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EFFECT OF INOCULANT ON THE DEGRADATION BEHAVIOUR OF MULTI LAYERED MILD STEEL/Al-Cr PLATE IN *PSIDIUM GUAJAVA* LEAF EXTRACT

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Abstract
The effect of an inoculant, [triethylamine (TEA)] on the corrosion behavior of multilayered mild steel/Al-Cr plates in guava leaf extract was investigated in 0.5M HCl solution using gravimetric based mass-loss test and potentiodynamic polarization techniques. The mild steel plates were sectioned into coupons of $4 \times 2mm$ and then pickled, after which they were coated at 750℃ with an Al-Cr alloy. The gravimetric-based mass loss test was carried out at room temperature for different concentrations and time intervals of 2.0, 4.0, 6.0, 8.0%v/v and 24, 48, 72, 96 hours respectively. The result showed that triethylamine (*TEA*) decreased the corrosion rate at the various concentrations indicating protection efficiency up to 59.02% in the gravimetric-based-mass-loss technique. Equally the potentiodynamic polarization technique indicates higher corrosion resistance of 98.49%. The two methods used for the evaluation of the degradation of multilayered mild steel/Al-Cr plates in 0.5M HCl/guava leaf extract medium were in agreement.

Keyword: Corrosion rate, linear polarization, Corrosion coupons, Inoculant molecules, Microstructure, Metals

1. Introduction

Carbon steel, the most widely used material accounts for approximately 85% of the annual steel production worldwide. Despite its relatively limited corrosion resistance, carbon steel is used in large tonnages in maritime application, nuclear and fossil fuel power plants, chemical processing, petroleum production and refining, pipelines, mining, construction and metal processing equipment (Atama, 2005; Abostra *et al*., 2009; Idu *et al*., 2015). Today, there are various engineering materials which have different areas of application. These materials are subject to environmental degradation. A class of these engineering materials is Metals. Metals have a wide range of application in modern engineering due to their superior mechanical properties. Metals are subject to degradation which may also be called corrosion (Abostra *et al*., 2009; Abdulwahab *et al*., 2015; Amitha and Bharathi, 2011). Corrosion is due to the reactivity of metallic elements with their environment and oxygen. Corrosion shortens the service life of metals and this poses a big problem to engineering designs and installations (Peabody, 2001; WanNik *et al*., 2010). This has led to investigations and studies on the control of this degradation so as to tackle this problem.

A significant amount of energy is put into a metal when it is extracted from its ores, placing it in a high-energy state. These ores are typically oxides of the metal such as hematite (Fe_2O_3) for steel or bauxite ($Al_2O_3.H_2O$) for aluminum (Umaru *et al*., 2016). One principle of thermodynamics is that a material always seeks the lowest energy state. In other words, most metals are thermodynamically unstable and will tend to seek a lower energy state, which is an oxide or some other compound. The process by which metals convert to the lower-energy oxides is called corrosion (Abdulwahab *et al*., 2015). Corrosion of most common engineering materials at near-ambient temperatures occurs in aqueous (water-containing) environments and is electrochemical in nature. The aqueous environment is also referred to as the electrolyte and, in the case of underground corrosion, is moist soil (Peabody, 2001).

Various research has demonstrated ways of controlling corrosion but due to the ever evolving technology, more research is needed to develop more effective and suitable corrosion control means so as to reduce the cost implication of corrosion and also increase the service life and maintainability of engineering equipment and structures. This work is there for focused on improving the corrosion resistance of a coated metal even in the presence of an inhibitor.

2. Experimental

2.1 Materials and equipment

The materials used in this research include; flat mild steel plates (low carbon steel), distilled water, Methanol, 192g of Al-92% Cr-8%, pure HCl, 0.5M HCl solution, guava leaf (psidium guajava) extracts and triethylamine solution. While some of the equipment used include; Potentiometer, digital weighing balance, desiccator, beakers, series of grit papers, measuring cylinder which were sourced from the Department of Metallurgical and Materials Engineering, Ahmadu Bello University, Zaria.

2.2 Sample preparation

The sample preparation involved cutting a 1mm thick mild steel plate into 10 small coupons of 4× 2 × 1 mm each. The coupons were polished using grit paper of size 600 and then pickled.

Table 1: Nominal chemical composition of low carbon steel, (Hassan, 2006)

Steel grade	%Carbon	%Silicon	%Manganese	%Phosphorus	%Sulphur	Copper
Nst	0.12-0.17	0.18-0.28	0.40-0.60	0.04-Max	0.04-Max	0.25

2.3 Pickling

This was carried out to remove the rust (oxide layer), grease and dirt from the surface of the steel. The samples were dipped in pure HCl of 16cm^3 for one minute each, washed under a running tap water and then transferred into warm water to remove any salt layer present. After which it was again dipped in cold water and swapped with a cotton wool immediately (Abdulwahab *et al*., 2015).

2.4 Hot dipping

In this step, the 8%-Cr and 92%-Al were charged into a crucible furnace and heated to about 750 ℃. The melt was stirred then the mild steel coupons were hot-dipped for 5seconds each at the same temperature and then left to normalize in the atmosphere (Mohammed and Dong, 2016).

2.5 Guava leaf extracts preparation

This was done using the soxhlet extractor. The soxhlet extractor is a piece of laboratory apparatus designed for the extraction of a lipid from a solid material. Typically, a soxhlet extractor is used when the desired compound has a limited solubility in a solvent. The solvent, methanol was heated to reflux. The solvent vapor then travels into a distillation arm and floods a chamber housing the thimble of powdered guava leaves. The condenser ensures that the solvent vapor cools and drips back the chamber housing the solid material. After this, the liquid obtained was then dried using an evaporating dish (Udom *et al.,* 2017; Omoruwou *et al.,* 2017).

2.6 Corrosion tests

2.6.1 Gravimetric-based mass loss test

At this stage, the 10 coupons were divided into two parts of 5 coupons each. 5 of the coupons were taken to the corrosion lab and a sample of 0.5M HCl was prepared from the acid medium. The 0.5M HCl solution was then divided into 5 beakers of 50 ml each. Thereafter 2g of powdered guava leaf extract was weighed and poured into each beaker. Varying concentration of 0.0, 2.0, 4.0, 6.0 and 8.0%v/v of the inoculant triethylamine was then added into the various beakers and the solution was stirred using a rubber spoon. The initial weight of each coupon was measured and recorded prior to immersion in the solution. The coupons were then kept for 24hrs, 48hrs, 72hrs and 96hrs time intervals after which they were washed with distilled water and consequently weighed (Umaru *et al*., 2013).

2.6.2 Potentiodynamic polarization test

The potentiodynamic polarization and linear polarization resistance was used to characterize the corrosion rate of the multilayered mild steel/Al-Cr plates in 0.5M HCl (200ml) solution containing 2g of guava leaf extract and inoculant of concentrations; 0.0, 2.0, 4.0, 6.0 and 8.0%v/v. A potentiostat coupled to a computer system, a glass corrosion cell kit with a platinum counter electrode, a saturated Ag/Ag reference electrode and multilayered mild steel/Al-Cr plates as working electrode were used. The working electrode specimens were positioned at the glass corrosion cell kit, leaving $1cm^2$ surface in contact with the solution. Polarization test was carried out in the 0.5M HCl/guava leaf extract with variation in concentration of inoculant at room temperature using the potentiostat. The polarization curves were determined by stepping the potential at a scan rate of 0.001V/sec. The polarization curves were plotted using Autolab data acquisition system and both the corrosion rate and potential were estimated by the Tafel extrapolation method. The data obtained was used to calculate the protection efficiency (IE) for the inoculant using equation 4 and corrosion rates were calculated using equation 1 respectively (Adams, 2014; Umaru *et al.,* 2017).

2.7 Measurement of corrosion rates

There are three main methods used to express corrosion rates (Umaru *et al.,* 2017)

a. Thickness reduction of the material per unit time.
b. Weight loss per unit area and unit time.
c. Corrosion current density.

$$R = {KW}/{ADT} \qquad (1)$$

Where:

R= Corrosion rate
K= Corrosion constant
A= Surface area in cm^2
W= Weight loss in grams
D= Density of material
T= Time of exposure in hours

For this case, corrosion rate is taken in $g/cm^2/hr$ (2)

The coupons used are cuboids in cross section, their surface area was calculated using;

$$\text{Surface area} = 2lw + 2lh + 2hw \qquad (3)$$

Where l is length, w is width and h is thickness.

Protection efficiency is given by;

$$P.E = \frac{PR^0 - PR}{PR^0} \qquad (4)$$

Where PR^0 polarization resistance in presence of inoculant/corrosion rate at certain inoculant concentration

PR is polarization resistance without inoculant/corrosion rate in absence of inoculant

3. Results and Discussion

3.1 Gravimetric measurement result showing Variation of corrosion rate with inoculant

The Figure 1 below shows the variation of corrosion rates with immersion time at room temperature for different concentrations of inoculant in 0.5M of HCl/guava leaf extract medium. It shows that the corrosion rates decrease as the concentration of the inoculant increases (Adams *et al*., 2014).

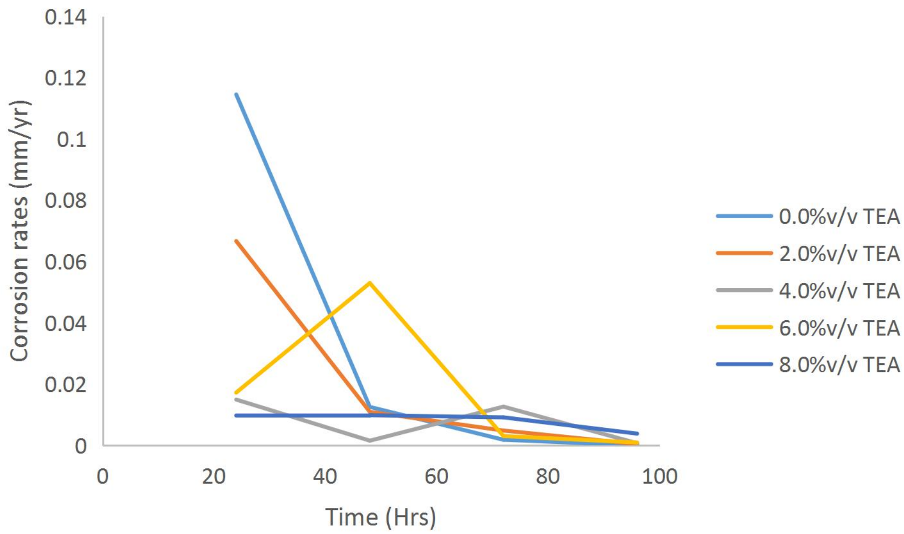

Figure 1: Variation of corrosion rates with time for different inoculant concentration.

The sample in 8.0%v/v concentration of inoculant showed excellent corrosion resistance. Similar trend was observed for samples in 6.0, 4.0 and 2.0%v/v concentration of inoculant. For example, the corrosion rate decreased from 0.01260mm/yr. to 0.00990mm/yr. in immersion time of 72hrs. The significant decrease in corrosion rate at increased inoculant concentration can be attributed to the adsorption of inoculant molecules on multilayered mild steel/Al-Cr alloy surface which act as physical barrier to restrict the diffusion of ions to and from the alloy surface and prevent the alloy atoms (ions) from precipitating in further anodic or cathodic reactions, hence resulting in a decrease in corrosion rate (Abdulwahab *et al*., 2013).

3.2 Potentiodynamic polarization Result

In the potentiodynamic polarization for multilayered mild steel/Al-Cr plates in 0.5M HCl/guava leaf extract environment (Table 3), different measurements consisting of potentiodynamic polarization corrosion rate, potentiodynamic polarization corrosion density (PP-Jcorr), and linear polarization resistance (LPR) were used as a criteria for evaluation of corrosion resistance of multilayered Al-Cr/mild steel plates in the environment.

Generally, the studies showed a decrease in corrosion rates with the addition of triethylamine as an inoculant. The corrosion potential and polarization decreased except at 4.0%v/v concentration indicating that triethylamine affects the cathodic reaction. The increase in Rp and corresponding decrease in jcorr generally suggested an improvement in corrosion resistance of the alloy in the presence of inoculant. This shows that the alloy was protected within the immersion time considered (Adams *et al*., 2014).

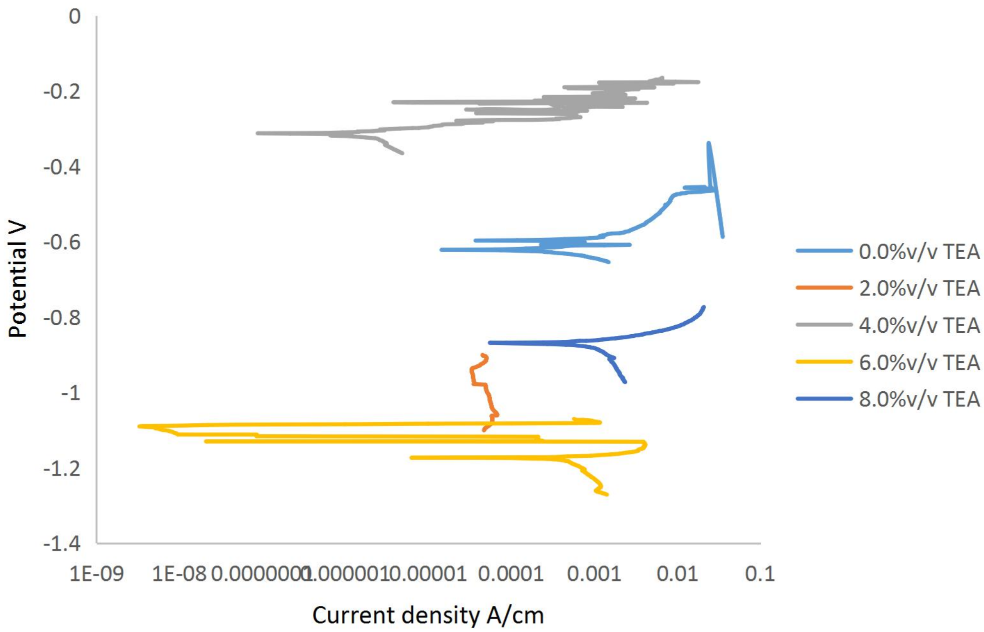

Figure 2: Potentiodynamic Polarization curves for multilayered mild steel/Al-Cr plates in 0.5M HCl solution and guava leaf extracts in absence and presence of different concentrations of triethylamine (TEA) as inoculant.

The inoculant showed high protection efficiency values of up to 98.49% at 4.0%v/v concentration. In the absence of the inoculant, i.e. the control medium at 24hrs the corrosion rate was 0.1145mm/yr. while at the same immersion time in 4.0%v/v of inoculant, the corrosion rate decreased to 0.01500mm/yr.

3.3 Protection efficiency

The results from the histogram showed that triethylamine had its highest protection efficiencies in both gravimetric and potentiodynamic polarization methods at inoculant concentration of 4%v/v in the 0.5M HCl/guava leaf medium.

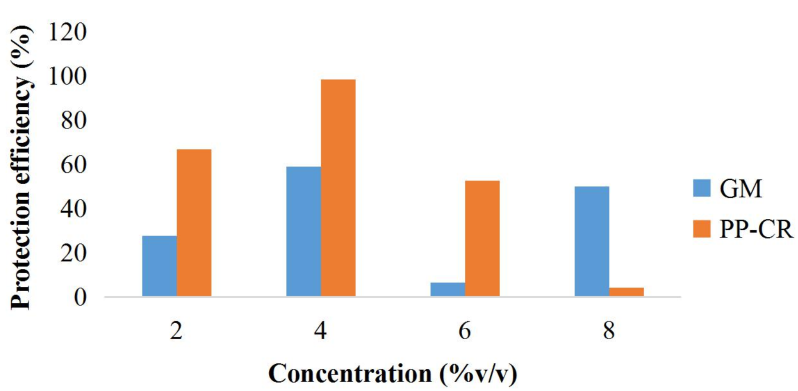

Figure 3: Variation of protection efficiency with inoculant concentration for gravimetric based mass loss test and potentiodynamic polarization test.

In potentiodynamic polarization studies, triethylamine showed up to 98.49% efficiency at concentration of 4%v/v while in gravimetric methods, triethylamine showed up to 59.02% protection efficiency at 4%v/v inoculant concentration.

4. Conclusion

The result showed that the inoculant, triethylamine (*TEA*) decreased the corrosion rate at the various concentrations indicating protection efficiency up to 59.02% in the gravimetric based mass loss technique. The potentiodynamic polarization technique indicates higher corrosion resistance of 98.49%. Finally, the two methods used for the evaluation of the degradation of multilayered mild steel/Al-Cr plates in 0.5M HCl/guava leaf extract medium were in agreement.

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