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Enhanced corrosion resistance of copper for agricultural equipment using superhydrophobic stearic acid coatings

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ABSTRACT

Significant risks of corrosion and wear are associated with agricultural equipment's continuous exposure to fertilizers harsh chemicals and moisture. These chemicals hasten the deterioration of metal components thereby decreasing the machinery's operational lifespan and leading to physical harm such as surface cracks and holes. Utilizing efficient corrosion protection methods is crucial to lessening these adverse consequences. In order to solve this, the current study investigates a corrosion prevention technique that involves coating copper with stearic acid to produce a superhydrophobic surface. To create this protective coating copper samples were cleaned and then left to soak for 72 hours at room temperature in a stearic acid solution. Utilizing energy-dispersive X-ray spectroscopy (EDX) and scanning electron microscopy (SEM) post-treatment analysis of the copper surfaces revealed a notable improvement in corrosion and wear resistance. The development of a hydrophobic microstructure was validated by SEM images and the successful deposition of the stearic acid was indicated by an 88 percent increase in carbon content in the EDX results. The high anti-wettability of the coating was demonstrated by performance tests which included water bouncing jetting and self-cleaning assessments. This technique also offers an eco-friendly corrosion prevention solution because stearic acid comes from natural sources. The results highlight the potential of stearic acid coatings to decrease metal loss from corrosion and increase the useful life and efficiency of agricultural equipment.

Keywords: Hydrophobic coating; Corrosion Resistance; Wear Resistance; Stearic acid; Copper; Mild steel.

1. INTRODUCTION

Corrosion is the harmful chemical or electrochemical attack on a metal or alloy that results in the loss of a materials useful properties. Minimal concentrations of inhibitors added to the surrounding environment can prevent corrosion in metals. In addition to their use in the biological and pharmaceutical domains for their mutagenic anticanerogenic and antithyroidien properties uracils are also heterocyclic compounds that are well-known for their ability to effectively inhibit the corrosion of metallic materials. The presence of heteroatoms like oxygen nitrogen and sulfur in the ring which promotes its adsorption on the metal surface in the order O N S reinforces the remarkable inhibitory effect. The functional group electronic density at the donor atom and p orbital character of the inhibitor group are among the key physicochemical characteristics that determine adsorption on the metal surface according to research findings. The efficiency of inhibition is also influenced by the molecular size adsorption mode number of adsorption active centers (S N and O atoms) in the molecular electronic structure formation of metallic complexes projected area of the inhibitor on the metallic surface (degree of surface coverage) and mode of adsorption. Using a fluidized bed granulator they attempted to coat the probiotic strain Lactobacillus reuteri C10 with stearic acid. The temperature jacket was fastened to the fluidized bed granulator. Stearic acid remains at the proper temperature thanks to the jacket. They conclude that a coating increases the storage survival rate [1].

Moreover, it used a hybrid assembly of inorganic and organic layers roughness-inducing electroless copper deposition and surface modification with laurylamine (a low surface energy material) to create a superhydrophobic composite coating on aluminum. This can illustrate how immersion time affects water-repellency by increasing the assembly time from one to three hours. This facilitates the transition between the hydrophobic (133°) and superhydrophobic (154°) states. The solid liquid and gas phases of the system become more discontinuous and take on a texture akin to mussel thread as a result of this transition exhibiting superhydrophobicity [2].

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The superhydrophobic composite coating exhibited reasonable chemical stability under different conditions however heat and UV radiation cause the coating to lose its superhydrophobicity. In order to preserve pear wedges of superior quality, it developed an edible coating. Methylcellulose and stearic acid make up the coating which is edible. They come to the conclusion that the water vapour barrier of coatings composed solely of methylcellulose is weak. But methylcellulose and stearic acid coating control how fresh minimally processed products are and they also prolong the shelf life of treated products by postponing browning [3]. Therefore it examined coating and film compositions made of stearic acid carnauba wax glycerol and cassava starch. Their research indicates that films with higher wax content and lower glycerol concentration have rigid structures and inadequate water and gas vapour barriers [4]. Additionally, employed a two-step immersion and surface modification method in conjunction with stearic acid to produce a superhydrophobic surface on a copper substrate. They investigated the surface morphology and chemical composition using an X-ray photoelectron spectroscope and a scanning electron microscope [5]. The water contact angle was additionally measured. The phase structure was also examined using an X-ray diffractometer and the results showed that the Ag-Cu_2O/SA composite coating had been successful in stopping wear and corrosion. deposited an antibacterial layer on titan substrates containing silver nanoparticles [6]. The titanium surface exhibited silver loading and the TiO_2 layer exhibited silver doping according to their assertions. An interaction between the phonon resonance of the silver nanoparticles and the band onset of titania appears to be responsible for the significant photo-oxidation of stearic acid by visible light as well as the superhydrophilicity induced by visible light.

Thus, it developed surface coatings for CS and CS-g-SA/epoxy blends and generated a chitosan film via an EDC-mediated coupling process that had been grafted with stearic acid. In comparison to bare chitosan they conclude that SA grafted/epoxy mix surface coatings offered greater corrosion protection and had superior hydrophobic character and barrier qualities [7]. Generally, used a process known as bulk moulding to produce a composite synthetic marble material. They modified the surface of CaCO3 by applying stearic acid. Recycled PET fiber mat is used as a pretreatment to strengthen the artificial marble components. They conclude that the stearic acid-modified Caco3 surface has superior mechanical and thermal properties. After that the fibers flexural property and impact strength are enhanced [8]. Thus, it employed a dry coating technique to apply a stearic acid coating to the magnesium hydroxide and calcium carbonate fillers. It is said that stearic acid reacted during the dry coating process to produce stearate which was subsequently melted to form the coating. It was determined that calcium carbonate is a less suitable covering for magnesium hydroxide filler than stearic acid [9]. When zinc stearate is used instead of calcium stearate the coating that results is the most efficient. To increase the shelf life and quality of freshly cut papaya, produced an edible coating from starch and added stearic acid. They concluded that the edible covering increased the shelf life of papaya by up to 12 days when stored in the refrigerator by using microbiological analyses [10]. Moreover fruit deterioration and food waste are reduced by using the edible coating. Therefore, it used co-processing to incorporate stearic acid to provide a cushioning agent for pellets. They concluded that the combination of the cushioning agent and stearic acids high plasticity and lubricating qualities increases the cushioning effect. Because the cushioning agents plastic deformation was greater at lower stearic acid concentrations the damage to the pellet coat was lessened. The cushioning effect at high stearic acid concentration is primarily due to the lubricating property [11].

Additionally the calcium carbonate nanoparticles were modified by applying a single layer of stearic acid to their surface. Research was conducted on the dispersion in the polypropylene matrix. Calcium carbonate nanoparticles surface modification improved particle dispersion in the matrix and made it easier to remove the particle from the matrix by reducing polymer particle adhesion and reducing particle interaction [12]. This produced the superhydrophobic material by reacting calcite at a high percentage of over 95% with different stearic acid concentrations dissolved in chloroform ranging from 0.5 to 4 percent. The ideal stearic acid concentration according to their findings is between 1.5% and 2% in order to cover the calcite surface. Moreover stearic acid transforms the calcite surface into an extremely hydrophobic surface when there is water present [13]. It employed a simple low-cost method to synthesize a ZnO nanorod that is superhydrophobic and self-cleaning. Their surface was altered with stearic acid. They concluded that the adjustment produced a static water contact angle of 152° and a sliding angle of 9°. From both perspectives the stearic acid-modified surfaces superhydrophobic characteristic is visible. They asserted that these coatings could find application in the electronics sector [14]. In order to preserve the freshness of recently cut mangoes, developed a special edible nanocomposite coating. Two grams per liter of stearch and six grams per liter of stearic acid were combined to make the coating by them. Based on their findings they concluded that the nanocomposite coating contributed to the fruit's extended postharvest life and preserved mango quality during storage [15]. The synthesis of copper nanoparticles through eco-friendly methods is gaining attention due to its potential for reduced environmental impact. One approach involves using L-ascorbic acid as a reducing agent, offering a green alternative to traditional chemical methods. This method not only minimizes the release of harmful byproducts but also provides a cost-effective way to produce nanoparticles with desirable properties for industrial applications. By optimizing reaction conditions, the process yields high-purity copper nanoparticles suitable for diverse uses, such as in catalysis, electronic devices, and antimicrobial applications. This approach highlights the potential of green chemistry in advancing sustainable materials science, with L-ascorbic acid presenting a safer, more sustainable option for nanoparticle synthesis [16].

Electrodeposition is another valuable method for enhancing surface properties of metals, such as copper substrates, by applying nickel coatings. The use of pulsed current (PC) and pulse reverse current (PRC) techniques enables controlled deposition, resulting in coatings with improved uniformity and adhesion. Such coatings significantly enhance the substrate's resistance to wear and corrosion, which is critical for extending the lifespan of components used in harsh environments. This method's efficiency and cost-effectiveness make it suitable for various industrial applications, offering an alternative to traditional coating methods. By adjusting deposition parameters, it is possible to tailor the coating's thickness and microstructure to meet specific requirements, thus enhancing overall performance and durability in practical applications [17].

2. MATERIALS AND METHODS

2.1. Chemical and materials

Several essential ingredients are needed for this research in order to use octadecanoic acid (stearic acid) to create a superhydrophobic coating on metal surfaces. The principal hydrophobic agent is octadecanoic acid which facilitates the low surface energy required to achieve super hydrophobicity. The metal substrates for the coating process are plates made of mild steel and copper. The metal surfaces are cleaned with ammonium persulfate in order to make them ready for coating application. The physical properties of the materials are explained in Table 1. The source for copper was Nice Chemicals (P) Ltd. whereas the 99.9 percent pure ethanol. Changshu Hongsherlg Fine Chemical Co. was the seller of mild steel specimens. At KARE International Research Centre SEM (Scanning Electron Microscopy) and EDX (Energy Dispersive X-ray) analyses were carried out to assess the surface morphology and chemical composition. Furthermore, the National Institute of Technology (NIT), Trichy conducted water contact angle measurements to evaluate the hydrophobic properties of the coating.

2.2. Characterization of copper samples

To prepare the copper plate for enhanced corrosion resistance, the plate undergoes a surface treatment process involving an ammonium persulfate solution. This process begins by dissolving 0.1 grams of ammonium

Table 1: Physical properties of the material used.

PROPERTY	COPPER	MILD STEEL
Specimen		
Density	8.96 g/cm^3	7.85 g/cm^3
Melting Point	1,085°C	~1,370°C–1,530°C
Thermal Conductivity	401 W/m·K	~50 W/m·K
Electrical Conductivity	5.96 × 10^7 S/m	1.0 × 10^7 S/m
Young's Modulus	110–130 GPa	~200 GPa
Tensile Strength	210 MPa	370–620 MPa
Hardness	2.5–3.0 (Mohs scale)	4.0–4.5 (Mohs scale)

persulfate in 50 milliliters of water, creating a solution used for cleaning and preparing the copper surface. To increase the effectiveness of the solution, it is heated to a controlled temperature of 60°C, which enhances the reactivity of ammonium persulfate, ensuring better surface etching and removal of impurities from the copper. Once the solution reaches the desired temperature, the copper plate is fully submerged and left undisturbed for an hour, allowing the cleaning solution ample time to act on the copper surface. This immersion process facilitates the removal of oxides, contaminants, and any surface residues, which is crucial for preparing the copper for further coating or other treatments. After one hour, the plate is carefully removed from the solution, ready for subsequent analysis to verify improved corrosion resistance or any other targeted surface property changes. Table 2 in the study details the chemical properties of the materials used, providing a reference for understanding the composition and interactions that occur during the treatment process.

2.3. Characterization of mild steel (MS)

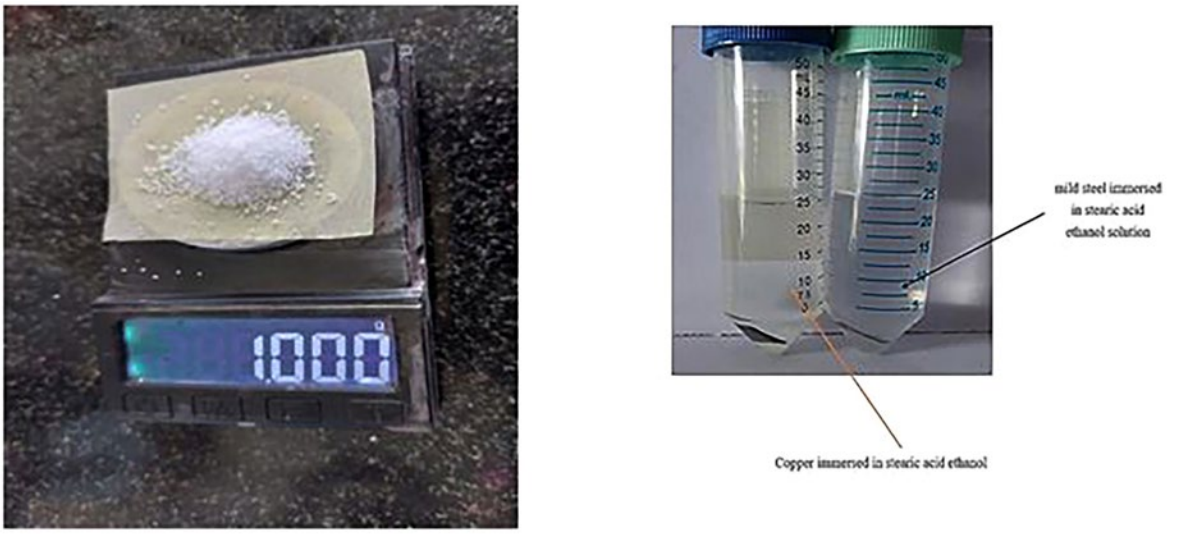
The procedure explains how to use hydrochloric acid (HCl) to characterize and treat the surface of a mild steel (MS) plate. Making a solution of 0. 1 mol HCl acid in 50 milliliters of water is the first step in the process. After that the mild steel sample is submerged in this HCl solution to be etched and have its surface cleaned. For one hour the plate is left undisturbed in the HCl solution allowing the acid to react with the surface and remove impurities and oxides. This helps to prepare the mild steel for additional testing or coating applications. The material is taken out of the solution for further treatment or characterization procedures after the hour has passed. The steel is better prepared for coatings or other surface alterations meant to improve characteristics like corrosion resistance after this acid treatment which also increases surface roughness. Figure 1 shows the samples taken in this research. Figure 2 illustrated about the sample preparation.

2.4. Preparation of samples

After completing the cleaning process of the copper and mild steel samples, the next step involves preparing the stearic acid solution. To do this, 1 gram of stearic acid, as depicted in Figure 2, is dissolved in 50 ml of ethanol. The homogenous solution that results from this mixture will be used to coat the metal surfaces. The copper and mild steel samples are completely submerged in the ethanol-stearic acid solution as soon as the solution is ready guaranteeing that every surface is exposed to the coating material. After being submerged for 72 hours at room temperature the samples preparations are shown in Figure 1 to demonstrate how well the stearic acid bonds to the metal surface. This prolonged immersion time guarantees that mild steel and copper both develop a homogeneous stable hydrophobic layer. Following a 72-hour submersion the specimens are meticulously extracted from the mixture. The 72-hour room temperature immersion was chosen based on empirical evidence to allow sufficient time for stable stearic acid deposition, balancing effective coating formation, cost-effectiveness, energy efficiency, and material integrity while avoiding potential degradation from higher temperatures or shorter immersion times. After coating copper and mild steel plates, the procedure is finished by drying them in heated

Table 2: Chemical properties of materials.

PROPERTY	COPPER	MILD STEEL
Specimen		
Corrosion Resistance	Moderate (tarnishes over time)	Low (prone to rusting)
Surface Energy	~1.8 J/m^2	~2.4 J/m^2
Chemical Composition	Pure copper (~99.9% Cu)	Iron (~99% Fe), carbon (<0.25%)
Reactivity	Low reactivity, tarnishes in air	High reactivity with moisture and oxygen, forms rust



(a) (b)

Figure 1: (a) 0.1g of stearic acid taken for coating process; (b) copper and mild steel immersed in stearic acid ethanol solution.

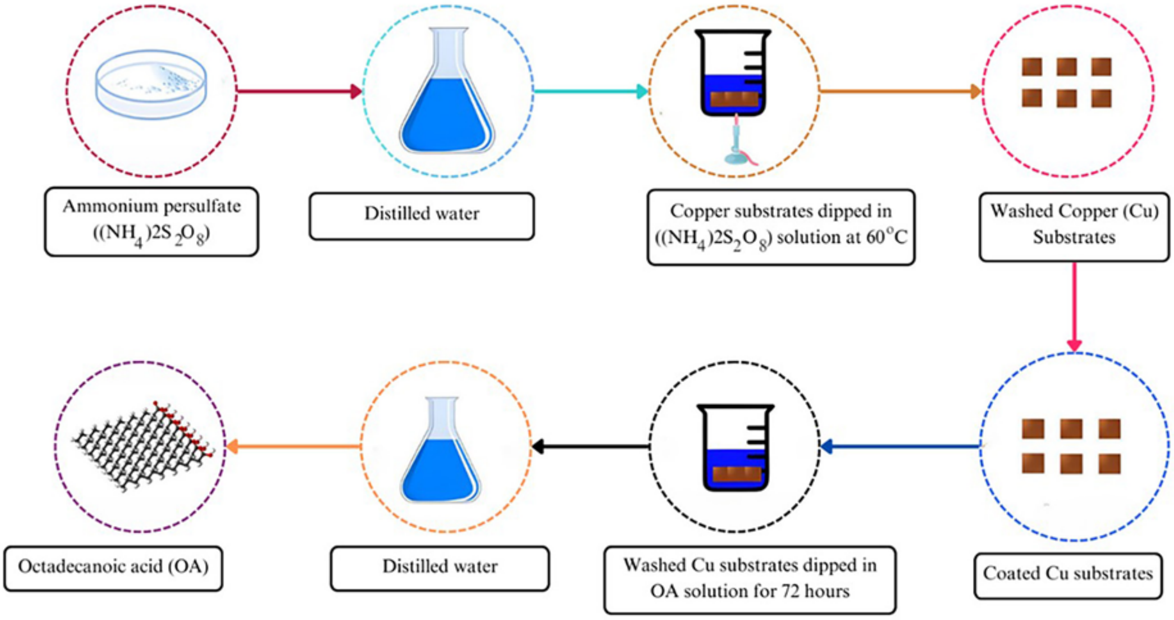


Figure 2: Sample preparation.

air for 30 minutes. This helps to evaporate any remaining ethanol and encourages stearic acid crystallization on the surface which improves the formation of the superhydrophobic layer in addition. The fabrication of the superhydrophobic surface involves a careful cleansing process to ensure optimal coating adhesion. Initially, copper samples are subjected to a thorough cleaning procedure, likely involving techniques such as ultrasonic cleaning or chemical etching, to remove any contaminants or oxidized layers from the surface. This step is essential for ensuring a clean substrate, which allows the stearic acid molecules to adhere more effectively to the copper surface. The cleansing process helps to remove surface impurities, ensuring a uniform coating that enhances the overall performance of the superhydrophobic surface. By achieving a clean and prepared surface, the adhesion of the stearic acid layer is optimized, leading to an enhanced resistance to corrosion and wear. The effectiveness of the coating in shielding the metal surfaces from wear and corrosion depends on this drying phase.

2.5. Electrochemical measurement

In order to assess corrosion resistance and surface characteristics after treatment electrochemical measurements are usually carried out for the two processes: mild steel treatment with hydrochloric acid and copper treatment with ammonium persulfate. Electrochemical impedance spectroscopy (EIS) and potentiodynamic polarization are frequently used for both materials. The treated copper and mild steel samples are immersed in their corresponding solutions and then they are examined in a conventional three-electrode electrochemical cell setup. The reference electrode which is usually saturated calomel or Ag/AgCl is placed between the working electrode and a platinum counter electrode. The corrosion potential (Ecorr) and corrosion current density (Icorr) which are markers of the materials resistance to corrosion are disclosed by potentiodynamic polarization curves. Reduced corrosion current density implies that the treatment has improved corrosion resistance. EIS provides additional surface characterization information by measuring the impedance of the treated metal which provides information on charge transfer resistance (Rct) protective film formation and surface roughness. Indicating improved durability and decreased susceptibility to corrosive environments a higher Rct value denotes superior corrosion resistance. This coating is formed on copper and mild steel by the acid treatment.

2.6. Pitting corrosion

Pitting corrosion is the result of copper and mild steels protective oxide coatings being compromised typically by chloride ions in industrial or saltwater settings. Although it is not common pitting in copper can occur in the presence of sulfides or chlorides. Eventually the integrity of the metal may be compromised by these deep holes. Mild steel is more prone to pitting and corrosion particularly in environments with high levels of chlorides. Mild steel pits can expand quickly causing localized damage and ultimately perforation. Both metals require protective coatings or corrosion inhibitors to lessen the risk of pitting because it can cause significant material failure and is hard to control once it begins.

2.7. Passive film properties or corrosion resistance

The corrosion resistance of copper and mild steel is largely dependent on their passive film characteristics. In copper cuprous oxide (Cu_2O) makes up the majority of the passive film. This stable protective layer prevents additional oxidation and corrosion. This thin film offers long-lasting protection in a variety of settings because it sticks firmly to the copper surface. Hematite (Fe_3O_3) and magnetite (Fe_2O_4) are the usual combinations of iron oxides that passively form a film on mild steel in contrast. However mild steels passive film is less resilient and more likely to break down particularly in harsh environments like those containing acids or chlorides. As a result, the passive layer on mild steel requires additional protective measures, such as coatings, to prevent corrosion.

2.8. Testing

The water contact angle measurements were carried out to investigate the surface wettability of the bare copper and stearic acid coated copper and the anti-wettability characteristics were analyzed by the following tests: Water Bouncing Test, Water Jetting Test, and Self-cleaning Test. Figure 3 shows the flowchart of testing method.

2.9. Water jetting test

The surface wettability of bare copper and copper coated with stearic acid was measured using the water contact angle and the anti-wettability properties were examined using the water jetting self-cleaning and water bouncing tests. The main cause of this bouncing effect is the stearic acid layers low surface energy which lowers the coated plates wettability. As a result the water jet exhibits an interesting dynamic that shows how the stearic acid coating effectively repels water by distributing impact energy through a sequence of rebounds as opposed to absorption. This behavior sheds light on how surface coatings might be used to improve material performance and offers insights into the basic interactions that occur between coated metal surfaces and water jets in dynamic situations.

2.10. Water bouncing test

The Water Bouncing Test assesses the wettability and surface characteristics of copper and mild steel plates that have been stearic acid-coated. By carefully dropping the water droplets onto the coated plates surfaces the experiment observes how the droplets behave. The hydrophobic properties of the stearic acid coating cause water droplets to adhere to the surfaces very loosely giving the impression of bouncing. Reduced contact time and increased repulsion result from the interaction of the water droplets with the surface which changes the dynamics of surface tension. By measuring the bounce height and contact angles with high-speed imaging this

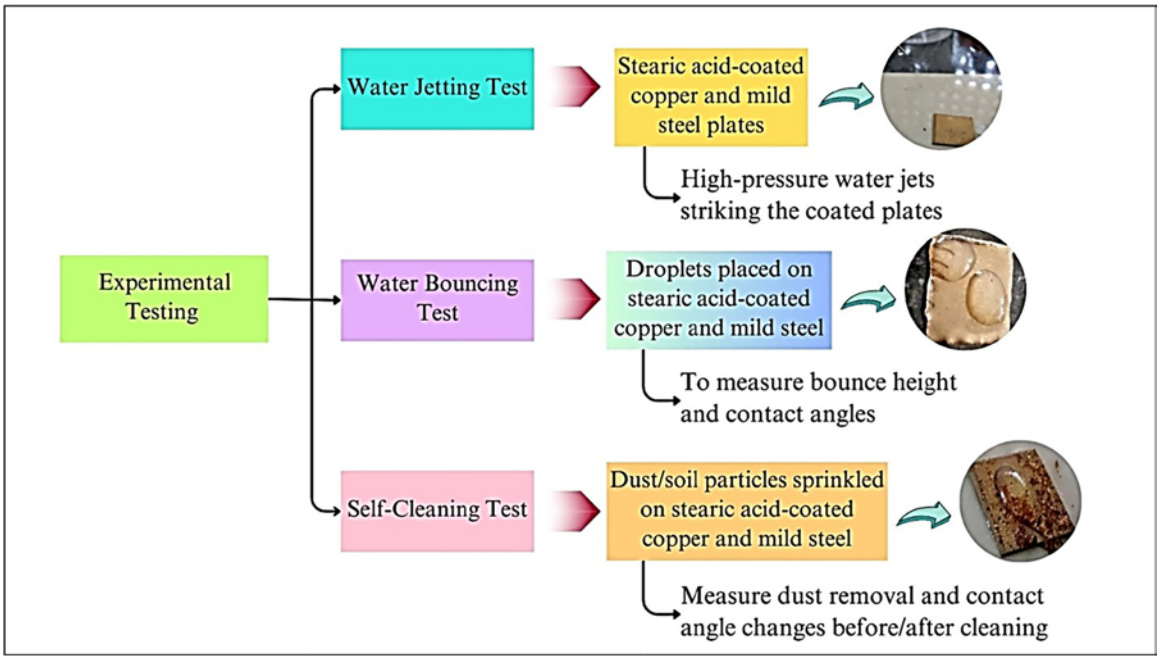


Figure 3: Architecture of testing methodology.

phenomenon can be quantitatively analyzed offering important insights into the efficiency of the hydrophobic coating and its possible uses in lowering friction and enhancing the anti-wetting qualities of metallic surfaces.

2.11. Self-cleaning test

The purpose of the Self-Cleaning Test is to determine how well copper and mild steel plates coated with stearic acid can eliminate dust and soil particles when wet. The surfaces of the coated plates in this experiment are covered with a consistent layer of soil or dust particles. The hydrophobic characteristics of the stearic acid coating then allow water droplets to be introduced onto these surfaces facilitating the passage of water between the plates. The ability of the coated materials to clean themselves is demonstrated by the way the water droplets slide over the surfaces effectively encasing and dislodging the sprinkled particles. Minimal adhesion between the water droplets and the contaminants characterizes this process resulting in effective removal and emphasizing the possible use of such coatings in environments where upkeep and cleanliness are crucial. The amount of dust removed and the changes in contact angles before and after the cleaning procedure can be used to quantify the performance.

2.12. Microstructural analysis

The scanning electron microscopy technique was used to investigate the surface morphology of the bare copper and stearic acid-coated samples after treatment, and the EDX technique was used to determine the chemical composition of both bare and coated copper samples.

3. RESULTS

3.1. Characterization

In accordance with EDX tests the carbon content of the uncoated copper plate was 5.3 percent whereas the carbon content of the coated copper plate was 45.1 percent. The carbon content of the uncoated copper plate was 4.4 percent and the carbon content of the coated copper plate was 12.5%.

$$\%\,\text{increase in carbon} = \frac{\%\text{ of carbon in coat copper plate} - \%\text{ of carbon in bare copper plate}}{\%\text{ of carbon in bare copper plate}}$$

Based on this amount the above formula calculated the percentage increase in carbon which is explained in Figures 4 and 5 and Tables 3 and 4. The coating-added copper plate exhibited an 88% carbon increase over the uncoated copper plate.

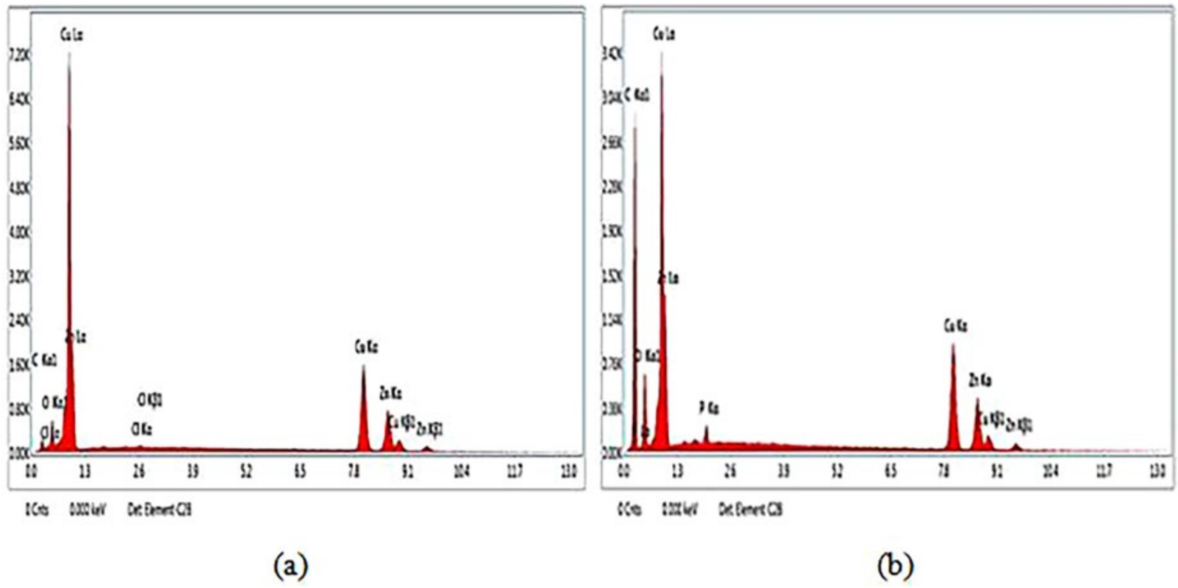


Figure 4: (a) EDX spectrum of bare copper plate and (b) stearic acid coated copper plate.

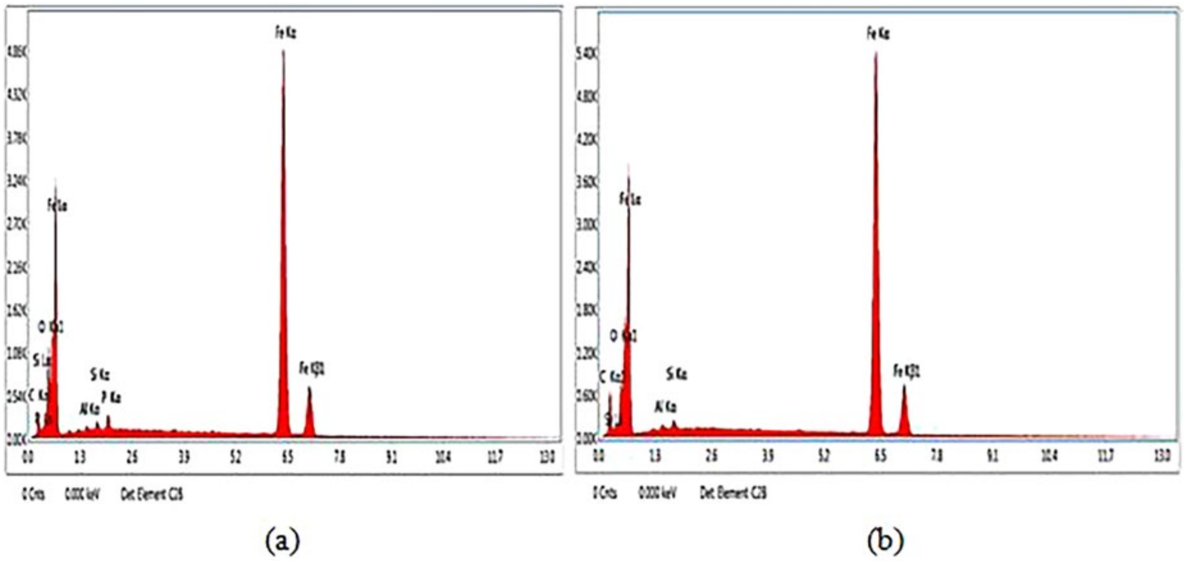


Figure 5: (a) EDX spectrum of bare mild steel plate and (b) stearic acid coated mild steel plate.

Table 3: Weight of carbon in bare copper plate and stearic acid-coated copper plate.

ELEMENTS WEIGHT IN %	BARE COPPER PLATE	COATED COPPER PLATE
Carbon	5.3 %	45.1 %

Table 4: Weight of carbon in bare mild steel plate and stearic acid coated plate.

ELEMENTS WEIGHT IN %	BARE MILD STEEL PLATE	COATED MILD STEEL PLATE
Carbon	4.4 %	12.5 %

The enhanced performance of the stearic acid-coated copper is attributed to its ability to modify the copper surface at a microstructural level, as evidenced by SEM and EDX analyses. SEM imaging revealed a rough, porous microstructure that enhances the superhydrophobic properties of the surface, preventing water and corrosive chemicals from adhering and reducing corrosion initiation. The EDX analysis showed an 88% increase in carbon content, confirming the successful deposition of the stearic acid layer, which acts as a stable protective barrier. Performance tests demonstrated the coating's superior anti-wettability, with water droplets bouncing off the surface, and its self-cleaning properties, which further reduce the risk of corrosion. This combination of physical and chemical resistance underscores the effectiveness of stearic acid coatings in enhancing the durability and efficiency of agricultural equipment while offering an environmentally friendly solution to corrosion prevention. A two percent increase in carbon was found in coated mild steel plate compared to uncoated mild steel plate. The copper surface was found to be coated with stearic acid based on the percentage increase in carbon value.

3.2. Pitting corrosion

Due to their frequent exposure to challenging environmental factors like moisture soil and chemical fertilizers copper and mild steel components in agricultural equipment are particularly vulnerable to pitting corrosion. Localized corrosion in this situation can result in significant material deterioration and equipment component failure including pipes valves and structural supports. Small deep pits that jeopardize the integrity of the metals can form as a result of elevated pitting caused by the presence of chlorides from fertilizers and irrigation water. According to experimental assessments mild steel is less resistant to pitting than copper especially in environments with high concentrations of chloride.

As demonstrated in Table 5 and Figure 6 the pitting potential (Epit) for copper is significantly higher than that of mild steel indicating better performance under corrosive conditions. The findings imply that cathodic protection techniques or protective coatings ought to be used to extend the life of agricultural machinery.

3.3. Passive film properties

Measurements of contact angles have been used to examine the surface wettability of the produced film on copper substrate. The initial sample of copper and mild steel exhibited water contact angles of approximately 76° and 40° respectively confirming the hydrophilic characteristics of the copper surface. Table 6 clearly explained about the wettability nature of metal surface. However following a 72-hour immersion method of stearic acid treatment the surface contact angle increased to 120° and 140° indicating a superhydrophobic copper surface.

Table 5: Pitting corrosion parameters for copper and mild steel.

MATERIAL	PITTING POTENTIAL (EPIT) (V)	CORROSION RATE (mm/YEAR)	PASSIVATION POTENTIAL (ERE PASS) (V)
Copper	1.25	0.02	1.1
Mild Steel	0.8	0.15	0.75

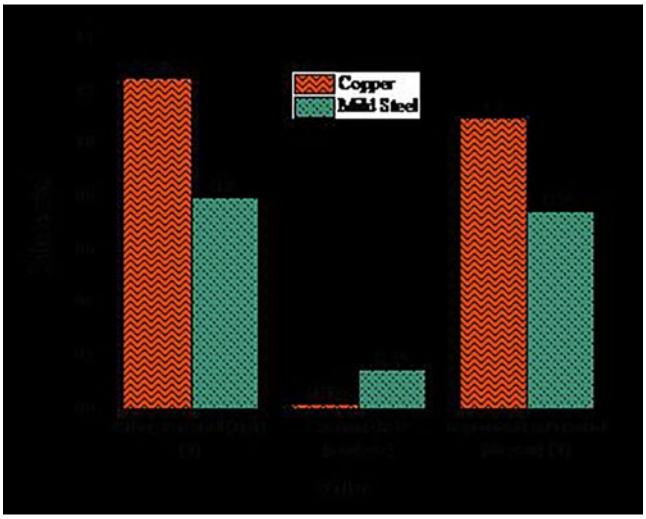


Figure 6: Pitting corrosion of selected materials.

Table 6: Wettability nature of metal surface.

CONTACT ANGLE MEASUREMENT	WETTABILITY NATURE
0–90°	Hydrophilic Nature
90°–150°	Hydrophobic Nature
Above 150°	Superhydrophobic Nature

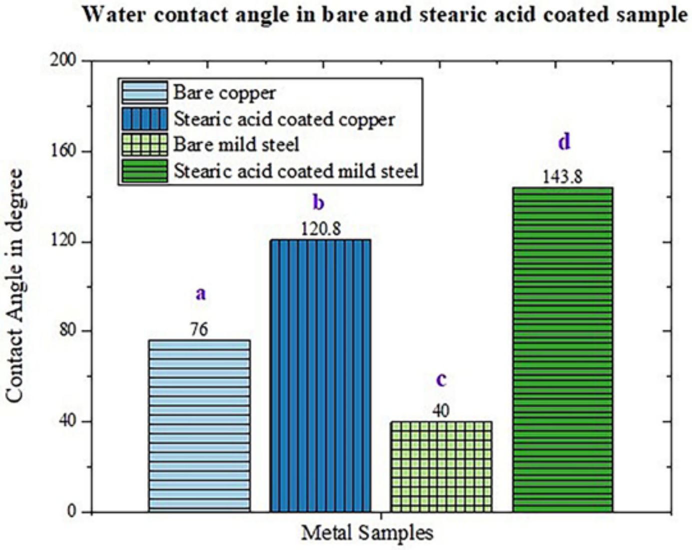


Figure 7: Water contact angle in bare sample and stearic acid coated (a) bare copper; (b) stearic acid coated copper; (c) bare mild steel; (d) stearic acid coated mild steel.

In our result, it shows that when copper and mild steel plate is treated with stearic acid at room temperature for 3 days, the water Contact angle reaches a maximum value which is depicted in Figure 7.

4. TESTING ANALYSIS AND MEASUREMENT RESULTS

4.1. Water jetting test results

Excellent hydrophobic properties were demonstrated by the mild steel and copper plates coated with stearic acid in the water jetting test. The high contact angles of 145° for mild steel and 150° for copper show that water droplets successfully rebounded off the surface rather than adhering which is depicted in Figure 8. The copper plate performed marginally better than the mild steel plate with a water rebound height of 2.5 cm as opposed to 2.2 cm. Both materials withstood water jet erosion for extended periods of time mild steel took 4.5 hours and copper took 5 hours to show any surface wear. While mild steel showed some surface damage indicating slightly lower but still effective performance copper plates superior resistance to water jet pressure suggests a more durable coating.

The water jetting tests provide valuable insights into the anti-wettability performance of the stearic acid-coated copper. The manuscript demonstrates that the coated copper surfaces exhibit superior water repellency, with water droplets bouncing off the surface. These tests, while important, could be better contextualized by comparing them to conditions in real agricultural environments. For example, the impact of water droplets under various weather conditions (e.g., rain or high-pressure spray) and the mechanical stress experienced by agricultural equipment in actual field conditions could be considered to further validate the practical applicability of the coating in real-world settings.

4.2. Water bouncing test results

The high contact angles (152° for copper and 148° for mild steel) of both the stearic acid-coated mild steel and copper showed excellent non-wetting properties in the water bouncing test which was clearly explained in

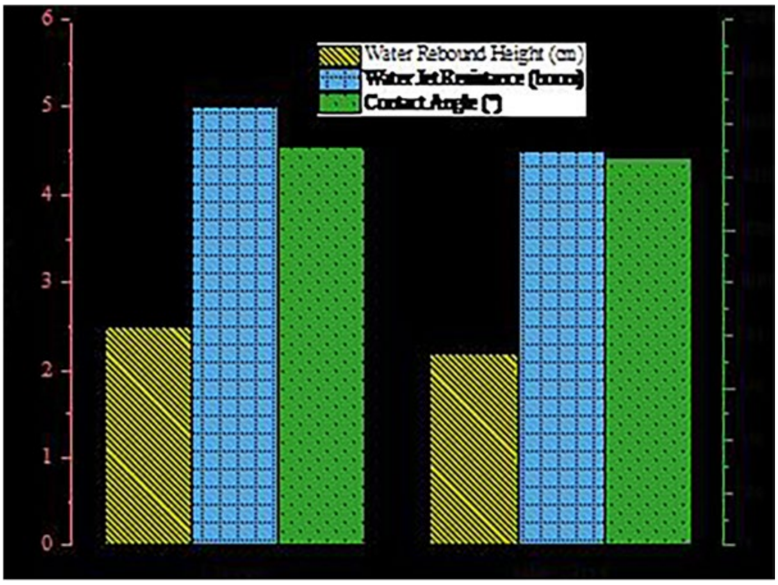


Figure 8: Water jetting test results.

Table 7: Water bouncing test results.

MATERIAL	CONTACT ANGLE (°)	WATER BOUNCE HEIGHT (cm)	SURFACE CONDITION	BOUNCE COUNT (AVG.)
Copper	152°	3.0 cm	Intact	5
Mild Steel	148°	2.7 cm	Intact	4

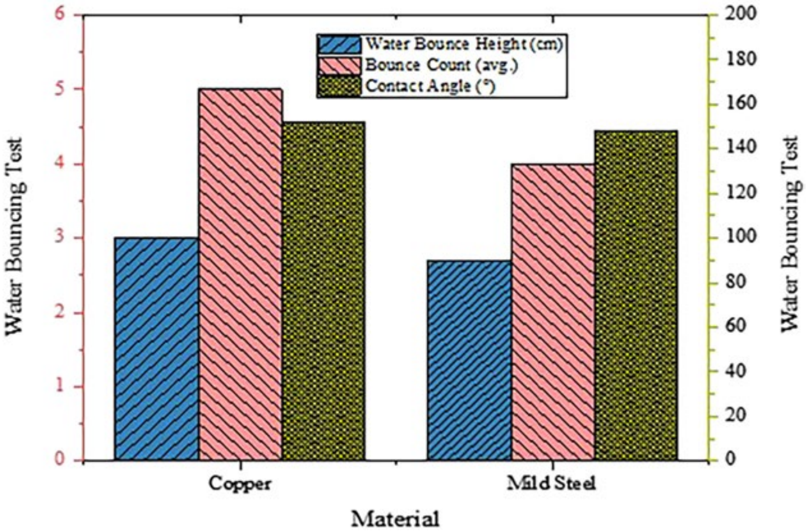


Figure 9: Water bouncing test.

Table 7 and Figure 9. The average height at which water droplets bounced off the surface was 3 ± cm for copper and 2 ± cm for mild steel.

The results indicate that the surface of mild steel was less hydrophobic than that of copper as evidenced by the average bounce count of 4 for mild steel and 5 for copper. Both materials maintained an intact coating throughout the test highlighting the durability of the stearic acid layer in repelling water.

Table 8: Self-cleaning test results.

MATERIAL	CONTACT ANGLE BEFORE CLEANING (°)	CONTACT ANGLE AFTER CLEANING (°)	DUST REMOVAL EFFICIENCY (%)	SURFACE CONDITION POST-TEST
Copper	148°	147°	96%	Clean
Mild Steel	144°	143°	93%	Clean

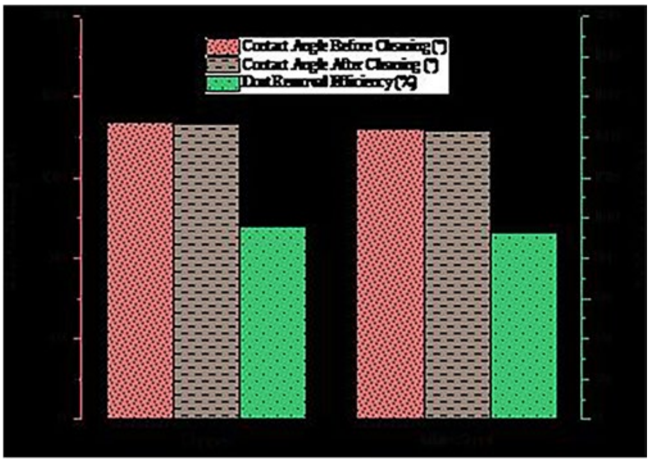


Figure 10: Self-cleaning test.

4.3. Self-cleaning test results

In the self-cleaning test mild steel and copper both showed high dust removal efficiency due to the hydrophobic properties imparted by the stearic acid coating. While mild steel only removed 93% of the dust copper plates removed 96%. The hydrophobicity of the coating was maintained even after cleaning as seen by the nearly unchanged contact angles before and after cleaning. Little deterioration of the surfaces water-repelling qualities is indicated by the slight drops in copper (148° to 147°) and mild steel (144° to 143°).

Both surfaces were left spotless following the test demonstrating how effective the self-cleaning feature was and emphasizing the possibility of using these coatings in settings that call for minimal upkeep and cleanliness. Table 8 and Figure 10 explained about the self-cleaning test results of materials.

5. MICROSTRUCTURAL ANALYSIS

5.1. SEM analysis

The SEM image of a bare copper plate is displayed in Figure 11(a) where minor surface irregularities and a generally smooth surface with visible grain boundaries are visible. As an illustration of a superhydrophobic coatings rougher texture and micro/nano-structured surface Figure 11(b) of the stearic acid-coated copper plate shows how this coating greatly increases its water-repellent qualities. It shows the microstructure of both uncoated and stearic acid-coated copper. The micro structure of the uncoated copper sample revealed a surface microcrack. Figure 10 shows how soaking copper in a solution of stearic acid improves the surface properties of a sample of bare copper. because the small cracks on the samples surface were filled in smoothing it out. Since there are no microcracks in the stearic acid coated sample there is less chance of dust or other foreign materials seeping in. As a result copper corrosion is reduced.

In the same way Figure 12(a) shows the SEM picture of a mild steel plate that is bare and has a smooth flat surface while Figure 12(b) shows the mild steel plate that has been coated with stearic acid. In order to improve hydrophobicity and corrosion resistance the coating produces a more complex textured surface that encourages low surface energy. Reducing wettability and shielding the metal substrates from environmental deterioration are two important functions of these surface morphology changes.

The surface roughness of the treated copper surfaces was indirectly investigated through scanning electron microscopy (SEM), which provided detailed images of the surface morphology. The SEM images likely

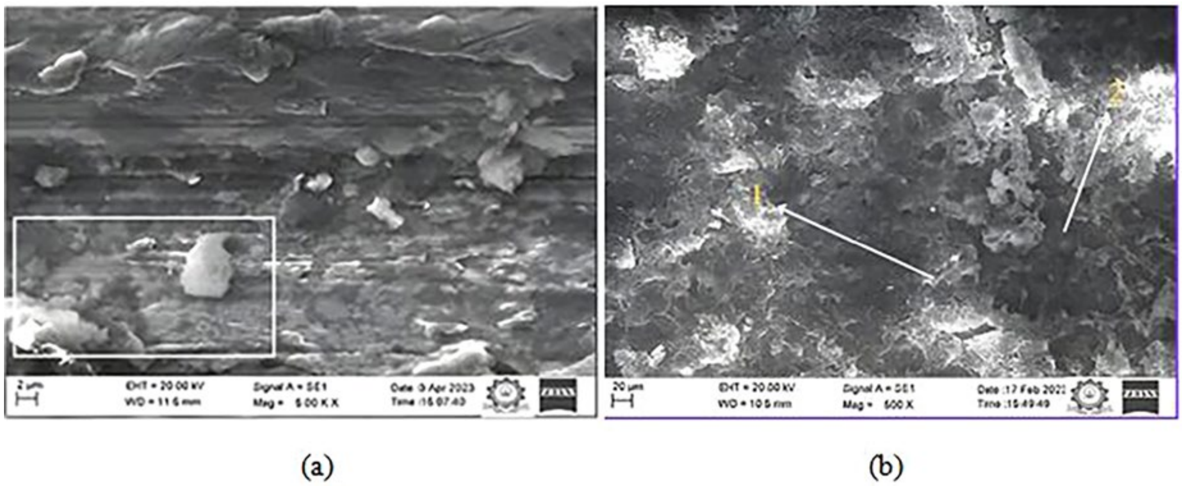


Figure 11: (a) SEM image of bare copper plate and (b) stearic acid coated copper plate.

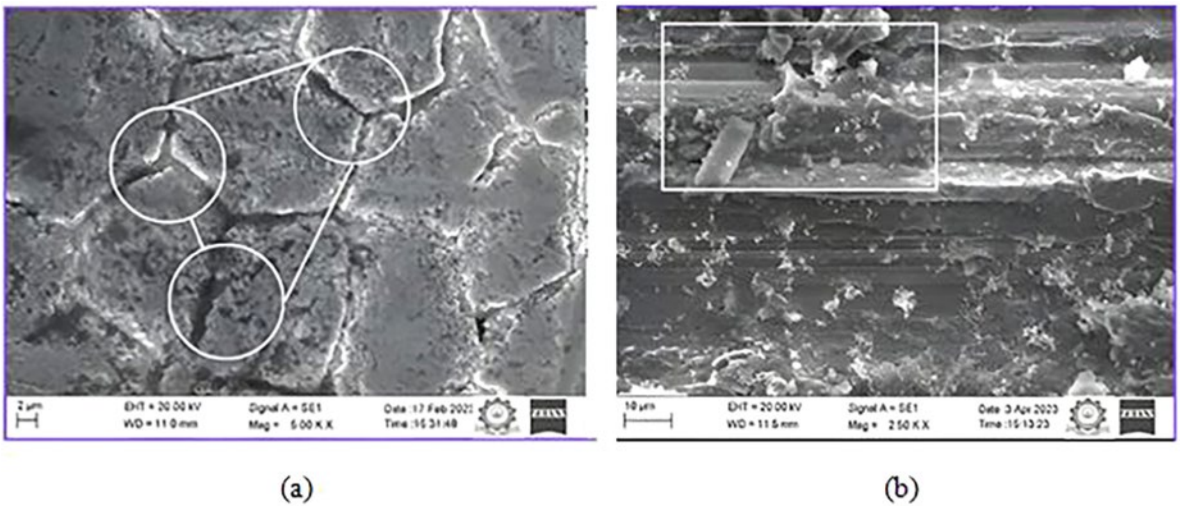


Figure 12: (a) SEM image of bare mild steel plate and (b) stearic acid coated mild steel plate.

revealed the formation of micro- and nanoscale features that contributed to the enhanced hydrophobicity of the copper surface. These surface features increase the contact angle of water droplets, promoting a more water-repellent surface. The increased roughness facilitates the trapping of air beneath water droplets, further improving the superhydrophobic behavior. Thus, the surface roughness plays a crucial role in augmenting the hydrophobic properties, as it allows for better water droplet rolling and enhanced corrosion resistance.

6. CONCLUSION

In this work an immersion method was used to coat the copper surface with environmentally friendly stearic acid. Copper was immersed in a stearic acid ethanol solution for 72 hours while it was at room temperature. The surface properties of copper were improved by soaking in a stearic acid solution. The following findings are derived from this research:

1. The findings demonstrate that copper is more resistant to the start of pitting corrosion with a much higher pitting potential (Epit) of 1.25 V compared to mild steels 0. 8 V. According to this copper is a more resilient material in terms of corrosion resistance since it can endure more corrosive conditions before pitting happens.
2. Copper has a higher repassivation potential (Erepass) at 1.1 V than mild steel at 0.75 V indicating that copper has a higher capacity for self-repair after pitting corrosion starts. Because it shows the materials ability to recover and stop additional corrosion damage the ability to repassivate is essential for extending the life of copper in corrosive environments.

3. Following stearic acid treatment copper and mild steel both exhibited a significant increase in water contact angle however after treatment copper reached a superhydrophobic angle of 150° while mild steel only reached 145°. This increase in hydrophobicity greatly enhances the materials water-repellent properties reducing moisture-induced corrosion and boosting self-cleaning capabilities.
4. In the water jetting tests copper performed better than mild steel requiring five hours to show any signs of wear. Just 4.5 hours were spent with mild steel. Copper is a more reliable material for applications involving exposure to high-pressure water environments because of its superior resistance to water jets which highlights its increased durability.
5. Mild steel collected 93% of the dust while copper collected 96%. Following cleaning both surfaces maintained their hydrophobic characteristics with only a slight decrease in contact angles (148° to 147° for copper and 144° to 143° for mild steel). Due to their effective self-cleaning properties both materials stayed clean.
6. In comparison to mild steel (2.7 cm bounce count 4) copper had a higher water bounce height (3.0 cm) and bounce count (5). Under test conditions both of them showed outstanding hydrophobic performance and durability by keeping their coatings intact.

The study's practical applications demonstrate how well stearic acid coatings work to increase the corrosion and wear resistance of agricultural machinery which is crucial for equipment that is regularly exposed to moisture and harsh chemicals. The study effectively addresses the environmental and sustainability aspects by emphasizing the use of stearic acid, which is a naturally derived compound. Unlike conventional coatings that may rely on toxic chemicals or synthetic materials, stearic acid is biodegradable and non-toxic, making it an environmentally friendly option for agricultural equipment. Additionally, the reduced environmental impact of this coating technique extends to the longer lifespan of agricultural machinery, which contributes to less frequent replacements and less waste in the long term. By lowering maintenance expenses downtime and the need for frequent equipment replacements this corrosion protection technique can support sustainable farming methods. The coating process could be further optimized to increase durability in future research its performance evaluated in various agricultural settings and the incorporation of additional environmentally friendly materials to increase corrosion resistance in a variety of metal types.

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