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Research Article

Keywords:

Posted Date: November 11th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11601187/v1

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Additional Declarations: No competing interests reported.

Electrospun cassava starch/poly(ethylene oxide) nanofibers incorporated with eugenol as a corrosion inhibitor for mild steel in HCl environment

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Abstract

Mild steel, also known as carbon steel, is a key material that is often used as a construction material in many industries. It mainly consists of a high amount of iron with a low carbon content. Due to the absence of alloying elements, mild steel lacks the ability to form a stable protective oxide film, leading to low corrosion resistance. Therefore, the introduction of corrosion inhibitors becomes essential to protect it in aggressive environments. This study investigates the potential of electrospun cassava starch/poly(ethylene oxide) (PEO) nanofibers incorporated with eugenol as a corrosion inhibitor for mild steel in 0.50 mol L^{-1} HCl solutions. Since cassava starch, PEO and eugenol contain heteroatoms, they form protective barriers on the mild steel surface to reduce corrosion. More importantly, mild steel specimens coated with nanofibers formed through electrospinning of cassava starch and PEO blend enhance the corrosion inhibition efficiency when dipped in eugenol. Mass loss measurements, electrochemical impedance spectroscopy (EIS), Tafel plot analysis and open-circuit potential (OCP) measurements independently verify the corrosion inhibition ability of the above electrospun system in the presence of eugenol. The highest inhibition efficiency of 94.0% is achieved with mild steel specimens coated with nanofibers of 98 nm dimensions formed with electrospun cassava starch/PEO mixed in 1:3 ratio followed by dipping in eugenol for 24 h. Moreover, the effect of pitting corrosion agents, such as NaCl and temperature on corrosion inhibition was also investigated.
Keywords: Cassava starch, Electrospinning, Eugenol, Mild steel, Nanofibers, poly(ethylene oxide) (PEO)

1. Introduction

Mild steel (MS), or carbon steel, has a low carbon content in the range of 0.05% to 0.25% by mass [1]. Generally, it is used in engineering applications for the production of automobile components, structural shapes and sheets that are used in plants, pipelines and bridges [2]. However, it has low corrosion resistance due to the absence of alloying elements, and hence, it lacks the ability to form a stable protective oxide film, leading to low corrosion resistance, especially in acidic environments. Hydrochloric acid is a widely used mineral acid in many applications, including water treatment, well acidification, chemical cleaning and acid pickling [3,4]. Synthetic organic corrosion inhibitors, despite their effectiveness, could be hazardous because of their toxicity to health and the environment [3]. On the other hand, organic corrosion inhibitors from plant extracts have proven to be effective, safe and economical against corrosion of metals.

Organic corrosion inhibitors typically contain heteroatoms such as oxygen, nitrogen, or sulfur, along with π-bonds or triple bonds. These functional groups enable inhibitors to adsorb directly onto the metal surface through interactions with the metal. This adsorption involves the transfer of electron pairs from the inhibitor molecules to the unoccupied d-orbitals of the mild steel surface, to form a protective layer that inhibits corrosion. Most of these inhibitors protect metals by adsorbing onto the metal surfaces through displacing water molecules on the surface, blocking the active sites and forming a protective layer that acts as a barrier between the acidic medium and the material [5,6,40].

This study involves the use of cassava starch (CS) and eugenol (EG), readily available, cost-effective green corrosion inhibitors. CS contains heteroatoms to interact with metallic surfaces [7]. However, native starch presents some drawbacks, such as low water solubility and poor stability when it is used at low pH [8], which can be overcome through chemical modification.

For example, carboxymethylated CS has been investigated as a corrosion inhibitor for carbon steel XC35 in NaCl solution [9], while CS graft copolymers have been used as a corrosion inhibitor for steel in HCl solution [10]. Further, CS graft copolymer prepared by grafting acrylamide onto CS has been used as an inhibitor for the corrosion of aluminum in HNO_3 solution [11]. On the other hand, EG is a naturally occurring phenolic compound, found in clove and cinnamon oil, containing heteroatoms and π-bonds. EG is found to be a corrosion inhibitor on AISI 1020 steel exposed to HCl [12]. EG modified into polyeugenol has been used as a corrosion inhibitor for carbon steel in HCl [13].

Nanosized materials play a significant role in corrosion science, due to their larger surface area-to-volume ratio [14]. Fibers with a diameter in the range of 1 nm to 100 nm are called nanofibers. Corrosion inhibition of carbon steel by polyaniline (PANI) nanofibers and effective release of corrosion inhibitors by cellulose nanofibers and zeolite particles have been reported [15,16]. Among various fabrication methods mentioned, electrospinning stands out to be the most versatile and widely adopted technique for producing continuous nanofibers. Electrospun nanofibers are utilized in different applications such as filtration, biomedical applications (drug delivery systems, tissue engineering, wound healing), textiles and sensors [17,18].

CS is composed of two structurally distinct molecules, which are amylose and amylopectin [19]. The amylose component is largely linear; hence, starch is used to form nanofibers using the electrospinning technique [20]. On the other hand, as CS contains a high amount of amylopectin, it is difficult to form fibers from pure CS. Among many studies on electrospun CS, fabrication of composite fibers by electrospinning a blend of polylactic acid in dichloromethane and CS in dimethyl sulfoxide has been recently reported [21]. Another study reported was on the esterification of CS with formic acid for the fabrication of electrospun fibers [22].

In this study, poly(ethylene oxide) (PEO) is used to enhance the electrospinnability of polymeric solutions. PEO is a high molar mass, non-ionic, biocompatible, biodegradable, low-toxic and water-soluble polymer with repeating CH_2-CH_2-O- units [23,24]. It gives excellent gelling and swelling behaviour due to its high hydrophilicity and chain entanglement properties in aqueous media. Water-soluble polymers are efficient corrosion inhibitors in different aqueous media due to the presence of functional groups containing N, P, O and S heteroatoms, which can donate electron pairs to the metals to form protective barriers [25]. Since PEO has a free electron oxygen group, which can form complexes with iron ions, the corrosion inhibition ability of PEO as an iron corrosion inhibitor in the electrolyte solution of NaCl has been studied [26]. In several studies, PEO was used to make electrospun fibers due to its excellent spinnability. In one study, electrospun PEO/sodium alginate core-shell nanofibers have been used in tissue engineering [24]. In another study, PEO-assisted fish collagen poly-ε-caprolactone (PCL) nanofiber membranes were prepared by electrospinning [27].

In this study, glutaraldehyde was used as the crosslinking agent to reduce hydrophilicity and to enhance the stability of the formed electrospun nanofibers.

The corrosion inhibition ability of electrospun nanofibers prepared either from CS or PEO has not been reported. In this research, the corrosion inhibition effect of electrospun CS/PEO nanofibers was investigated using a multi-technique approach, including mass loss measurements, electrochemical impedance spectroscopy (EIS) analysis, Tafel plots and open-circuit potential (OCP) measurements. Mass loss measurements provide an overall idea about the system. EIS analysis provides details on the corrosion mechanism of the system. The corrosion inhibition efficiency was determined using Eq. (1)

$$\% \text{ IE} = \frac{C_{R0} - C_{Ri}}{C_{R0}} \times 100\% \quad (1)$$

Where C_{R0} is the corrosion rate without the inhibitor and C_{Ri} is the corrosion rate with the inhibitor [42].

2. Materials and Methods

2.1. Materials

Fresh cassava roots (*Manihot esculenta*) were purchased from the local market. Formic acid (90%, BDH Laboratories Ltd.) was used to dissolve CS. PEO and CS were used to prepare electrospun nanofibers using glutaraldehyde (98%) as the crosslinking agent. MS specimens, purchased from a local hardware, were washed with acetone. HCl (37%, Sigma-Aldrich) was used as the corrosive medium. EG was extracted from clove buds purchased from the local market. NaCl (BDH Laboratories Ltd.) was used to test the effect of pitting corrosion agents.

2.2. Extraction of CS

Initially, fresh roots were washed, peeled, chopped into approximately 1 cm^3 cubes and then pulverized in a high-speed blender for 5 min. Thereafter, the pulp was suspended in ten times its volume of water, stirred for 5 min, and filtered using double cheesecloth. Next, the filtrate was allowed to stand for 2.0 h for the starch to sediment, and the top liquid was decanted and discarded. Then, the sediment was broken and water was added as in the first step. The mixture was stirred for 5 min and filtered using double cheesecloth. Then, the filtrate was allowed to stand for 2.0 h for the starch to sediment. The top liquid was decanted and discarded. Finally, the sediment was washed and dried at 65 °C for 12.0 h [28].

2.3. Preparation of electrospun nanofibers

2.3.1. Electrospinning using cassava starch

First, cassava starch polymeric solutions were prepared with strengths of 15%, 20%, 25% and 30% (*w*/*v*) in 75% formic acid. These solutions were stirred at ambient temperature using a magnetic stirrer until the solutions became homogeneous. Next, these solutions were loaded into a 10 mL plastic syringe and connected to the TONGLI Tech TL-F6 electrospinning instrument. Finally, electrospinning instrumental parameters were optimized as shown in Table 1 [22].

Table 1: Optimized instrumental parameters for electrospinning of cassava starch.

Voltage (kV)	Drum speed (rpm)	Tip-to-collector distance (cm)	Flow rate (mL/h)
10 - 23	700 - 720	10.00 15.00 20.00	0.5 – 1.0

2.3.2. Electrospinning using PEO

A sample of 0.700 g of PEO powder was dissolved in 10.00 mL of distilled water and stirred at room temperature for 24 h using a magnetic stirrer. Next, the solution was loaded into a 10 mL plastic syringe and connected to the TONGLI Tech TL-F6 electrospinning instrument. Then, the electrospinning instrumental parameters were optimized as shown in Table 1.

2.3.3. Electrospinning using CS/PEO

A sample of 0.700 g of PEO powder was dissolved in 10.00 mL of distilled water and stirred at room temperature for 24 h using a magnetic stirrer. Thereafter, 0.700 g of CS was dissolved in 10.00 mL of distilled water and stirred at 75 °C for 2.0 h using a magnetic stirrer. Then, the two solutions were mixed and stirred for 2.0 h. The resulting solution was loaded into a 10 mL plastic syringe and connected to the TONGLI Tech TL-F6 electrospinning instrument. Then, electrospinning instrumental parameters were optimized as shown in Table 2.

Table 2: Optimized solution and instrumental parameters for electrospinning of CS/PEO.

The ratio of PEO:CS (w/w)	Voltage (kV)	Drum speed (rpm)	Tip-to-collector distance (cm)	Flow rate (mL/h)
1:1	10 - 23	700 - 720	10.00	0.5 – 1.0
1:2			15.00	
2:1			20.00	
3:1				

2.4. Crosslinking

The polymer solution was electrospun onto MS specimens. Next, these specimens were placed in an airtight desiccator containing 1.00 mL of 25% (v/v) aqueous glutaraldehyde solution in a Petri dish. Next, the desiccator was kept for 4.0 h at ambient temperature. Thereafter, samples were kept in a fume hood for 1.0 h to remove extra glutaraldehyde [29].

2.5. Extraction of EG

A sample of 100.000 g of dried clove buds was subjected to steam distillation with 100.00 mL distilled water, and 120.00 mL of distillate was collected. Next, the distillate was placed in a 250 mL separatory funnel and extracted with three 15.00 mL portions of dichloromethane. Thereafter, a small amount of anhydrous $CaCl_2$ pellets were added to the combined CH_2Cl_2 extracts. Next, the flask was swirled for 1-2 min to complete the drying process. Thereafter, the extraction was carried out using three 10.00 mL portions of 5% aqueous NaOH solution. Next, the combined aqueous extracts were acidified to pH 1.0 with concentrated HCl acid and the liberated EG was extracted with three 8.00 mL portions of CH_2Cl_2 [30].

2.6. Preparation of metal specimens

Commercially available MS plates were cut into small pieces with the dimensions of 4.0 cm × 1.0 cm × 0.2 cm. Then, 1.5 cm × 1.0 cm × 0.2 cm portions of the specimens were painted using lacquer to reduce contact with atmospheric moisture. Next, the specimens were washed with distilled water, followed by acetone and air-dried before each experiment. Thereafter, the

unpainted sections (2.5 cm × 1.0 cm × 0.2 cm) of specimens were immersed in the corrosive medium to carry out experiments.

2.7. Mass loss measurements

The initial mass of MS specimens was recorded on an analytical balance (AA 220/C/2). Then, they were immersed in the corrosive medium with or without inhibitors. Specimens were removed from each test solution, wiped, dried and the mass was recorded after every 24 h. Thereafter, percentage mass loss values were calculated using Eq (2).

$$\text{Percentage mass loss} = \frac{m_0 - m}{m_0} \times 100\% \quad (2)$$

where m_0 is the initial mass and m is the mass after exposure to the test solution [41].

2.8. Electrochemical measurements

EIS and Tafel slope studies were carried out using Autolab electrochemical analyzer with Ag/AgCl/KCl(aq) reference electrode, a platinum counter electrode and a working electrode (MS specimen). EIS measurements were obtained within the frequency range from 1×10^{-1} Hz to 1×10^{6} Hz at a scan rate of 10 mV/s. Tafel plots were obtained using a potential range from -0.1 V to +0.1 V at a scan rate of 100 mV/s and steps of 0.01 V [38].

2.9. Open circuit potential (OCP) measurements

The potential of the working electrode (MS specimens) with or without inhibitors was recorded with respect to the Ag/AgCl/KCl(aq) reference electrode. MS specimens were immersed in the corrosive medium when the measurements were taken. Thereafter, specimens were kept in an open environment. Potential values were recorded after every 10 min during the first hour, then at 2.0 h intervals up to 8.0 h, and finally at 24 h intervals for 15 days.

3. Results and Discussion

3.1. Morphology of electrospun nanofibers

Starch fibers were fabricated by electrospinning using formic acid as a solvent. Because it has high vapor pressure, a crucial characteristic of solvent evaporation. In the polymeric solution, formic acid performs the dissolution and complete gelatinization of starch at ambient temperature by leaching amylose from the amylopectin structure. This weakens the structure, and consequently, the starch chains absorb more solvent molecules. This results in swelling of the molecule. An esterification occurs during the chemical gelatinization with formic acid, called O-formylation, where the formate group is inserted at the C6 position of the glucose units. This chemical modification reduces the crystallinity of starch by breaking the regular H-bond network of starch, making it more amorphous and soluble. These characteristics are helpful in making a smooth and more stable electrospinnable solution [22]. According to the SEM images shown in **Figure 1**, although beads were observed, fiber formation was not. This may be due to the presence of a high amount of branched amylopectin in CS [32]. Synthetic polymers such as PEO are used to facilitate the formation of nanofibers by enhancing the electrospinnability

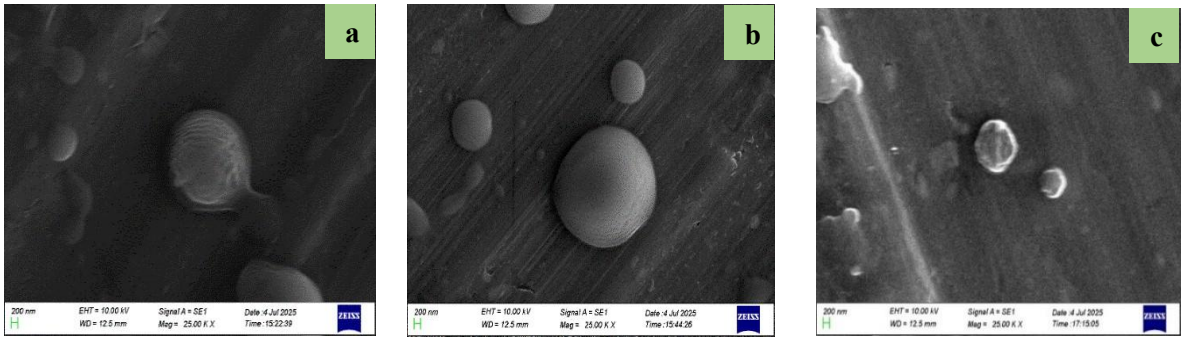


Figure 1: SEM images of electrospun CS solutions prepared with a) 15% b) 20% and c) 25% (w/v) CS in formic acid.

Uniform nanofibers with a minimum number of beads were formed by electrospinning PEO under the optimized conditions as noticed in **Figure 2** with an average diameter of 30 nm.

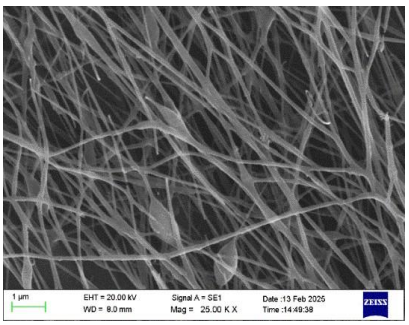


Figure 2: SEM image of electrospun PEO at 10 cm tip-to-collector distance; 0.6 mL h^{-1} flow rate and 20 kV voltage.

According to the SEM images shown in **Figure 3**, successful nanofiber formation was observed at a PEO: cassava starch ratio of 3:1 (w/w). Other parameters used were a 10 cm tip-collector distance, 0.6 mL h^{-1} flow rate and 20 kV voltage. The average diameter of 98 nm of the synthesized nanofibers reveals that electrospun CS/PEO nanofibers exhibit a higher diameter than electrospun PEO nanofibers (having a 30 nm diameter, as shown in **Figure 2**). This is probably due to increased solution viscosity upon introduction of CS into the polymeric solution and the presence of higher polymer solid content. When CS is heated in water, granules are broken and a smooth gelatinized starch solution is formed [32]. Thereafter, the gelatinized starch solution forms H-bonds with the PEO solution to produce a homogeneous polymer solution. Crosslinking with glutaraldehyde (GA) makes this polymer blend less water-soluble. As GA is a dialdehyde, it forms acetal bridges with hydroxyl groups. Since CS contains hydroxyl groups, they can form bridges between starch molecules to enhance stability. This network formation enhances the dimensional stability, thermal stability and stability under high physical stress of the polymer blend. [29]

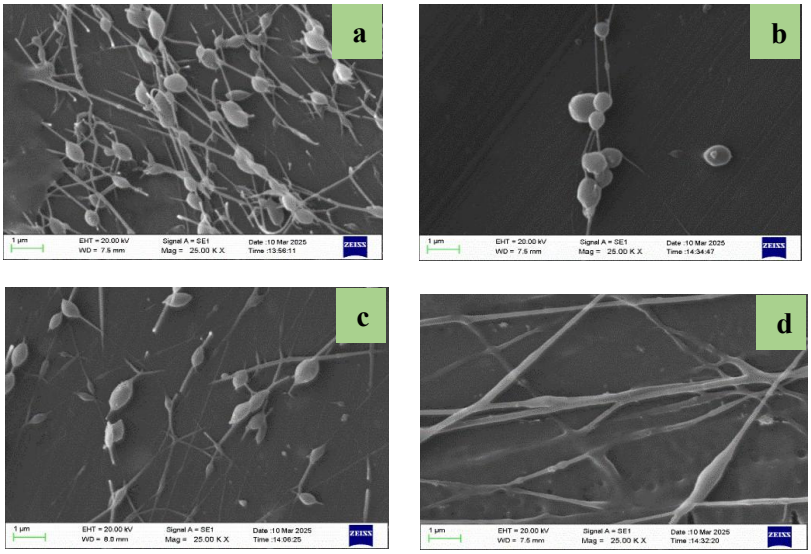


Figure 3: SEM images of a) 1:1 b) 1:2 c) 2:1 and d) 3:1 PEO:cassava starch electrospun fibers

3.2. Mass loss measurements

3.2.1. Investigation of optimal corrosive medium

According to **Figure 4**, the extent of corrosion of the blank MS has increased when the acid concentration and contact time are increased. This is expected due to the increase in H_3O^+ concentration. On the other hand, smaller mass loss at lower acid concentrations is due to the formation of an oxide film/protective layer on the MS surface. However, at high acid concentrations, the passive film/protective layer gets dissolved and the mass loss percentage increases due to the aggressive nature of the chloride ions. Based on these results, an HCl solution of 0.50 mol/L was selected as the corrosive medium for further studies, since it provides measurable, reproducible corrosion while avoiding overly aggressive attack; otherwise, protective films will be destroyed immediately.

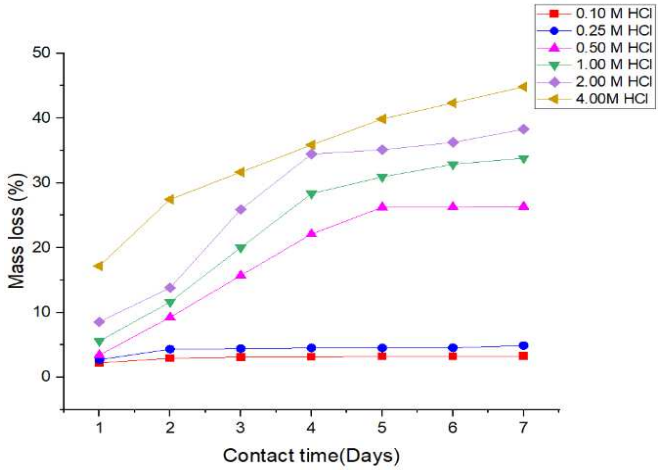


Figure 4: Percentage mass loss of MS at different HCl concentrations.

3.2.2. Investigation of the optimum time for electrospinning

According to **Figure 5**, mass loss percentages of electrospun CS/PEO-coated MS specimens were much lower than that of the blank MS specimen, indicating the corrosion inhibition ability of the electrospun CS/PEO coating. Further, it is observed that there is not much of a difference in the mass loss percentages with the change in contact time, indicating that an increase in the electrospinning time does not have a significant influence on inhibition efficiency because even in a short deposition time, surface coverage is high. Thus, a 20-minute deposition time was taken for further studies due to its time efficiency.

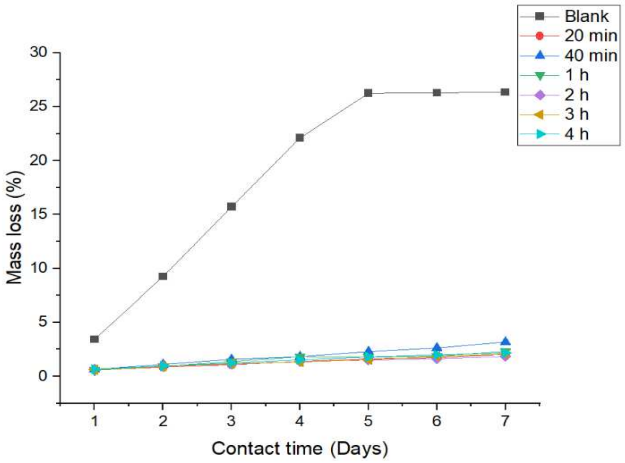


Figure 5: Percentage mass loss of electrospun CS/PEO-coated MS specimens at different time periods.

3.2.3. Mass loss measurements for different inhibitors

Figure 6 indicates that electrospun CS/PEO-coated MS specimens dipped in eugenol for 24 h (CS/PEO/EG 24 h) have the lowest mass loss compared to the other coatings. CS has heteroatoms, which can form a protective layer and reduce corrosion. EG itself also shows a good inhibition efficiency. It can strongly chemically adsorb onto the mild steel surface due to the presence of heteroatoms and a π-electron-rich aromatic ring. The non-polar nature of eugenol due to the aromatic ring and propene side chain makes it hydrophobic and water repellent. Eugenol has an antioxidant property that enhances its antimicrobial action against microbial attack [33]. These characteristics of eugenol help to enhance the barrier properties.

PEO is a hydrophilic polymer. Hydrophilicity can be reduced to some extent by crosslinking it with GA. Electrospun PEO nanofibers initially act as a physical barrier to block the initial corrosion. However, after some time, gradual swelling is observed due to the absorption of water by the hydrophilic polymeric fibers. Upon swelling, slow release of PEO molecules from the fiber matrix to the medium occurs. Since PEO contains heteroatoms, it can transfer electron pairs to the unoccupied orbitals of iron on the mild steel surface, forming a protective layer, thereby reducing corrosion [36].

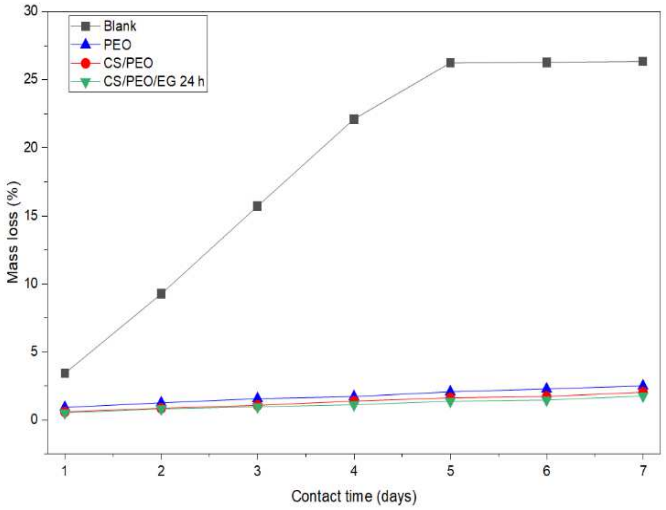


Figure 6: Mass loss percentages of different inhibitors coated MS surfaces.

3.2.4. Effect of pitting corrosion agents on CS/PEO/EG 24 h coating

According to **Figure 7**, mass loss increased with an increase in the concentration of NaCl, which is accounted for the presence of Cl^-, a pitting corrosive agent. When there is a high Cl^- concentration, it can break down the protective barrier formed by the coating [35]. Due to this breakdown, corrosion becomes more rapid and aggressive [39].

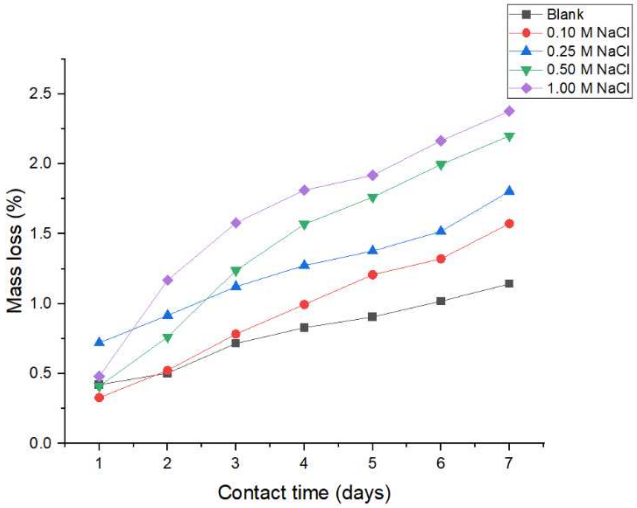


Figure 7: Mass loss percentage of CS/PEO/EG 24 h coated MS specimens at different NaCl concentrations.

3.2.5. Investigation of the effect of temperature on CS/PEO/EG 24 h coating

Since corrosion is a chemical reaction, the rate of the corrosion reaction increases with the increase in solution temperature, leading to higher mass losses [37]. This behaviour is illustrated in **Figure 8**. At high temperatures, the coating would become soft, thereby increasing the permeability of the coating. This would allow more corrosive ions to penetrate the metal surface.

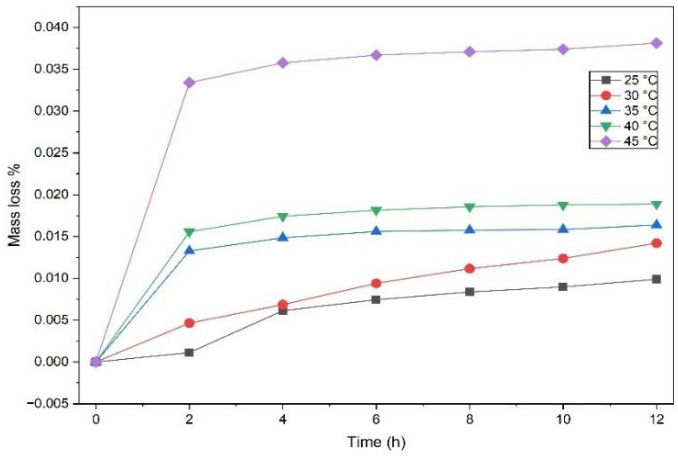


Figure 8: Mass loss percentages of CS/PEO/EG 24 h coated MS specimens at different temperatures

3.3. Electrochemical studies—EIS, potentiodynamic polarization (Tafel slope) and open circuit potential analysis

Nyquist plots for different inhibitor-coated samples exhibit complex impedance behavior consisting of three distinct features across the frequency spectrum as shown in **Figure 9**. For the purpose of evaluating coating performance, the analysis was mainly focused on the third semicircle, which appeared in the low-frequency region, due to the fact that the semicircle corresponding to the higher frequency range having negative real component of impedance and the middle response being negligibly small. Moreover, the changes in polarization resistance values under different experimental conditions are visible in the third semicircle. Hence, this was used to determine the polarization resistance (R_p) at the metal coating interface.

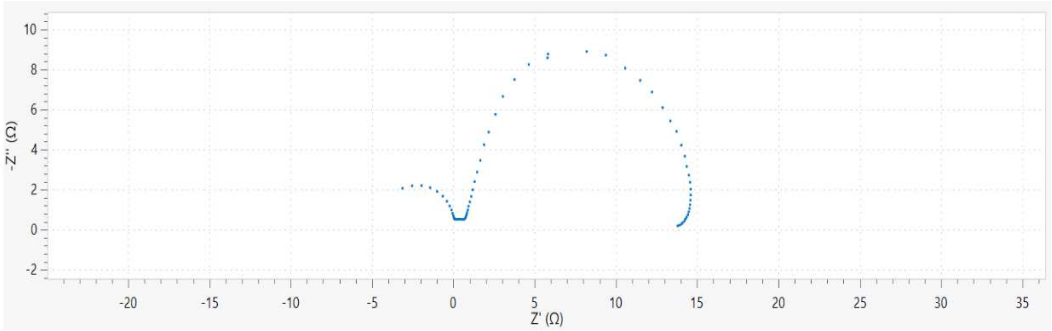


Figure 9: Nyquist plot for CS/PEO/EG 24 h coated MS within the entire frequency range

According to **Figure 10**, electrospun CS/PEO dipped in eugenol for 24 h showed the highest charge transfer resistance. Since CS, PEO and EG have heteroatoms, they can form a better protective barrier against corrosion than other combinations. R_p values for different inhibitor-coated mild steel were indicated in **Table 3**.

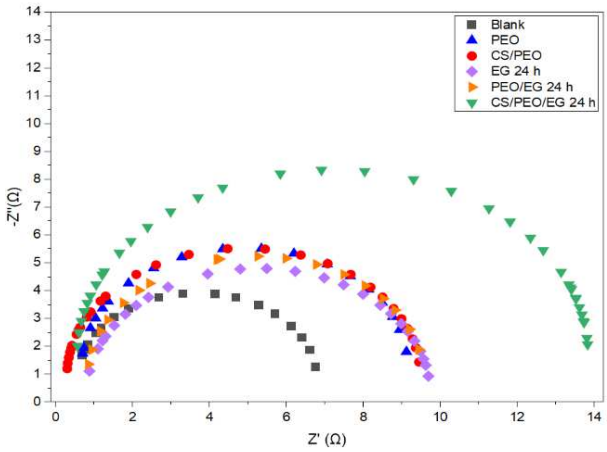


Figure 10: Nyquist plots of different inhibitor-coated mild steel.

Table 3: Polarization resistance (R_p) values of mild steel for different inhibitors.

Sample	Blank	PEO	CS/PEO	EG 24 h	PEO/EG 24 h	CS/PEO/EG 24 h
Polarization resistance (Ω)	6.02	8.06	8.59	8.85	8.89	12.90

According to the **Figure 11**, electrospun CS/PEO dipped in EG for 24 h showed a more positive potential than others, indicating a lower corrosion than other combinations

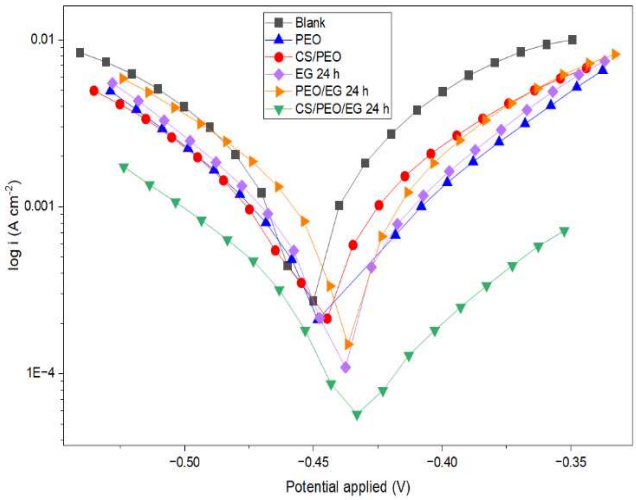


Figure 11: Tafel plots of different inhibitors coated MS surfaces

According to **Table 4**, electrospun CS/PEO/EG 24 h exhibits the best corrosion inhibition ability among the other inhibitors because it has the lowest corrosion rate, current and a more positive potential compared to others. Further, results indicate that all three components: PEO, CS and EG have the ability to inhibit corrosion in MS. The inhibition ability of electrospun CS can be identified by comparing the corrosion rates of only electrospun PEO-coated mild steel in HCl and electrospun CS/PEO-coated MS in HCl, that is 2.16 mmpy and 1.62 mmpy, respectively. This reduction in corrosion rate indicates the effect of CS as a green corrosion inhibitor on the MS surface.

Table 4: Tabulated values for corrosion potentials (E_{corr}), corrosion current (I_{corr}) and corrosion rate (in mm per year) of different inhibitors-coated MS specimens.

Sample	E_{corr} (V vs. Ag/AgCl/Cl^-)	$I_{corr} \times 10^{-4}$(A cm^{-2})	Corrosion rate (mmpy)	Inhibition efficiency (%)
Blank	-0.46	14.36	3.34	-
PEO	-0.45	9.27	2.16	35.33
CS/PEO	-0.44	6.97	1.62	51.5
EG 24 h	-0.44	6.61	1.54	53.89
PEO/EG 24 h	-0.44	6.22	1.49	55.39
CS/PEO/EG 24 h	-0.43	0.86	0.20	94.01

Open circuit potential (OCP) is the natural potential of a metal in an electrolyte in the absence of an external current. As corrosion is an electrochemical process, a low potential is favored to cause oxidation (metal dissolution), while a more positive potential disfavors the oxidation process. This is because, when it has a positive potential, it tends to attract electrons instead of releasing electrons. Then, a more positive OCP shows better corrosion resistance and vice versa [34]. As observed in **Figure 12** and **Figure 13**, fluctuations were due to surface reactions, protective film formation and metal degradation. According to **Figure 13**, as the electrodes approached the equilibrium conditions after 15 days, the potential of each electrode showed a stable potential. At the equilibrium condition, anodic and cathodic reactions on the metallic surface are balanced and the potential remains constant. Since the blank has the lowest corrosion resistance, it indicates a low potential. CS/PEO/EG 24 h coated mild steel indicated the highest potential at equilibrium, as it forms the best corrosion-resistant protective barrier.

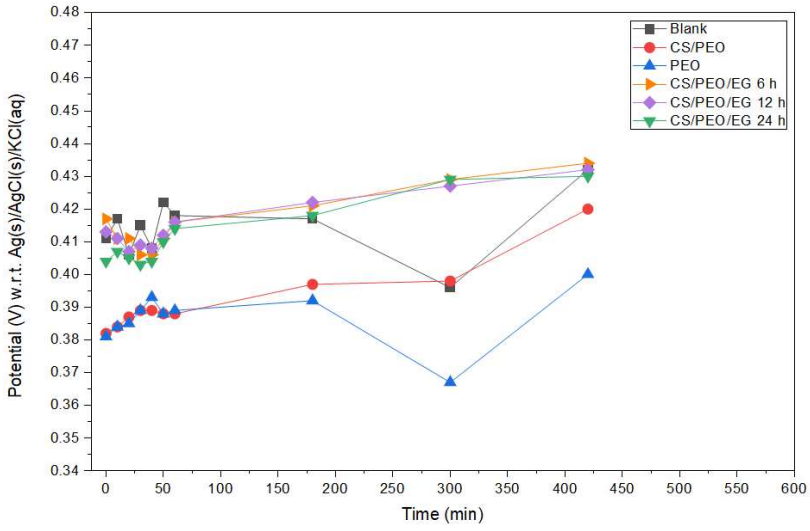


Figure 12: OCP of different inhibitors coated mild steel specimens within the first day

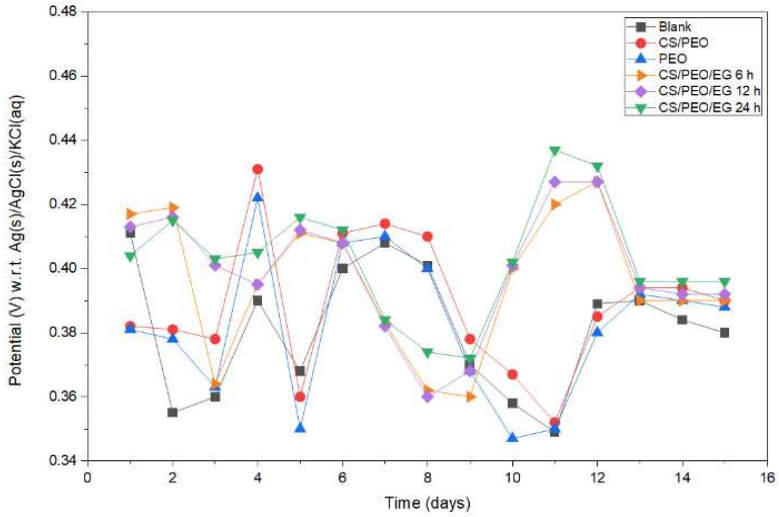


Figure 13: OCP of different inhibitors coated mild steel specimens up to 15 days

4. Conclusion

Preparation of electrospun nanofibers only from native CS is difficult due to the formation of beads when formic acid is used as the solvent. With the aid of PEO, electrospun CS/PEO nanofibers were formed successfully. The optimized parameters for successful nanofiber formation are 3:1 (PEO:CS), 10 cm capillary-collector distance, 0.6 mL h^{-1} flow rate and 20 kV voltage. Electrospun CS/PEO-coated MS dipped in eugenol for 24 h is found to exhibit the best corrosion inhibition with 94% inhibition efficiency. CS, PEO and EG exhibit corrosion inhibition ability due to the presence of heteroatoms in their structures. In the presence of pitting corrosion agents, such as Cl^-, the inhibition efficiency of the CS/PEO/EG 24 h coating is reduced due to the breakdown of the protective layer and further, an increase in solution temperature also leads to the reduction of inhibition efficiency due to the increase in the rate of corrosion reactions.

5. Acknowledgments

Special appreciation for the immense support provided by the Department of Chemistry, University of Peradeniya.

6. Data Availability Statement

The data that support this study will be shared upon reasonable request to the corresponding author.

7. Conflicts of Interest

The authors declare that there are no conflicts of interest.

8. Declaration of Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

9. Author Contributions

W.S.S. Gunathilake and N. Priyantha (Corresponding author) contributed to the conceptualization of the study, formal analysis, writing - review & editing, investigation, Validation, project administration, resources and supervision. Data analysis, methodology, software, data curation, visualization and writing the original draft of the manuscript were done by H.B.Hapukotuwa. All authors contributed to reviewing and editing of the manuscript.

10. AI Use Statement

No AI tools were used in the preparation of this manuscript.

11. Declarations

Consent to participate

Not applicable.

Consent to publish

Not applicable.

12. Ethical approval

Not applicable. This research did not involve any human or animal subjects

13. Abbreviations

Full Name	Abbreviation
Electrochemical impedance spectroscopy	EIS
poly(ethylene oxide)	PEO
Open-circuit potential	OCP
Mild steel	MS
Cassava starch	CS
Eugenol	EG
Scanning electron microscope	SEM
Glutaraldehyde	GA
Polarization resistance	R_p
Corrosion potential	E_{corr}
Corrosion current	I_{corr}

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