Construction and Building Materials 189 (2018) 95–101

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

# The inhibition behavior of a water-soluble silane for reinforcing steel in 3.5% NaCl saturated $Ca(OH)_2$ solution

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## HIGHLIGHTS

- A water-soluble silane (APTS) was firstly investigated as corrosion inhibitor for reinforcing steel in alkaline solution.
- The silane behaves excellent corrosion inhibition efficiency and far beyond the traditional inhibitor of DMEA.
- The organic silane can be alternative for new generation of organic corrosion inhibitor.

## ARTICLE INFO

*Article history:*
Received 24 May 2018
Received in revised form 22 August 2018
Accepted 23 August 2018

*Keywords:*
Corrosion inhibitor
Silane
Amino alcohol
Saturated $Ca(OH)_2$ solution
Reinforcing steel
$Cl^-$

## ABSTRACT

The inhibition performance of a water-soluble silane on reinforcing steel in saturated $Ca(OH)_2$ solution contaminated by $Cl^-$ was investigated and compared with commonly organic inhibitor N,N-dimethylethanolamine (DMEA) using electrochemical techniques and surface analysis measurements. The results indicate that the lower concentration of APTS has better inhibition efficiency than DMEA, the largest inhibition efficiency are 70.1% and 97.4% for DMEA and APTS after 72 h immersion. DMEA promotes the interfacial layer by formation of $CaCO_3$ deposited on steel surface, while APTS changes the character of steel surface by adsorption and effectively inhibits the pitting corrosion.



## 1. Introduction

The reinforcement steel in concrete is normally in a passive state due to alkaline environment. However, the $Cl^-$ can diffuse through concrete and damage the steel rebar, which is one of the major reasons for deterioration of reinforcement concrete structures [1,2]. The application of corrosion inhibitors has been considered as one of most practical methods to inhibit the steel corrosion for its low cost and easy handling [3].

Corrosion inhibitors can be classified into two types of surface applied and admixture inhibitors composed of organic or inorganic substance. Nitrite-based substance was traditional inorganic inhibitor, which had been largely researched and proved the effective admixture. However, the risk of toxicity and damage of the environments for nitrite has restricted its use [4,5]. Therefore, more and more researchers are focusing on investigation of environmentally friendly inhibitors, such as amino alcohol, carboxylate, glycoside etc. [6–11]. DMEA is one kind of amino alcohol inhibitor, which had been largely investigated and applied in engineering, but the inhibition efficiency of DMEA is relatively lower only at 63–74% and only can improve the chloride threshold level when complex with organic acid [12,13]. Besides, there are some environment organic substances with higher corrosion inhibition efficiency, such as phytic acid and polyhydroxy C-glycosidic ketone. The largest the inhibition efficiency of them can be up to 84% and 99%, respectively [14,15], but these agents will delay cement setting and affect the cement strength.

Recent years, the use of silane impregnation for pre-treatments of galvanized steel and others alloy had been investigated and

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https://doi.org/10.1016/j.conbuildmat.2018.08.151
0950-0618/

exerted the better corrosion protection performance [16–18]. To the best of our knowledge, few articles focused on the silane as admixture to prevent the corrosion of reinforcement steel, except the hydrophobic silane as surface treatment on concrete for mitigating corrosion of steel by waterproof [19]. However, the hydrophobic silane cannot effectively be added into concrete for its poor dispersion in concrete or solution.

Therefore, the present study is to investigate the effectiveness of a water-soluble silane ((gamma-aminopropyltriethoxysilane (APTS)) as newly inhibitor for reinforcement steel in saturated $Ca(OH)_2$ solution. The electrochemical corrosion behavior of steel influenced by APTS was investigated by linear polarization resistance (LPR), potentiodynamic polarization curves, electrochemical impedance spectroscopy (EIS). The morphology and composition of steel surface were also evaluated by SEM, EDX and XRD. All of test were compared with amino alcohol inhibitor DMEA [12,20,21]. Besides, the corrosion inhibition mechanism of APTS and DMEA was also discussed.

## 2. Experimental work

### 2.1. Materials and sample preparation

The material used for present work was normal carbon steel cut from the steel bar. The composition is C 0.22%, Mn 1.4%, Si 0.35%, S 0.05%, P 0.045% and the rest of Fe. The steel were all ground gradually with SiC emery paper from $240^{\#}$, $400^{\#}$, $1000^{\#}$ to $2000^{\#}$, then polished by $Al_2O_3$ polishing powder with fineness 2.5 μm, finally rinsed with ethanol.

The APTS and DMEA are both chemical grade. Their molecular structures are shown in Fig. 1. The electrolyte are 3.5 wt% NaCl saturated $Ca(OH)_2$ solution with and without corrosion inhibitor. The blank specimen is steel in solution without inhibitor. The APTS and DMEA specimens are steel in solution containing different concentration of APTS and DMEA, respectively. All of the solutions are prepared from grade chemicals and bi-distilled water and keep the pH at 12.5 by NaOH.

### 2.2. Electrochemical measurements

A PAR 4000 electrochemical workstation (Princeton applied research) and a three-electrode flat plate corrosion cell were used for electrochemical measurements. The steel serves as working electrode leaving an exposed working area 1 $cm^2$, a platinum foil and Ag/AgCl electrode were used as counter electrode (CE) and reference electrodes (RE). RE was connected by salt bridge. Electrochemical tests were conducted after 1 h of the RE put into buffer solution when open circuit potential was stabilization.

Linear polarization resistance curve (LPR) was used to clarify inhibitors concentration on the inhibition effectiveness of steel. The sweep rate is 0.166 mV/s from -10mv to 10 mV versus the open circuit potential (OCP). The concentration of DMEA is 1, 5, 10, 15, 20, 30, 60, 120 and 240 mmol/L and the concentration of APTS is 1, 5, 10, 15, 20 and 30 mmol/L. The optimization content was chosen 120 mmol/L and 20 mmol/L for DMEA and APTS, respectively. Then the EIS and potentiodynamic polarization curves were implemented in the solution with those optimization concentrations for two kinds of inhibitors, respectively. EIS was performed at the OCP in the frequency range of 100 kHz–10 mHz with a 10 mV amplitude signal. After EIS tests, potentiodynamic polarization curves was conducted at a sweep rate of 0.5 mV/s from −200 mV vs OCP, stopped when the current density was up to 2 mA. All electrochemical tests were conducted on electrode in solution after 72 h immersion. The results of LPR were the average of three times tests, while the EIS and potentiodynamic polarization curves were chosen from one of three parallel tests.

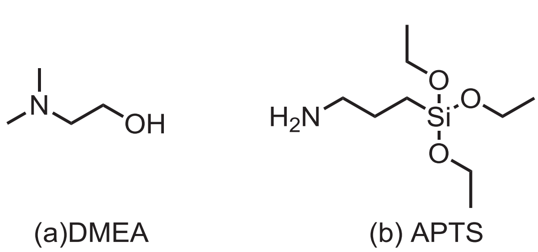


**Fig. 1.** Chemical structure of DMEA and APTS.

### 2.3. Surface analysis

Scanning electron microscopy (SEM) equipped with energy dispersive x-ray (EDX) analysis was employed to observe the morphologies of specimens in 3.5 wt% NaCl saturated $Ca(OH)_2$ solution with and without inhibitors after 72 h immersion. The equipment of SEM is from EDAX OCTANE PRO. The substrate composition on steel surface influenced by inhibitors was also examined by X-ray Powder Diffraction (XRD) from degree 5 to 80.

## 3. Results

### 3.1. Influence of inhibitors concentration on the corrosion resistance of steel

Fig. 2 depicts the linear polarization resistance ($R_p$) for electrode in 3.5 wt% NaCl saturated $Ca(OH)_2$ solution with different concentration of inhibitors. Where $R_p$ are fitted from linear polarization curves and represent the ability of inhibitor retard corrosion process. It can be seen that the $R_p$ increase with inhibitor concentration and become relatively stable when the concentration is larger than 120 mmol/L for DMEA. However, $R_p$ are sharply improved with APTS concentration increases. The maximum $R_p$ of APTS is much more one order of magnitude largely than that of DMEA, even though the concentration of APTS is only 20 mmol/L. It obviously indicates that the APTS has the better corrosion inhibition performance than DMEA. Base on the LPR results, the optimization concentration was 20 mmol/L and 120 mmol/L for APTS and DMEA, respectively.

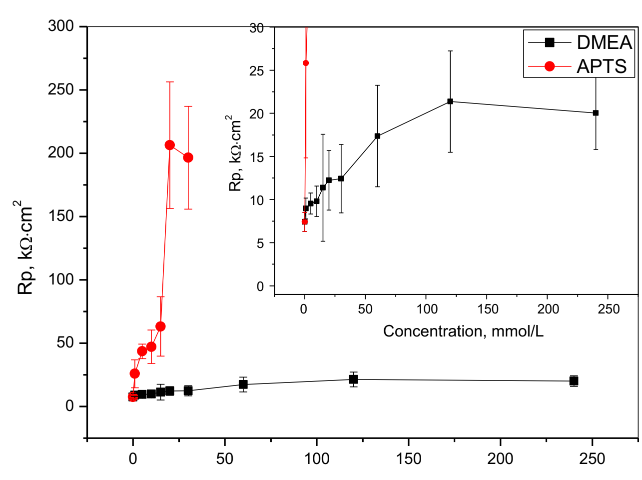


**Fig. 2.** Linear polarization resistance of steel in 3.5 wt% NaCl saturated $Ca(OH)_2$ solution with different concentration of corrosion inhibitors after 72 h immersion.