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Research Article

Alkaline Corrosion Control Using Sustainable Natural Inhibitors

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Abstract: *Using natural corrosion inhibitors from calcium carbonate has gained attention in corrosion prevention approaches as it offers comparable and significant benefits compared to other corrosion inhibitors. Consequently, eggshells with a high amount of calcium carbonate were proposed as a corrosion inhibitor to evaluate the effect on the corrosion behavior of mild steel. In this study, eggshell waste was extracted in an ethanol solution using a Soxhlet extractor and concentrated using a rotary evaporator to produce the proposed natural corrosion inhibitor. The characteristics of the inhibitor were then examined and verified through FTIR and XRD analysis. The corrosion performance was then evaluated through the weight loss method in 30% Sodium Hydroxide. The corrosion rate and inhibiting efficiency were also performed to analyse the effect of eggshell concentration on the mild steel. Additionally, increasing the eggshell concentration decreases the corrosion rate and increases the inhibitor efficiency. This is due to CaCO3 in eggshells, a barrier to metal surfaces. Results indicate that selecting eggshell as a natural corrosion inhibitor successfully and confirmable protected the surface. Thus, this study is a viable utilization of sustainable use from eggshell waste in reducing the corrosion occurrence of mild steel in an alkaline environment.*

1. INTRODUCTION

Corrosion (Ideozu, 2013) is a natural degradation process that occurs when metals interact with their surrounding environment, leading to a gradual loss of material properties and structural integrity. Mild steel is widely used in industries such as construction, marine, manufacturing, and chemical processing due to its low cost (Dhar et al., 2024), good mechanical strength, and ease of fabrication.

However, mild steel is highly susceptible to corrosion, particularly when exposed to aggressive environments such as alkaline solutions containing chloride ions. Continuous corrosion can cause severe structural damage, equipment failure, safety risks, and significant economic losses due to repair, replacement, and maintenance.

To control corrosion, industries commonly use chemical corrosion inhibitors(Asmara et al., 2024) such as chromates, phosphates, and amines. Although these inhibitors are effective, many of them are toxic, hazardous to human health, and harmful to the environment. The growing concern over environmental sustainability and safety has driven research toward the development of eco-friendly and biodegradable corrosion inhibitors derived from organic or waste materials.

Eggshell waste, which is rich in calcium carbonate ($CaCO_3$), has attracted attention as a potential natural corrosion inhibitor (Younas et al., 2025). Calcium carbonate can form a protective barrier on metal surfaces, reducing direct contact between the metal and the corrosive environment. Utilizing eggshell waste not only provides an environmentally friendly alternative to conventional inhibitors but also contributes to waste reduction and sustainable material reuse. Therefore, this study investigates the potential of eggshell-based organic material as a corrosion inhibitor for mild steel in an alkaline sodium hydroxide solution.

2. LITERATURE REVIEW

Corrosion is a complex electrochemical process that significantly affects the durability, safety, and economic performance of mild steel, especially in aggressive environments (Tyagi, 2023). Various types of corrosion and their damaging effects have been widely reported, leading to the development of multiple prevention methods such as coatings, cathodic protection, and corrosion inhibitors. While conventional chemical inhibitors are effective, their toxicity, high cost, and environmental impact have encouraged the search for greener alternatives. Organic corrosion inhibitors derived from natural or waste materials have shown promising performance due to their ability to adsorb onto metal surfaces and form protective layers (Budiarsa et al., 2024). Calcium carbonate, particularly from eggshell waste, has been identified as a potential eco-friendly inhibitor because of its availability, low cost, and corrosion-resisting properties (Putkham et al., 2018). Therefore, based on previous studies, eggshell-based organic inhibitors present a sustainable and effective approach for reducing corrosion of mild steel, supporting the objectives of this study.

3. METHODOLOGY

3.1 Samples and Solution Preparation

Eggshell waste was collected, washed to remove impurities, and boiled for 10–15 minutes to eliminate bacteria before being dried under sunlight and further heated in an oven at 110–120 °C for 2 hours. The dried shells were blended into fine powder, sieved for uniform particle size, and stored in an airtight container. The eggshell powder was then extracted using ethanol through Soxhlet extraction *(Olunusi & Ramli, 2025)*, followed by vacuum filtration and oven drying to obtain the eggshell-based corrosion inhibitor. Mild steel samples were cut into dimensions of 50 mm × 25 mm × 2 mm, ground and polished to achieve a smooth surface, cleaned, and dried before testing. A 30% sodium hydroxide (NaOH) solution was prepared as the corrosive medium, and different inhibitor concentrations (1 g, 3 g, 5 g, 7 g, and 9 g) were added separately and stirred until homogeneous. The prepared mild steel samples were fully immersed in the solutions and kept at room temperature for 7 and 14 days for corrosion testing.

3.2 Characteristics Testing

The characteristics of the eggshell-based corrosion inhibitor were analyzed using Fourier Transform Infrared Spectroscopy (FTIR) *(Tang & Zhang, 2025)* to identify the functional groups and chemical compounds present in the material. FTIR analysis was carried out using a Bruker VERTEX 70 spectrometer, which measures the absorption of infrared radiation by the sample over a specific wavelength range. This technique allows the identification of key functional groups associated with calcium carbonate and organic compounds in the eggshell extract. The FTIR results were used to confirm the presence of active components responsible for forming a protective layer on the mild steel surface and contributing to corrosion inhibition.

3.3 Weight Loss Testing

The weight loss method was used to evaluate the corrosion rate of mild steel and the effectiveness of the eggshell-based corrosion inhibitor in an alkaline environment. Each mild steel sample was cleaned, dried, and weighed using a digital balance to record the initial weight before immersion. The samples were then fully immersed in a 30% sodium hydroxide (NaOH) solution with different eggshell inhibitor concentrations and without inhibitor as a control. The immersion was carried out at room temperature for 7 and 14 days. After the immersion period, the samples were removed, rinsed with distilled water, cleaned to remove corrosion products, dried, and weighed again to obtain the final weight. The difference between the initial and final weights was used to determine the weight loss, corrosion rate, and inhibitor efficiency.

4. FINDINGS

4.1 FTIR Results

FTIR spectroscopy was used to characterize the eggshell powder and identify its functional groups and heteroatoms, which are important for adsorption onto the mild steel surface. FTIR spectra were recorded for eggshell powder at concentrations of 1 g, 3 g, 5 g, 7 g, and 9 g. The results confirm that calcium carbonate ($CaCO_3$) is the main component of the eggshell powder, as shown by characteristic carbonate absorption bands that closely match those of industrial $CaCO_3$ (SUPRIADI et al., 2023). A broad band between 3230 and 3500 cm^{-1} corresponds to O–H stretching, indicating the presence of moisture or surface hydroxyl groups, while a weak band around 2960–2970 cm^{-1} is attributed to C–H stretching from residual organic matter. The strong peaks at approximately 1410–1420 cm^{-1} and 875 cm^{-1} further confirm the presence of carbonate ions. These functional groups enhance the adsorption of eggshell powder onto the mild steel surface, forming a protective layer that improves corrosion inhibition (Bhardwaj et al., 2025).

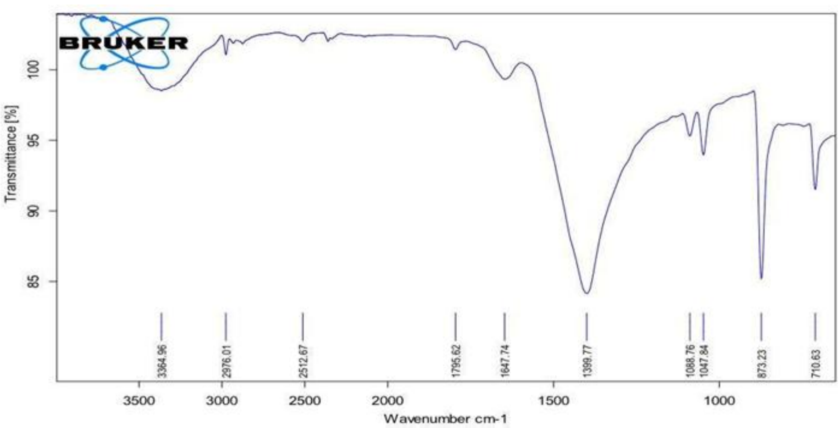

Figure 1 FTIR Result For Eggshell

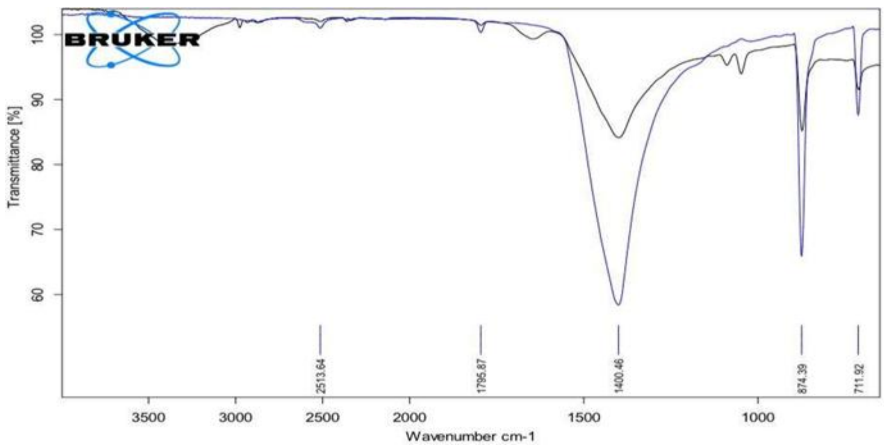

Figure 2 FTIR Result For Eggshell vs CaCO3 Industry

4.2 Weight Loss Result

Table 1 Data corrosion rate and inhibitors efficiency at several concentrations

Concentration	Corrosion Rate (mm/year)	Inhibitor Efficiency (%)	Corrosion Rate (mm/year)	Inhibitor Efficiency (%)
	7 days	7 days	14 days	14 days
Raw	0.4445	0	0.6659	0
1	0.2998	32.5466	0.1982	55.4037
3	0.1286	71.0559	0.1237	72.1739
5	0.0723	83.7267	0.0629	85.8385
7	0.0409	90.8075	0.0121	97.2671
9	0.0282	93.6646	0.0116	97.3913

5. Discussion

A similar trend was observed in samples that were immersed for 14 days, as the 0% eggshell sample experienced tremendous corrosion damage with a corrosion rate of 0.6659 mm/y compared to other types of samples. This is followed by adding 1 grams of eggshell at an average of 0.1982 mm/y, 3 grams at an average of 0.1237 mm/y, and 9 grams at an average of 0.0116 mm/y of corrosion rate. It was concluded that longer immersion times resulted in a higher corrosion rate. This matter confirms that corrosion damage has been caused by the active anion NaOH on the metal surface of the control sample due to the unavailability of eggshell extract.

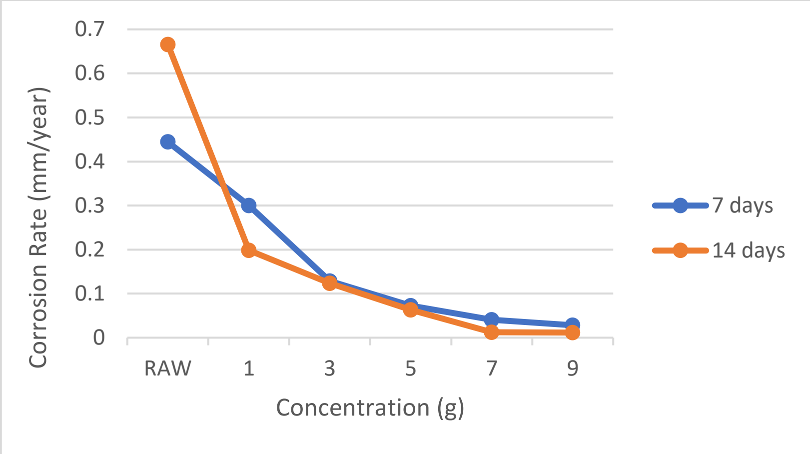

Figure 3 Corrosion rate(mm/y) vs difference concentrations(grams)

Figure 4 shows the inhibiting efficiency of the samples concerning different eggshell concentrations. In contrast to the corrosion rate, the inhibition efficiencies increased with the eggshell concentration. The maximum eggshell concentration of 93.6646 % and the lowest corrosion rate of an average of 0.0282 mm/y were achieved at 7 days. For 14 days, inhibition efficiency was achieved with the highest eggshell concentration at 97.3913 %, corresponding to the lowest corrosion rate of 0.0116 mm/y of average value. This result showed that increasing the immersion time also increased the inhibiting efficiency of the mild steel. The surface was exposed to more hydroxyl cation (OH+) elements. This shows strong inhibitory adsorption of eggshell in a 30% Sodium Hydroxide solution for 7 days and 14 days. Meanwhile, the higher amount of CaCO3 helps develop the surface's barrier properties.

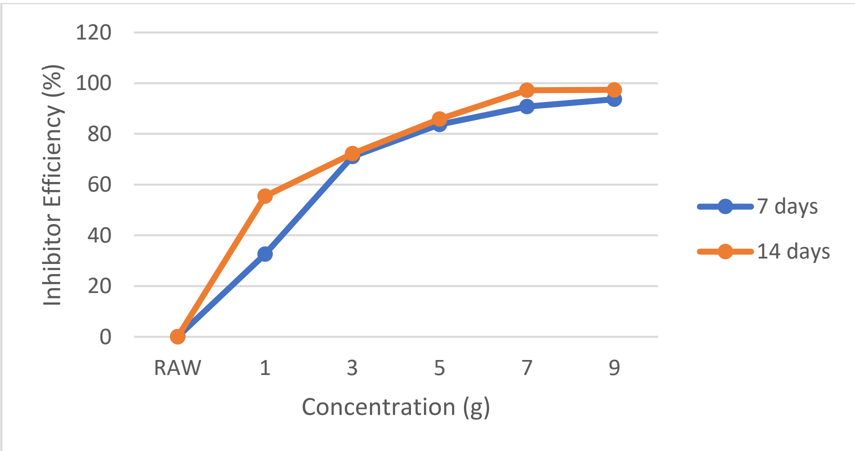

Figure 4 Inhibitor efficiency(%) vs difference concentrations(grams)

6. CONCLUSION

This study demonstrates that eggshell extract, mainly composed of calcium carbonate ($CaCO_3$), has strong potential as an environmentally friendly corrosion inhibitor for AISI 1020 steel in alkaline conditions. FTIR and XRD analyses confirmed the dominance of $CaCO_3$, which contributes to the formation of a protective layer on the steel surface. Corrosion tests showed that inhibition efficiency increased with inhibitor concentration, with the highest efficiency achieved at 9 g due to a more stable protective film. Although longer immersion times increased the overall corrosion rate, the eggshell extract effectively reduced surface damage, especially at higher concentrations. Overall, eggshell waste is confirmed as a sustainable, non-toxic, and cost-effective corrosion inhibitor, supporting its potential as a green alternative to conventional synthetic inhibitors.

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