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Utilization of Glass Waste in Modifying Coating for Corrosion Control of Mild Steel

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Abstract

Corrosion remains the predominant mechanism of material degradation in industries, necessitating a sustainable protection methods. Waste glasses are continuously generated globally, most of which are disposed to landfills causing severe environmental pollution. The research focus on utilizing these waste for corrosion control. Samples of mild steel was fabricated into 2×1 cm² and surface treated with abrasive paper and various chemical solvents. Waste glass was beneficiated, crushed and sieved into uniform particle size of 30 µm before X-Ray Flourescence (XRF) analysis. A coating was prepared using polyester based resin, organic compounds, pigments and incorporating with waste glass at a ratio of 1:2. Mild steel was coated using hand lay-up method then subjected to Electrochemical Impedance Spectroscopy (EIS) in acidic medium (3.5 wt% NaCl solution). The results shows an effective coating adhesion to the substrate with a thickness of 5 mm, the composition of waste glass confirmed the presence of SiO_2 (71.20), Al_2O_3 (2.12%), Sb_2O_3 (2.20%), CaO (7.04%), MgO (1.36%), BaO (1.47%), and Fe_2O_3 (0.26%). The corrosion analysis of coated samples revealed a desirable anti corrosion characteristics with respect to frequency, charge transfer and phase angle of 1187.3Ohm.cm^2, 47.7Ω cm^2, and -65.4Hz respectively, compared to uncoated samples with frequency, charge transfer and phase angle of 641.Ohm.cm^2, 31.5cm^2, and -72.39Hz respectively. The findings demonstrate the potential of waste glass in improving the corrosion resistance of coatings due to high SiO_2 content, highlighting its economic and sustainable additive for corrosion control of mild steel.

Keywords: coating, corrosion, mild steel, waste glass

1.0 Introduction

The thirst for minimizing environmental impact by pollution have led many industries to push for sustainable materials that can easily be recycled. Waste glass, as a class of disposed and non-biodegradable materials being generated globally have recently gain a momentum in rivalling plastic materials for eco-friendliness. This is possible due to its infinite recyclability at affordable energy and low carbon emission. On the other hand, Corrosion remains a natural disaster in industrial application. The degradation of metallic structures by corrosion poses significant economic and environmental costs [1]

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[2]. It has been reported that corrosion costs across five major industrial sectors in the United States; namely infrastructure, utilities, transportation, production, and manufacturing is amounting to approximately $137.9 billion annually [3]. Developing nations like Nigeria should avoid these costly repairs by utilizing the abundant local raw materials and technology that are affordable and sustainable for corrosion control.

Coatings, as a class of corrosion control measure, acts as barrier to prevent the corrosive medium from reaching the substrate. Different types of protective coatings for protecting metals from aggressive reactions are available but often deteriorate over time, thereby exposing the bare steel surfaces susceptible to corrosion and demanding turnaround maintenance [4]. The integration of corrosion inhibitors and potential waste materials will presents a promising approach in delaying the corrosion process while reducing environmental waste [5].

Waste glasses takes more than 4000 years to decompose in the environment [6], posing serious concern due to ecological challenges. These urge necessitate the need in exploring innovative strategies of utilizing these waste for industrial applications. Recent studies have explored the incorporation of glass waste into construction materials, including concrete and surface coatings, to enhance mechanical strength and durability [7–9]. Similarly, hybrid nanocomposite coatings incorporating inorganic fillers such as SiO_2 have shown improved barrier properties and corrosion resistance [10,11]. Given the inherent strength, chemical stability, and fine particle characteristics of glass, this study aims to investigate the potential of waste glass as a reinforcing additive in coatings for corrosion protection of mild steel.

2. Materials and Methods

2.1 Sample collection and processing

2.1.1 Waste Glass

Post-consumer waste glass (external cullet) was randomly collected and processed according to waste management standards [12]. The samples, comprising mixed glass types, were beneficiated and pulverized using a planetary micro mill (Pulverisette 7) to a fine particle size of 30 μm, following ASTM D6913 [13].

2.1.2 Mild Steel

Marine-grade mild steel (S275) was obtained from Dana Steel Ltd., Katsina, Nigeria. Its composition (wt%) was ≤0.18 C, ≤1.4 Mn, ≤0.035 Si, ≤0.050 S, and ≤0.045 P. The samples were cut into 2×1 cm² coupons, surface-treated with abrasive paper, washed with detergent, degreased with acetone, rinsed with distilled water, and air-dried to ensure good adhesion in accordance with ISO 8501-1 [14].



Fig. 1: Waste glass.



Fig. 2: Waste Glass powder



Fig. 3: Surface Treatment of samples.



Fig. 4: Surface treated samples

2.2 Coating Preparation

The coating matrix was formulated using a polyester resin system containing an aliphatic polyamine hardener and an accelerator at a weight ratio of 1:2 [15] [16]. Pigments were added to achieve a greyish tone, and waste glass powder was incorporated into the coating mixture at a molar ratio of 1:2. Methyl Ethyl Ketone Peroxide (MEKP) served as the curing agent. The mixture was stirred thoroughly to achieve homogeneity and uniform particle distribution.

The coating was applied to pre-treated steel substrates using the hand lay-up technique, labelled as WG+P, and allowed to cure for one week at ambient temperature in accordance with ASTM D1640/D1640M [17]. The resulting cured coating thickness of 5 mm.



Fig. 5: Coating preparation



Fig. 6: Addition of glass powder



Fig. 7: Application of gel coat



Fig. 8: Cured sample

2.3 Chemical Analysis

The chemical composition of the waste glass powder was determined using X-Ray Fluorescence (XRF) at Umaru Musa Yar'adua University, Katsina. A binder (20%) was mixed with the powdered sample (80%) of each samples to keep the material in position during the test. The whole mixture was pressed at 140 kN to form a stable pellet. The analysis was conducted using a Minipal 4 spectrometer.

2.4 Corrosion Analysis

Electrochemical Impedance Spectroscopy (EIS) analysis was performed using a Gamry Potentiostat (Model 600, SN24086) at the African University of Science and Technology, Abuja. Figure 9 shows the schematic setup for electrochemical analysis, which was carried out in a three-electrode configuration with a graphite rod as counter electrode, while the coated steel served as the working electrode, and saturated calomel electrode (SCE) as reference electrode

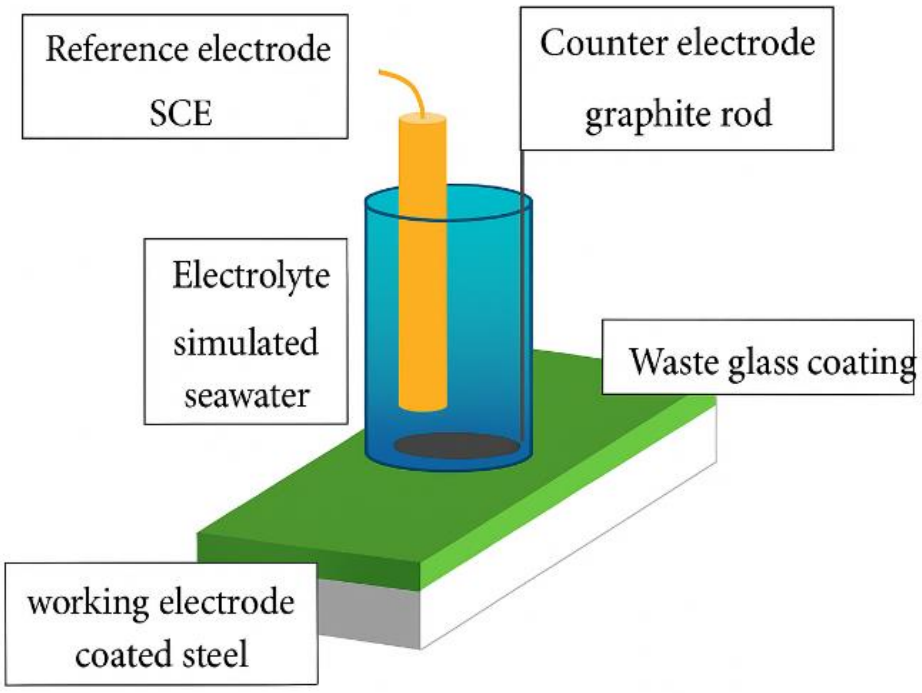


Fig. 9: Experimental Set-up for EIS analysis.

The EIS analysis was carried out in 3.5 wt.% NaCl solution which act as simulated sea water environment. Impedance spectra were recorded across a frequency range of 10 mHz–100 kHz. The coatings were synthesized over mild steel and were used as a protection between the electrolyte and uncoated mild steel samples.

3. Results and Discussion

3.1 Chemical Analysis of Waste Glass

The XRF analysis (Table 1) revealed that SiO_2 constituted approximately 71.20% of the waste glass, confirming its silicate-rich nature and potential as a reinforcing filler in coatings. The high SiO_2 content is known to enhance coating density, reduce porosity, and improve barrier resistance against corrosion [18].

Table 1: XRF result of waste glass

S/N	Oxide	Conc. (%)
1.	Fe_2O_3	0.26
2.	ZnO	0.01
3.	MgO	1.36
4.	Al_2O_3	2.12
5.	SiO_2	71.20
6.	P_2O_5	0.16
7.	SO_3	0.38
8.	Cl	0.17
9.	K_2O	0.23
10.	CaO	7.04
11.	TiO_2	0.16
12.	Cr_2O_3	0.02
13.	MnO	0.06
14.	As_2O_3	0.32
15.	Rb_2O	0.01
16.	SrO	0.52
17.	ZrO_2	0.08
18.	PbO	0.05
19.	Sb_2O_3	2.20
20.	BaO	1.47

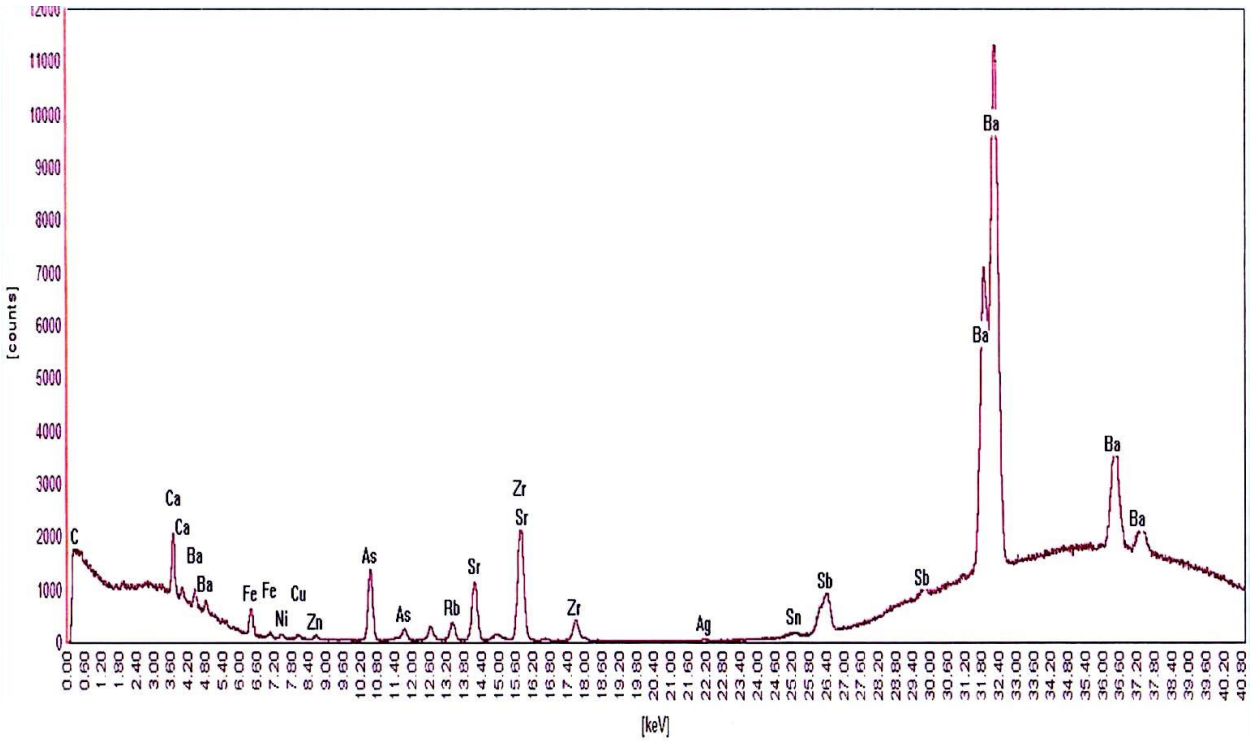


Fig. 10: EDXRF Spectra of waste glass

According to the literature, Al_2O_3 (2.12%) and Sb_2O_3 (2.20%) enhance thermal stability and structural integrity, while CaO (7.04%) adds to the coating's mechanical strength and stability [19]. Hardness and corrosion resistance are improved by minor oxides such as MgO (1.36%), BaO (1.47%), and FeO_3 (0.26%) [20]. Waste glass powder composition has a positive influence in modifying the properties of a coating [22].

3.2 Corrosion Analysis

The result of the EIS is represented by the Nyquist plot in Figure 11 revealed a charge transfer resistance for the mild sample as (31.5 Ω cm^2) and reference sample has (41.2 Ω cm^2), while the coated sample WG+P exhibited (42.7 Ω cm^2), and reference sample has (41.2 Ω cm^2). It was clearly observed from the zoom-in section that the impedance behaviour of the bare mild steel sample is below compared to the reference sample with difference of (9.7 Ω cm^2). This indicate that the uncoated sample cannot resist transfer of ions thereby accelerating the corrosion rate.

Fig. 11: Nyquist plot of coated and uncoated mild steel (WG+P)

The Nyquist curves present a single capacitive loop and resistive behaviours over at frequency range, which is usually related to charge transfer phenomenon. The capacitive plots are semicircles (imperfect semicircle arc), this is accredited to frequency spreading as a consequence of inhomogeneous behaviour of electrode surface.

The EIS spectrum in high frequency region is attributed to coating behaviour, and the low-frequency region corresponds to corrosion reaction [23]. The capacitance component is thought to be the double layer capacitance of the corrosion at the steel surface and the resistances in the spectrum are thought to be the coating resistance in the high frequency region, and a charge transfer resistance in low-frequency region corresponds to corrosion reaction.

The plots exhibit a small partial arc at the high-frequency range suggesting a low charge-transfer resistance, followed by a linear line in the low-frequency range. The resistance in the high-frequency region showed the resistance of the

film, while the resistance in the low-frequency region showed the charge transfer resistance (R_{CT}). Figure 12, is informative as it present the resistance as a function of the frequency in 3.5 wt % NaCl solution.

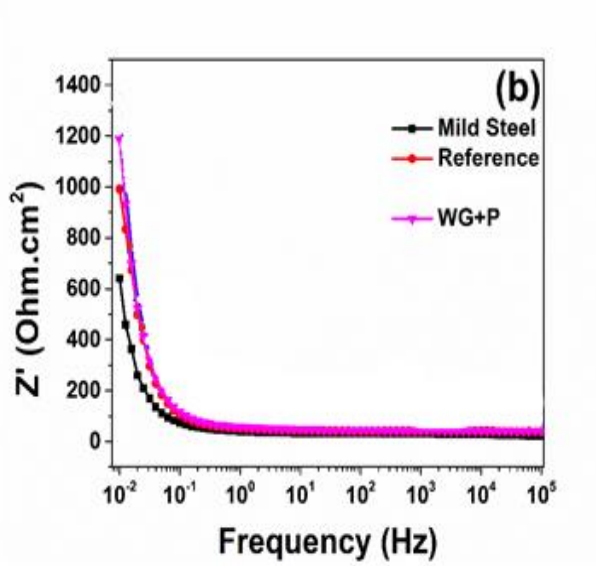


Fig. 12: Resistance as a function of frequency

It is observed that coated sample WG+P exhibited the resistance of (1187.3 Ohm.cm^2), reference (991 Ohm.cm^2), and the mild steel (641 Ohm.cm^2). In general, the higher value of the resistance signifies the lower the corrosion rate. This is consistent with the decrease in the corrosion resistance of the coated steel surface. The impedance plots also revealed the dominance of coating capacitance in the high-frequency regime and coating resistance in the low-frequency regime. This is attributed to the thickness of the coatings, the formation of adsorption layer on the steel surface. The adsorbed surface acts as barrier for charge-transfer at the electrode surface.

Sample WG+P shows a high frequency value above the reference sample with difference of (196.3 Ohm.cm^2), indicating the coating resist charge transfer which is attributed to coating performance. Similarly, it was clearly observed that the frequency of the bare mild steel sample is below compared to the reference sample which served as a graphite rod with difference of (350 Ohm.cm^2). This indicate that the uncoated sample has a poor resistance of ion transfer to the corrosive medium, thereby accelerating the corrosion rate. Similarly, Figure 13 and 14 is informative as it gives simultaneous measurement of modulus of impedance with respect to frequency. A high magnitude of impedance signifies an excellent barrier property of the surface coating and corresponds to less corrosive ions being in contact with the metal surface.

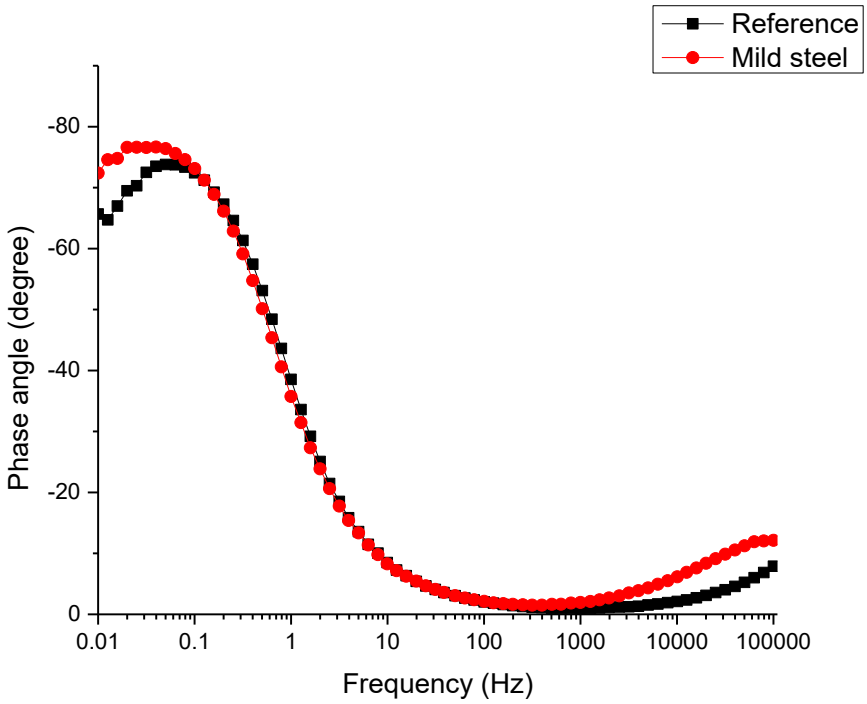


Fig. 13: Bode plot of uncoated mild steel.

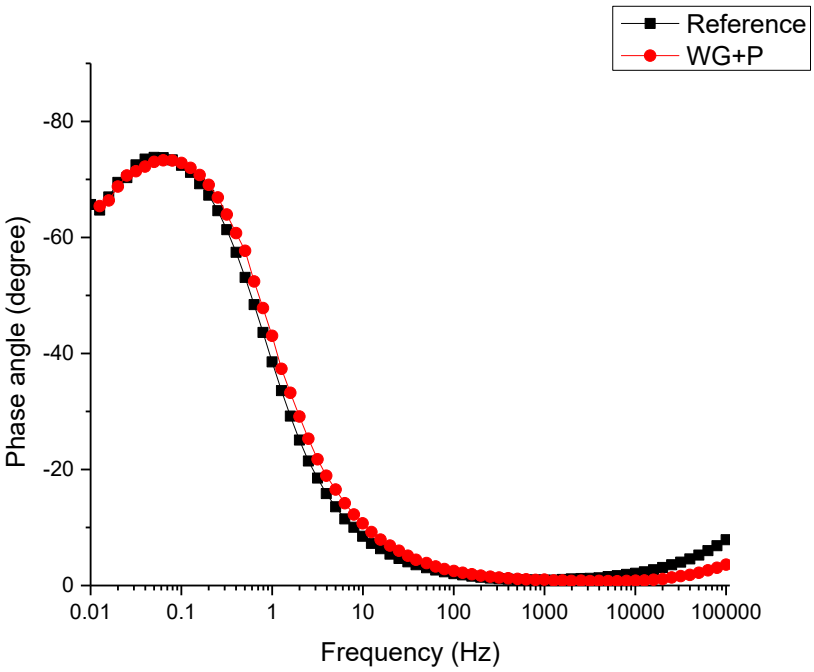


Fig. 14: Bode plot of coated mild steel (WG+P)

It was observed that WG+P exhibited the phase angle of -65.4Hz, Mild steel -72.39Hz, and Reference -65.68Hz. The Bode plots shows peaks for all samples in the low frequency region. The total impedance in this region is mainly due to the impedance of coating defects and can be regarded as a measure of coating protectiveness in accordance with the findings of notable researchers [24].

4. Conclusion

Based on the EIS data, waste glass powder generated from the disposed waste glasses in the environment was proved to significantly improve the barrier properties of the coating, and corrosion resistance of mild steel. This can be attributed to the high content of SiO_2 that was present in the waste glass as revealed from the XRF result. However, due to the strength nature of the SiO_2, coatings modified with the oxide will enhance its strength and durability against the corrosive environmental. However, this study demonstrate the potential application as well as economic importance of glass waste into useful additive material, thereby reducing environmental pollution caused by glass wastes in our environment.

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