	100	100	100	100	100	100	100	100

Formulation constants: Solid content 47.6%, pH $\geq$ 8 and pigment binder ratio 1.8.

TABLE IV
Physical, Chemical, and Mechanical Properties of Paint Films of Group I

Test	Formula no.											
	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
Adhesion	Gt0	Gt0	Gt0	Gt0	Gt0	Gt0	Gt0	Gt0	Gt0	Gt0	Gt0	Gt0
Hardness	5H	5H	5H	4H	4H	4H	3H	3H	2H	2H	2H	H
Ductility	6.1	6.2	6.2	6.2	6.3	6.3	6.4	6.5	6.6	6.7	6.8	6.8
Bending	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Acid resistance	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Alkali resistance	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Water resistance	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass

TABLE V
Water Up-Take (%) for Paint Films of Group I

Formula no.	Time (days)					
	5	10	15	20	25	30
B1	11.23	13.35	15.65	18.16	19.94	21.11
B2	9.31	12.32	13.36	15.85	17.50	17.76
B3	9.04	11.80	13.58	15.56	17.36	17.65
B4	8.49	11.48	13.44	14.75	15.52	16.50
B5	6.53	10.41	12.50	13.93	14.91	15.56
B6	5.21	9.30	11.42	12.50	14.04	14.58
B7	5.18	8.96	11.05	12.28	13.34	14.03
B8	5.28	9.52	11.53	12.58	13.57	14.39
B9	8.01	11.04	13.10	14.53	15.46	16.22
B10	8.58	11.55	13.53	15.03	16.25	17.55
B11	9.94	12.53	14.35	16.50	17.58	19.30
B12	10.55	13.11	15.05	16.93	18.25	19.75

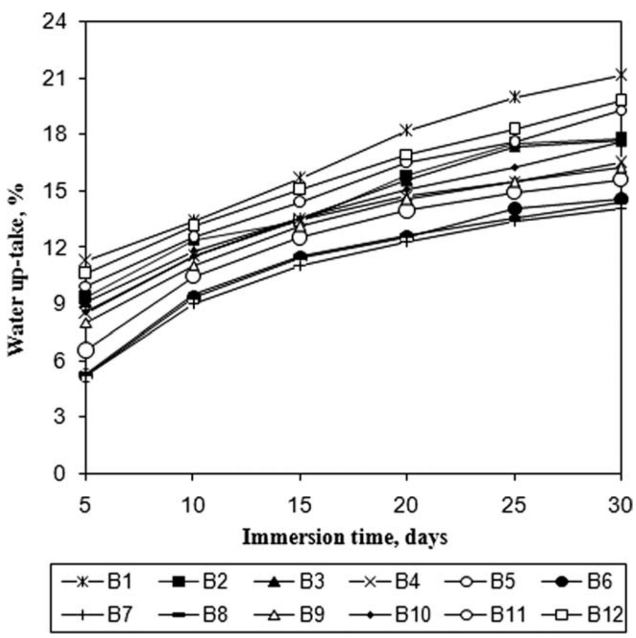


Figure 2 The variation in water up-take (%) with time of immersion of Group I.

in case of B5–B9 formulations. Figure 3 represents photographs of metal plate's failure around the scribe and degree of rusting of metal surface, after 28 days immersion in seawater. The photographs go hand in hand with the corrosion resistance test and B5–B9 showed the best corrosion resistance.

Weight loss variation of paint films of this group were given in Table VII and plotted in Figure 4. Weight loss measurements declared that the addition of 2-MT adduct decreased weight loss of mild steel, i.e., it had inhibition efficiency (IE). The increase of the amount of 2-MT adduct enhanced corrosion resistance up to 0.10 (Formula B7). At higher concentrations of 2-MT adduct than that concentration, corrosion starts to appear again in the scratch with some loss of adhesion of the paint films to the metal surface. The slightly higher values of weight loss observed in paint Formula B11, B12 may be explained as follows.

The emulsified adduct at optimum concentration may form an adsorbed monolayer film on the metal surface and the adduct molecules may direct themselves to be adsorbed on the metal surface via the lone pairs of electrons on the sulfur atom of the (—SH) group and oxygen atom of the hydroxyl

TABLE VI
Corrosion Resistance Tests for Paint Films of Group I

Test formula no.	Corrosion resistance	Degree of blistering	Corrosion scratch test
B1	s.t.	8F	B
B2	v.s.t.	8F	B
B3	v.s.t.	6F	B
B4	v.s.t.	6F	B
B5	c	10	A
B6	c	10	A
B7	c	10	A
B8	c	10	B
B9	c	10	B
B10	v.s.t.	6F	C
B11	v.s.t.	6F	C
B12	v.s.t.	8F	C

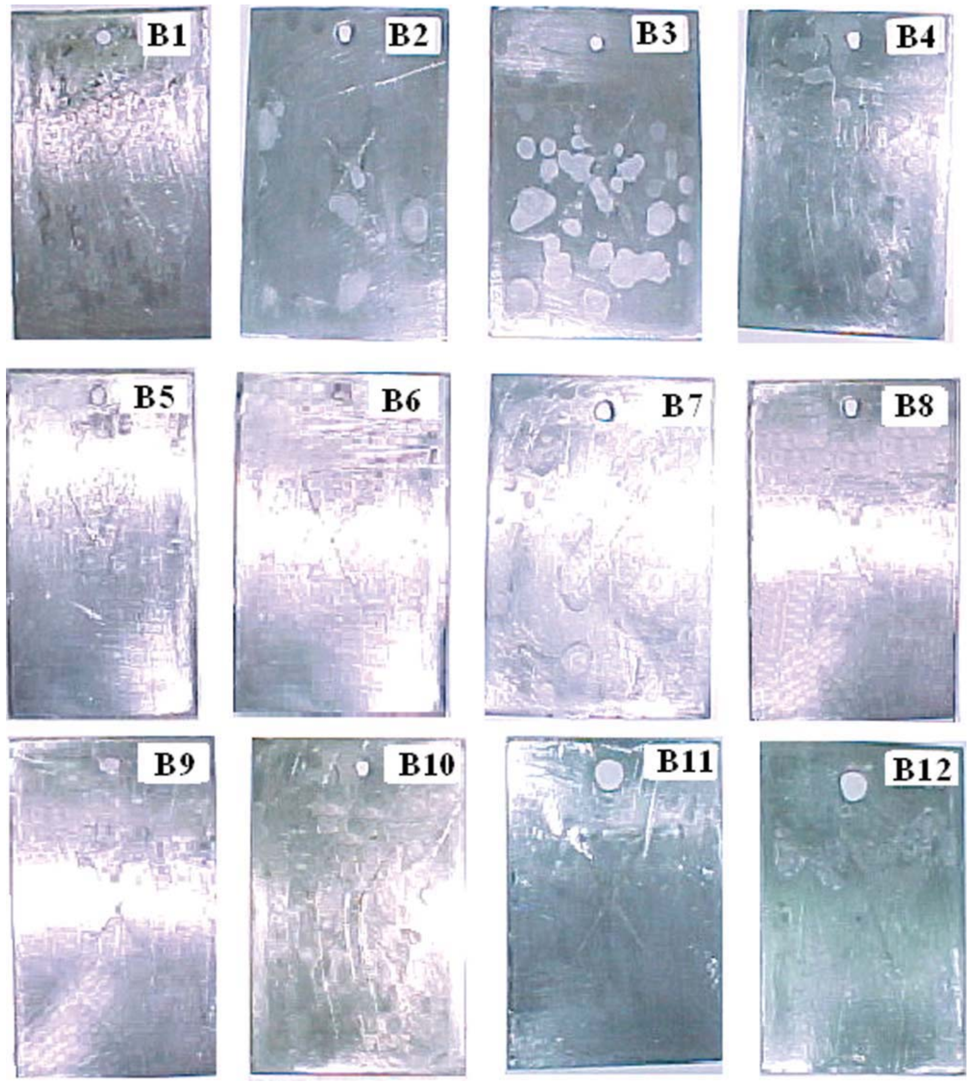


Figure 3 Corrosion progress under paint films of Group I after 28 days immersion in artificial seawater. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

group. Because of this adsorption, the adhesion of the paint films may be improved. Moreover, the orientation of the inhibitor molecule may be changed, hydrocarbon tails of the oil, which is originally hydrophobic in character, may find the chance to orient themselves away from the metal interface toward the coat bulk, and thus further protection was provided by the formation of originally hydrophobic network, which excludes water and aggressive ions from the metal surface. Figure 5(a) may explain the proposed mechanism.

On the other hand, the excess amounts of the emulsified adduct may lead to random distribution of the excess amount in the bulk of emulsion paint film. These unarranged polar molecules may act to drive more water molecules from the surrounding medium through the hydrophilic groups; consequently, they may oppose the action of protection

TABLE VII
Weight Loss Measurements (mg/cm^2), for Steel Panels Under Paint Films of Group I

Formula no.	Time (days)					
	10	20	30	40	50	60
B1	0.115	0.210	0.396	0.568	0.790	0.971
B2	0.104	0.192	0.306	0.415	0.523	0.626
B3	0.097	0.181	0.276	0.374	0.461	0.552
B4	0.083	0.170	0.247	0.313	0.381	0.443
B5	0.075	0.138	0.201	0.265	0.323	0.385
B6	0.051	0.085	0.130	0.181	0.240	0.315
B7	0.025	0.063	0.108	0.151	0.210	0.273
B8	0.036	0.074	0.122	0.170	0.226	0.287
B9	0.058	0.112	0.169	0.218	0.279	0.328
B10	0.071	0.125	0.184	0.244	0.310	0.363
B11	0.080	0.152	0.220	0.280	0.343	0.403
B12	0.082	0.160	0.236	0.302	0.361	0.426

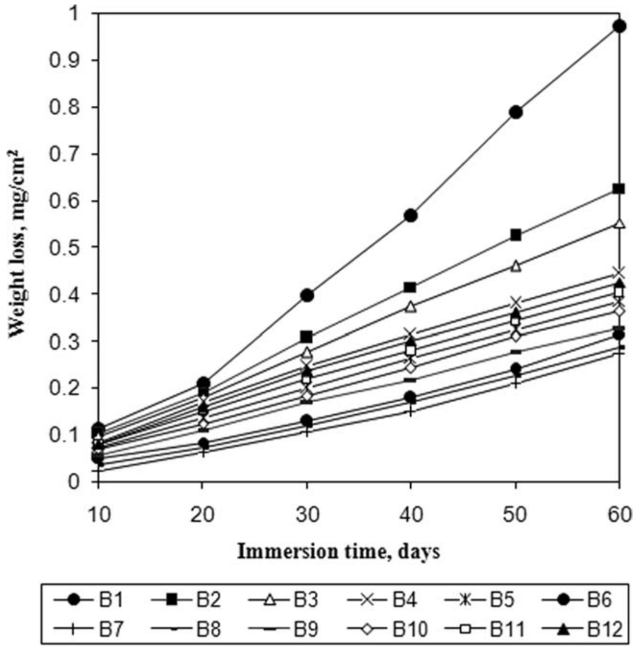
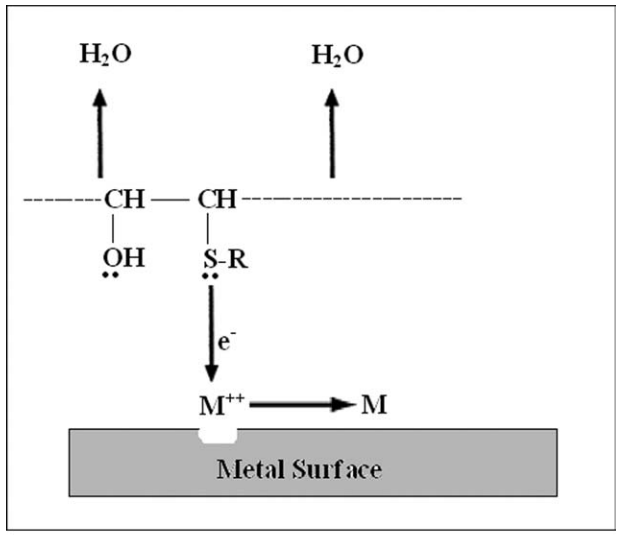


Figure 4 The dependence of weight loss on the immersion time for paint formulations of Group I.



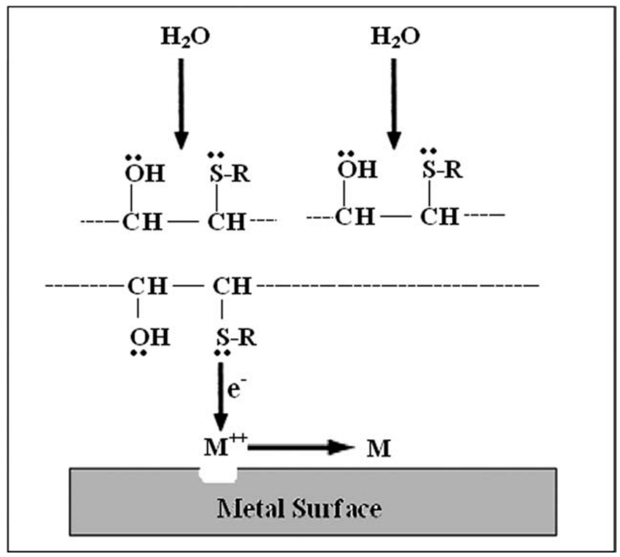


Figure 5 (a) Mechanism of corrosion inhibition at optimum concentration of inhibitor. (b) Mechanism of corrosion inhibition at higher concentration of inhibitor.

and produce emulsion paint films of less protective properties on prolonged exposure. Figure 5(b) may illustrate this phenomenon.

It was stimulating to study the IE of different concentrations of (2-MT) adduct in urabrid AC 100 emulsion binder. The percentage of IE can be measured according to the following equation:

$$\text{IE}\ (\%) = \{(W_o - W_i)/W_o\} \times 100$$

where W_o is the weight loss values for metal of paint films without adduct, and W_i is the weight loss values in the presence of 2-MT adduct. Both Table VIII and Figure 6 represent the efficiency of different concentration of the adduct as corrosion inhibitor at concentrations (0.05, 0.06, 0.07, 0.08, 0.09, 0.10, 0.11, 0.12, 0.13, 0.14, and 0.15) in urabrid AC 100 paint films after 60 days immersion in artificial seawater.

Group II: Optimization of the best sulfur adduct as corrosion inhibitor

The aim of this group was to arrange the prepared emulsified adducts of 2-MT, 2-MBT, 2-MMT, and 3-MMT according to their efficiencies as corrosion inhibitor for mild steel. Four formulations based on urabrid AC 100 emulsion resin containing fixed concentration 0.10% as solid adduct.

This group comprised four paint formulations in addition to blank formula as shown in Table IX. The paint formulations B7, B13, B14, and B15 contained fixed concentration 0.10%, which was found to be the optimum concentration, of the prepared sulfur

TABLE VIII
Corrosion Inhibition Efficiency of Different Concentrations of (2-MT) Adduct

2-MT conc.	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15
IE (%)	35.53	43.15	54.38	60.35	67.56	71.88	70.44	66.22	62.62	58.49	56.12

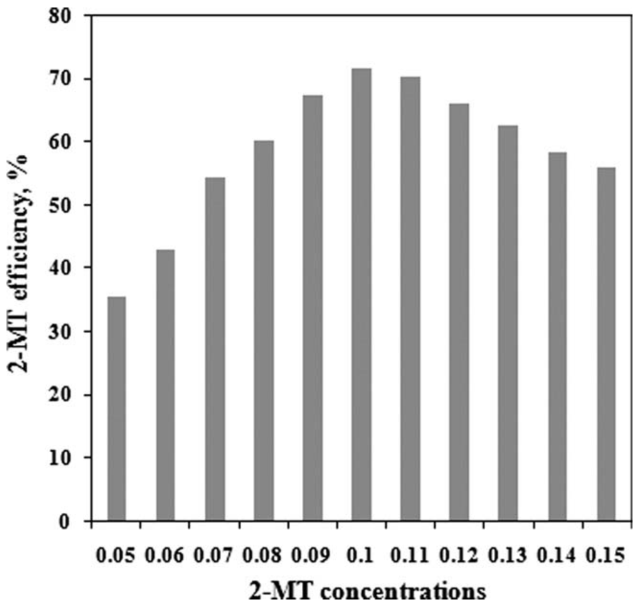


Figure 6 Variation of 2-MT concentrations versus corrosion inhibition efficiency.

adducts 2-MT, 2-MBT, 2-MMT, and 3-MMT, respectively.

Physical, chemical, and mechanical properties of paint films of this group were given in Table X. The obtained results indicated that the addition of the emulsified thiol adducts had more or less no effect on the investigated properties. All films of the investigated formulations showed excellent adhesion on steel panels, which was the basic requirement for high corrosion inhibition performance. The results of other properties such as hardness, ductility, and bending were reasonable and nearly equal to the blank. On the other hand, all paint films of this group were not affected by acids, alkali, and water, and this provided a distinguished chemical resistance of the paint films. This means that the addition of the prepared adducts had more or less no effect on the paint films.

The influence of emulsified thiol adducts on water up-take percentage of paint films of Group (II) up to 30 days was intensively studied. The obtained results were collected in Table XI and represented graphically in Figure 7.

Water up-take measurements showed that the paint formula B15, which contained 3-MMT adduct, had the lowest water up-take value. The water up-take of the emulsified prepared adducts could be arranged in the following descending order: 3-MMT > 2-MMT > 2-MBT > 2-MT.

The corrosion tests of the samples were evaluated as a function of immersion time. Blistering of the paint films, corrosion under the paint films, and rating of failure at the scribe were followed up at the end of immersion time (28 days). The results of this group were given in Table XII and represented graphically in Figure 8.

Corrosion resistance results declared that the blank Formula B1, which did not contain inhibitor, showed slight tarnishing corrosion resistance. Other formulations that contained inhibitors had best

TABLE IX
Emulsion Paint Formulation of Group II

Composition	Formula no.				
	B1	B7	B13	B14	B15
Mill base (I)	47.1	47.1	47.1	47.1	47.1
Urabrid AC100	39.54	39.54	39.54	39.54	39.54
Texanol	0.5	0.5	0.5	0.5	0.5
Flash rust inhibitors	2.0	2.0	2.0	2.0	2.0
Butyl glycol	1.0	1.0	1.0	1.0	1.0
Ethanol amine	1.0	1.0	1.0	1.0	1.0
2-MT	–	0.10	–	–	–
2-MBT	–	–	0.10	–	–
2-MMT	–	–	–	0.10	–
3-MMT	–	–	–	–	0.10
Anti-foaming agent	0.2	0.2	0.2	0.2	0.2
Biocide	0.1	0.1	0.1	0.1	0.1
Drier	0.2	0.2	0.2	0.2	0.2
Water	8.16	8.06	8.06	8.06	8.06
Thickener	0.2	0.2	0.2	0.2	0.2
Total weight	100	100	100	100	100

Formulation constants: Solid content 47.6%, pH $\geq$ 8 and pigment binder ratio 1.8.

TABLE X
Physical, Chemical, and Mechanical Properties of Paint Films of Group II

Tests	Formula no.				
	B1	B7	B13	B14	B15
Adhesion	Gt0	Gt0	Gt0	Gt0	Gt0
Hardness	5H	3H	4H	3H	3H
Ductility	6.1	6.3	6.2	6.3	6.4
Bending	Pass	Pass	Pass	Pass	Pass
Acid resistance	Pass	Pass	Pass	Pass	Pass
Alkali resistance	Pass	Pass	Pass	Pass	Pass
Water resistance	Pass	Pass	Pass	Pass	Pass

TABLE XI
Water Up-Take (%) for Paint Films of Group III

Formula no.	Time (days)					
	5	10	15	20	25	30
B1	11.23	13.35	15.65	18.16	19.94	21.11
B7	5.18	8.96	11.05	12.28	13.34	14.03
B13	4.13	7.90	9.87	11.50	12.83	13.15
B14	3.16	5.84	8.15	10.35	11.12	12.00
B15	2.21	4.52	6.90	8.61	10.05	11.17

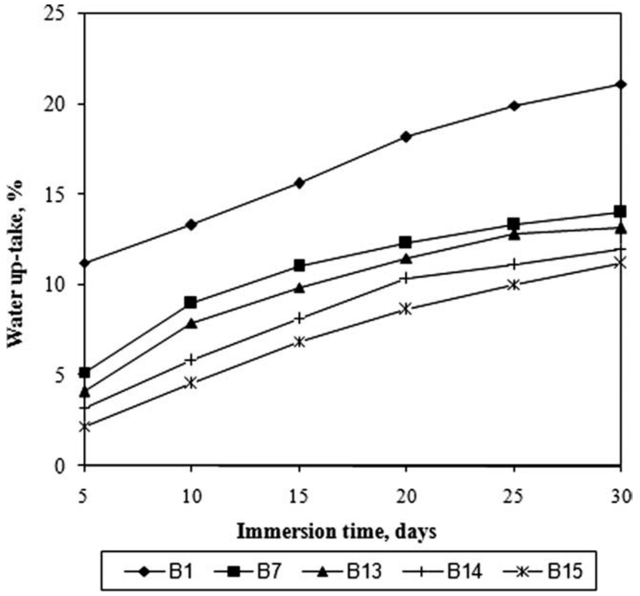


Figure 7 The variation in water up-take (%) with time of immersion of Group II.

corrosion IE, where bright clean surfaces were investigated under the paint films.

Weight loss measurements were given in the Table XIII and plotted in Figure 9. IT was revealed that the minimum weight loss values (0.241 mg/cm^2) had been observed with the steel panel coated by Formula B15, which contained 3-MMT adduct all over the immersion period (60 days).

A comparative study of corrosion inhibitors performance of the prepared emulsified adducts after 60 days 2-MT, 2-MBT, 2-MMT, and 3-MMT according to their inhibition efficiencies was shown in Table XIV and represented in Figure 10.

As could be seen that 3-MMT adduct revealed superior corrosion IE (about 75.18%), whereas in the case of 2-MMT adduct (about 74.87%), corrosion IE was attained. With respect to 2-MBT and 2-MT adducts, the IE were about 73.22% and 71.88%, respectively.

Finally, it could be concluded that the prepared adducts could be adsorbed on the mild steel surface and displaced water molecules on the surface to form a compact barrier thin film. This film could make coordination bond between inhibitors and iron

TABLE XII
Corrosion Resistance Tests for Paint Films of Group III

Test	Formula no.				
	B1	B7	B13	B14	B15
Corrosion resistance	s.t.	c	b	b	b
Degree of blistering	8F	10	10	10	10
Corrosion scratch test	B	A	A	A	A

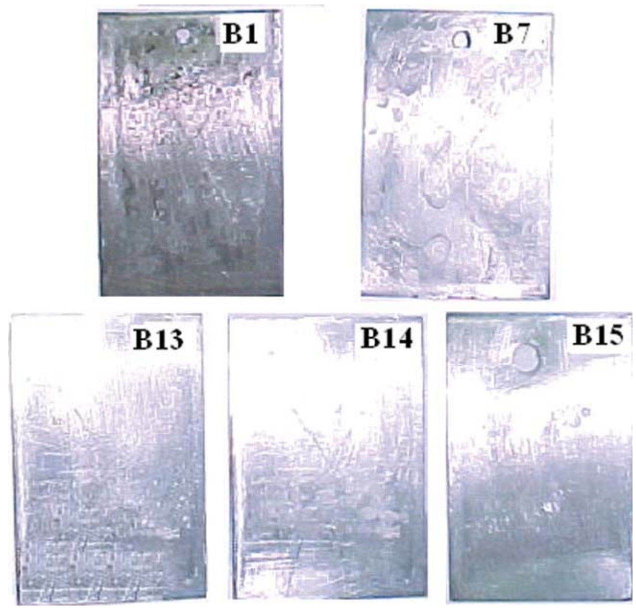


Figure 8 Corrosion progress under paint films of Group II after 28 days immersion in artificial seawater. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

TABLE XIII
Weight Loss Measurements (mg/cm^2), for Steel Panels Under Paint Films of Group II

Formula no.	Time (days)					
	10	20	30	40	50	60
B1	0.115	0.210	0.396	0.568	0.790	0.971
B7	0.025	0.063	0.108	0.151	0.210	0.273
B13	0.023	0.056	0.095	0.140	0.196	0.260
B14	0.018	0.043	0.081	0.123	0.177	0.244
B15	0.016	0.039	0.072	0.118	0.164	0.241

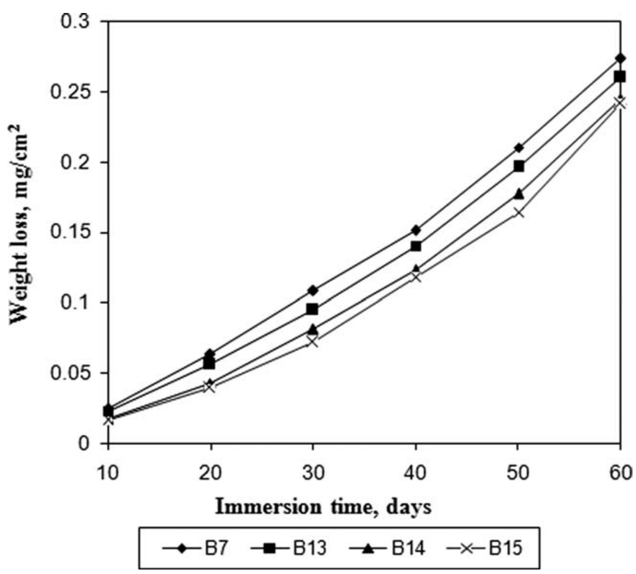


Figure 9 The dependence of weight loss on the immersion time for paint formulations of Group II.

TABLE XIV
Corrosion Inhibition Efficiency

Adduct type	2-MT	2-MBT	2-MMT	3-MMT
Efficiency (%)	71.88	73.22	74.87	75.18

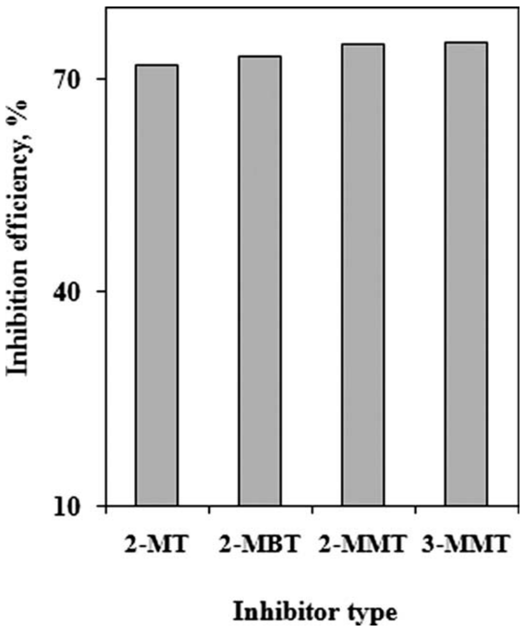


Figure 10 Adduct inhibitors versus corrosion inhibition efficiency.

surface causes higher IE. The ability of the molecule to chemisorb on the steel surface was depend on the electron density around the adsorption center of corrosion inhibitor.[23,24]

The obtained results indicated that the inhibition effeciency of the prepared adducts at the chosen concentration increased in the order: 2-MT < 2-MBT < 2-MMT < 3-MMT adducts. The difference in IE between the highest and lowest efficiency was low (3.3%).

CONCLUSIONS

Steel panels could be protected by addition of small concentrations of the emulsified 2-MT adduct to emulsion paint formulation free of anticorrosive pigments, and its optimum concentration range was found to be ranging from 0.09 to 0.11 g per 100 g of urabrid AC 100 emulsion paint. The efficiency of the emulsified prepared adducts as corrosion inhibitors could be arranged in the following descending order: 3-MMT > 2-MMT > 2-MBT > 2-MT.

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