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Galvanic Corrosion Susceptibility of Electro-Chemical Metals Under Acidic Medium

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ABSTRACT: *Electrochemical metals in installations, production and construction services suffer series of problems ranging from corrosion and oxidation, crack propagation, abrasion and wear, etc. This means that these metals undergoes loss of weight, strength, form, etc with time, leading to structural, mechanical, thermal etc failures.*
Therefore, the need for an evaluation of metallic weight loss with time under aggressive environments can not be over emphasized.
In this study, bimetallic couples of Copper/Aluminium (Cu/Al), Aluminium/Iron (Al/Fe), and Copper/Iron (Cu/Fe), with designations: copper alloy, (CuAl10Fe2-C), Aluminium alloy, (Al6063) and Mild (low carbon) steel, (AISI 1018), were in electrical contact by clamping with a non-corrosive polymeric rope, thereby setting-up galvanic cells.
The bimetallic couples were subjected to an electrically conducive solution of 0.5M dilute teraoxosulphate VI acid (sulphuric acid) H2SO4(aq).
The process showed an evolution of hydrogen gas (H2) and an accelerated rate of corrosion of iron (steel alloy) at 25oC as a result of oxygen concentration
While iron in the copper/Iron (Cu/Fe) couple underwent accelerated corrosion rate, copper on the other hand was being cathodically protected by protective oxide films.
The couples were checked, cleansed, rinsed, dried and re-weighed at intervals of 120hours (5days) for 480hours (20days). Results of weight loss (mg) against exposure time (hrs) showed that the bimetallic couples in electrochemical contact containing mild steel, (i.e. Cu/Fe and Al/Fe), has the highest weight loss in 20 days (480 hrs), thus: 12,760mg of 74,290mg, (17.18% lost), and 26,600mg of 52,900mg (50.28% lost), while Cu/Al bimetallic couple, suffer a lower weight loss, thus: 690mg of 56,420mg, (1.2% lost), under aggressive conditions.
Keywords*: Galvanic corrosion, electro-chemical series, hydrogen gas evolution, sulphuric acid, mild steel, copper alloy, aluminium alloy.*

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I. INTRODUCTION

Galvanic corrosion is caused when two metals pieces in electrical contact with each other, or adjacent metal areas are at different electrochemical potentials. In this case the metal parts will constitute a "Galvanic Cell", (i.e. the more active metal or metal area) will corrode. At the same time, the noble metal part, with the more positive electrochemical potential, will be "Cathodically Protected" from corrosion.[27].

Relative sizes of the anodic and cathodic areas are extremely important in galvanic corrosion because corrosion is caused by a current flow from the anode (more active metal) to the cathode (more noble, or less active metal). Large cathode and a small anode means high current densities at the anode and, hence, high corrosion rates. Such area ratio (large cathode/small anode) is therefore highly unfavourable.[21]

In practical circumstances, corrosion of the anode may be 100 or 1,000 times more than if the two areas were the same.

In bolted joints, for example, such as pipe flanges, the relative sizes of the cathodic and anodic areas are very important. An anodic area that is small in relation to the cathodic area accelerates the corrosion. Where flanges and bolts are dissimilar metals, the bolting metal should be cathodic (more noble) than the flange metal. Steel rivets in a copper plate will corrode much more severely than a steel plate with copper rivets.
Also,steel screws corrode when in contact with brass in a marine environment; or if copper and steel tubing are joined in a domestic water heater, the steel will corrode in the vicinity of the junction. [2]

Engineering materials of iron/steel, copper, aluminium, etc are applied as structural and component materials to installations and facilities in process and production systems, air treatment and gas purifications, transport, civil/structural, water and sewage treatment, heating and cooling systems, power/energy installations, etc either as individual materials or in pair with other materials. This material pairing is meant to harness sustainable materials properties like: Hardness and stiffness, shock/impact resistance, tensile strength, corrosion, abrasion and wear resistances, low thermal expansion coefficients, low specific gravities, etc [14]

Under operating conditions this paired materials are in electrical contact, either by welding, soldering or clamping, and as a result galvanic cells are set-up, where the "less noble" material losses weight (as anode), and the "more noble" material retains or adds weight as a result of being coated or protected by "protective oxide films" (as cathode).

The position of the materials (metals) in the galvanic or electrochemical series grades engineering materials (metals) according to their potentials, generally measured with respect to the standard calomel electrode (SCE) in volts (V). In this regard, the "anode" or "less noble" metals of the negative end of the electrochemical or galvanic series at 25^{o}C, such as magnesium alloys, aluminum alloys, and zinc, with half-cell reactions and potentials (v), thus:

$Mg^{2+} + 2e^{-} = Mg$, (-2.356v), $Al^{3+} + 3e^{-} = Al$, (-1.676v), and $Zn^{2+} + 2e- = Zn$, (-0.7626v) are more likely to be affected than those at the "cathodic" or "noble" end of the series like gold, graphite/carbon and platinum, with half-cell reactions and potentials (v), thus: $Au^{3+} + 3e^{-} = Au$, (1.52v), graphite/carbon (+0.30 to +0.20), and $Pt^{2+} + 2e^{-} = Pt$ (+1.18) respectively. [15]

Galvanic corrosion is highly necessitated by the nature of environment (corrosion conducive nature of environment). The metal junction must be bridged by an electrolyte, where the velocity of particles determines the corrosion rate, in the degree of concentration or aggressiveness of the solution/environment. In some cases 6% H_2SO_4(aq), 4%HCl(aq) and 1.2% HNO_3(aq) etc are used as corrosive environments, owing to a pH range of <4. [26]

Temperature of 25^{O}C are instrumental to galvanic corrosion cases, because when a metal is subjected to thermal or cryogenic gradient, the ambient condition becomes a threshold for the formation of areas of galvanic cells and development of preferential attack.

In this test analysis, bimetallic couples of Copper/Aluminum (Cu/Al), Aluminum/Iron (Al/Fe), and Copper/Iron (Cu/Fe), with designations: copper alloy, (CuAl10Fe2-C), Aluminum alloy, (Al6063) and Mild (low carbon) steel, (AISI 1018), were in electrical contact by clamping with a non-corrosive polymeric rope, thereby setting-up galvanic cells.

The bimetallic couples were subjected to an electrically conducive solution of 0.5M sulphuric acid ($H_2SO_{4(aq)}$).

The process showed an evolution of hydrogen gas (H_2) and an accelerated rate of corrosion of iron or steel alloy at 25^{o}C, as a result of oxygen concentration.

While iron in the copper/Iron (Cu/Fe) couple underwent accelerated corrosion rate, copper on the other hand was being cathodically protected by protective oxide films.

E.M.F. SERIES AND GALVANIC SERIES

The E.M.F. series is an orderly arrangement of the standard potentials for all metals. The more negative values corresponds to the more reactive metals. Position in the E.M.F. series is determined by the equilibrium potential of a metal in contact with it's ions at a concentration equal to unit activity of two metals composing a cell, the anode is more active in equilibrium and are both unity. Since unit activity corresponds in some cases to impossible concentrations of metal ions because of restricted solubility of metal salts. The e.m.f. series has only limited use for predicting which metal is anodic to another.

Table 1.0, Electromotive Force, (Emf) series.

	Electrode Reaction	Electrode Potential, E, (Volts) At 25^{0}C
(Noble)	$Au^{3+} + 3e^{-} = Au$	+1.50 (Cathodic)
	$Pt^{2+} + 2e- = Pt$	+1.2
	$Ag^{+} + e^{-} = Ag$	+0.80
	$Cu^{+} + e^{-} = Cu$	+0.52
	$Cu^{2+} + 2e^{-} = Cu$	+0.34
	$2H^{+} + 2e^{-} = H_2$	0.00 (Reference)
	$Fe^{3+} + 3e^{-} = Fe$	-0.05

	$Pb^{2+} + 2e^- = Pb$	-0.13
	$Sn^{2+} + 2e^- = Sn$	-0.14
	$Ni^{2+} + 2e^- = Ni$	-0.25
	$Cd^{2+} + 2e^- = Cd$	-0.40
	$Fe^{2+} + 2e^- = Fe$	-0.44
	$Cr^{3+} + 3e^- = Cr$	-0.74
	$Zn^{2+} + 2e^- = Zn$	-0.76
	$Al^{3+} + 3e^- = Al$	-1.66
	$Mg^{2+} + 2e^- = Mg$	-2.37
(Base)	$Li^+ + e^- = Li$	-3.05 (Anodic)

Another factor that alters the galvanic position of some metals is the tendency, especially in oxidizing environments to form specific surface films. These films shift the measured potential in the noble direction. In this state, the metal is said to be passive. Hence chromium although normally near zinc in the e.m.f. series behaves galvanically more like silver in many air-saturated aqueous solutions because of a passive film that forms over it's surface.

The metal acts like an oxygen electrode instead of like chromium, hence, when coupled with iron, chromium becomes the cathode and current flow accelerates the corrosion of iron. In the active state, (e.g. in hydrochloric acid), the reverse polarity occurs; that is, chromium becomes anodic.

Because of the limitations of the e.m.f. series for predicting galvanic relations, and also because alloys are not included, the galvanic series is an arrangement of metals and alloys in accordance with their actual measured potentials in a given environment. The potentials that determines the position of a metal in the galvanic series include, steady-state values in addition to truly reversible values, hence, alloys and passive metals are included. The galvanic series for metals in sea-water is given in the table 2.0 below.

Some metals occupy two position in the passive, whereas in the e.m.f. series only the active positions are possible, since only in this state is true equilibrium attained. The passive state, on the contrary, represents a non-equilibrium state in which the metal, because of surface films, is no longer in normal equilibrium with it's ions. Although only one e.m.f. series exists, there can be several galvanic series because of differing complexing tendencies of differences in tendency to form surface films. In general, environment and the relative positions for each series may vary from one environment to another.

The damage incurred by coupling two metals depends not only on how far apart they are in the galvanic series, (potential difference), but also on their relative areas and the extent to which they are polarized. The potential difference of the polarized electrodes and the conductivity of the corrosive environment determine how much current flows between them.

Table 2.0, Galvanic Series In Flowing Sea Water, Liquid Junction Potentials (Volts Versus Saturated Calomel Reference Electrode).

S/N.	***Material***	***Corrosion Potential, Volts, (Saturated Calomel Half-Cell)***	
1.	Magnesium and Magnesium Alloys	-1.60 to -1.63	Anodic - active
2.	Aluminum – Anode	-1.10	
3.	Zinc	-0.98 to -1.03	
4.	Aluminum Alloys	-0.76 to -1.00	
5.	Mild Steel (clean & shiny)	-0.60 to -0.71	
6.	Mild Steel (rusted)	-0.20 to -0.50	
7.	Cast Iron (not graphitized)	-0.60 to -0.71	
8.	Stainless steels	-0.46 to -0.58	
9.	Stainless Steel, Type 316 (active in saltwater)	-0.43 to -0.54	
10.	Aluminum Bronze (92% Cu, 8% Al)	-0.31 to -0.42	
11.	Copper	-0.30 to -0.57	
12.	Naval Brass (60% Cu, 39% Zn)	-0.30 to -0.40	
13.	Red Brass (85% Cu, 15% Zn)	-0.30 to -0.40	
14.	Red Brass (85% Cu, 15% Zn)	-0.30 to -0.40	

15.	Muntz Metal (60% Cu, 40% Zn)	-0.30 to -0.40	
16.	Admiralty Brass (71% Cu, 28% Zn, 1% Sn)	-0.28 to -0.36	
17.	Aluminum Brass (76% Cu, 22% Zn, 2% Al)	-0.28 to -0.36	
18.	Silicone Bronze (96% Cu max, 0.80% Fe, 1.5% Zn, 2.00% Si, 0.75% MN, 1.60% Sn)	-0.26 to -0.29	
19.	90% Cu, 10% Ni	-0.21 to -0.28	
20.	75% Cu, 20% Ni, 5% Zn	-0.19 to -0.25	
21.	Lead	-0.19 to -0.25	
22.	70% Cu, 30% Ni	-0.18 to -0.23	
23.	Stainless steel, Type 304 (passive)	-0.05 to -0.10	
24.	Stainless steel, Type 316 (passive)	-0.00 to -0.10	
25.	Titanium	+0.06 to -0.05	
26.	Platinum	+0.25 to +0.19	
27.	Carbon, Graphite, Coke	+0.30 to +0.20	Cathodic – noble

NERNST EQUATION AND POURBAIX DIAGRAM FOR IRON

The Nernst equation enables the determination of cell potential under non-standard conditions. It relates the measured cell potential to the reaction quotient and allows the accurate determination of equilibrium constants, (including solubility constants).

A horizontal line represents a reaction that does not involve pH; that is, neither H^+ nor OH^- is involved, as in the reaction, $Fe^{2+} + 2e^- \rightarrow Fe$. For this equilibrium, using the Nernst equation, we obtain,

$$\Phi = \Phi^o - 2.303RT/nF \log 1/(Fe^{2+}),$$

$$\Phi = -0.440 + 0.0296 \log(Fe^{2+}),$$

If (Fe^{2+}) is taken as 10^{-6}, then $\Phi = -0.617$, a horizontal line on the diagram.

A vertical line involves H^+ or OH^-, but not electrons; for example, $2Fe^{3+} + 3H_2O \rightarrow Fe_2O_3 + 6H^+$. In Figure 1.0, the vertical line separating Fe^{3+} from Fe_2O_3 corresponds to this reaction. For this equilibrium we have,

$$K = (H^+)^6/(Fe^{3+})^2$$

$$\text{Log } K = 6\log(H^+) - 2\log (Fe^{3+})$$

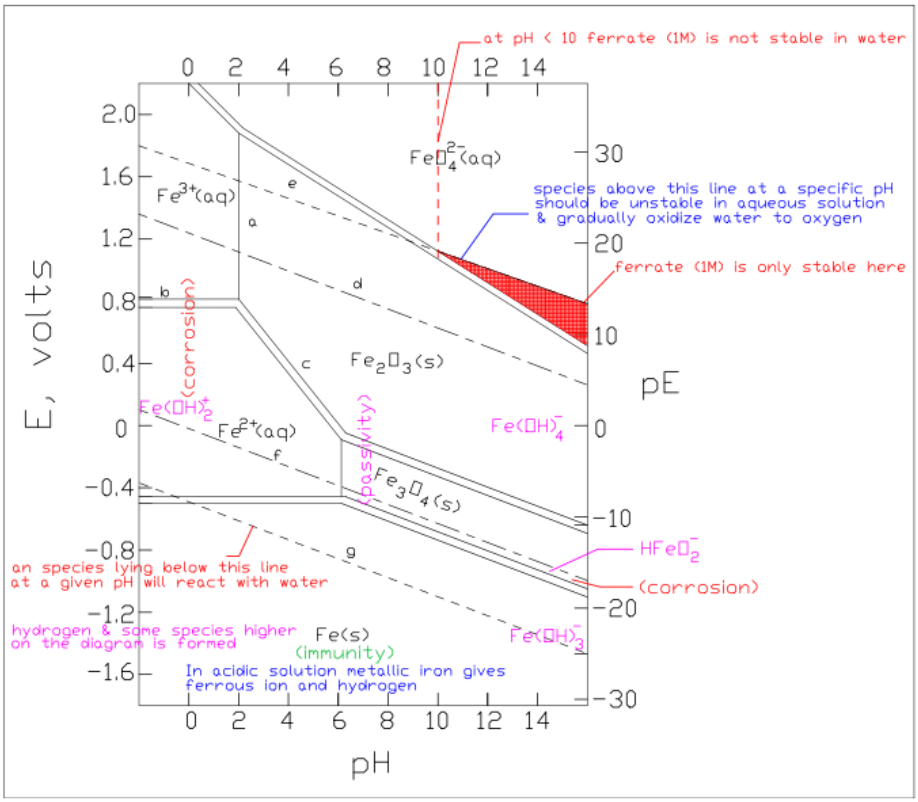


Fig. 1.0: Pourbaix Diagram for the Iron-water system at 25°C, considering Fe, Fe_3O_4, and Fe_2O_3, as the only solid substance,

$$\text{Log}K = -6\ \text{pH} - 2\log (Fe^{3+})$$

Since $\Delta G^o = -RT \ln K$ and $\Delta G^o = -8240$J/mole, we obtain

$$\text{Log}K = 1.43$$

$$\text{Log}\ (Fe^{3+}) = -0.72 - 3\text{pH}$$

Taking $(Fe^{3+}) = 10^{-6}$, we have pH = 1.76.

In the pourbaix diagram for iron, Figure 1.0, the vertical line at pH 1.76 represents the equilibrium reaction, $2Fe^{3+} + 3H_2O \rightarrow Fe_2O_3 + 6H^+$. To the right of this line (i.e., at pH > 1.76), Fe_2O_3 is the stable phase; and this oxide, as a protective film, would be expected to provide some protection against corrosion. To the left of this line (i.e., at pH < 1.76), ferric ions in solution are stable, and corrosion is expected to take place without any protection afforded by a surface oxide film.

A sloping line involves H^+, OH^-, and electrons. For example, the sloping line separating Fe^{2+} from Fe_2O_3 represents the reaction $Fe_2O_3 + 6H^+ + 2e^- \rightarrow 2Fe^{2+} + 3H_20$. For this reaction, we have,

$$\Phi = \Phi^o - 2.303RT/nF \log (Fe^{2+})^2/(H^+)^6,$$

Since $\Phi^o = 0.728$ V and n = 2, we get,

$$\Phi = 0.728 - 0.0296\ (Fe^{2+}),$$

$$\Phi = 0.728 - 0.0592/2 \log (Fe^{2+})2 + 0.0592/2 \log (H^+)^6$$

$$\Phi = 0.728 - 0.0592 \log (Fe^{2+}) - 0.1776\ \text{pH}$$

Taking $(Fe^{2+}) = 10^{-6}$, we obtain,

$$\Phi = 1.082 - 0.1776\text{pH}$$

This line in Figure 1.0 represents the equilibrium, $Fe_2O_3 + 6H^+ + 2e^- \rightarrow 2Fe^{2+} + 3H_2O$. To the right of this line, Fe_2O_3 is a stable phase that is expected to form a surface oxide film that protects the underlying metal from corrosion. To the left of this line, Fe^{2+} is a stable species in solution.

The pH values in pourbaix diagrams are those of solution in immediate contact with the metal surface. This value in some instances (e.g., Fe in aerated H_2O) differs from that of the bulk solution.

Soluble hypoferrites ($HFeO_2^-$) can form in very alkaline solutions within a restricted active potential range. Soluble ferrites (FeO_2^{2-}) can form in alkaline solutions at very noble potentials, but the stable field is not well-defined.

When any reaction involves ions other H^+ or OH^-, it is assumed, in general, that the activity equals 10^{-6}. Thus the horizontal line at -0.62V means that iron will not corrode below this value to form a solution of concentration > $10^{-6}M$ Fe^{2+} in accord with $Fe \rightarrow Fe^{2+} + 2e^-$, $\Phi = -0.44 + (0.059/2)\log (10^{-6}) = -0.62$V. If a value other than 10^{-6} is used, the lines separating the phases are shifted.

The fields marked Fe_2O_3 and Fe_3O_4 are sometimes labeled ‘’passivation’’ on the assumption that iron reacts in these regions to form protective oxide films. This is correct only insofar as passivity is accounted for by a diffusion barrier oxide layer. Actually the Flade potential, above which passivity of iron is observed in media such as sulfuric (H_2SO_4) or nitric (HNO_3) acid, parallels line f and d, intersection 0.6V at pH = 0. For this reason, the passive film may not be any of the equilibrium stoichiometric iron oxides.

SPECIAL CORROSION TYPES

i. BIMETALLIC CORROSION:

This is the corrosion associated with the current from an electrical coupling of dissimilar metals in an electrolyte (i.e. wet corrosive environment).

This results in the preferential attack of the more active (less noble, or anodic) metal, while the corrosion of the other metal, or cathodic metal component) slows down or stops completely. This corrosion type is also known as Contact Corrosion or Two-Metal Corrosion.

The cause of bimetallic corrosion is very simple, and is related to the essential concepts of ‘corrosion’ as an electro-chemical process.

When two dissimilar metals or alloys are exposed to a corrosive or (electrically) conductive solution or environment, and when these metals are either in direct contact, or are electrically connected by a conductor, or by the conductive medium then a “galvanic cell” is set up, in which the less noble part will act as the anode and will corrode away as a result of the electric current flow in the galvanic cell.

*AREA EFFECTS:*Relative sizes of the anodic and cathodic areas are extremely important in bimetallic corrosion (and in galvanic corrosion in general).
The corrosion is caused by a current flow from the anode (more active metal) to the cathode (more noble, or less active metal). Large cathode and a small anode means high current densities at the anode and, hence, high corrosion rates. Such area ratio (large cathode/ small anode) is therefore highly unfavorable.

ii. THERMO-GALVANIC CORROSION:

Thermo-galvanic corrosion is the corrosion resulting from an electrochemical cell (galvanic cell) caused by a thermal gradient.
CAUSE: When a metal is subjected to a thermal gradient by uneven heating or dissipation of heat, this has a similar effect on the metal as galvanic corrosion. The metal is differentially polarized and anodic and cathodic areas are formed, causing preferential attack to develop.

iii. STRESS CORROSION CRACKING

Stress corrosion cracking's are internal stresses (residual) that develops on materials because of tensile loading, thereby breaking the grain boundaries of the materials structure, making the material susceptible to corrosion. It is the product of tensile stress (including residual stress remaining after fabrication) and localized corrosion which combine to produce a brittle cracking of metal under certain conditions. Examples of environments which enhance stress corrosion are high pH amine solutions for most common steels and chloride bearing solutions for most stainless steels as well as certain aluminium alloys.

iv. MICRO-BIOLOGICAL CORROSION

Micro-biological corrosion is the deterioration of materials caused directly or indirectly by bacteria, algae, moulds or fungi; singly or in combination.
Under anaerobic conditions, as may occur in compacted clay soils, corrosion may be stimulated by the activity of micro-organisms such as the sulfate-reducing bacteria (e.g, desulfovibrio desulfuricans).
Bacteria corrosion is possible under aerobic conditions as well. In this situation corrosion is often the result of the production of a corrosive metabolite (e.g., an acid), or may be caused by bacteria like ferrobacillus ferrooxidans that may directly oxidize iron into iron oxides or hydroxides, or which may lead to the formation of deposits with the creation of oxygen concentration cells.
Other corrosive actions exerted by micro-organisms also have to do mainly with the formation of concentration cells, possibly in combination with fouling problems.

II. STATEMENT OF PROBLEM

Considerable amount of work has been done on the study of Galvanic corrosion in an attempt to study certain materials at different temperatures and environments. But very little has been done on electrochemical materials (metals) in pair or individually, under aggressive operational service conditions (acidic particular motion), and the effects of the aqueous systems and velocities on the weight loss of exposed materials with respect to time and ambient conditions.

III. OBJECTIVES OF THE STUDY

The MAIN objectives in the accomplishment of this research study is to analyze and evaluate the corrosion conditions of certain electrochemical materials (metals) that are constantly applied under aggressive operational service conditions, and to proffer mitigative measures in order to enhance sustained operational service integrity of installations and facilities.
Therefore, the SPECIFIC objectives in the accomplishment of this research work includes the following:

i) To study the corrosion behavior of iron/steel alloy in pair with copper alloy (Fe/Cu pair) under aggressive conditions.
ii) To analyze the service performance of iron/steel alloy in pair with aluminum alloy (Fe/Al pair) under aggressive conditions.
iii) To study the effect of protective oxide films on the corrosion rate of materials in the copper alloys/aluminum alloys couple, (Cu/Al pair) under aggressiveservice performance.

iv) To determine the effects of mineral acids (aqueous) on the corrosiveness of iron/steel alloys, aluminum alloys, and copper alloys.

v) To study the service implication of galvanic and electrochemical series (positions and potentials) on the corrosive behaviors of electrochemical materials (metals) in electrical contacts.

vi) To analyze the relationship existing between materials weight loss against exposure time for individual and paired metals under aggressive conditions.

IV. MATERIALS AND METHODS

4.1, MATERIALS:

The materials for this experiment includes, mild steel, copper alloy, aluminum alloy coupons, all in rectangular strip forms of 2 pieces each, 0.5 mol concentration of tetra-oxosulphate (vi) (sulphuric acid) electrolyte, 500ml conical flask, 250ml beaker, 25ml cylindrical beaker, nylon thread, plastic container, hack-saw, file, emery paper, weighing balance and digital pH meter.

Table 3.0: Properties Of The Electrochemical Materials, (Metals) Test Coupons, (Materials Laboratory, FUTO, 2018).

	Mild Steel (AISI 1018)	Aluminum Alloy, Al 6063	Copper_Alloy, CuAl10Fe2-C
Melting Temperature, (^{0}C)	1,450	650	1,083
Density, (gm/cm^3)	7.85	2.70	8.89
Modulus Of Elasticity, (Gpa)	205	70	118
Tensile Strength, (Mpa)	370	185	550
Coefficient Of Thermal Expansion, (x10^{-6}/^{0}C)	12.0	23.0	16.8

Table 4.0, Chemical Composition Of Mild (Low carbon) Steel, With Material Designation, AISI 1018, (Federated Steel Mills, Otta, Ogun State, Nigeria, 2019).

Constituents	Carbon, C	Sulphur,S	Manganese, Mn	Phosphorus,P	Iron,Fe
% Composition	0.14-0.20	⩽0.05	⩽0.60-0.90	⩽0.04	98.81-99.26

Table 5.0, Chemical Composition Of Aluminium Alloy, Material Designation, Al6063, (Aluminium Rolling Mills, Otta, Ogun State, Nigeria, 2019).

Constituents	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti	Al
% Composition	0.45	0.22	0.02	0.03	0.50	0.02	0.03	0.02	98.71

Table 6.0, Chemical Composition Of Copper Alloy, Material Designation, CuAl10Fe2-C.

Constituents,	Copper, Cu	Aluminium, Al	Iron, Fe	Manganese, Mn	Nickel, Ni
% Composition,	83.0-89.5	8.5-10.5	1.0-3.0	2.0	1.5-4.0

4.2, EXPERIMENTAL SET-UP:

The metallic specimens (mild steel, aluminium alloy, and copper alloy), were each clampes on the vice and two strips each cut from the stock, measuring approximately, 90x25x2.5mm dimensions.

After cutting each was filed to remove rough and irregular edges, and then two grades of sand paper (emery paper grades, 166 and 220) respectively, were used to smoothen the rough surfaces.

Afterwards, the samples were weighed separately and tied together with nylon ropes; Cu/Fe, Cu/Al, and Al/Fe respectively.

The Digital pH Meter was used to test for the degree of aggressiveness of the 0.5M $H_2SO_{4(aq.)}$ electrolyte at different stages of the dilution process, before subsequent immersion/suspension of test coupons in the solution contained in plastic containers.

The specimens (test coupons) were weighed separately and then in pairs, (Cu/Fe, Cu/Al, and Al/Fe) and afterwards tied together in intimate contact using nylon thread and then immersed in the H_2SO_4 electrolyte, with the other end of the threads tied to the wooden bar placed across the plastic bowl. This position allowed the coupled test specimens to stay afloat, but well submerged by the electrolyte.



Fig. 2.0, Dimensioned Metallic Specimens, (Mild Steels, Aluminium Alloys, And Copper Alloys),



Fig. 3.0, Pairs Of Corrosion Test Coupons, (Cu/Fe, Cu/Al, And Al/Fe).



Fig. 4.0, Sample Weighed On The Digital Weighing Machine,



Fig.5.0, Digital pH Meter: Showing Distilled Water In Beaker,



Fig. 6.0, Digital pH Meter: After The Addition Of 25ml Of 0.5M H_2SO_4,



Fig.7.0, Digital pH Meter: Both Beakers Contain pH Of Reading, 4 Value,

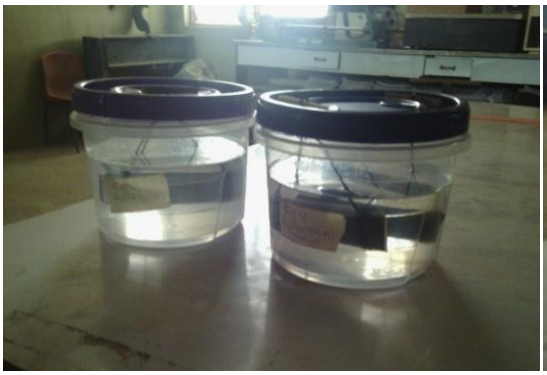


Fig. 8.0, Paired Test Coupons, Immersed In 0.5 Mol. Concentration Of $H_2SO_{4(aq)}$Electrolyte After 120Hrs,

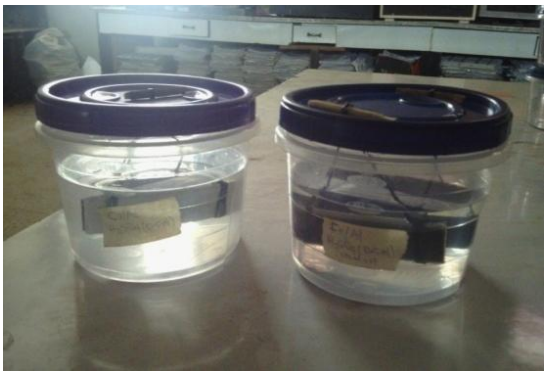


Fig. 9.0, Paired Test Coupons, Immersed In 0.5Mol. Concentration Of $H_2SO_{4(aq)}$Electrolyte Before 480Hrs,

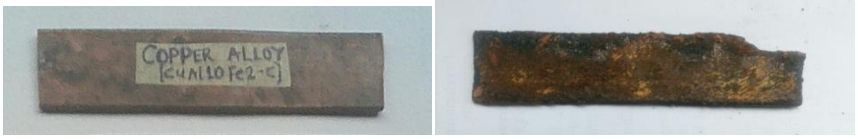


Fig. 10.0, Group A. Corrosion Test Specimens,(Mild Steels And Copper) After 480Hours Exposure In 0.5Mol. Aqueous H_2SO_4.

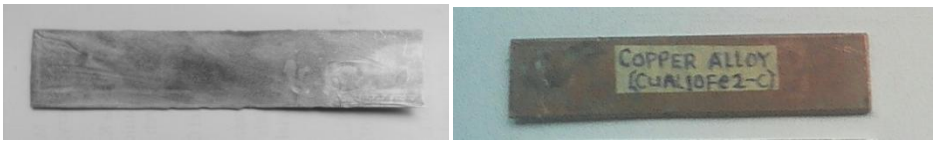


Fig. 11.0, Group B. Corrosion Test Specimens, (Copper And Aluminium) After 480Hours Exposure In 0.5Mol. Aqueous H_2SO_4.

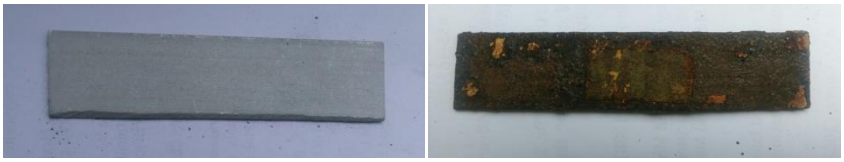


Fig. 12.0, Group C. Corrosion Test Specimens, (Aluminium And Mild Steel) After 480Hours Exposure In 0.5Mol. Aqueous H_2SO_4.

V. RESULTS AND DISCUSSIONS,

5.1, RESULTS,

Prior to immersion of the samples, they were weighed. On immersion of the test coupons into the dilute acid electrolyte, very tremendous effervescence occurred, which lead to the rapid evolution of hydrogen gas as noticed and so much bubbles that clung to the walls of the container. After a period of 120 hours, each metallic pair was brought out , separated, rinsed, brushed and weighed.

Each metal in the pair was separately weighed before collectively weighing both.The results of the weights after equal time intervals were obtained.

The weight loss measurement was used to evaluate the rate of corrosion. The test specimens with equal surface areas are weighed, tied and corroded for about 120 hours, after which they were rinsed, dried and again re-weighed. The difference between initial weights and weights after specific periods (time intervals) were obtained.

After obtaining the weight loss after a specified time interval, a plot of weight loss versus exposure time was drawn for each of the metallic pairs/individual metals used in this experiment.

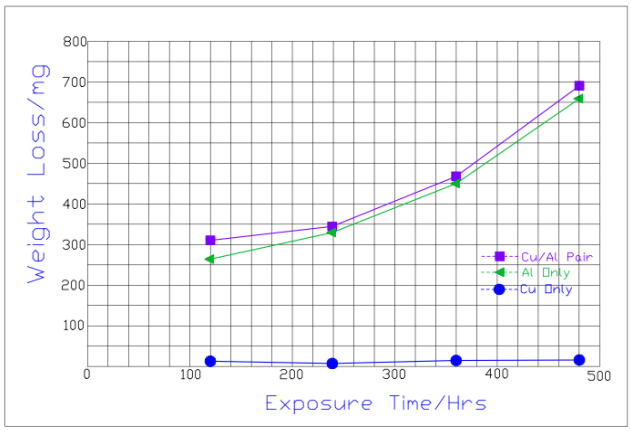


Fig. 13.0, Weight Loss(mg) Vs Exposure Time(Hrs) For Group A.(Cu/Fe) Specimens At 25^{0}C.

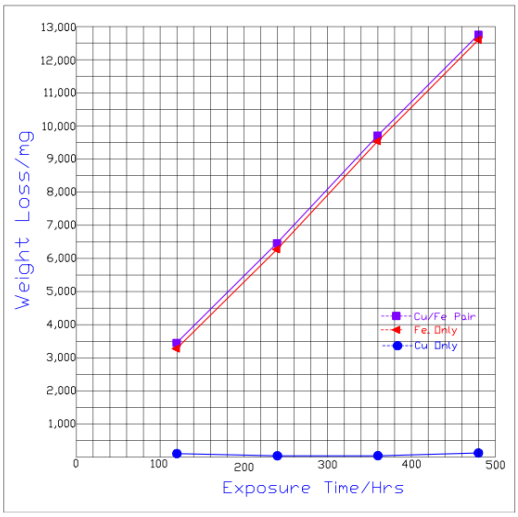


Figure 14.0, Weight Loss(mg) Vs Exposure Time(Hrs) For Group B. (Cu/Al) Specimens At 25^{0}C.

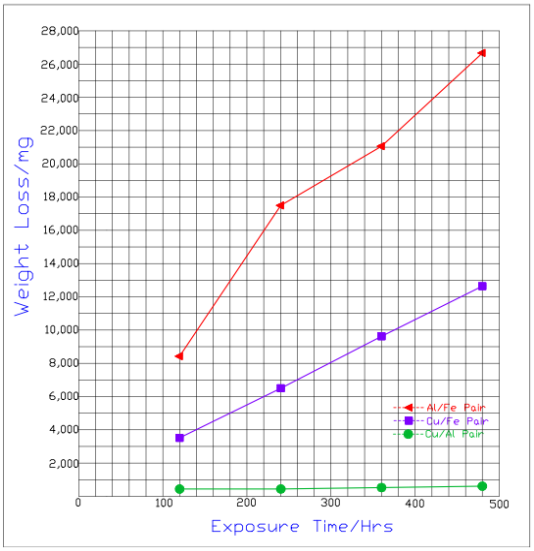


Figure 15.0, Weight Loss(mg) Vs Exposure Time(Hrs) For Group C. (Al/Fe) Specimens At 25^{0}C.

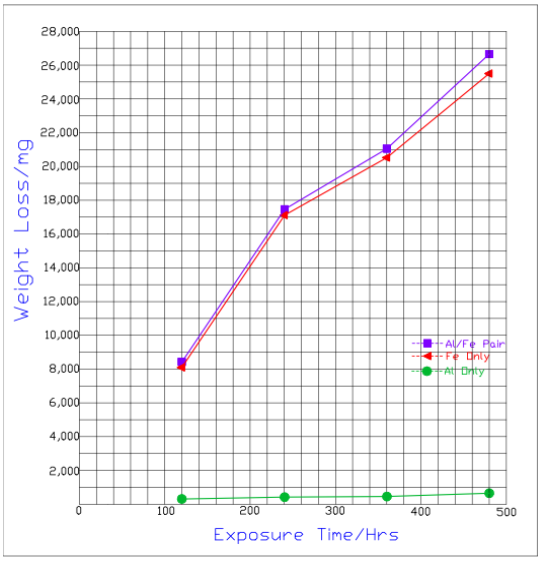


Figure 16.0, Weight Loss(mg) Vs Exposure Time(Hrs) For Respective Pairs At 25^{0}C.

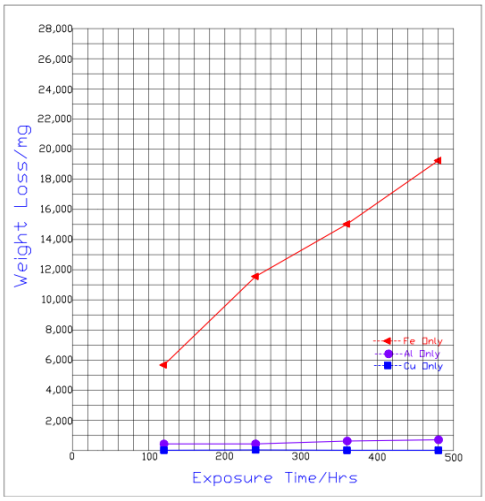


Figure 17.0, Weight Loss(mg) Vs Exposure Time(Hrs) For Individual Metals On Average At 25^{0}C

5.2, DISCUSSIONS

A plot of weight loss (mg) against exposure time for Cu/Fe and Al/Fe shows higher values for weight loss, while that of Cu/Al was lower.

Figure 15.0, (Al/Fe) pair with the highest weight loss value of 26,600mg of 52,900mg (50.28%) after 480hrs exposure time was as a result of the inability of protective oxide films to be formed due to a close electromagnetic force values of -1.66 and -0.44 values for Al and Fe respectively.

This was followed by (Cu/Fe) pair in figure 13.0, with 12,760mg of 74,290mg (17.18%).

But Cu/Al in figure 14.0, experienced the lowest weight loss value of 690mg of 56,420mg (1.2%), owing to the passivation of aluminium, thereby reducing corrosion rate.

VI. CONCLUSION AND RECOMMENDATIONS

6.1, CONCLUSION

Results from the experiment show that when dissimilar metals coupled electrically are immersed in an electrolyte, there is selective corrosion of the least noble metal.

This selective attack is dependent on factors, such as; cathode to anode area ratio, polarization effect, and the temperature of the system.

The corrosion rate of Cu/Fe and Al/Fe system were the highest while the passivating oxide film on aluminium formed a protective layer, allowing mild steel to corrode preferentially.

In engineering designs, dissimilar metals in the system should be insulated from each other, and proper heat treatment of alloys should be carried out in order to control the effect of galvanic corrosion.

6.2, RECOMMENDATIONS

The recommendations from this research study are as follows: In the design and installation of facilities members, thus:

i. Selection combination of metals close together in the galvanic series, (useful as first approximation only).
ii. Provide for complete dielectric insulation of dissimilar metals. Select adequate materials for this insulation.
iii. Avoid unfavourable area ratio effects (i.e. small anodic and large cathodic areas should be avoided); extend distance between dissimilar metals in a conductive medium.
iv. Avoid threaded joints between metals far apart in the galvanic series; use welded, brazed, or fused joints instead; specify compatible welding and brazing alloys.
v. Apply coatings, but with caution (coatings contain pinholes). Especially, coating on the cathode should have low porosity. Do not fully rely on painting.
vi. Corrosion inhibitors may be helpful, since they reduce the aggressiveness of the environment.
vii. Prevent access of air and/or water to the joint of the two metals.

6.3, CONTRIBUTIONS TO KNOWLEDGE,

This research work contributes to knowledge in the following ways:

i. Coupling two metals widely separated in the galvanic or electrochemical series lead to accelerated attack of the more active metal. However, protective oxide films and a number of other effects tends to reduce galvanic corrosion.

ii. Subjecting metals in electrochemical contact into aqueous acidic electrolyte (environment), shows tremendous effervescence of hydrogen gas evolution, leading to concentration of oxygen gas, and subsequent oxidation and corrosion.

iii. Air and/or water access to joints of two dissimilar metals in a conductive medium promotes the generation of galvanic cells, where the metal with the lowest electrochemical potential will corrode, while the more positive electrochemical potential metal will be cathodically protected from corrosion.

iv. In Engineering designs, dissimilar materials (metals) in installations, productions and constructions should be insulated from each other, and proper heat treatment of alloys should be carried out in order to control the effects of galvanic corrosion.

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