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Corrosion studies of ductile and grey cast iron using moringa oleifera seed oil as an inhibitor in cassava juice

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Abstract- Electrochemical studies of ductile and grey cast iron have been investigated. The corrosion resistance properties of ductile and grey cast iron were measured using linear polarization in cassava juice solution in the presence of moringa oleifera seed oil as an inhibitor. The influence of the amount of inhibitor was investigated using potentiodynamic scanning and scanning electron microscope (SEM). The results obtained shows that Moringa oleifera seed oil inhibits the corrosion of both ductile and grey cast iron in cassava juice with highest inhibition efficiency of 67% and 79% respectively. The inhibitor also show a mixed mode reaction. The scanning electron microscopic analysis indicate that the electro deposition of moringa seed oil on the material surface form a protective layer and obviously, increase significantly the corrosion resistance properties and improved the performance in service. The significant decrease in hardness value of the materials in cassava juice was attributed to the presence of cyanide in cassava.

Keywords: Corrosion Studies, Ductile Cast Iron, Grey Cast Iron, Moringa Oleifera Seed Oil, Inhibition Efficiency.

I. INTRODUCTION

The degradation of engineering materials through corrosion is a persistent and costly global challenge, with implications spanning safety, economics and sustainability. The food processing industry is a particularly aggressive environment for materials, as equipment is routinely exposed to complex, acidic, and often corrosive organic media (Dariva and Galio, 2017).

Cast irons, specifically grey and ductile (nodular) cast iron, are foundational materials in this sector due to their excellent castability, machinability, vibration damping capacity, and favourable cost- to - performance ratio (Davis, J.R., 1996). They are widely used in the manufacture of critical components such as mills, crushers, press plates, pipelines, and gears. However, their high carbon content and multiphase graphite-microstructure render them particularly susceptible to corrosion in acidic process fluids, leading to material loss, product contamination, and premature equipment failure. One such corrosive medium of significant industrial relevance is cassava (Manihot esculenta Crantz) juice (Oluwole et al., 2019).

The acidic nature and unique chemical composition of cassava juice create electrochemical environment that aggressively attacks ferrous materials. While both grey and ductile cast irons are used in cassava processing equipment, their distinct microstructures- grey iron with its interconnected graphite flakes and ductile iron with its isolated graphite nodules result in fundamentally different corrosion mechanism and rates (Reynaud, A. 2011). Understanding this differential corrosion behavior is crucial for informed material selection, yet comparative studies in this specific medium remain limited.

The traditional and most effective method for mitigating corrosion involves the use of synthetic inorganic inhibitors, such as chromates and phosphates. However, their toxicity, high cost, and adverse environmental impact have driven stringent regulations and a global search for eco-friendly alternatives (Sastri, V.S., 2011). Hence, the rise to the field of green corrosion inhibition which explores the application of naturally occurring, biodegradable, and non-toxic substances. Plant extracts and oil are a

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particularly promising class of green inhibitors, as they are rich in phytochemicals such as alkaloids, flavonoids, saponins, and fatty acids containing heteroatoms and conjugated double bonds that can adsorb onto metal surfaces to form protective film (Raja, P.B. and Sethuraman, M.G., 2008). Among the numerous plants under investigation, moringa oleifera has garnered significant attention (Odusote, J.K., and Yahya, R.A., 2010). However, a significant research gap exists in the literature concerning the performance of extracted moringa seed oil. Distinct from the aqueous extract, as a corrosion inhibitor in a real world, complex industrial medium like cassava juice. Furthermore, a direct comparative analysis of its efficacy on the two most common engineering cast irons- grey and ductile is absent.

This study, therefore, aims to fill this critical knowledge gap by investigating the corrosion behavior of grey and ductile cast iron in raw cassava juice and evaluating the inhibition efficiency of moringa oleifera seed oil. The research employs electrochemical techniques to establish the corrosion kinetics and mechanism and to determine the optimal inhibitor concentration. The outcomes are expected to provide a dual benefit: offering a cost effective, sustainable, and non-toxic corrosion control strategy for cassava processing industry, while simultaneously providing materials engineers with comparative performance data on grey and ductile cast iron for service in acidic agro-industrial environments.

II. EXPERIMENTAL PROCEDURE

2.1 Preparation of the test sample

Ductile and grey cast iron used for the research was sourced from Ajaokuta Steel Company, Ajaokuta, Kogi State Nigeria. Its spectrometer chemical composition are presented in Table 1 and 2. The ductile and grey cast iron samples were cut into pieces measuring 10 mm × 10 mm, polished using successive grades of silicon carbide papers of grades P60, P120, P600, P1000 and P1200 grit, degreased in ethanol, dried in acetone and stored in desiccator prior to use as described by Umoren et al., 2011 and Odusote et al.,2016.

Table 1: Chemical Composition of As-received Ductile Iron

Elements	Fe	C	Si	Mn	P	S	Cr	Mo	Ni	Co	Ti	Al
Composition (%)	Balance	2.96	1.39	1.14	0.02	0.0056	0.042	<0.005	0.145	0.0076	0.028	0.01

Table 2: Chemical Composition of As-received Grey Cast Iron

Elements	Fe	C	Si	Mn	P	S
Composition (%)	Balance	2.50	1.56	0.80	0.10	0.10

2.2 Extraction and Preparation of Moringa Oleifera Seed Oil

Moringa oleifera seed oil extraction and preparation involved the collections of Moringa Oleifera fruit sourced from a farm in Isanlu, Kogi State, Nigeria, followed by drying, which stimulates the opening of the fruits to separate the seed and other impurities. They were then dried in an electric oven to eliminate moisture. Dried Moringa Oleifera seeds were milled into paste using thermal Willey mill. 10 gram of the paste was weighed and placed on a filter paper which was folded carefully. The filter paper containing the sample was then inserted into the Soxhlet apparatus. 200 ml of the solvent (hexane) was poured into a 500 ml round bottom flask with the sample. It was heated at 60 oC for 6 hours after which the sample was removed and transferred into the air oven to dry at 105 oC for 20 minutes. The oil was recovered by solvent evaporation. It was heated at a low temperature until the solvent finally evaporated leaving behind the oil. The phytochemical screening was there by carried out on the extract and inhibition test solutions were prepared from the extract to obtain 1, 2, and 4 mil in 250ml of cassava fluid.

2.3 Potentiodynamic Polarization Measurement

It involved polarization of a working electrode and monitoring the current that is produced as a function of time and potential. The test was carried out using three electrode cell assemblies at room temperature with the Autolab VERSASTAT4 equipped with Versa STUDIO. The metal samples were embedded in polyester resins, polished and used as the working electrode, platinum rod was used as the counter electrode and saturated silver/silver chloride electrode as reference electrode. The electrolyte used for the study was 250ml of cassava fluid in the absence and presence of varying concentrations of Moringa Oleifera seed oil as inhibitor. The electrochemical measurement was carried out for about 30 minutes according to ASTM standard and reported by Haleem et al., (2017) for corrosion to reach a steady state at a scan rate of 0.5 mv/s to determine the current density, corrosion rate and inhibition efficiency [10]. Surface coverage and inhibition efficiency were calculated using equation 1 and 2 respectively. This was also reported according to Alaneme et al., 2015 and Sabirneeza et al., 2014.

$$(\Theta) = \frac{I\ corr - I\ corr(i)}{I\ corr} \quad (1)$$

where; I corr and I corr(i) are corrosion current density in the absence and presence of the inhibitor respectively.

$$(IE\ \%) = \frac{C.R0 - C.R1}{C.R0} \times 100 \quad (2)$$

where; C. R_0 and C. R_1 are corrosion rate in the absence of inhibitor and presence of inhibitor respectively.

III. RESULT AND DISCUSSIONS

3.1 Phytochemical Screening of Moringa Oleifera Seed Oil

Phytochemical screening was carried out on moringa oleifera seed oil and the result shows the presence of active constitutents responsible for corrosion inhibition of most metals (table 3). This work in agreement with the findings of Kasolo et al., 2010. Many previous research have attributed the inhibitory properties of most green plants to the presence of active agents such as flavonoids, tannins, saponins and alkaloids (Ebenso and Ekpe, 1996; Odusote and Ajayi, 2013; Ajayi et al., 2014 and Alaneme et al., 2015).

Table 3: The Phytochemical Screening of Moringa Oleifera Seed Oil

S/N	CONSTITUENT
1	Alkaloids ++
2	Flavonoids ++
3	Glycoside +++
4	Phlobatannins -
5	Tannins ++
6	Terpenoids +
7	Saponin +
8	Steroids +++
9	Oxalate +
10	Pheno +

3.3 Electrochemical Studies

3.3.1 Corrosion behaviour of ductile cast iron in cassava juice

Figure 1 shows the linear polarization tafel plots for the ductile cast iron in cassava juice in the absence and presence of different concentrations of Moringa Oleifera seed oil. The anodic and cathodic site tafel value and corrosion current density derived after extrapolations are given in details as observed in table 4. The corrosion current density (icorr), corrosion potential (Ecorr) and corrosion rate (CR) were obtained from the tafel plots and are recorded.

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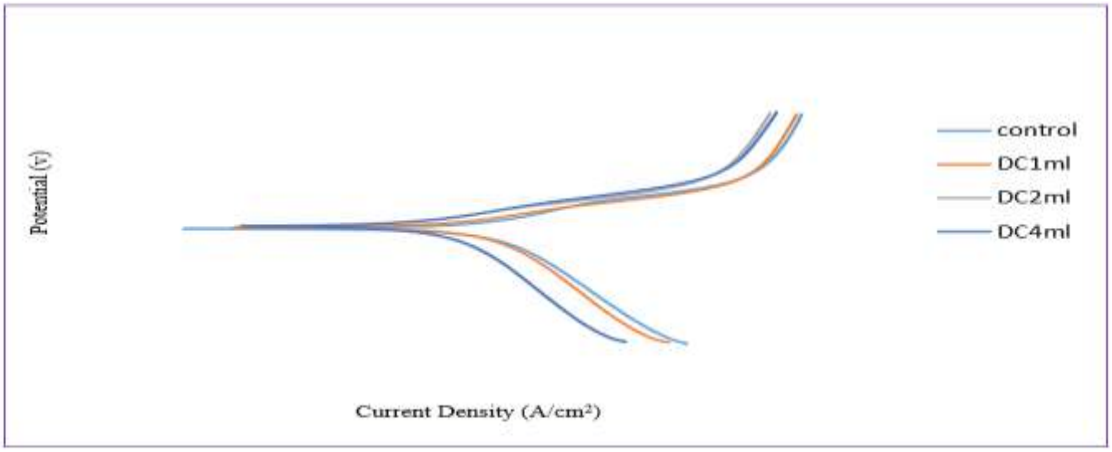

Figure 1: potentiodynamic polarization curve for ductile iron in cassava Juice

From the extrapolation, it was deduced that the samples immersed in cassava juice in the presence of moringa oleifera seed oil was found to experience a significant decrease in corrosion current density as against the uninhibited sample (As-received/control), hence, the lower corrosion rate (table4). This reveal that the moringa oleifera seed oil effectively inhibits the corrosion rate of the ductile cast iron in the cassava juice medium (Umoren et al., 2011).

It was evident from the figure 1 that the cathodic and anodic Tafel slopes of the curves were shifted toward the low potential region in the presence of the moringa oleifera seed oil. Abdel-Rehim et al., opined it is an indication that the inhibitor controlled both the cathodic and anodic reactions and thus behave as mixed type inhibitor (Olubunmi et al., 2020).

From the table 4, it can also be observed, the inhibition efficiency found to increase with the concentration of inhibitor with maximum inhibition efficiency of 67% at a concentration of 2mil in the test solution. This shows a significant decrease in the rate of corrosion was achieved as a result of inhibitor deposition.

Table 4: potentio dynamic polarization data for ductile iron in cassava juice

Inhibitor concentration (mil)	I_{cor} (A/cm^2)	E_{cor} (v)	C.R (mmpy)	Efficiency (%)
As-received/control	26.659	-0.5536	0.30839	_
DC1	18.553	-0.5515	0.21462	30
DC2	8.896	-0.5481	0.10292	67
DC4	10.327	-0.5487	0.11947	61

3.3.2 Corrosion behaviour of grey cast iron in cassava juice

Figure 2 shows the linear polarization tafel plots for the grey cast iron in cassava juice in the absence and presence of different concentrations of Moringa Oleifera seed oil. The anodic and cathodic site tafel value and corrosion current density derived after extrapolations are given in details as observed in table 4. The corrosion current density (icorr), corrosion potential (Ecorr) and corrosion rate (CR) were obtained from the tafel plots and are recorded.

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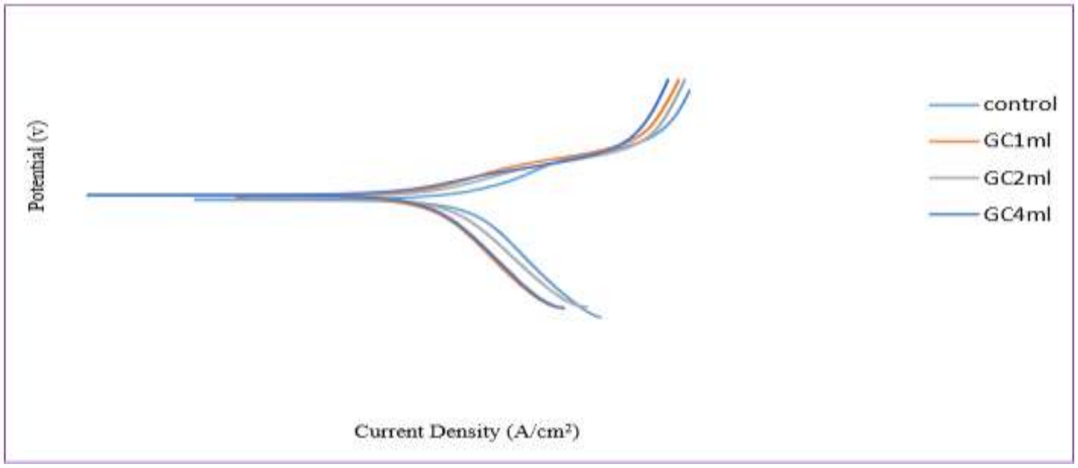

Figure 2: potentiodynamic polarization curve for grey iron in cassava juice

It was observed from the tafel plots that the higher the potential, the lower the corrosion rate and the higher the inhibitor efficiency. Hence, the rate of corrosion of grey cast iron decreases significantly in the presence of moringa oleifera seed oil compared to the control sample in the cassava juice and was found to be dependent on the concentration of the inhibitor. This agrees with Olubunmi, et al., (2020) that the extract inhibit the corrosion of grey cast iron in cassava juice.

According to Fayomi, (2015), the materials with the highest polarization resistance (slope of the Tafel plot) and the lowest corrosion current density have the highest corrosion resistance than the other materials. Therefore, it was observed that sample GC4 exhibit the highest corrosion resistance in the test solution with 79% efficiency follow by GC1 and GC2 of 64 and 51% respectively (table 5). This means that a good geometric decrease in magnitude of the corrosion rates was attained after moringa oleifera seed oil deposition. Further observations from table 5 revealed that inhibition efficiency was found to increase with the concentration of inhibitor, with maximum efficiency of 79% at a concentration of 4mil. This increase in inhibition efficiency is due to the increase in the number of constituent molecules of moringa oleifera seed oil adsorbed on the metal surface at higher concentration (Zhang and Hua, 2009). So that the active sites of the metal are protected by the inhibitor molecules.

Table 5: potentiodynamic polarization data for grey iron in cassava juice

Inhibitor concentration(mil)	I_{cor} (A/cm^2)	E_{cor} (v)	C.R (mmpy)	Efficiency (%)
As-received/Control	35.161	-0.5671	0.40674	_
GC1	12.547	-0.5631	0.14515	64
GC2	17.131	-0.5634	0.19817	51
GC4	7.391	-0.5536	0.085506	79

3.4 Scanning electron microscopy

Figure 3-4 shows the micrograph structure of grey and ductile iron immersed in cassava juice in the absence and presence of moringa oleifera seed oil as an inhibitor. The images were indicative of the changes that accompany the corrosion and protection on the metal surface.

Figure 3a and 4a shows evident of damage caused to the surface with visible cracks and pits. This was resulting from the aggressive environment/metal interface reactions which make the material more susceptible to corrosion attack.

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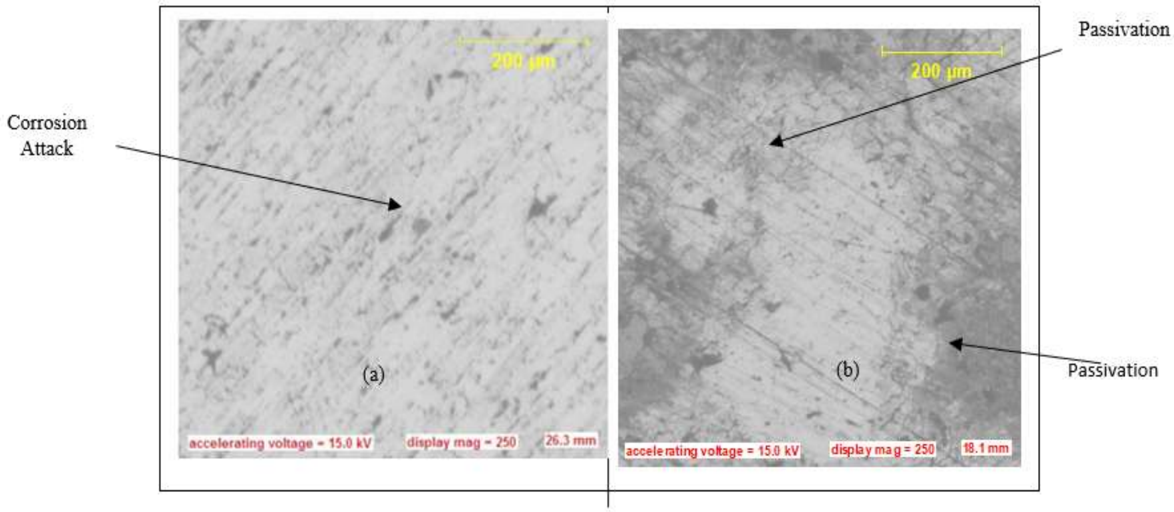

Figure 3: Scanning electron micrograph of grey cast Iron in cassava juice showing
(a) Morphology in the absence of inhibitor
(b) Morphology in the presence of inhibitor

However, the resulting micrograph from figure 3b and 4b revealed the formation of a protective layer that serves as inhibition to corrosion attack thereby increasing the corrosion resistance of both ductile and grey cast iron in cassava juice. This protective layer is attributed to the presence of active constituents in the moringa oleifera seed oil. This restricts the diffusion of ions to or from the metal surface and hence retards the overall corrosion process (Chaubey et al., 2015).

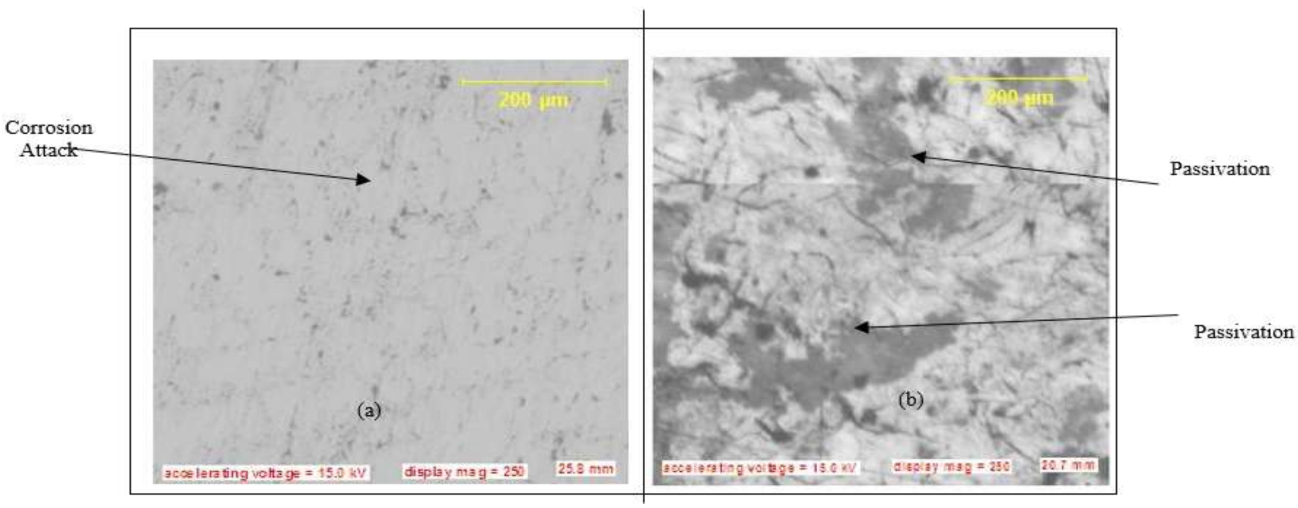

Figure 4: Scanning electron micrograph of ductile cast iron in cassava juice showing
(a) Morphology in the absence of inhibitor
(b) Morphology in the presence of inhibitor

3.5 Hardness Studies

The Rockwell hardness (HRA) value of ductile and grey cast iron before and after electrochemical studies in cassava juice was taken and is presented in table 6. From all indications, the hardness value of ductile iron decreased from 44.87 to 38.13HRA while grey cast iron in the same environment experience a significant decreased in hardness value from 38.35 to 30.63 HRA. This trend of significant decrease observed indicates a great effect of cassava juice on the hardness properties of both grey and ductile cast iron.

Table 6: Hardness Values of Ductile and Grey Cast iron Before and After Immersed in Cassava Juice

Materials	Control sample(HRA)	Immersed sample(HRA)
Ductile cast iron	44.87	38.13
Grey cast iron	38.35	30.63

The trend of decrease in the hardness of both ductile and grey cast iron in cassava juice may be traced to cassava which contains hydrocyanic (HCN) called cyanide. The acid which is an organic solvent is known to be good corrosion medium for iron since corrosion affect the hardness of a material (Alagbe, 2009) and (Adamu et al., 2014).

IV. CONCLUSIONS

The following conclusions are drawn from the present study:

1. moringa oleifera seed oil inhibits the corrosion of both ductile and grey cast iron in cassava juice.
2. moringa oleifera seed oil acted as a mixed type inhibitor.
3. the inhibition of both ductile and grey cast iron in cassava juice is in a concentration dependent manner.
4. the corrosion resistance of grey cast iron is better compared to ductile cast iron in the presence of moringa oleifera seed oil with highest inhibition efficiency of 79% and 67% respectively.
5. the inhibitive effect displayed by moringa oleifera seed oil can be attributed to the presence of active constituents such as flavonoids, tannins, saponins and alkaloids.
6. scanning electron micrograph revealed the formation of a protective layer that serves as inhibition to corrosion attack thereby increasing the corrosion resistance of both ductile and grey cast iron in cassava juice.
7. both ductile and grey cast iron in cassava juice experience a significant decrease in hardness value when compared to the control samples..

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