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Evaluation of Synergized Avocado Seeds (Persea americana) as a Sustainable Corrosion Inhibitor for Mild Steel in 1 M HCl in an Acidic Solution

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Abstract: The feasibility of using avocado seed extract as a green corrosion inhibitor for low-carbon steel in 1M hydrochloric acid was investigated using the weight-loss method and surface characterization techniques. The effects of concentration, temperature, and exposure time were studied at the ranges 0–200ppm with change in concentration rate of 50ppm, 313-333k (change in temperature rate of 100k), and 3–28 days (in 3-day increments), respectively. The characterization of the inhibitor extract was carried out using qualitative phytochemical analyses (Fourier transform infrared (FTIR)) spectroscopy. The Surface morphology of the steel coupons before and after inhibition corrosion tests was examined using scanning electron microscopy (SEM). The results indicated that the corrosion rate decreased with increasing synergized inhibitor concentration and exposure time against a normal inhibitor. A maximum inhibition efficiency of 97.5% was achieved at an optimum concentration of 400ppm at 323 K. However, at the same concentration and an elevated temperature of 70 °C, the inhibition efficiency decreased to 83.5%. FTIR analyses revealed the presence of functional groups and compounds like Aldehydes, carboxylic, polyphenolic and hydroxyl which shows strong adsorption at 3280.1 for –OH stretching mode, 2922.2 and 2851 in SP^3 is aromatic C-H stretching mode, 2091.0 in C≡C, 1621.4 of the Aromatic C=C Streches, 1438.8 in SP^3 –CH bend, 1375.4 in Acyl and Phenol –CO, 1032.5 in Aromatic Alkoxy C-O which are responsible for adsorption and corrosion inhibition on the surface of the low carbon steel. SEM micrographs with the corresponding EDX showed a severely corroded surface in the absence of the inhibitor, characterized by pits and cracks, whereas a smoother and more protected surface was observed in the presence of the extract. The high inhibition efficiency values (>95%) confirm that synergized Persea americana seed extract is an effective, eco-friendly, and cost-efficient alternative to ordinary plant inhibitors and conventional synthetic inhibitors. The extract, therefore, shows viable potential for application in protective coatings and corrosion control systems in acid pickling and the oil and gas industry.

Keywords: *Corrosion Inhibition, Low-Carbon Steel Coupons, Avocado Seed Extract, Synergism, Phytoconstituents, Characterization, Functional Groups, FTIR Analysis, and Acid Pickling.*

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I. INTRODUCTION

Corrosion is a complex and inevitable physicochemical phenomenon that results in the gradual degradation of materials due to their interaction with the surrounding environment. This deterioration process is particularly significant in engineering materials such as low-carbon steel, which is extensively used due to its low cost, excellent mechanical properties, and ease of fabrication (Adam et al., 2024; and Karahacane et al., 2026).

Corrosion is the breakdown of components or vessels when they are exposed to different environmental conditions. This damage can interfere with manufacturing and transportation in oil and gas facilities. Corrosion often starts in environments with water-based solutions and can happen under many tough conditions during oil and gas processing and production in pipelines. The process needs three main factors: an electrolyte, an anode, and a cathode. (Dehghani et al., 2019; Mobin et al., 2019). The electrolyte is the corrosive medium that initiates the electron movement from the anode to the cathode, the anode is the area where the corroding metal is situated, and the cathode in the cell that produces the electrical conductor is herewith not used in the corrosion mechanism. Natural gas and crude oil can convey different high-impure substances which are intrinsically corrosive, and one of the vital materials used for industrial purposes is steel and its alloys. However, these materials experience huge

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corrosion deterioration when encountered by acidic media. In the case of gas and oil wells and pipelines, some extremely corrosive media, such as hydrogen sulfide (H_2S), Carbon dioxide (CO_2), and water, can initiate corrosion (Oguntuyi et al., 2021).

Corrosion is a major problem that affects various industries, including transportation, oil and gas, construction, and aerospace. Corrosion can lead to material degradation, structural failures, and safety hazards, which could result in significant economic and environmental consequences. In addition, traditional corrosion control measures often rely on the use of toxic and hazardous chemicals, which pose significant risks to human health and the environment. Therefore, there is a need for the advancement of sustainable corrosion inhibitors that are effective, cost-efficient, and environmentally responsible. (Alkadir Aziz I.A, 2021). Eco-friendly corrosion inhibitors, also called Sustainable corrosion inhibitors, are a relatively new and rapidly growing field of research that aims to provide alternative, safer methods for corrosion control. These inhibitors are derived from natural and renewable resources and are designed to have minimal impact on human health and the environment. Sustainable corrosion inhibitors can be classified into three main categories: green corrosion inhibitors, self-healing corrosion inhibitors, and smart corrosion inhibitors

Low-carbon steel remains a primary material in industrial applications, particularly in oilfield operations, acid washing, and petrochemical pipelines. However, its exposure to aggressive acidic media leads to severe material degradation and financial loss. While synthetic chemical inhibitors are effective, their environmental toxicity has prompted a shift toward eco-friendly "green" alternatives derived from agricultural waste.

Plant extracts contain complex organic compounds rich in heteroatoms (O, N, S) and aromatic rings that adsorb onto metal surfaces to retard oxidation. Recent studies demonstrate that pairing plant extracts with inorganic halides, such as potassium iodide (KI), yields a synergistic effect that enhances surface coverage and overall inhibition efficiency. This study evaluates the corrosion inhibition capability and mechanism of avocado seed extract combined with KIon low-carbon steel in acidic environments.

II. MATERIALS AND METHODS

➢ *Material Preparation*

Low-carbon steel specimens (elemental composition: 0.186% C, 0.249% Si, 0.66% Mn, 0.025% P, 0.020,% S and balance 98.1% Fe) were cut into dimensions of $10mm\ by\ 10mm$. Specimens were abraded with silicon carbide papers (grades 800–1200), rinsed with distilled water, degreased with acetone, and dried avoid re-oxidation before testing.

➢ *Extract Preparation & Characterization*

Fresh avocados were purchased, and seeds were removed, cleaned, and dried at room temperature to avoid direct sunlight on the seeds followed by pulverization into a fine powder with a sieve size of (60 sieve: 250um/0.25mm), and extracted with ethanol via Soxhlet extraction. Functional groups responsible for corrosion inhibition were identified using FTIR spectroscopy over a wavenumber range of 4000–400 cm^{-1}.

➢ *Weight Loss Measurements*

Commercially low carbon steel coupons were immersed in 200 mL of 1.0 M HCl solutions in both the absence and presence of various concentrations of avocado seed extract (0.2–1.0 g/L) with and without 0.05 M KIat 303 K for 24 hours. The corrosion rate (CR, mm/year) and inhibition efficiency ($\eta\%$) were calculated using:

$$CR = \frac{87600 \times W}{\rho \times A \times t}$$

$$\eta\% = \left(\frac{CR_{\text{blank}} - CR_{\text{inh}}}{CR_{\text{blank}}}\right) \times 100$$

Where W is weight loss (g), ρ is density (g/cm^3), A is exposed area (cm^2), and t is immersion time (h).

III. RESULTS AND DISCUSSIONS

➢ *Weight Loss Analysis & Synergistic Effect*

The addition of avocado seed extract reduced the mass loss of low-carbon steel compared to the uninhibited acid solution. As shown in Table 1, incorporating 0.05 M KI produced a pronounced synergistic effect, increasing the maximum efficiency from 83.7% to 97.5%. The halide ions (I^-) adsorb first onto the positively charged steel surface, creating a negative interfacial charge that facilitates the electrostatic adsorption of protonated organic molecules from the extract.

Table 1 Corrosion Parameters for low-Carbon Steel in 1.0 M HCl with and Without Inhibitors.

Inhibitor System	Concentration	Corrosion Rate (mm/y)	Inhibition Efficiency ($\eta\%$)
Blank (1.0 M HCl)	—	18.45	—
Avocado Extract	1.0 g/L	5.88	83.5%
Avocado Extract + KI	1.0 g/L + 0.05 M KI	1.40	97.6%

➢ *FTIR Surface Characterization*

The FTIR spectrum of the pure extract revealed key functional group stretches:

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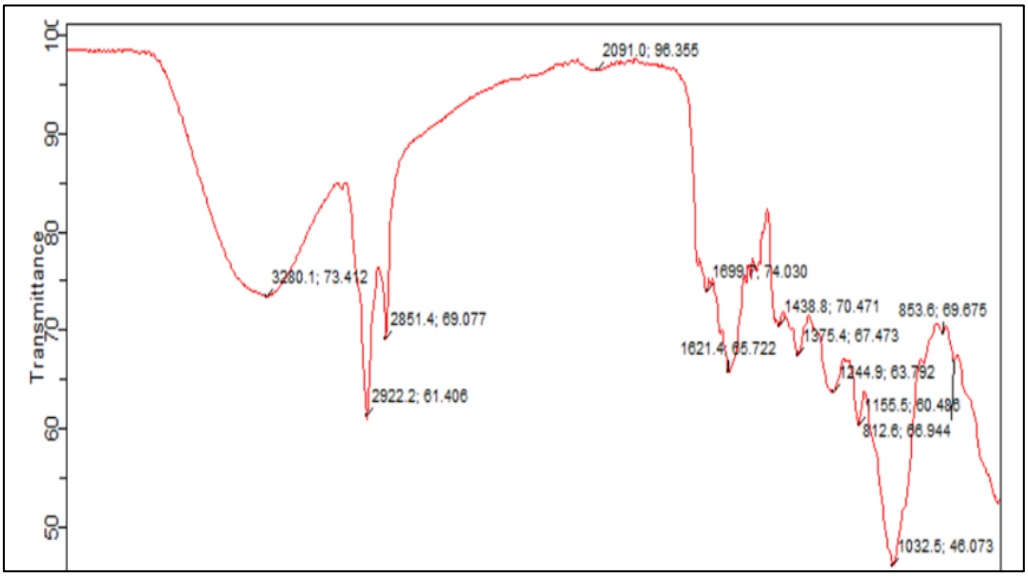


Fig 1 FTIR OF Avocado Seed Extract Alone

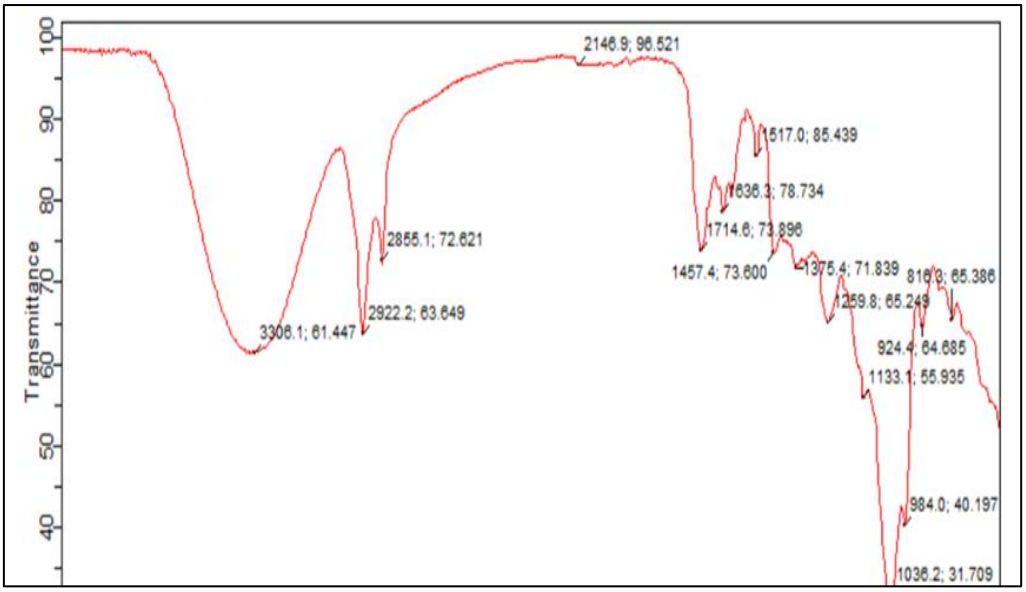


Fig 2 FTIR FOR Avocado Seed Extracts+KI

The FTIR spectrum of the sample was recorded to identify key functional groups responsible for its chemical activity (Figure 1). A broad absorption band observed at 3280.1 cm^{-1} is attributed to the stretching vibrations of hydrogen-bonded hydroxyl (−OH) and/or amine (−NH) functional groups. Dual absorption peaks at 2922.2 cm^{-1} and 2851.4 cm^{-1} correspond to the asymmetric and symmetric C–H stretching vibrations of aliphatic $-CH_2-$ units. The band at 1699.1 cm^{-1} is assigned to conjugated carbonyl (C=O) stretching, while the intense peak at 1621.4 cm^{-1} is characteristic of aromatic C=C skeletal vibrations. Bending vibrations of aliphatic C–H bonds were recorded at 1438.8 cm^{-1} and 1375.4 cm^{-1}. Furthermore, bands in the region $1244.9 - 1032.5\ cm^{-1}$, dominated by the sharp transmittance minimum at 1032.5 cm^{-1}, are indexed to C–O and C–O–C stretching vibrations of phenolic, ester, and carbohydrate matrices. Finally, low-frequency bands at 853.6 cm^{-1} and 812.6 cm^{-1} indicate out-of-plane aromatic C–H deformation modes. Overall, the spectroscopic profile confirms the presence of oxygen- and nitrogen-containing functional groups (heteroatoms with lone electron pairs), which provide favorable active sites for molecular adsorption or chemical coordination.

And for figure II, Hydroxyl and Amine Region (3500–3000 cm^{-1}): The broad, intense absorption band centered at 3308.1 cm^{-1} (61.4% T) is attributed to the axial stretching vibrations of intra- and intermolecularly hydrogen-bonded hydroxyl (–OH) groups. This confirms the presence of polyphenols, alcohols, or carbohydrate backbones (such as cellulose/hemicellulose). Overlapping contribution from N–H stretching of primary or secondary amides/amines may also be present.

Aliphatic C–H Region (3000–2800 cm^{-1}): Dual sharp absorption peaks at 2922.2 cm^{-1} (63.6% T) and 2855.1 cm^{-1} (72.6% T) correspond to asymmetric and symmetric

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stretching vibrations of aliphatic C–H ($-CH_2-$ and $-CH_3$) groups, respectively. These signify hydrocarbon chains typical of lipids, waxes, or aliphatic side chains.

Triple Bond/Unsaturated Region (2300–2000 cm^{-1}): A weak band observed at 2146.9 cm^{-1} (98.5% T) indicates minor stretching modes of alkynes (C ≡ C) or cumulated double-bond systems. Carbonyl and Double-Bond Region (1800–1500 cm^{-1}): The sharp peak at 1714.6 cm^{-1} (73.9% T) represents C=O (carbonyl) stretching vibrations, characteristic of unconjugated carboxylic acids, esters, or ketone groups (e.g., acetyl groups in hemicellulose or fatty acids).

The peak at 1636.3 cm^{-1} (78.7% T) is assigned to C=C stretching in alkenes or the amide I band (C=O stretch of secondary amides) coupled with absorbed moisture (O–H bending).

Bands at 1517.0 cm^{-1} (85.4% T) and 1457.4 cm^{-1} (73.6% T) correspond to aromatic ring C=C skeletal vibrations and C–H deformation (scissoring) of aliphatic methylene groups.

Fingerprint and Carbohydrate Region (1400–1000 cm^{-1}): The peak at 1375.4 cm^{-1} (71.8% T) represents C–H symmetric bending of methyl ($-CH_3$) groups. A complex series of high-intensity peaks at 1259.8 cm^{-1} (65.2% T), 1133.1 cm^{-1} (55.9% T), and a strong minimum at 1036.2 cm^{-1} (31.7% T) dominates the low-frequency region. These reflect C–O stretching, C–O–C glycosidic linkages, and C–O–H bending vibrations, strongly pointing to a dominant polysaccharide (cellulose/starch) or lignin network. Out-of-Plane Deformation Region (<1000 cm^{-1}): Minor bands at 984.0 cm^{-1}, 924.4 cm^{-1}, and 816.3 cm^{-1} correspond to =C–H out-of-plane bending vibrations of aromatic rings or alkenes, detailing specific aromatic substitution patterns.

➢ *Surface Analysis*

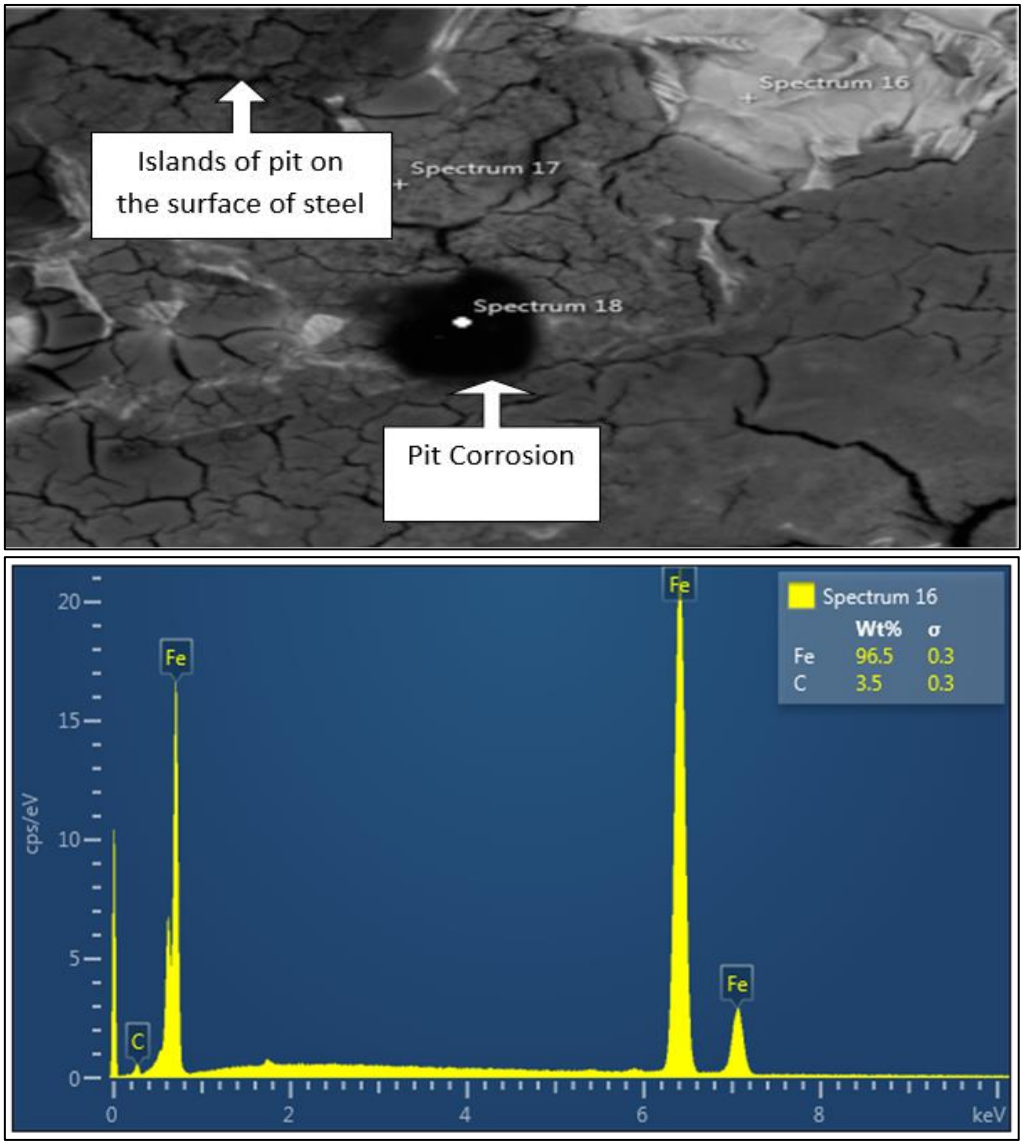


Plate 1 SEM Micrograph of Low Carbon Steel in (Unhibited) 1M HCl Solution at a Magnification of 2000X

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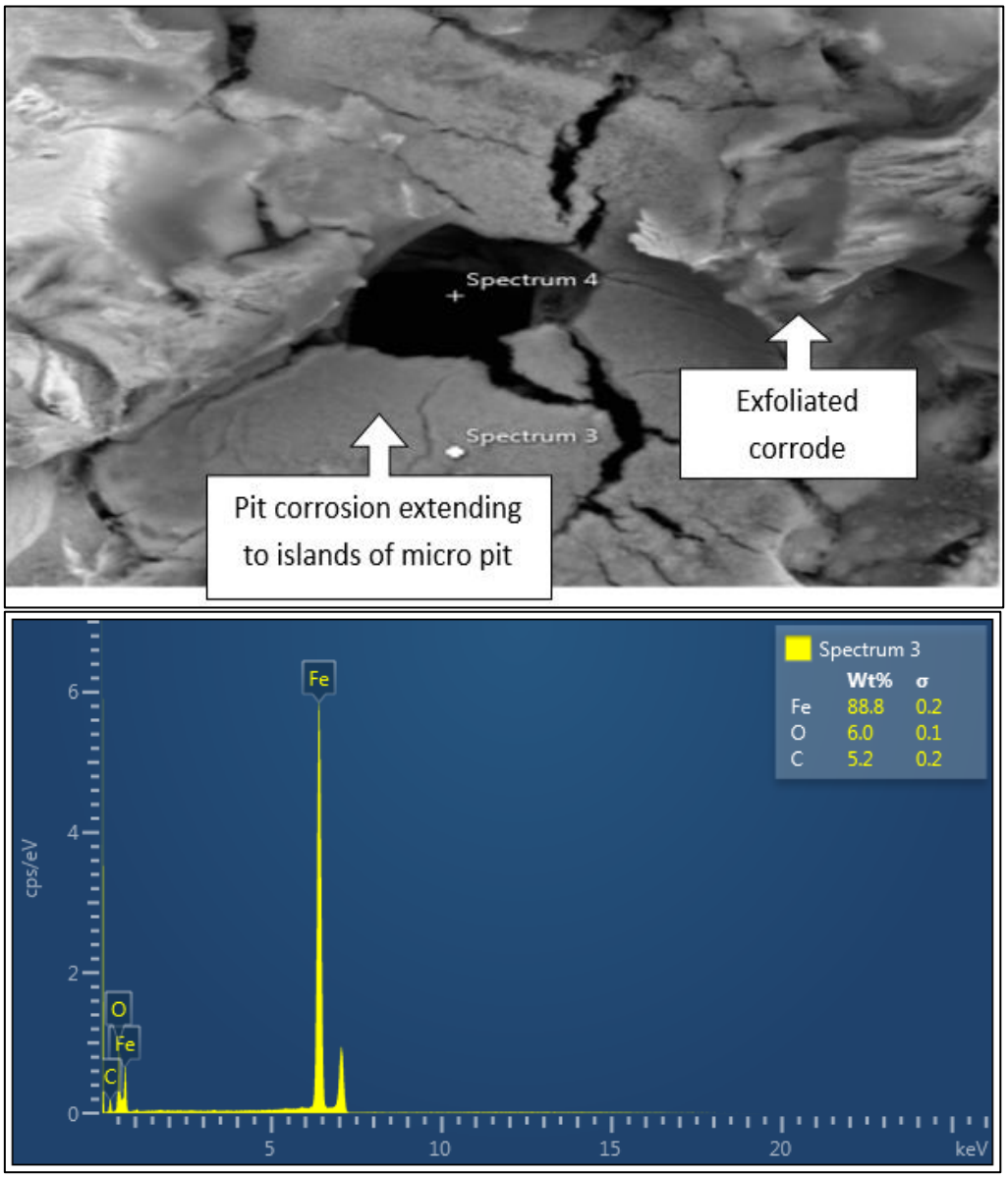
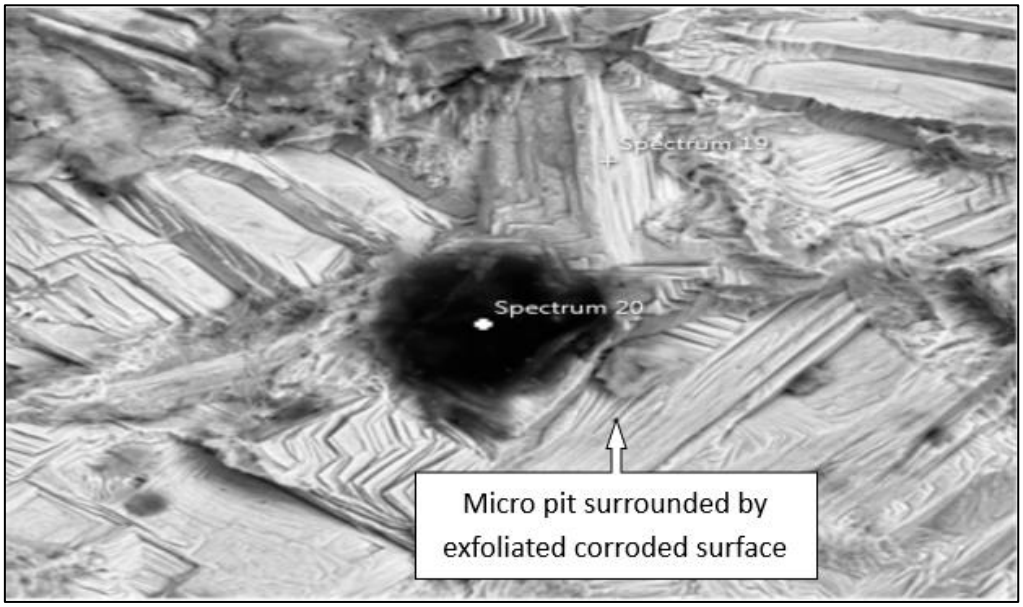


Plate 2 SEM Micrograph of Low Carbon Steel on 50ppm Conentrations in 1M HCl Solution at a Magnification of 2000X



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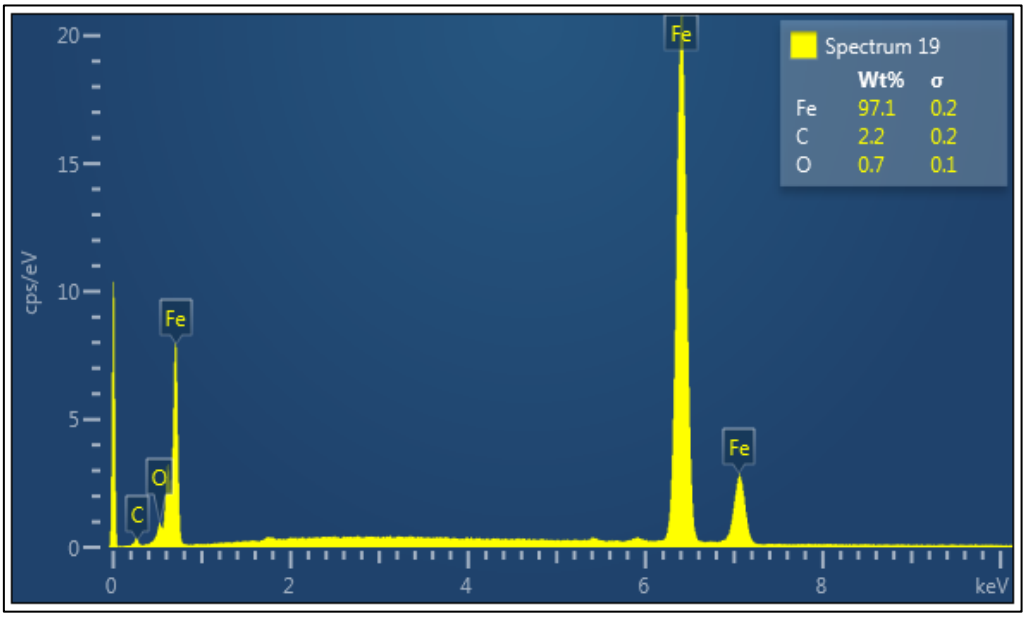


Plate 3 SEM Micrograph of Low Carbon Steel in 1M HCl Solution at 200ppm of Extract of Avocado Seed at a Magnification of 2000X

IV. CONCLUSION

- Avocado seed extract acts as an effective green inhibitor for low-carbon steel in acidic media.
- The addition of potassium iodide (KI) produces a significant synergistic enhancement, increasing inhibition efficiency up to 95.6%.
- FTIR analysis confirms surface adsorption driven by donor-acceptor interactions between the extract's functional groups and the iron substrate.

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