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THE POTENTIALS OF LARD-EXPIRED IBUPROFEN BLENDS AS CORROSION INHIBITOR ON A53 MILD STEEL IN 1M HCL

B.U. Anyanwu[1,*], L.O. Jayesimi[2], S.E. Apeh[1], K.L. Olaitan[1], O.O. Olamide[1], S.O. Owoeye[3], O.A. Adewumi[1], O.O. Oluboba[1] and B.J. Okon[1]

[1.]Mechanical Engineering Department, Federal University of Agriculture, Abeokuta, Nigeria.
[2]Industrial and Production Engineering Department, University of Ibadan, Nigeria.
[3.]Mechatronics Engineering Department, Federal University of Agriculture, Abeokuta, Nigeria.

*Correspondence e-mail: anyanwubu@funaab.edu.ng

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Abstract. The mitigation of metal dissolution in highly aggressive media, such as that of acids is a critical industrial priority, owing to the attendant wide applications. This study was aimed to investigate the potentials of lard-expired ibuprofen blends as corrosion inhibitor on A53 mild steel immersed in a one molar hydrochloric acid (1M HCl) solution. Rendering process was used to extract lard from pig fat. Several concentrations of lard and expired ibuprofen was formulated and then employed as inhibitors. Gravimetric methods was used to determine corrosion rates of the inhibited samples in 1M solution of hydrochloric acid, while optical microscopy (OPM) was used to analyse the surface morphology of the samples. The result showed that all the inhibited samples had lower corrosion rate values than the uninhibited sample (control) with corrosion rate value of 0.7820 mm/yr. Sample S4, with an inhibitor concentration of 60% lard: 40% ibuprofen gave the lowest corrosion rate value of 0.3599 mm/yr. This corresponded to a corrosion protection efficiency of 54%. Sample S1 with inhibition concentration of 90% lard: 10% ibuprofen, had the highest corrosion rate of 0.4572 mm/yr. among the inhibited samples with a protection efficiency of 42%. The OPM images showed fewer corrosion products on the inhibited samples than the uninhibited one and this corresponded with the results from the gravimetric analyses. The findings revealed that the lard-expired ibuprofen mixture was able to inhibit corrosion on the A53 steel in hydrochloric acid media.
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Keywords: Metal, Gravimetric, Lard, Inhibitor, Corrosion

1. Introduction

The protection of metallic structures against environmental degradation is a tenacious challenge in modern materials science and industrial engineering. A53 steel is one of the common classes of mild steels used in construction, petroleum, and chemical processing industries due to their very good weldability and tensile strength properties (Anyanwu *et al.*,2021; Degarmo, 2012; Callister, 2007). However, A53 steels, just like other classes of mild steels, undergo rapid electrochemical dissolution in strong acidic and basic media, which often leads to structural failure that many a times result to significant economic losses. More so, some area of application where A53 steels

are used, involve "pickling" or acid descaling processes where the metal is exposed to aggressive mineral acids like hydrochloric acid (Ikeuba *et al.*,2015; Abdollahi and Nikfar, 2014). Such acid interaction facilitates the attack of the steel surfaces by chloride ions in the acid. To combat this, corrosion inhibitors, cathodic protection, coatings etc, are employed as a primary line of defence on the steel surfaces (Joseph, 2008; Lucas, 2019; and El-Haitout *et al.*,2022).
Traditionally, synthetic organic compounds containing nitrogen, sulphur, or oxygen atoms have been utilized to form protective films. While effective, many of these conventional inhibitors are expensive and pose severe toxicological risks to both human health and aquatic ecosystems (Solomon *et al.*,2021; Syed, 2006). This has spurred a global shift toward formulation of green and organic inhibitors, focusing on the development of eco-friendly ones derived from natural products and pharmaceutical sources (Al-Turkustani, and Al-Marhabi, 2012; Tijani *et al.*,2021; Narang *et al.*,2023; Vaszilcsin *et al.*,2023; Mamand et al, 2026).
Recently, the concept of synergistic inhibition has gained traction. This involves combining two or more substances to achieve a higher protective efficiency than either could provide individually. Pig oil (also known as lard) is an organic oil extracted from pork meat. They have been applied successfully as green metal cutting fluids to aid cooling and lubrication of metals during machining operation of mild steel. They contain active fatty acids species like stearic and linoleic acids that contributes to formation of insoluble metal soaps which aids adsorption and film formation on metallic substrates. These metallic soaps create hydrophobic and adherent layers that serves as corrosion protective layers on substrates (Anyanwu *et al.,* 2023). Ibuprofen on the hand, is a widely used nonsteroidal anti-inflammatory drug that has been used successfully for corrosion rate reduction in metals due to its functional group components that promotes adsorption on metal surfaces. Its carboxylic acid group (-COOH) has been found to be capable of donating electron density and forming coordination bonds with metal atoms. It also contains a relatively large hydrophobic moiety that helps create water repellent protective films on metallic substrates (Tasic *et al.*,2019; Akande *et al.*,2020; Fajobi *et al.*,2019; Fajobi *et al.*,2021; Viteri *et al.*,2024).
This study focuses on a novel mixture of pig oil (lard) and expired ibuprofen. The integration of lard and ibuprofen is hypothesized to create a "hybrid" protective layer. The ibuprofen molecules are expected to act as an anchor, adsorbing onto the active sites of the steel, while the pig oil molecules interlock with the ibuprofen to thicken the hydrophobic barrier.

2. Materials and Method

The experimental procedures employed in the study followed recommendations from relevant texts and literatures, such as Anyanwu *et al.* (2021); Anyanwu *et al*,(2023); Odunlami *et al.*,(2021); El-Harrari *et al.*,2023; Sorkhabi and Seifzadeh, (2006) etc.

2.1. Material preparation and chemical composition of the 'as received' A53 steel
The metal substrate used was A53 steel, sourced from a local market in Ibadan, Oyo State of Nigeria**.** The steel was cut into dimensions of 1 x 1 cm. Each piece was smoothened out by a surface grinder until they were suitable for immersion. Prior to the experiments, the surfaces were cleaned to remove any pre-existing oxides or contaminants, after which their weights were measured with an electronic weighing scale. The chemical composition of the 'as received steel was done via an atomic spectrometer.

2.2. Formulation of lard and expired ibuprofen inhibitor mixture
Lard (L) or simply oil from pork meat (pig) was extracted by heating with low heat until all the oils were extracted. 100 mg of ibuprofen, expired within a period of 3 months ((I) was dissolved

in 100 ml water on a bottle and homogenised properly until it formed the required liquid mix. The inhibitor formulation was then formulated according to Table 1 (Tasic *et al*, 2019).

Table 1. Formulation of inhibitor concentration

Inhibitors	L	I	L	I	L	I	L	I	L	I	L	I
% conc.	90	10	80	20	70	30	60	40	50	50	0	0
Beaker	1		2		3		4		5		Control	
Sample ID	S1		S2		S3		S4		S5		C	

2.3. Substrate immersion

The solution (formulated inhibitor) in each beaker was stirred and each piece of the steel (coupons) was immersed in them**.** The beaker was stored in a cool dry place at room temperature, and revisited after the number of days specified for each sample.

2.4. Corrosion rate determination of the samples

The corrosion rates of the samples were determined by gravimetric method, following the standard practice for laboratory immersion corrosion testing of metals, as reported by Anyanwu *et al.*,2021. The already inhibited coupons were weighed before and after immersion in the corrosion medium for 240, 360, 480, 600 and 720 hours respectively. The coupons were then removed and dried. The difference in weight was taken and recorded. The corrosion rate values, efficiency of the inhibitor and degree of surface coverage were then computed with Equations 1 – 3, respectively.

$$CR = \frac{8.76\times10^4 \Delta W}{\rho A T} \quad (1)$$

$$Inhibitor\ Efficiency\ (\%) = 100\left\{1 - \frac{CRi}{CRu}\right\} \quad (2)$$

$$\theta = \left\{1 - \frac{CRi}{CRu}\right\} \quad (3)$$

where CR = corrosion rate (mm/year), W = weight loss (g), ρ = density of the sample (g/mm^3), A = exposed area (cm^2), T = exposure time (H), Θ = degree of surface coverage, CR_i = corrosion rate of inhibited samples, and CR_u = corrosion rate of uninhibited samples.

2.5 Determination of Microstructural Behaviour of the Inhibited Mild Steel

An optical microscope was used to determine the morphology of the inhibited samples at a magnification 400X.

3. Results and Discussion

3.1. Chemical composition of the A53 steel.

The chemical composition of the ‘as received steel is shown in Table 2. Steel types are normally classified based on the percentage of carbon in their composition. The percentage composition of carbon in the ‘as received’ steel sample (C = 0.22%) falls within the range specified for mild steels (Anyanwu *et al.*,2021, Chinwuko *et al.*,2014; Akande *et al.*,2020). The ‘as received’ A53 steel sample is therefore one of the numerous classes of mild steel, employed in structural and construction applications.

Table 2. Chemical composition of the 'as received' A53 steel

Elements	C	Fe	Mn	P	Cu	S	Si	K
Composition, %	0.22	98.80	0.80	0.02	0.10	0.02	0.03	0.01

3.2. Results for corrosion rates

The results of corrosion study for all the samples are shown in Table 3 – 4, and Figures 1 – 2. From the computed results (Table 2), it can be seen that the average corrosion rate values for all samples (inhibited and uninhibited) ranged from 0.3599 – 0.7820 mm/yr. This actually showed the potency of the corrosive media, as lots of the chloride ions were able to attack the samples' surface and cause corrosion products within the exposure time of the study. This is expected, due to the fact that a one molar acidic solution was employed as the corrosive media and the outcome followed the same trend as reported by Majunath and Nayak (2019) who used 0.5 molar concentration in their study. However, the inhibitor did its job, as all inhibited samples recorded lower corrosion rates values than the uninhibited sample. Sample S4, with an inhibitor mix of 60% lard and 40% ibuprofen, had the least corrosion rate value of 0.3599 mm/yr. This was followed by sample S5 (0.3655 mm/yr.), with 50:50 % of lard and ibuprofen mixture. The least among the inhibited samples (sample S1), had a corrosion rate value of 0.4572 mm/yr. When compared with the control sample, C, which was uninhibited, and a value 0.7820 mm/yr, all the inhibited samples recorded quantifiable corrosion protection on the substrate (A53 steel). This is certainly not unconnected with the active layers of chloride repellant protection layer formed on the inhibited samples by the inhibitors (Tasic *etal* 2019, Anyanwu *et al.* 2021).

Table 3. Corrosion data

Time	240H		360H		480H		600H		720H		Average CR, mm/yr
Sample ID	$\Delta W, g$	CR, mm/yr	$\Delta W, g$	CR, mm/yr	$\Delta W, g$	CR, mm/yr	$\Delta W, g$	CR, mm/yr	$\Delta W, g$	CR, mm/yr	
S1	0.0164	0.7625	0.0168	0.5208	0.0174	0.4045	0.0175	0.3255	0.0176	0.2728	0.4572
S2	0.0135	0.6277	0.0146	0.4526	0.0147	0.3418	0.0148	0.2753	0.0149	0.2309	0.3857
S3	0.0131	0.6091	0.0142	0.4402	0.0144	0.3348	0.0145	0.2697	0.0147	0.2278	0.3763
S4	0.0129	0.5998	0.0132	0.4092	0.0137	0.3185	0.0138	0.2567	0.0141	0.2185	0.3599
S5	0.0130	0.6045	0.0133	0.4123	0.0139	0.3232	0.0142	0.2641	0.0144	0.2232	0.3655
Control	0.0167	0.7765	0.0251	0.7780	0.0337	0.7835	0.0422	0.7849	0.0508	0.7873	0.7820

Furthermore, the weight loss of all samples tends to increase as the exposure time increases (Figure 1). This confirms the reason why the samples' corrosion rate values increased with exposure time. For every hour the samples were exposed to the media, there was continued chloride attack on the surface of the substrates, even though, the protective layers formed by the inhibited ones try to reduce or resist such attacks and this agrees to some of the findings by Anyanwu et al, (2021) and Akande et al, (2020). It therefore, amounts to how concentrated the inhibitors are on the substrate's surface. Hence, the higher the inhibitors concentration, up to the 60% lard to 40% ibuprofen composition, the more resistant the inhibited samples were to the chloride ion attack on the substrate.

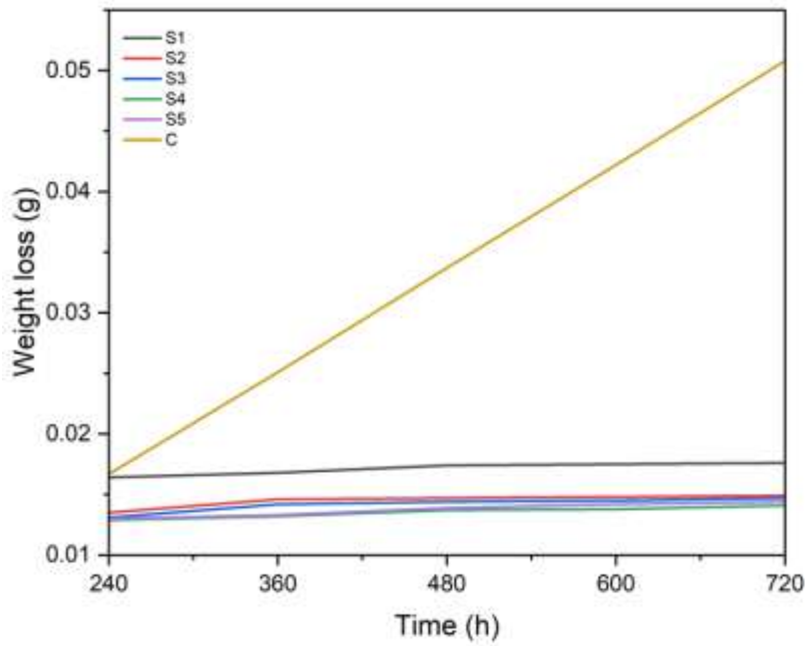

Figure 1. Rate of weight loss for all samples

3.3. Inhibitor efficiency and degree of surface coverage

The inhibitor degree of surface coverage is shown on Figure 2, and this directly gives the protection efficiencies of the inhibitor. The substrate recorded a degree of surface coverage by the inhibitors ranging from 0.42 – 0.53 (Figure 2). This corresponds to protection efficiency of 42% - 54% on the inhibited samples. Again, sample S4 recorded the highest inhibition with a protection efficiency of up to 54%. This was closely followed by sample S5, with a protection of 53%. Although, not particularly high, when looked considered on a scale of 100%, but the inhibitors still offered a protection of up to 54%. The increase in the degree of surface coverage and protective efficiency as the volume concentration of inhibitors increases, indicates that the inhibitors adsorb on the surface of the Metalwhich suggests that at lower volume concentration of the inhibitor, the deteriorating effect of 1M HCl on the metal will be higher. Furthermore, corrosion was reduced by the mechanism of adsorption and cathodic inhibition. The inhibitors combine their inhibitive properties to reduce corrosion. The active fatty acids species like stearic and linoleic acids on the lard, as well as the carboxylic acid group (-COOH) on the ibuprofen contributed to the formation of insoluble metal soaps which aids adsorption and film formation on the substrates. These metallic soaps created hydrophobic and adherent layers that serves as corrosion protective layers on substrates (Akande *et. al*, 2019).

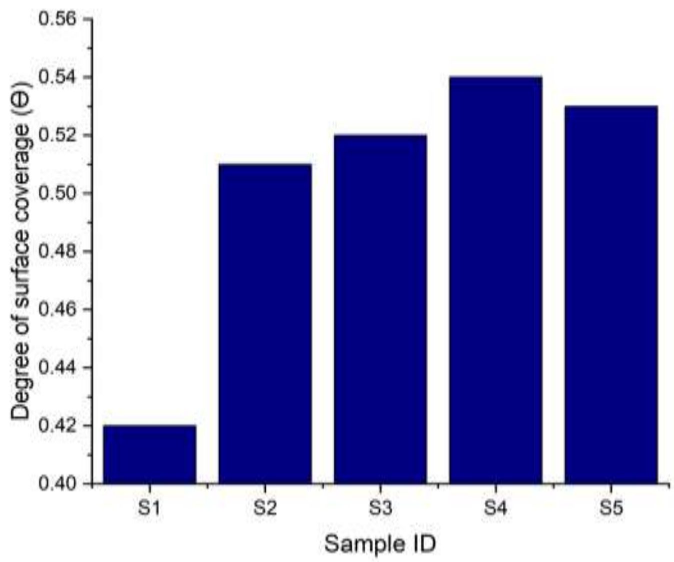

Figure 2. Inhibitor degree of surface coverage on samples

3.4. Results for microstructure

From the OPM images (Figure 3), there is evidently an indication of the effect of the inhibitor on the corrosion rate of the samples in corrosive media. All the samples exposed, had different degrees of corrosion products formed on their surfaces, suggesting a varying degree of surface protection. The study by Akande *et al*., (2020) reports that a varying degree of surface protection occasioned by varying concentrations of inhibitors creates different levels of corrosion products formed on the surfaces of inhibited samples and this, no doubt is connected to part of the reasons why the OPM images in this study has varying degrees of pitting corrosion.

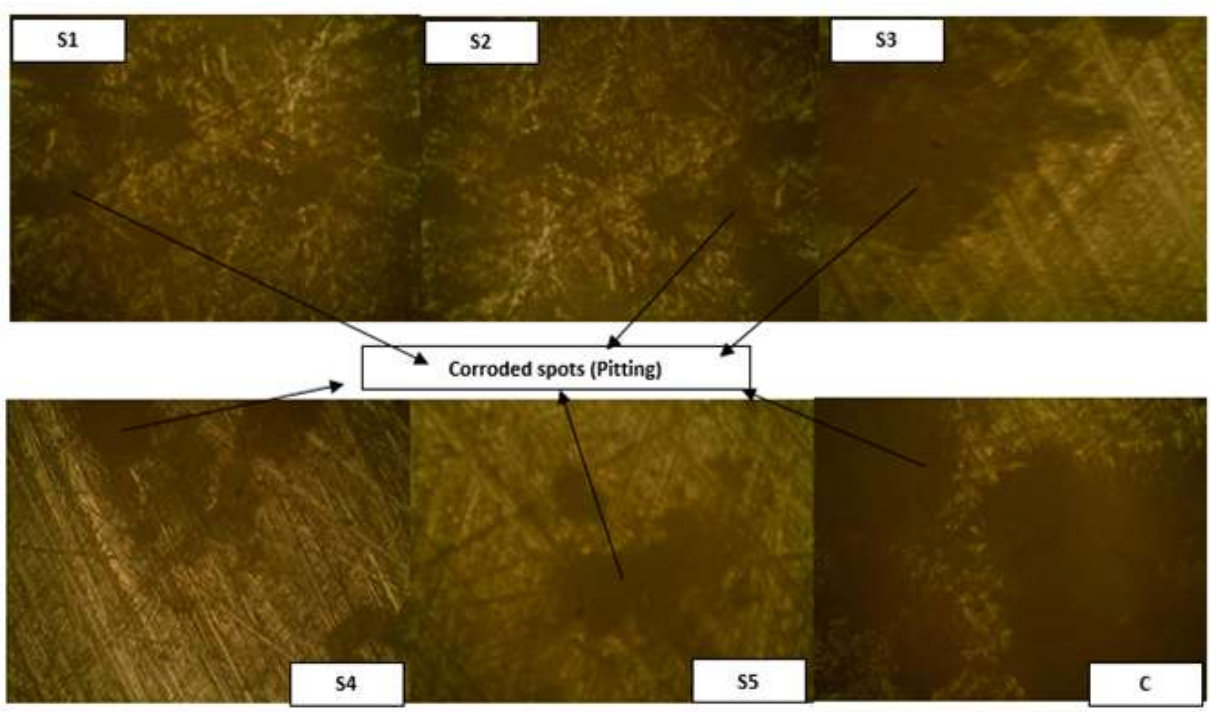

Figure 3. OPM images of the samples

This is not unconnected with continuous attack of the chloride ions on the samples' surface. The images show that, sample S4 appear to have fewer corroded spots (pitting corrosion) in comparison to the other samples, especially that of the control (C). The control (C) has no inhibitor effect as there was no inhibitor in the medium which the samples were immersed. The OPM images further confirms the quantitative values derived from the gravimetric analyses carried out.

4. Conclusion

Organic corrosion inhibitors were successfully formulated with several concentrations of lard and expired ibuprofen mixture. A53 steel samples were immersed on the formulation and thereafter corroded on 1M solution of hydrochloric acid. Gravimetric method and optical microscopy was used successfully to determine the corrosion rates and morphologies of the inhibited and uninhibited samples, respectively. The following findings were deduced from the study:

i. All the inhibited samples were able to inhibit the effect of corrosion product formation on the A53 steel samples.
ii. Sample S4, with an inhibitor mix of 60% lard and 40% ibuprofen, had the least corrosion rate value of 0.3599 mm/yr compared to the uninhibited one (control sample) with a value 0.7820 mm/yr.
This corresponded to inhibitor efficiency of 54% on the A53 steel substrate. Thus, the active layers of chloride repellant protection layer formed was formed on the inhibited samples by the inhibitors, thereby lowering corrosion rate.
iii. The OPM images showed fewer corrosion products on the inhibited samples than the uninhibited one and this corresponded with the results from the gravimetric analyses.
iv. The study has therefore shown that lard-expired ibuprofen mixture can be used as green (organic) inhibitors for A53 steel corrosion protection in hydrochloric media.

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