Effect of Ethanolic Extract of *Melia Azedarach* Fruit on Enhancing the Performance of Epoxy Coating for Corrosion Prevention of Mild Steel in 3.5 wt% NaCl

Milad Sheydaei [a,b,*]

[a] *Department of Polymer Engineering, Faculty of Engineering, University of Garmsar, Garmsar, Iran*

[b] *Corrosion Research Group, University of Garmsar, Garmsar, Iran*

Editor's note: Metals are prone to corrosion, and while chemical inhibitors are commonly used for protection, their toxicity limits their application. Sheydaei evaluated the anti-corrosion potential of ethanolic extract from *Melia Azedarach* fruit on mild steel in 3.5 wt% NaCl. The extract was used as a green modifier for sodium montmorillonite (Na+-MMT), creating a novel nanofiller (MA-MMT) incorporated into an epoxy coating. X-ray diffraction (XRD) confirmed that *Melia Azedarach* compounds penetrated the clay galleries, and polarization results indicated improved corrosion resistance with increased MA-MMT content, confirming its role as a mixed-type inhibitor.

doi: 10.22034/jams.2026.260307

How to cite: M. Sheydaei, *Journal of Applied Material Science*, **2026**, 2, 260307.

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Journal of Applied Material Science **2026**, 2, 260307
How to cite: M. Sheydaei, *Journal of Applied Material Science*, **2026**, 2, 260307.
Journal homepage: **jams.hsu.ac.ir**

Communication

Effect of Ethanolic Extract of *Melia Azedarach* Fruit on Enhancing the Performance of Epoxy Coating for Corrosion Prevention of Mild Steel in 3.5 wt% NaCl

Milad Sheydaei [a,b,*]

[a] *Department of Polymer Engineering, Faculty of Engineering, University of Garmsar, Garmsar, Iran*

[b] *Corrosion Research Group, University of Garmsar, Garmsar, Iran*

Abstract

Metals are always subject to damage by corrosion. Therefore, the use of chemical inhibitors has always been the most common solution to protect metals from corrosion. However, due to the toxicity of most chemical inhibitors, their use has been limited. For this reason, researchers are constantly evaluating alternative methods to chemical inhibitors. One of these methods is the use of plant extracts. Typically, they contain bioactive compounds that have antimicrobial properties in addition to anti-corrosion properties. In this study, an attempt was made to evaluate the anti-corrosion potential of the ethanolic extract of *Melia Azedarach* fruit on mild steel in 3.5 wt% NaCl. For this purpose, the ethanolic extract of *Melia Azedarach* fruit was used as a green modifier for sodium montmorillonite (Na^+-MMT) to produce a novel nanofiller (MA-MMT) that was incorporated into an epoxy (EP) coating to protect mild steel against corrosion. X-ray diffraction (XRD) analysis confirmed the successful penetration of *Melia Azedarach* compounds into the clay galleries. Polarization results showed that the corrosion resistance gradually improved with increasing MA-MMT content. Also, MA-MMT acted as a mixed-type inhibitor.

Keywords: Green chemistry; Sodium montmorillonite; Inhibition efficiency.

1. Introduction

One of the most important problems that threatens any metal structure is corrosion [1]. Countries constantly allocate huge budgets for the problems that this mysterious phenomenon creates for metal structures [2]. Mild steel always has a special place in the eyes of industrialists in various applications [3]. It is commonly used in the production of various products such as machinery parts, reinforcement bars, ship hulls, transmission pipelines, and storage tanks [4, 5]. Although mild steel has many advantages, it always has limitations such as its high susceptibility to corrosion (especially in aggressive environments) [6]. Among the

* Corresponding author.
Email address: md.sheydaei@fmgarmsar.ac.ir (M. Sheydaei)

Received 26 August 2026
Revised 05 September 2026
Accepted 06 September 2026
Available online 07 September 2026

https://doi.org/10.22034/jams.2026.260307

various methods of corrosion control, the use of polymer coatings and chemical inhibitors is still one of the most common [7-12]. Although chemical inhibitors have a high ability to prevent corrosion, their toxicity and harmful environmental effects severely limit their use [13]. Many of them contain heavy metals that pose serious risks to aquatic life and human health [14, 15]. Therefore, researchers have investigated various candidates as green inhibitors. The use of plant extracts has been considered one of the most promising. Plants are in the spotlight due to their ease of availability, renewability, biodegradability, and non-toxicity [16]. Among the diverse plant species, the *Melia Azedarach* tree, native to Australia, is known as a prolific seed producer and is invasive outside its native range and is considered a weed in many countries because of its ability to colonize an area (via seeds dropped by birds) if left unchecked [17, 18]. In this study, the corrosion resistance of epoxy coatings was evaluated using ethanolic extracts of *Melia Azedarach* fruit and Na^+-MMT.

2. Experimental

2.1. Materials

The Mild Steel was obtained from Iranian Mobarakeh Steel Company. The Na^+-MMT (purity ≥ 98%) and mild steel were obtained from Rockwood Company (USA). Epoxy resin (Bisphenol A diglycidyl ether, purity ≥ 99%) and curing agent (Jeffamine D230, purity ≥ 99%) were supplied by Taak Resin Kaveh Company (Iran). Also, *Melia Azedarach* fruit (see Figure 1) was obtained from the Garmsar University Park area (Garmsar, Semnan Province, Iran). Also, solvents and other consumables were purchased from Merck Chemical Company.

Figure 1. *Melia Azedarach* tree.

2.2. *Preparation of extract, MA-MMT, and EP/MA-MMT coatings*

Fruit extract and MA-MMT were prepared as reported in the literature [9-12]. To prepare the coatings, first, the EP (containing MA-MMT) was added to xylene and methyl ethyl ketone (1:1). Next, the mixture was stirred for 30 min, then the curing agent was added at a ratio of 1:2 (relative to resin), and stirring continued for another 5 min. The prepared coating mixture was applied onto the substrates. The mild steel was covered with the mixture and kept at ambient temperature for 1 day, and finally placed in an oven at 80 °C for 24 h. Also, all ratios used were by weight. The concentrations of MA-MMT (0, 1.5, and 3 wt.%) were selected. Also, the thickness of the layer applied to the substrates was 120 μm, and the final thickness (after drying) was 80 ± 5 μm.

2.3. *Measurements*

XRD measurements were performed using an X'Pert Pro MPD diffractometer (Panalytical). A field emission scanning electron microscope (FE-SEM, MIRA4 model-TESCAN) was used to evaluate the coatings. Electrochemical measurements were performed using a potentiostat/galvanostat instrument (CorrTest CS350) with a conventional three-electrode cell configuration. The corrosion current density (i_{corr}) was determined by Tafel extrapolation of the anodic and cathodic branches. The Corrosion Rate (C.R) and Inhibition efficiency (IE%) were calculated via Equations 1 and 2. It should be noted that in Equation 1, the corrosion current density (μA/cm^2), molar mass (g/mol), charge number, and density (g/cm^3) of the tested metal are i_{corr}, MW, n, and d, respectively. Also in Equation 2, i_{corr} (pure) and i_{corr}

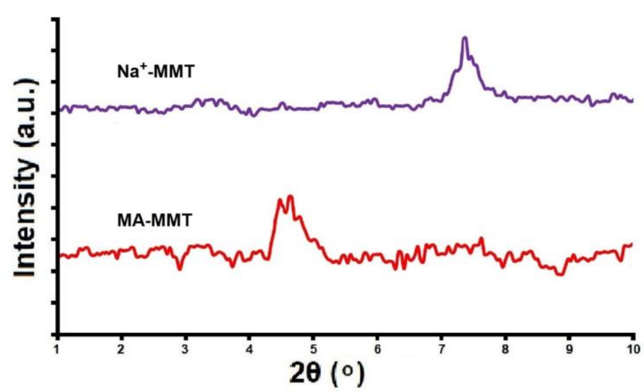

Figure 2. XRD patterns of Na^+-MMT and MA-MMT.

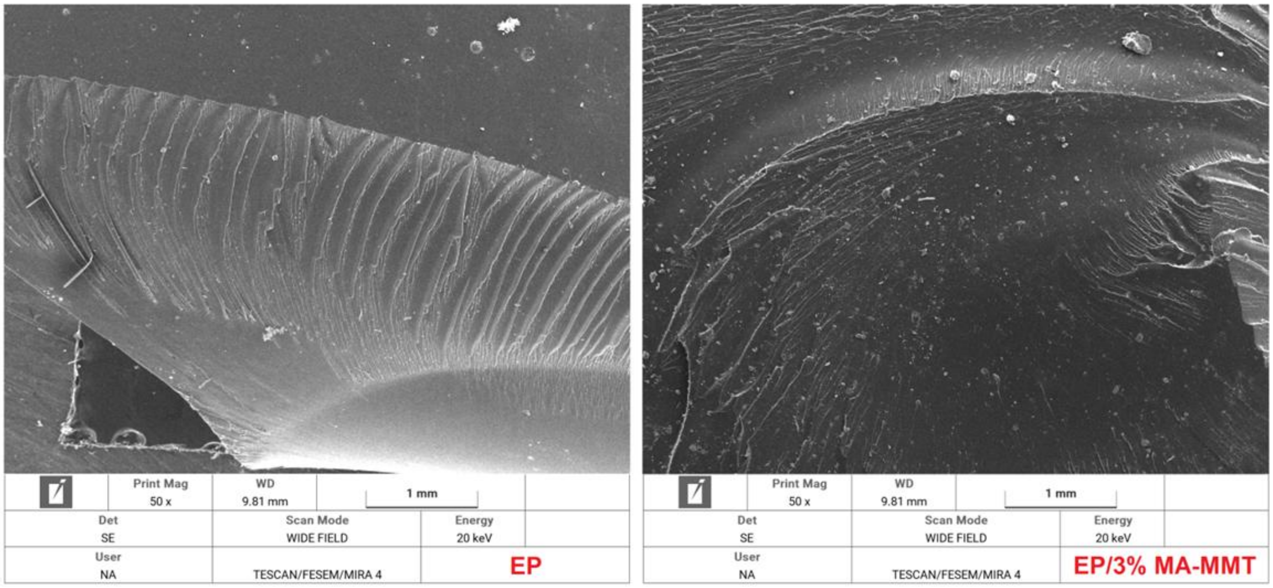

Figure 3. FE-SEM images of the EP and EP/3%MA-MMT.

(nanocomposite) are the corrosion current densities of pure and with nanoparticle coatings, respectively.

$$CR = \frac{0.0032 i_{corr} Mw}{nd} \quad (1)$$

$$IE = \frac{i_{corr(pure)} - i_{corr(nanocomposite)}}{i_{corr(pure)}} \times 100 \quad (2)$$

3. Results and discussion

Figure 2 shows the XRD patterns of Na^+-MMT and MA-MMT. As the XRD results show, there is a change in the pattern of Na^+-MMT after modification. In fact, a peak shift and also a change in *d*-spacing are observed, such that Na^+-MMT has a peak at 7.4° (*d*-spacing = 10.46 Å) and MA-MMT has a peak at about 4.6° (*d*-spacing = 18.17 Å). These changes, which have also been reported in the literature, are related to the absence of Na^+ cations after modification and the presence of plant compounds [9, 10]. Figure 3 shows the FE-SEM images of EP and EP/3% MA-MMT samples, in which nanoparticles are clearly visible. Also, the desired dispersion of nanoparticles is clearly observed on the fracture surface of the nanocomposite sample.

The polarization results performed after 30 days of immersion showed an improvement in the corrosion behavior of the EP coatings reinforced with MA-MMT. The results and polarization curves are reported in Table 1 and Figure 4, respectively. The addition of MA-MMT caused a shift in E_{corr} towards less negative values. Also, the EP coating showed the most negative potential, which is related to the high corrosion sensitivity, while the EP/3% MA-MMT coating showed a less negative potential, which is related to the presence of nanoparticles. In fact, the nanoparticles can act as a barrier and prevent the penetration of corrosive ions [9, 10]. The potential shift (<85 mV) after the addition of nanoparticles classifies MA-MMT as a mixed-type inhibitor, i.e., it can actively suppress both anodic metal dissolution and

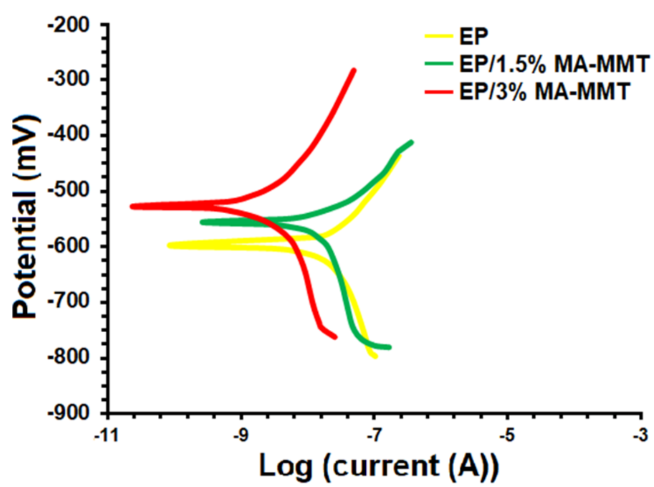

Figure 4. Polarization test results of samples after immersion in a 3.5% NaCl solution.

Table 1. Electrochemical parameters obtained from the polarization tests

Sample	i_{corr} (μA/cm^2)	E_{corr} (mV)	C.R (mpy)	IE (%)
EP	(11.098 ± 0.62) × 10^{-3}	−606.257 ± 2.1	0.0109 ± 0.0006	-
EP/1.5% MA-MMT	(4.016 ± 0.34) × 10^{-3}	−561.362 ± 3.6	0.00351 ± 0.0002	63.81 ± 1.8
EP/3% MA-MMT	(1.106 ± 0.04) × 10^{-3}	−534.462 ± 3.1	0.00116 ± 0.0001	90.03 ± 1.2

cathodic oxygen reduction reactions [19]. Also, a decrease in the values in i_{corr} was observed with the loading of nanoparticles. Similarly, a decrease in C.R values is observed with the loading of nanoparticles. Also, IE values are seen with the presence of nanoparticles, and these values increased with increasing nanoparticle content.

The inhibition mechanism is directly related to the bioactive compounds in *Melia Azedarach* (see Figure 5), including terpenoids, flavonoids, steroids, acids, anthraquinones, alkaloids, saponins, and tannins [17, 18]. These compounds can adsorb onto the mild steel surface, attributed to π-electron transfer between oxygen atoms and the aromatic rings of compounds with empty *d*-orbitals on the mild steel surface [9-12]. Also, MMT causes the path of corrosive species to be longer [2, 9, 10]. Moreover, Figure 6 summarizes the inhibition mechanism.

4. Conclusions

In summary, a corrosion inhibitor was prepared using ethanolic extract of *Melia Azedarach* fruit and Na+-MMT. XRD results showed that *Melia Azedarach* fruit compounds were successfully incorporated into the clay layers. Also, with increasing MA-MMT content in the matrix, corrosion resistance increased. In fact, the compounds present in *Melia Azedarach* fruit were able to prevent the penetration of aggressive species to the metal surface. Also, according to the polarization test results, MA-MMT is classified as a mixed inhibitor.

Conflict of Interest

The authors declare no conflict of interest.

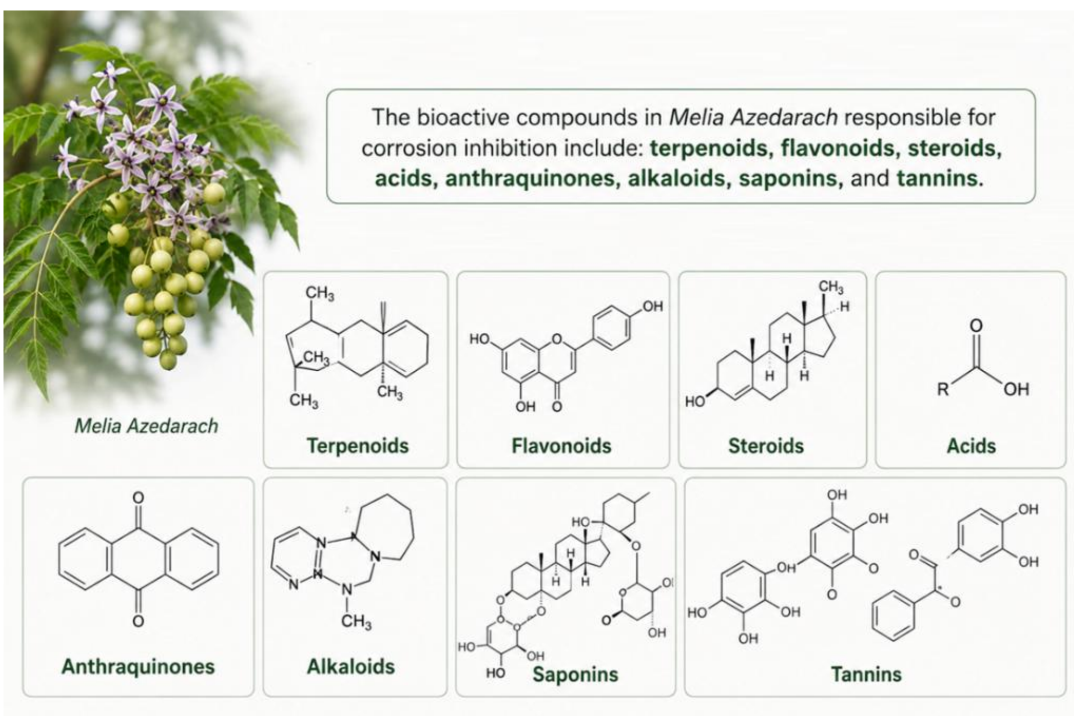

Figure 5. Compounds in *Melia Azedarach* fruit.

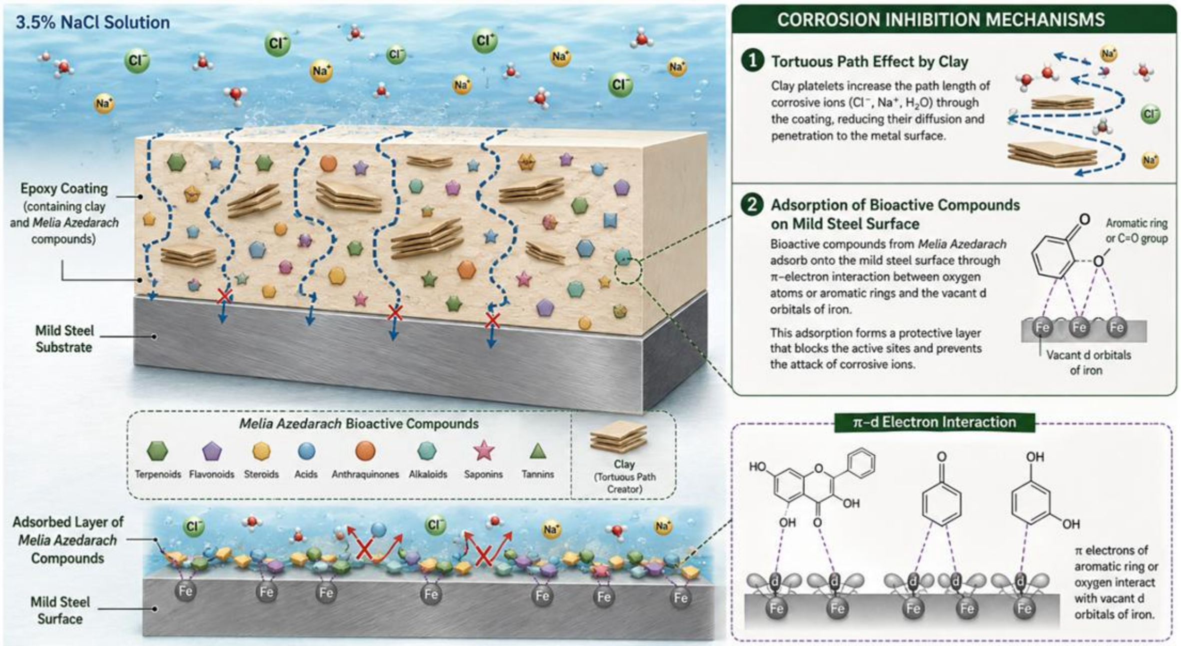

Figure 6. Function of MA-MMT in EP coating to improve corrosion resistance.

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