Journal of nanoporous Systems

Original Research Paper

Preparation and characterization the polymer/Zeolite nanocomposite as anti-Corrosion coatings

Behnia Sadat Mirhoseini

[1]*Department of Chemistry, Faculty of Science, Arak University, Arak, Iran*

Article history
Received: 7 July 2025
Revised: 25 August 2025
Accepted: 10 September 2025

*Corresponding Author: Behnia Sadat Mirhoseini
Department of Chemistry, Faculty of Science, Arak University, Arak, Iran

Email: behniamirhoseini1394@gmail.com

Abstract: Corrosion is a pervasive issue and degradation phenomenon with serious effects on human life and national economic development and also severe security implications. therefore, issues such as accurate assessment, prevention and prediction with environmentally friendly anti-corrosion materials based on the nanotechnology with high activity are fundamental to maintaining the integrity of many critical components and installations. The anti-corrosive of the present work is based on a novel phosphate-free nanocomposite containing polymer/zeolite nanocomposite. Polymer nanocomposites of polyaniline (PANI)-based NaY zeolite was synthesized by in situ chemical oxidative microemulsion polymerization by rapid mixing in a hydrochloric acid medium as anticorrosion nanocomposite coating to study its performance. DLS analysis was used to characterize the particle size of the prepared nanocomposite. The obtained results and also AFM images show that the used nanocomposite can more effectively prevent corrosion up to 90% without using any amine and oxygen scavenger. The improvement in the corrosion resistance of C1018 alloy due to the application of polymer/zeolite coating can be attributed to the uniformity and the inert nature of this coating.

Keywords: Nanocomposite, Anti-corrosion, Polyaniline, Zeolite

Introduction

The complex structure of boilers is used for two primary functions: water heating and vapor generation. To prevent the corrosion of metal components in boilers, the use of an anti-corrosive is essential [1, 2]. For power generation, garbage incineration, and similar processes that use a superheater or a steam turbine, ion-exchange water, reverse osmosis (RO), or desalinated water are typically used as an additional feed for boilers. These boilers are typically operated at a concentration factor ranging from 30 to 100, which is one of the water quality control factors. Instead of using a caustic alkali substance, these boilers add a phosphate salt to adjust the pH of the boiler water for corrosion prevention. They also add a neutralizable amine or ammonia to elevate the pH of the boiler feed-condensate system. This helps prevent elution of iron, which in turn reduces the amount of iron transferred into a boiler tank. In recent years, however, the amount of organic substances that have unintentionally been transferred to a boiler tank has increased due to the use of various water sources and impaired water quality. Additionally, the blow rate has been reduced to conserve energy and water. An organic oxygen scavenger is now used instead of hydrazine [3]. Under these circumstances, the pH of the boiler water often decreases problematically. The problem can be solved in one of two ways: either the phosphate salt level of the boiler water is increased, or a phosphate salt-type boiler compound (a sodium phosphate-sodium hydroxide mixture) with a Na/PO_4 mole ratio of 3 or higher is used. In the above case, a phosphate salt hide-out phenomenon or alkali corrosion may occur, which could be problematic [4].

The term "phosphate salt hide-out phenomenon" refers to the deposition of the phosphate salt that has been dissolved in boiler water. This deposition is caused by a rapid change in concentration or pressure [3-6]. However, there's a catch with the anti-corrosive compounds: they can't fully raise the pH of boiler water. Also, they require

a significant amount to be added to feed water. This demand has led to the development of anti-corrosive formulations that exhibit effective anti-corrosive properties even when used in small amounts [6-10].

Anti-corrosive materials can be made more effective by using nanotechnology. To this end, Akbarian et al. examined the impact of nanoparticulate silver on the corrosion protection performance of polyurethane coatings on mild steel in a sodium chloride solution [9]. The present project is aimed at resolving the aforementioned issues through the application of nanotechnology. The objective of our research is to develop a novel nanocolloid formulation that functions as an anti-corrosive agent. This formulation aims to enhance the effectiveness of maintaining the pH balance of boiler water, thereby preventing the corrosion of boiler tanks and the entire boiler system, including the feed-condensate system, without the need for excessive amounts of phosphate salt. We believe the amine compound used in this research should be low-volatility with high thermal stability and a high degree of dissociation.

Polyaniline (PANI) is a conductive polymer that has been investigated for its potential in anti-corrosion applications. It's known for its ability to protect metals from corrosion, particularly in acidic environments. Coating or filler applications are possible with PANI, which provides a protective barrier against corrosive agents [11].

The production of zeolite-based films for use as anti-corrosive protective coatings saw a surge in interest and a jump in knowledge over 15 years ago. This was due to the pioneering efforts of Yan and his research group [12].

To better evaluate the anti-corrosion mechanisms of zeolite coatings, it is essential to conduct a more in-depth analysis of how this performance is correlated with the structure and morphology of the coatings. This will allow us to identify the phenomena that trigger the barrier, self-repairing, and self-healing mechanisms of zeolite-based composite coatings.

We are currently examining the role of microemulsion systems in preparing a controllable size and morphology [13-17] of polymer nanocomposite [18-25] as corrosion inhibitor [24-28]. This examination builds on our previous research on microemulsion systems as soft templates [29-31], and nanoreactors [32-34] for nanomaterials synthesis [35-38].

The polymer/zeolite nanocomposite was characterized by DLS analysis. A systematic investigation was conducted to test the anti-corrosion behavior of polymer/zeolite nanocomposite. AFM was used to confirm the monolayer formation of the anticorrosion sample on the surface of C1018 alloy after treatment. The effect of inhibitor concentration and temperature were optimized. Additionally, the test piece corrosion rate (mdd) was calculated based on thickness measurement data and iron determination by colorimetric method using o-phenanthroline was performed.

Materials and Methods

Chemicals

Commercial *lecithin* *(*$C_{46}H_{89}NO_8P$) was used *as surfactant to produce oil-in-Water microemulsion*, as used by food manufacturers from an Iranian company. Aniline monomer (AR grade) and HCl were purchased from Merck. *Potassium persulfate, used* as a hydrophilic oxidizing agent for polymerization of MMA was purchased from Haihang Industry Co. NaY zeolite was purchased from ECHEMI Co., and deionized water (0.055 µS/cm) which was produced in our lab with PKA (Smart two pure) instrument. C1018 alloy that the chemical compositions of the alloys are summarized in Table 1, was received.

Table 1. The chemical compositions of the exemplary alloy

C	Si	Mn	Fe	P	S
0.14-0.20	-	0.60-0.90	98.81 – 99.26 (as remainder)	≤ 0.040	≤ 0.050

Characterization

A common technique, DLS analysis with the Bettersize (an optical nanoparticle size analyzer from Nanoptic 90), was employed to confirm the average particle size and polydispersity index (PDI). Before DLS analysis, the prepared sample was sonicated for six minutes. Atomic Force Microscopy (AFM) (BRISK) was used to confirm the monolayer formation of the anticorrosion sample on the surface of C1018 alloy after treatment.

Polymer/zeolite nanocomposite preparation

To prepare polyaniline/zeolite nanocomposite, an oil-in-water microemulsion system consisting of lecithin as surfactant, aniline monomer as apolar phase, and water was prepared at adjusted concentrations of the lecithin (0.02 M) that was the best performance to control size and

morphology same as our previous works [37]. In this procedure, aniline was polymerized using hydrochloric acid (HCl) as a catalyst and ammonium persulfate (KPS) as an oxidizing agent. For the preparation of pure polyaniline, two equimolar solutions of aniline (2.5 mL) and APS (6.0 g) were dissolved in 25 mL of 0.01 M *lecithin* surfactant solution in 1 M HCl under magnetic stirring for several minutes. Then, the APS solution was suddenly added to the aniline solution at a low temperature (approximately 0 °C) under constant stirring for 6 h and then green precipitate was obtained and filtered. The precipitate was then washed several times with deionized water and 1M HCl until the filtrate became nearly colorless. The product was then dried in an oven at an approximate temperature of 60 °C for 12 h. For the synthesis of the polyaniline/zeolite nanocomposite, a solution of aniline and HCl (1M) at equal concentrations was prepared using a magnetic stirring technique. Before the in situ microemulsion polymerization of aniline, NaY zeolite was added at a volume ratio of 0.5%. Then, the solutions were sonicated for 25 minutes using ultrasound to prevent agglomeration of the nanoparticles and allow the HCl-doped aniline to deposit on the zeolite surface via electrostatic interactions. The *in-situ* polymerization was then carried out by suddenly adding the KPS solution to the HCl 1M solution while continuing to stir, filter, wash, and dry as described in the PANI synthesis by rapid mixing.

Preparation of anti-corrosion nanocolloid

For this purpose, 25 g of the above-mentioned powder was dispersed in 1 L pure water of (ion-exchange water) and used for the corrosion test in boiler.

The sol-gel process is typically considered for the preparation of silica-containing nanoparticles in which alkoxy precursors are used under acidic or alkaline conditions. In this method, surfactant molecules are used as a template [21].

Corrosion study

Corrosion study with gravimetric analysis

To study the impact of acid corrosion inhibitor, inhibitor concentration, and also the impact temperature, weight loss-based C1018 alloy surface corrosion analysis for all experiments was carried out at different temperatures from 303 K to 343 K in 0.1 M HCl in the absence of inhibitor as control sample and the presence of new green inhibitor at concentrations of 2-10 ppm that the total exposure time of 5 days was selected. The experiment conditions were as follows: 50 ml of uninhibited or control sample and working solution (inhibited corrosion solution) was employed, and the size of the metal surface C1018 samples was 8.7 cm × 1.4 cm × 0.1 cm. The following equation (Eq. 1) was utilized for the calculation of the corrosion (%) of the prepared green inhibitor and control sample.

$$\text{Corrosion (\%)} = W_o - W / W_o \times 100 \quad (1)$$

where W_0 and W are the weight loss of C1018 alloy in the absence and the presence of the acid anti-corrosive, respectively. In corrosion study, an acid corrosion inhibitor provides sufficient corrosion inhibition so that a pitting index has definitions of the integers [27].

The corrosion rate (mdd) of a test piece is based on the daily amount of corrosion (mg) for an area of 100 cm².

The test piece corrosion rate (mdd) was calculated based on thickness measurement data using a Thickness Meter (PCE-CT 80-FN0D5), which has an accuracy of ±(1% of reading + 1 µm) after foil calibration. This meter can be used on many materials, such as iron, steel, aluminum, copper, brass, and stainless steel, with a diameter of 17 mm (0.67 in). Iron determination by colorimetric method using o-phenanthroline was performed [40].

Results and Discussions

DLS analysis

Fig. 1(a and b) shows the DLS analysis of all samples composed of pure polyaniline and polyaniline/zeolite nanocomposite prepared using the microemulsion system as soft template. DLS particle size analyzers are used to measure the size of very small particles (0.6 nm to 6 um) in solution. The size distribution of the pure polyaniline nanoparticles and polyaniline/zeolite nanocomposite was measured with DLS technique. The intensity-weighted size average values (Z-average) and the polydispersity index (PdI) for both pure polyaniline and polyaniline/zeolite nanocomposite were (56.24 nm and 0.52) and (123.10 nm and 0.43). The particle size range of DLS depends on the properties of the analyzed species, such as refractive index or density, as well as the surrounding formulation, mainly the viscosity. The mean size and size distribution of polyaniline/zeolite nanocomposite *could become smaller by ultra*-sonication treatment and a decrease in the mean size of 74.15 nm was obtained. Sonication had a significant effect on the decrease of both mean droplet size (Z-average) and size distribution (PdI) of polyaniline/zeolite nanocomposite. Sonication treatment led to create an interfacial wave. The obtained interfacial wave produces microbubbles, the collapse of which resulted in the disruption of oil droplets, reducing their particle size to less than 100 nm scale.

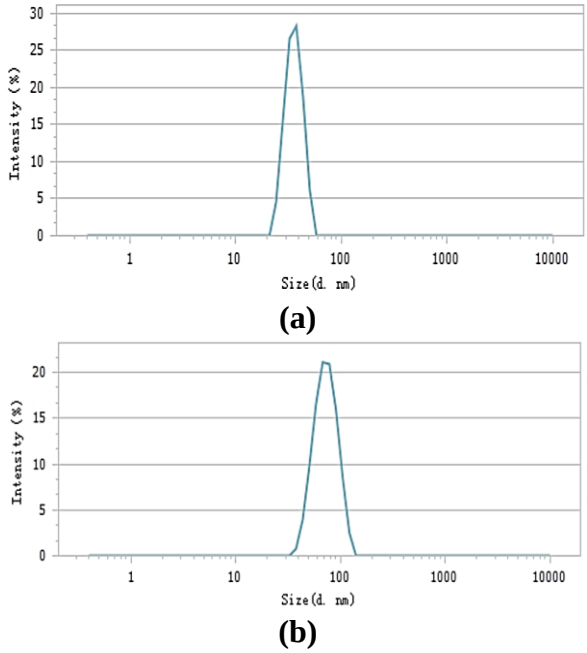

Fig. 2. DLS analysis of (a) pure polyaniline and (b) polyaniline/zeolite nanocomposite prepare in microemulsion system

Corrosion study

The concentration effect of corrosion inhibitor

All experiments on the effect of the corrosion inhibitor concentration to evaluate the corrosion activity and efficiency and also corrosion rate were conducted at standard room temperature by using the weight-loss method after 4 days of immersion in acidic solution. Fig. 2, presents the results obtained for the weight loss experiments and calculation of the corrosion rate and efficiency. The results obtained show nanoemulsion has a high efficiency compared to the macroemulsion. For the nanoemulsion inhibitor when the concentration of nanoemulsion was increased to 6 ppm, the corrosion rate decreased and the inhibitor efficiency increased and then with more increase in inhibitor concentration, the inhibitor efficiency was kept without any remarkable changes. The highest inhibition efficiency of about 93 % was achieved when a 6 ppm inhibitor was used. From the data gained, the inhibitor showed an excellent result for inhibiting the corrosion of C1018 steel in an acidic solution [28]. No corrosion protection was observed for the control sample (only acidic solution) in the absent of both inhibitors and rust on the surface of C1018 obtained.

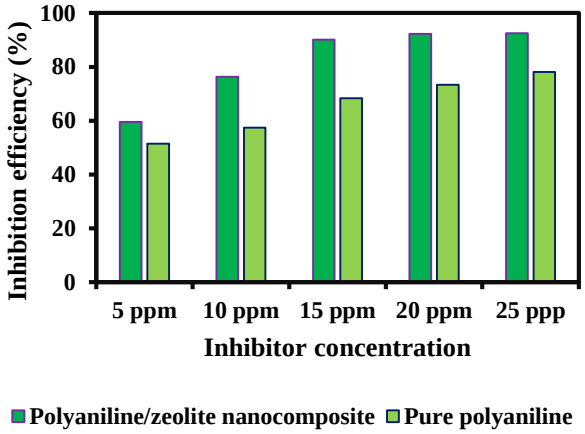

Fig. 2. The effect of pure polyaniline and polyaniline/zeolite nanocomposite corrosion inhibitor concentration for the protection of the C1018 alloy at 303 K.

The effect of temperature on the corrosion inhibition efficiency

The effect of temperature on the inhibition activity of pure polyaniline and polyaniline/zeolite nanocomposite corrosion inhibitor was studied using weight loss at 303 K, 323 K, and 343 K with 20 ppm concentration of corrosion inhibitor for both samples that mentioned above (Fig. 3). To further elucidate their inhibition efficiency, thermodynamic parameters such as temperature are very useful for shedding light on the adsorption behavior of corrosion inhibitors on the surface of C1018 alloy. It is shown that the corrosion of C1018 increases with temperature and the corrosion rate for pure polyaniline sample was faster compared to the polyaniline/zeolite nanocomposite. It shows a better inhibition performance at 303 K compared to the inhibitor efficiency at 323 K and 343 K with inhibitor efficiency of 92.5 % in the presence of polyaniline/zeolite nanocomposite and 73.3 % in the presence of the pure polyaniline.

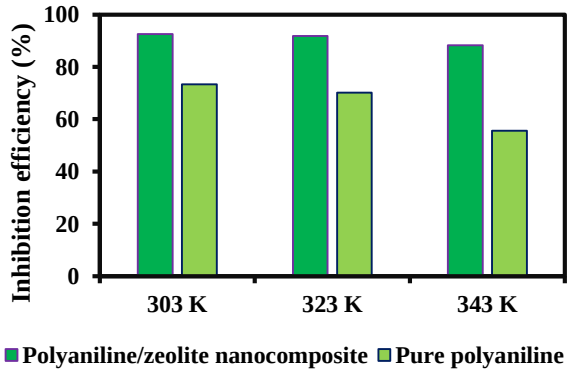

Fig. 3. The effect of temperature on the inhibition efficiency of pure polyaniline and polyaniline/zeolite nanocomposite corrosion inhibitor (20 ppm) after 4 days for the protection of the C1018 alloy in acidic

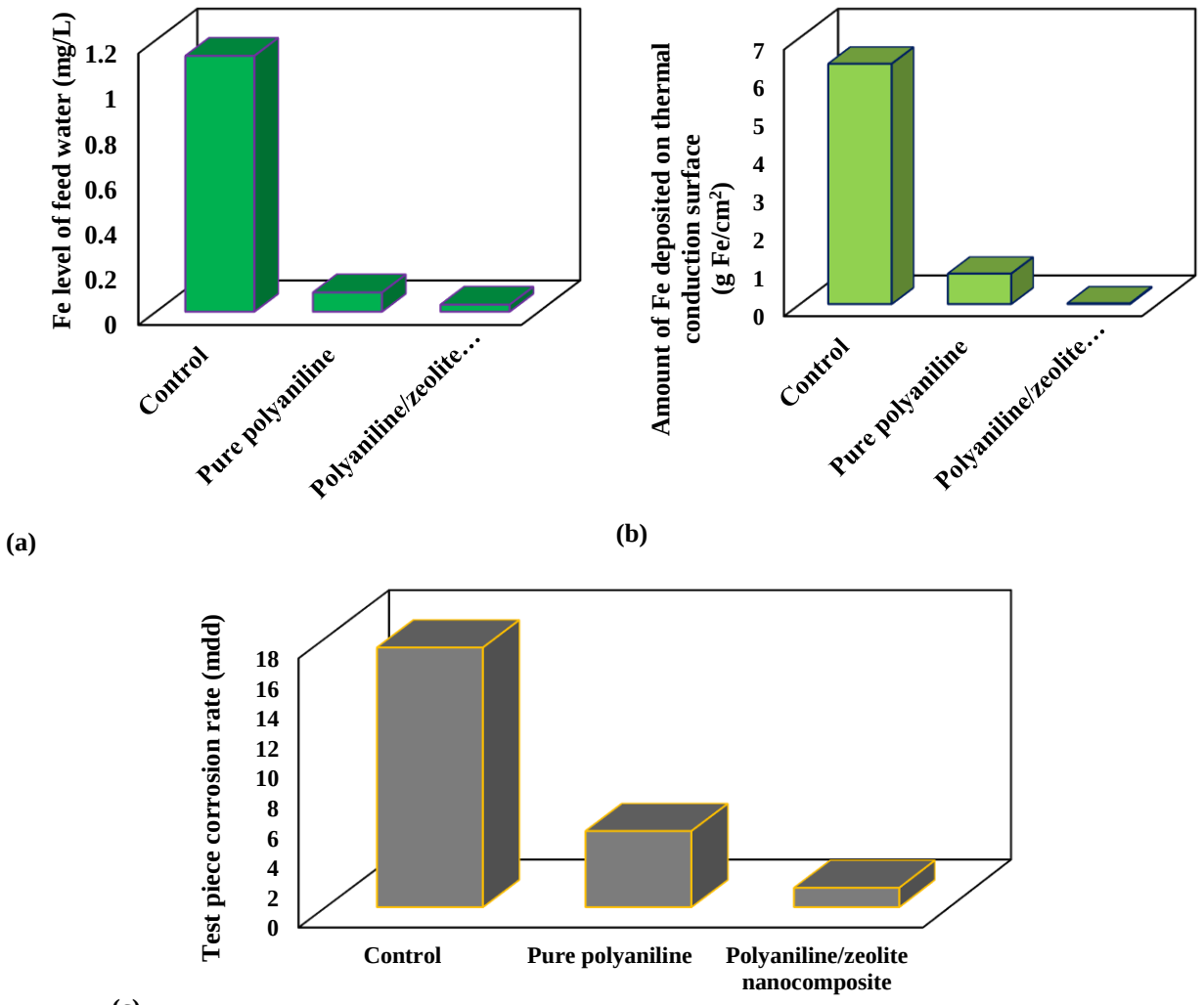

Fig. 4. (a) Fe level of feed water (mg/L), (b) Amount of Fe deposited on thermal conduction surface (mg Fe/cm^2) and test piece corrosion rate (mdd)

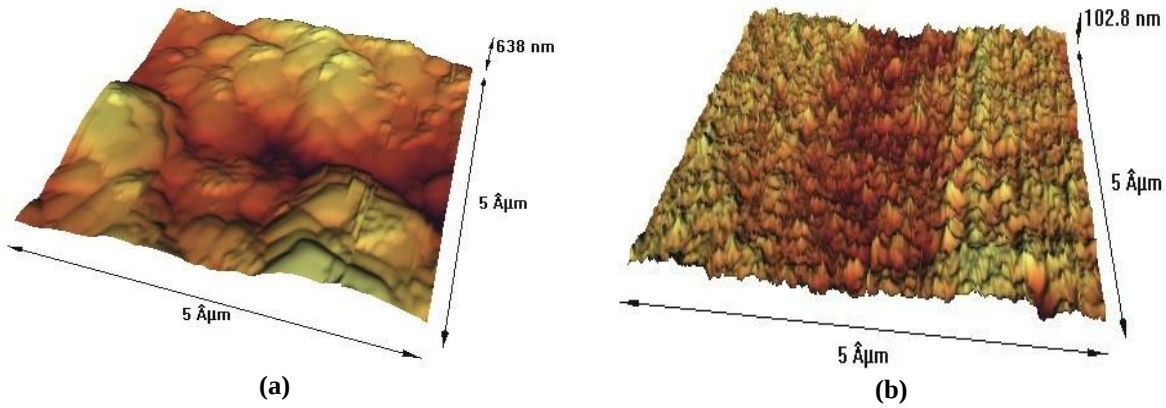

Fig. 5. AFM images of the surface of C1018 alloy after treatment with (a) pure polyaniline and (b) polyaniline/zeolite nanocomposite

Anti-corrosive activity and proposed mechanism

Fig. 4-(a-c) the anti-corrosion investigation based on the Fe level of feed water (mg/L), amount of Fe deposited on the thermal conduction surface (mg Fe/cm^2), and test piece corrosion rate was examined with the pure polymer and polyaniline/zeolite nanocomposite (20 ppm, 303 K). As can be seen from Fig. 4, it was confirmed that the prepared corrosion inhibitor prepared by polyaniline/zeolite nanocomposite has the best anti-corrosion performances in all test (Fe level of feed water, amount of Fe deposited and corrosion rate). The reason for this event relates to the increase in the nanocomposite surface area that is capped with lecithin molecules. The amine groups of polyaniline coordinated with hydroxyl groups on the surface of zeolite provided stable complexes against diffused oxygen. The interaction of lecithin molecules and amine molecules led to the formation of a nanometric layer on the surface of metal. The nanometric layer coated on the surface of the alloy is highly strong under dissolved oxygen and more effectively protects the surface of the alloy. Pure polyaniline has the weak anti-corrosive activity in the same condition for three tests.

AFM analysis

The AFM image Fig. 5 (a and b) shows a thin film formation of (a) pure polyaniline and (b) polymer nanocomposite monolayer as covered steel sample, applied to the steel surface after being exposed to a corrosive HCl solution for 4 days. In this study, non-contact mode was used to study the behavior of the monolayer that formed on the surface of the alloy after treatment. The non-contact mode has the advantage that the tip never makes contact with the sample and therefore cannot disturb or destroy the sample. Clearly, for the polymer/zeolite-covered surface, globular and monodispersed nanospheres compacted and aligned near each other, forming an anticorrosive shield monolayer against the corrosive environment. In the pure polyaniline-covered alloy surface, large globular nanospheres with high polydispersity that formed a rough layer on the surface [27]. The strong interaction of the inhibitor with the steel surface helps make the surface reaction visible to confirm the film forming for both samples; in contrast, surface diffusion of adsorbents on metal surfaces for polymer/zeolite is often fast within the time scale observed under the microscope, making identification of film forming simple. These PF-A nanospheres on the surface are present at a much higher density than the pure polyaniline nanostructures seen by AFM images. The improvement in the corrosion resistance of C1018 alloy due to the application of polymer/zeolite coating can be attributed to the uniformity and the inert nature of this coating [41].

Conclusions

In order to attain the production of the anti-corrosion material, extensive studies are conducted. In this work, it is found that these materials can be attained by a unique combination of nanotechnology by preparation of polyaniline/zeolite nanocomposite with a specific structure including an amino group and a hydroxyl group in the molecule, in particular. In this research, a new type of polyaniline/zeolite nanocomposite was prepared by a microemulsion system and tested to understand the anti-corrosive activity compared to the pure polyaniline. The results show that the anti-corrosion formulation produced polyaniline/zeolite nanocomposite has the best performance. The improvement in the corrosion resistance of C1018 alloy due to the application of polymer/zeolite coating can be attributed to the uniformity and the inert nature of this coating.

References

[1] Goyal, A., Pouya, H. S., Ganjian, E., Claisse, P., A review of corrosion and protection of steel in concrete, ***Arab. J. Sci. Eng.***, **2018**, 43 5035-5055. https://doi.org/10.1007/s13369-018-3303-2.

[2] Angst, U. M. Challenges and opportunities in corrosion of steel in concrete, ***Mater. Struct.***, **2018**, 51, 1-20. https://doi.org/10.1617/s11527-017-1131-6.

[3] Edraki, E., Banimahd Keivani, M., Eco-friendly inhibitors for corrosion protection of metallic surfaces-a mini review, ***Asian. J. Green. Chem.***, **2020**, 4, 283-296.

[4] Grigoriev, D., Shchukina, E., Shchukin, D. G., Nanocontainers for self-healing coatings, ***Adv. Mater. Interfaces,*** **2017**, 4, 1600318. https://doi.org/10.1002/admi.201600318.

[5] Stefanoni, M., Angst, U., Elsener, B., Corrosion rate of carbon steel in carbonated concrete-A critical review, ***Cem. Concr. Res.***, **2018**, 103, 35-48. https://doi.org/10.1016/j.cemconres.2017.10.007.

[6] Edraki, M., Mousazadeh Moghadam, I., Banimahd Keivani, M., Fekri, M. H., Turmeric extract as a biocompatible inhibitor of mild steel corrosion in 3.5% NaCl solution, ***I. J. O. C.,*** **2019**, 7, 146-159.

[7] Nardeli, J. V., Fugivara, C. S., Taryba, M., Montemor, M. F., Ribeiro, S. J., Benedetti, A. V., Novel healing coatings based on natural-derived polyurethane modified with tannins for corrosion protection of AA2024-T3, ***Corros. Sci.***, **2020**, 162, 108213. https://doi.org/10.1016/j.corsci.2019.108213.

[8] Arriba-Rodriguez, L. D., Villanueva-Balsera, J., Ortega-Fernandez, F., Rodriguez-Perez, F., Methods to evaluate corrosion in buried steel structures: a review,

Metals, **2018**, 8, 334. https://doi.org/10.3390/met8050334.

[9] Akbarian, M., Olya, M. E., Mahdavian, M., Ataeefard, M., Effects of nanoparticulate silver on the corrosion protection performance of polyurethane coatings on mild steel in sodium chloride solution, ***Prog. Org. Coat.***, **2014**, 77, 1233-1240. https://doi.org/10.1016/j.porgcoat.2014.03.023.

[10] Ikhmal, W. M., Maria, M. F., Rafizah, W. A., Norsani, W. N., Corrosion inhibition of mild steel in seawater through green approach using Leucaena leucocephala leaves extract, ***Int. J. Corros. Scale Inhib.,*** **2019**, 8, 628-643. https://doi.org/10.17675/2305-6894-2019-8-3-12.

[11] Grgur, Branimir N., Aleksandra S., Popović, Salem, A., Influence of Alkyd Composite Coatings with Polyaniline Doped with Different Organic Acids on the Corrosion of Mild Steel, ***Metals***, **2023**, 13, 1364. https://doi.org/10.3390/met13081364.

[12] Calabrese, L., Edoardo, P., A Brief Overview on the Anticorrosion Performances of Sol-Gel Zeolite Coatings, ***Coatings***, **2019**, 9, 409. https://doi.org/10.3390/coatings9060409.

[13] Salabat, A., Mirhoseini, F., Polymer-based nanocomposites fabricated by microemulsion method, Polym, ***Compos***., **2022**, 43, 1282–94. https://doi.org/10.1002/pc.26504.

[14] Salabat, A., Mirhoseini, F., Mahdieh, M., Saydi, H., A novel nanotube-shaped polypyrrole-Pd composite prepared using reverse microemulsion polymerization and its evaluation as an antibacterial agent, ***New J. Chem***., **2015**, 39, 4109–4114. https://doi.org/10.1039/c5nj00175g.

[15] Salabat, A., Mirhoseini, F., Arjomandzadegan, M., Jiryaei, E., A novel methodology for fabrication of Ag-polypyrrole core-shell nanosphere using microemulsion system and evaluation of its antibacterial application, ***New J. Chem.*** **2017**, 41 (21), 12892–12900. https://doi.org/10.1039/c7nj00678k.

[16] Salabat, A., Mirhoseini, F., Valirasti, R., Engineering poly (methyl methacrylate)/Fe_2O_3 hollow nanospheres composite prepared in microemulsion system as a recyclable adsorbent for removal of benzothiophene, ***Ind. Eng. Chem. Research***, **2019**, 58, 17850-1785. https://doi.org/10.1021/acs.iecr.9b04322.

[17] Salabat, A., Mirhoseini, F., Abdoli, K., A microemulsion route to fabrication of mono and bimetallic Cu/Zn/γ-Al_2O_3 nanocatalysts for hydrogenation reaction, ***Scientia Iranica***, 2018, 25, 1364-1370. https://doi.org/10.24200/sci.2018.5023.1048.

[18] Mirhoseini, B. S., Salabat, A., A novel surfactant-free microemulsion system for the synthesis of poly (methyl methacrylate)/Ag nanocomposite, ***J. Mol. Liq***. **2021**, 342, 117555. https://doi.org/10.1016/j.molliq.2021.117555.

[19] Salabat, A., Mirhoseini, F., Masoumi, Z., Mahdie, M., Preparation and characterization of polystyrene-silver nanocomposite using microemulsion method and its antibacterial activity, ***J. N. S.***, **2014**, 4, 377-382.

[20] Alimohamadi, F., Salabat, A., Effect of surfactant type on the particle dispersion in Ag/polystyrene nanocomposite prepared by microemulsion method, ***Colloid Nanosci. J.***, **2023**, 1, 112-118. https://doi.org/10.52547/CNJ.1.2.112.

[21] Salabat, A., Mirhoseini, F., A novel and simple microemulsion method for synthesis of biocompatible functionalized gold nanoparticles, ***J. Mol. Liq***., **2018**, 268, 849–853. https://doi.org/10.1016/j.molliq.2018.07.112.

[22] Mirhoseini, F., Salabat, A., Ionic liquid based microemulsion method for fabrication of poly(methyl methacrylate)–TiO_2 nanocomposite as highly efficient visible light photocatalyst, ***RSC Adv***., **2015**, 5, 12536–12545. https://doi.org/10.1039/c4ra14612c.

[23] Mirhosseini, F., Salabat, A., Iinvestigation of operational parameters on the photocatalytic activity of a new type of poly (methyl methacrylate)/ionic liquid-tio_2 nanocomposite, ***Iranian J. Chem. Chem. Eng***., **2019**, 38. 101-114. https://doi.org/10.30492/IJCCE.2019.37613.

[24] Noor Mohammad Beigi, M., Noor Mohammad Beigi, H., Anticorrosion study based on the film formed by a green nano-assembled aspartic amino acid-reinforced polysaccharide monolayer; thermodynamic study, ***Colloid Nanosci, J***., **2025**, 2(4), 409-418. https://doi.org/10.61186/CNJ.2.4.409.

[25] Noor Mohammad Beigi, M., Boosting the impact of cinnamaldehyde-contained polymer microemulsion on the corrosion of C1018 alloy in an acidic medium, ***Colloid Nanosci. J***., **2024**, 2(1), 220-227. https://doi.org/10.61186/CNJ.2.1.220.

[26] Mirhoseini, B. S., Noor Mohammad Beigi, M., A novel nanocolloid system based on the poly(methyl methacrylate) nanoparticles as anticorrosive agent for boiler; a pilot -scale study, ***Colloid Nanosci. J.***, **2023**, 1, 139-146. https://doi.org/10.61186/CNJ.1.3.139.

[27] Mirhoseini, B. S., Mirhoseini, F., The role of internal intensifier microemulsion for monitoring acid anticorrosion activity of enhanced cinnamaldehyde contained-PMMA nanocolloid in industrial pipeline simulations, ***Nano Science and Technol. J.***, 2024, 2(1), 1-11.

[28] Mirhoseini, B. S., Allam, E., A new combination of amino and mercapto type coupling agent to fabricate polymer-coated cobalt ferrite nanocomposite as corrosion inhibitor with high performance film-forming, ***Colloid Nanosci. J***., 2024, *2*(3), 369-381. https://doi.org 10.61186/CNJ.2.3.369.

[29] Mirhoseini, B. S., Salabat, A., Photocatalytic filter, United States patent 10828629.
[30] Salabat, A., Mirhoseini, F., Applications of a new type of poly (methyl methacrylate)/TiO_2 nanocomposite as an antibacterial agent and a reducing photocatalyst, ***Photochem. Photobiol. Sci***., **2015**, 14(9), 1637–1643. https://doi.org/10.1039/c5pp00065c.
[31] Mirhoseini, F., Salabat, A., Removal of methyl tert - butyl ether as a water pollutant by photodegradation over a new type of poly (methyl methacrylate)/TiO_2 nanocomposite, ***Polymer Composites***, **2018**, 39(4), 1248–1254. https://doi.org/10.1002/pc.24059.
[32] Mirhoseini, F., Salabat, A., Antibactrial activity based poly (methyl methacrylate) supported TiO_2 photocatalyst film nanocomposite, ***Tech. J. Eng. Appl. Sci.***, **2015**, 5, 115-118.
[33] Salabat, A., Mirhoseini, F., Photo-induced hydrophilicity study of poly(methyl methacrylate)/TiO_2 nanocomposite prepared in ionic liquid based microemulsion system, ***Current Appl. Polym. Sci***., **2018**, 2(2), 112–120. https://doi.org/10.2174/2452271602666180803141554.
[34] Kamali, F., Faghihi, K., Mirhoseini, F., High antibacterial activity of new eco-friendly and biocompatible polyurethane nanocomposites based on Fe_3O_4/Ag and starch moieties, ***Polym. Eng. Sci.***, 2022, 62(5), 1444-1462. https://doi.org/10.1002/pen.25934.
[35] Salabat, A., Mirhoseini, F., Nouri, F. H., Microemulsion strategy for preparation of TiO_2–Ag/poly(methyl methacrylate) nanocomposite and its photodegradation application, ***J. Iranian Chem. Soc***., **2022**, 20, 599–608. https://doi.org/10.1007/s13738-022-02693-7.
[36] Mirhoseini, F., Salabat, A., Polymer nanocomposite based composition and method for controlling water hardness, United States patent 11136247.
[37] Hoseini, M., Hamidi, S., Salehi, E., Mohammadi, A., Mirhoseini, F., Ravaghi, M., Multi-variate multi-objective optimization of production conditions for electro-spun skin scaffold using RSM and investigation of gamma irradiation effects on the properties of the optimized sample, ***Heliyon***, **2024**a, 10 (12), e3294. https://doi.org/10.1016/j.heliyon.2024.e32941.
[38] Mirhoseini, F., Mirhoseini, B. S., Noor Mohammad Beigi, M., Understanding the photodegradation of amoxicillin antibiotic using visible light sensitized poly(methyl methacrylate)/TiO_2 nanocomposite, ***Nano Sci. Technol. J.***, **2023**, 1(1), 38-48. https://doi.org/10.22034/nstj.2023.707804.
[39] Salabat, A., Mirhoseini, B. S., Mirhoseini, F., Ionic liquid based surfactant-free microemulsion as a new protocol for preparation of visible light active poly(methyl methacrylate)/TiO_2 nanocomposite, ***Sci. Rep.***, **2024**, 14, 15676. https://doi.org/10.1038/s41598-024-66872-7.
[40] Tripathi, A. D., Gupta, K. A., Malik, S., Iron determination by colorimetric method using O-phenanthroline, ***Bull.Pure Appl. Sci***., **2019**, 38, 171-175. https://doi.org/10.5958/2320-320X.2019.00018.9.
[41] Banerjee, P. C., Woo, R. P., Grayson, S. M., Majumder, A., Raman, P. K. S., Influence of Zeolite Coating on the Corrosion resistance of AZ91D magnesium alloy, ***Materials***, 2014, 7(8), 6092-6104. https://doi.org/10.3390/ma7086092.
[42] Mirhoseini, B. S., Niazi, R., Investigation of the power between cinnamon essential oil macro and nanoemulsions as green corrosion inhibitors, ***Colloid Nanosci. J***., 2024, 2(1), 261-269. https://doi.org/10.52547/CNJ.2.1.261.