

# Improvement on the Corrosion Resistance and Fatigue Failure of The Cast Aluminium Alloy 7050 For The Engineering Application

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## Abstract:

One of the most commonly used aluminum alloy for structural applications is 7050 Al alloy due to its attractive properties such as low density, high strength, ductility, and toughness. It has been extensively utilized in aircraft structural parts and other highly stressed structural application. Aluminum alloy 7050 can be both hard and clear coat anodized. They are usually used for Gears, shafts, aircraft parts, valve part, low production plastic mould tools, blow molds for plastic bottles and military hardware's. 7xxx series Al alloys are sensitive to localized corrosion, such as inter granular corrosion, exfoliation corrosion and stress corrosion cracking (SCC). The aluminum 7050 alloy has good material properties for engineering application unfortunately; it has poor resistance to corrosion. Therefore, there is need, the microstructure of aluminum 7050 be significantly modified by casting of the specimen and heat treatment, which subsequently improve its corrosion behavior. Cast aluminum alloy (AA7050) has been precipitation treated and anodized in Tartaric-sulfuric acid (TSA). The effect of precipitation treatment and precipitation treatment plus TSA anodization on corrosion improvement of the cast AA7075 was investigated. The microstructure and morphology of the samples were studied using metallurgical microscope and scanning electron microscope with energy disperse x-ray (SEM EDS). Weight loss method was used to access the corrosion behaviour of the alloy in 0.5 M NaCl. Results obtained indicates significant role of precipitation treatment, precipitation and TSA on corrosion improvement of AA 7050. The microstructure of the precipitation treated samples in palm kernel oil and SAE 40 engine oil showed precipitates of MgZn<sub>2</sub>. The anodic film coating of the precipitation treated in palm kernel oil plus TSA anodized sample recorded highest micro hardness value of 124.33 HV, while the least value of 178.67HV was recorded for sample precipitation treated in SAE 40 engine oil and TSA. Precipitation treated and TSA anodized samples showed higher corrosion resistance improvement, with the palm kernel oil treated recording 22.05% corrosion penetration rate, while palm kernel oil treated and TSA anodized sample recorded 17.86% corrosion penetrated rate.

**Keywords:** Corrosion resistance, AA 7050, Precipitation hardness, anodization, Micro hardness and Weight loss.

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## I. Introduction

Corrosion has been found to be the most predominant cause for failures of buried metal pipes, storage tank, ferrous metal, nonferrous, and alloys. Corrosion is a dangerous and extremely costly problem. Corrosion on materials can reduce materials ductility by weakening its bonds and making more brittle. This can lead to fatigue failure especially when exposed to stress, very strong acid or alkaline environments outside the pH range from 4 to 9. Corrosion in Engineering causes huge damages on the human safety, economic, social impact, water, soil, and air pollution. Corrosion occurs during the production, processing, storage and transport processes.

The research work is to improve on the corrosion resistance and fatigue failure of the material (Aluminum Alloy 7050), for Engineering applications, especially in the field of transportation, aerospace, and military hardware. Aluminum 7050 alloy has good material properties for engineering applications unfortunately; it has poor resistance to corrosion and fatigue failure (Campbell, 2018).

It has been extensively utilized in aircraft structural parts and other highly stressed structural applications (Isadarea *et al.*, 2013; Mohammad and Esmaeil, 2010; Woei-Shyan and Wu-Chung, 2000). Aluminium alloy 7050 can be both hard and clear coat anodized. They are usually used for Gears, shafts, aircraft

parts, valve part, low production plastic mould tools, blow moulds for plastic bottles and military hardwires. 7xxx series Al alloys are sensitive to localized corrosion, such as inter granular corrosion, exfoliation corrosion and stress corrosion cracking (SCC). Therefore, further applications of the 7xxx series Al alloys require enhanced corrosion resistance

Aluminium alloys is an important material for tribological applications due to its good capability to be strengthened by precipitation, good wear resistance and high thermal and electrical conductivity (Godard, 2019).

Aluminum is the second most widely used metal, highly valuable due to its unique combination of properties such as low density (approximately 2.7), high ductility, and improve mechanical strength achieved by suitable alloying and heat treatments (Chiu, 2018). One of the most commonly used aluminum alloy for structural applications is 7050 Al alloy due to its attractive comprehensive properties such as low density, high strength, ductility, toughness and resistance to fatigue (Hemz, 2017).

It is necessary to modify the surface of previously machined parts by anodizing treatment to improve wear and corrosion resistance of aluminum alloys (Li, 2018). During this anodization, a thin anodic oxide layer of about 1 to 3  $\mu\text{m}$  thickness is formed, which is intended to improve the adhesion between the metallic substrate and the applied top-coat. However, in some places, the surface of the aluminium alloy is subjected to enhanced mechanical properties and resistance to wear in particular (Isadarea, *et al.*, 2020).

Anodization of aluminium alloy in tartaric-sulfuric acid (TSA) is a recent development free from chromate and is regarded as environmentally-friendly. Its offers shorter duration of electrolysis and produces excellent corrosion resistance (Oluyemi, *et al.*, 2019). Several investigators have found that anodizing and alloying aluminum improves corrosion resistance, abrasive resistance and improve mechanical properties.

Labisz *et al.*, (2018) studied the effect of anodization of cast aluminum alloys produced by different casting methods. Experiment results showed that the anodized alloy both  $\text{AlSi}_9\text{Cu}_3$  and  $\text{AlSi}_{12}$  indicate lower loss in weight in comparison with the non-anodized alloys. It also stated that the casting method influenced the abrasive resistance; sand mould cast alloys present the lower loss in weight during the carried out test, then they demonstrated the greater abrasive resistance.

Li, (2018) in his studies on mechanical properties, corrosion behavior and microstructure of 7050 aluminum alloy with various aging treatments, concluded that, T6 treatment when compared with retrogression and re-aging (RRA), T73, T616 and high temperature pre- precipitation (HTPP) aging cause the discontinuous distribution of the  $\eta$  precipitates at the grain boundary, which decreases the intergranular corrosion and exfoliation corrosion susceptibility of the alloy.

Lateef *et al.*, (2018) studied effect of heat treatments on the microstructure of aluminum- zinc alloy (Al-Zn) and found that: the arrangement of microstructure grains and pores are more even with the oil quenched method than any other heat treatment methods in Al-Zn alloy, there is relationship between the heat treatment method (oil quenched) and microstructure of Al-Zn alloy, and oil quenched aluminum zinc alloy (Al-Zn) is more appropriate for the production of armored vehicles, military bridges, motorcycle and bicycle frames, and air frames.

Madakson *et al.* (2019) studied the effect of anodization on the corrosion behavior of aluminum alloy in HCl and NaOH and concluded that aluminum alloy 7050 corrodes faster in 1.0M HCl than in 1.0M NaOH solution and that anodizing helps to reduce the corrosion rate of Al-alloy in both media.

Kuburi *et al.* (2020) reported on their studies on effect of corrosion on the microstructure of anodized aluminum alloy that: process of anodizing improves the mechanical properties of 7050 aluminum alloy by making the grain finer, that corrosion in acidic medium has more damage to the microstructure of the alloy than in the base, and that the presence of  $\text{Cl}^-$  serves to improve the destruction of the passive films at localized regions.

In their studies on the effect of heat treatment on some mechanical properties of 7050 aluminum alloy, Olawale *et al.* (2018) concluded that formation of micro segregation embrittled 7050 aluminum alloy, and have negative effects on the mechanical properties and its applications. They suggested rapid solidification and appropriate heat treatment process.

Forno and Bestetti, (2019) investigated the influence of electrolytic solution composition on the structure and corrosion properties of the anodic oxide. The optimal electrolyte solution suitable to produce the best corrosion resistance oxides consist of 3M KOH, 0.21- 0.25M  $\text{NaPO}_4$  and 0.15M  $\text{Al}(\text{NO}_3)_3$ .

Thompson, (2019) studied the effect of current density on anodic film growth on Al-Cu alloy and indicated that the film thickness increases as the time increases in the range between 25- 60 minutes, and moreover, increasing the time of anodizing to more than 60 minutes has no significant effect. In this case, the formation rate of anodic coating is equal to the dissolution rate of the anodic coating.

Talib *et al.* (2015) carried out a comparative study for anodizing aluminum alloy 1060 by different types of electrolyte solutions and concluded that the film thickness of the anodic film increased with increasing time and voltage of anodizing and decrease with decrease acid concentration. In general, it was found that the anodic film thickness increases to a maximum limit at 60 minutes in oxalic acid ( $\text{C}_2\text{H}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$ ) 10% wt,

phosphoric acid ( $H_3PO_4$ ) 10% wt and tartaric acid ( $C_4H_6O_6$ ) 10% wt. As for boric acid ( $H_3BO_3$ ) 10% wt with 0,3% borax, the film thickness increases up to the maximum limit at 50 minute and after this time, decrease in film thickness gradually happened.

Tsai and Hsiao, (2020) investigated the effect of heat treatment on anodization and electrochemical behavior of AZ19D magnesium alloy. They analyzed the anodic films formed on AZ19D magnesium alloy after heat treatment and investigated their electrochemical properties. Experimental result shows that the formation of anodic film on AZ19D Mg alloy could greatly improve corrosion resistance. It also shows that highest polarization resistance in 3.5wt% NaCl could be obtained on the solution-annealed and air-cooled AZ19D Mg alloy. Higher volume of  $\beta$  phase precipitated on the surface was responsible for the formation of a very resistant anodic film against corrosion.

## II. Material, Equipment and Methods

**The materials used in this work include:** Aluminum scrap, magnesium scrap, copper scrap, zinc scrap, abrasive emery grinding paper, Ethanol (ACS Reagent grade), 500 ml; Sulfuric acid (Analytical Reagent grade 95% concentration, 1.83g/ml), 100ml; Nitric acid (Analytical Reagent grade 90% concentration, 1.48g/ml), 500 ml; Sodium hydroxide (Laboratory Reagent grade,  $\geq 98\%$ ), 100g; Hydrochloric acid, distilled water, 10 L); SAE 20W/50 engine oil (AMMASCO), 4L; Freshly extracted Palm kernel oil (4 L) from Muda Lawal Market Bauchi State, Nigeria.

**Equipment used for this research work include;** Electric furnace for heat treatment; Brand/make/ model; search Tech instruments, 5x-5-12 Box-Resistances N0.2392, Charcoal fired crucible furnace, Energy Dispersive X-ray Fluorescence (EDXRF) machine, model; Minpal 4 No. DY 1055, Photographic Visual Metallurgical microscope: Model No. NJF-120A, Scanning Electron Microscope (SEM), Sensitive laboratory electric weighing balance Model No. FA2004

### 2.1 Methods

#### 2.1.1 Material development

The AA 7050 was cast using; aluminium scrap (cut into smaller pieces), Zn scrap, magnesium (in form of chips) and copper ligand (50% Cu-50% Al). A locally made charcoal-fired crucible furnace of 4kg was used for melting. The melting process was set up by placing charcoal inside the furnace and then ignited it until the charcoal started burning freely. A cleaned graphite crucible was then positioned inside the furnace and allowed to be heated to red-hot. Aluminium scrap was then charged into the red-hot crucible pot inside the furnace and allowed to melt at  $660^{\circ}C$  other charge were added respectively. The molten metal alloy was super-heated to casting temperature of  $730^{\circ}C$  for fluidity and easy removal of slag (the temperature was measured by inserting the tips of thermocouple wire inside the molten metal). The molten metal was then poured into a cylindrical metallic mould of 350 mm length by 20mm diameter and allowed to cool. The cast alloy was then removed from the mould and machined to samples sizes of 14 mm diameter and 10mm length. The composition of the cast aluminium alloy is shown in Table 1.

#### 1.1.2 Determination of chemical composition of the cast

In order to determine the actual chemical composition of the cast, X-ray Fluorescence (XRF) was carried out on the cast sample using EDXRF machine model, which is in accordance with (ASTM, 2015).

**Table 1: Chemical Composition of the cast AA7050**

Elements	Composition (wt %)
Mg	1.05
Zn	5.56
Cu	1.06
Fe	1.10
Ca	0.02
Ni	0.009
Others	0.0008
Al	Balance

#### 1.1.3 Precipitation treatment process

Samples was heated to solution zed at  $510^{\circ}C \pm 5^{\circ}C$ , soaked for 3 hours and then quickly remove5d and plunged into separate containers containing different quenching media (palm kernel oil and SAE40 engine oil) at ambient temperatures as specified in (Capelossi, 2016). Thereafter, the quenched samples were aged at temperature of  $170^{\circ}C \pm 5^{\circ}C$  and then allowed to cool in air. Palm kernel oil was used to compare its suitability as alternative quenching to SAE40 engine oil for industrial heat treatment of aluminum alloys.

**2.1.4 Condition of anodization**

Prior to anodization, samples were subjected to alkaline cleaning in 5% NaOH solution for 5 min followed by DE smutting in 25% HNO<sub>3</sub> for 2 min, washed, rinsed, dried and weighed. Cleaned and weighed (W<sub>1</sub>) AA 7050 samples were then anodized in solution of 40g/l H<sub>2</sub>SO<sub>4</sub> +80g/l C<sub>4</sub>H<sub>6</sub>O<sub>6</sub> at 12 V for 20 min at 37<sup>o</sup>C temperature (Capelossi, 2016). After the samples were removed from the electrolyte solution and completely rinsed with water, the samples were immersed in hot boiling water for sealing. The sealing time was about 30 min. The sealing process was carried out to decrease the oxide porosity and makes the oxide layer more flat and uniform.

**2.1.5 Experimental setup for anodization**

The anode (cast AA 7050) and cathode (stainless steel 0.050mm thick with dimension of 120 mm by 110 mm) samples were connected with electric wires and partially dipped into the electrolyte solution (Tartaric-sulfuric acid), which act as a medium for transporting the ionic species. The anode and the cathode were then connected to a positive and negative terminal of a 12 V battery which act as D. C power supply. A multi-meter was connected in series with electrode to measure the current and voltage passing through it (Alessandro and Pagliarello, 2019). When voltage was applied between the anode and cathode, pores were nucleated and grown on the surface of samples.

**2.1.6 Determination of coating thickness**

The coating thickness was determined by first weighing the anodized samples with the anodic coating film (W<sub>2</sub>). The weighed sample (W<sub>2</sub>) was then subjected to stripping by immersing it in a solutions containing 20g/l of chromium trioxide and 35ml/l of phosphoric acid, at 100<sup>o</sup>C for 30min. Sample was then rinsed, dried and weighed (W<sub>3</sub>). From these weights the coating ratio is calculated as for ratio are calculated as follows:

Coating ratio,

$$C_R = \frac{(W_2 - W_3)}{(W_1 - W_3)} \dots \dots \dots (1)$$

Where, W<sub>2</sub> - W<sub>3</sub>= weight of the anodic oxide

W<sub>1</sub> - W<sub>3</sub> =total weight of Al 7050 reacting (20)

The thickness of the anodic coating was calculated from the weight of anodic coating surface area and density of the anodic film as follows:

$$T = (W_2 - W_3) \times 10^3 \times \rho \dots \dots \dots (2)$$

Where, A= surface area (cm<sup>2</sup>)

$$T = 2\pi Rh + 2\pi(R_2-r_2) + 2\pi r \dots \dots \dots (3)$$

ρ= density (g/cm<sup>3</sup>) which is about 2.6g/cm<sup>3</sup>

D=mass/volume of substance

A=total surface area of the sample in cm<sup>3</sup>

T=exposure time in hours, in the medium (Sigamani, 2021).

**III. Results and discussions**

**3.1 Chemical composition of the cast alloy**

The zinc content in the chemical composition of the cast sample indicates that the cast is aluminum-zinc based alloys. The zinc composition of 5.560 wt% is well within composition range for aluminum alloy 7050 (Davis, 2016). The copper content in the sample also indicated that most of the scrap components used was originally produced from aluminum-zinc-copper based alloys. The copper contents in the cast sample (1.06 wt %) is within the range of 1.2-2.0 wt% normally recommended for commercial aluminium 7050 alloys.

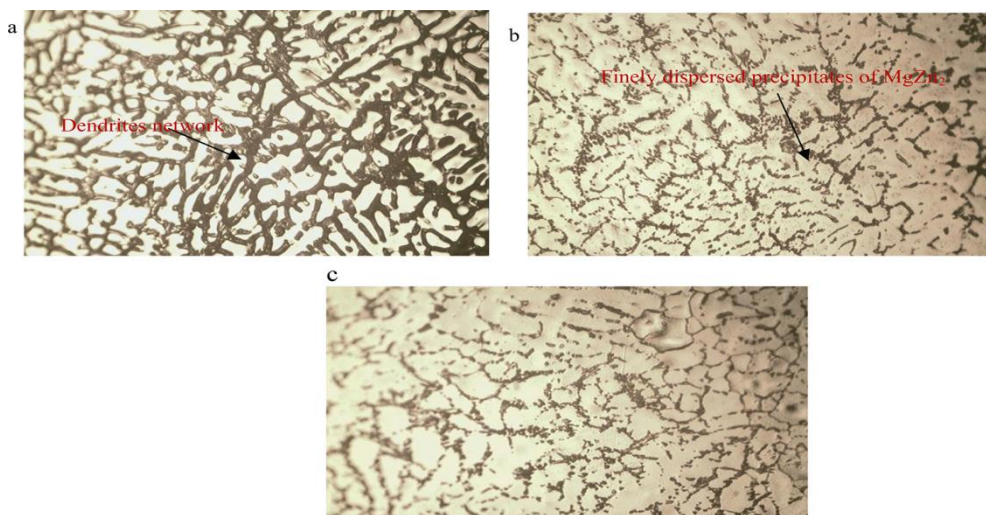
**3.2 Characterization of AA 7050 Samples**

The as-cast and the treated AA7050 samples were characterized using metallurgical microscope and SEM EDS. The results are presented in Figure 1a and Figure 2(a-f). Figure 1a-c shows the microstructure of AA 7050 samples for as-cast and precipitation conditions. The microstructure of this type of alloys is generally said to be characterized by μ precipitates (normally MgZn<sub>2</sub>) as can be observed in Figure 1a-c. The microstructure of the cast sample (Figure.1a) shows dendritic networks and micro segregation of MgZn<sub>2</sub> in aluminum matrix (ASTM, 2015). From the microstructure, it can be seen that the precipitation treated sample (Figure 1b and c) have finer grains and consequently more grain boundaries than the cast alloy. This is based on the fact that there is an increase in the volume of the precipitated intermetallic compounds during precipitation treated process and also refinement of the precipitated constituent particles (ASTM, 2015). The grains of the palm kernel oil treated samples, this is due to slower cooling rate of the palm kernel oil. Aging heat treatment of Al-Zn-Mg-Cu alloy lead to formation MgZn<sub>2</sub> intermetallic phase (Adeyemi, 2019). Figure 2(a-f) shows the SEM EDS micrographs

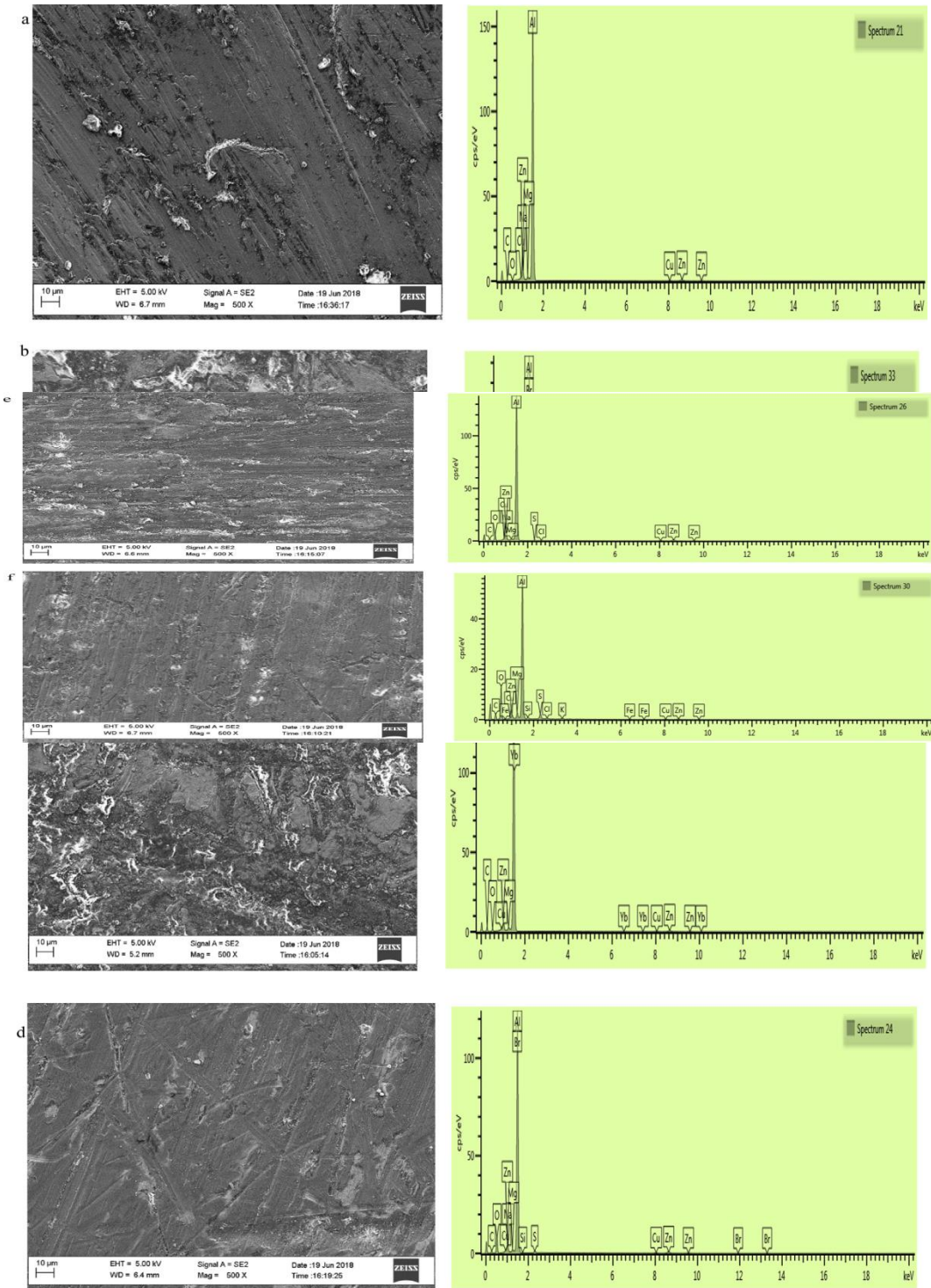
of the surface morphologies of TSA anodized AA7050 samples subjected to precipitation treatment process. Differences exist in the morphologies of the layers obtained for the as cast, precipitation treated and anodized samples, as can be seen in Figure 3.2(a-f). The surface of the precipitation treated in SAE40 engine oil and TSA anodized samples exhibited the most compact layer with fewer surface pores (Adeyemi, 2019). Micro cracks were visible on all the surface of the samples. These micro cracks may likely be caused by internal stress generated by the growth of the oxide at the substrate/oxide interface.

### 3.3 Micro Hardness and Coating Thickness of the Anodic Film

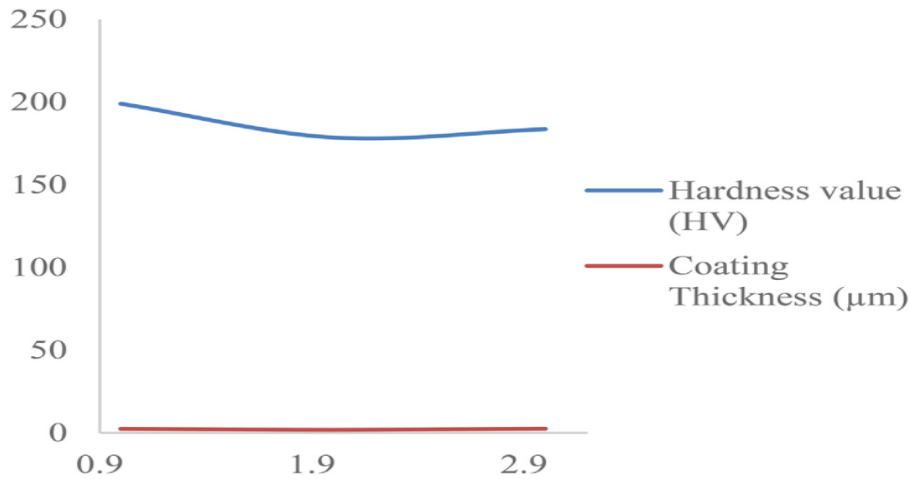
Figure 3, shows variation of hardness value with the coating thickness of the anodic film formed on the as cast, heat treated and heated and anodized samples in TSA. Initial decrease and increase in both micro hardness and coating thickness was observed. Highest micro hardness value of the anodic film was recorded at 186 HV for annealed plus TSA anodized sample. At very high coating thickness (248.38 $\mu\text{m}$ ), the micro hardness is maximum and hence the rate of formation of coating is more. The difference in weight gain between various coatings correlates their surface morphology (Chiu Sheng-Chien, 2018). However, tartaric acid addition causes the film thickness to reduce.



**Figure 1: Optical Micrograph of the cast AA 7050, showing  $\alpha$ - Al (white) and intermetallic phase (black), Mag  $\times 100$ : (a) as cast, (b) Precipitation Treated in Palm Kernel Oil, (c) Precipitation Hardened in SAE 40 engine oil.**



**Figure 2: SEM Micrograph of the samples: (a) as cast, (b) precipitation treated in palm kernel oil, (c) precipitation treated in SAE40 engine oil and anodized in TSA (e) precipitation treated in palm kernel oil and anodized in TSA and (f) precipitation treated in SAE40 engine oil and anodized in TSA.**



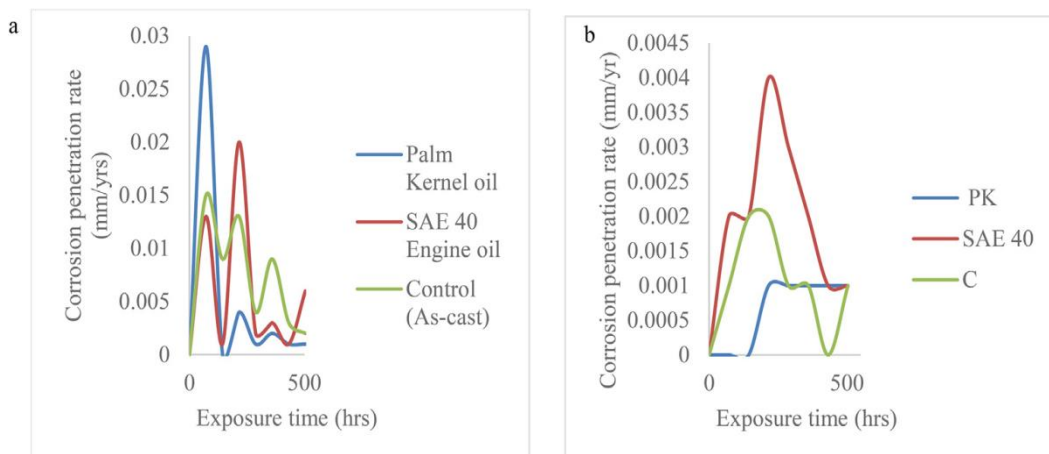
**Figure 3: Variation of Hardness Values with Coating Thickness**

In sulfuric acid with tartaric acid is faster than that in sulfuric acid alone. This result agrees with findings (Chunjuan *et al.*, 2018). Comparing the as cast and anodized samples with the heat treated and anodized samples shows that heat treatment have not improved both the hardness values and coating thickness of the anodic film formed on the samples. This result is in agreement with the result (Olawaye, 2018).

### 3.3 Weight Loss Corrosion Analysis

Figure 4a-b shows observation of corrosion penetration rate with exposure time of precipitation-treated AA 7050 coupons exposed to 0.5 M NaCl solution. It can be seen from Figure 4a that all the precipitation treated samples shows uniform initial step raise in corrosion penetration rate of the precipitation treated samples with the control sample, the two precipitation treated samples recorded less corrosion penetration rate with the palm kernel treated sample recording the lowest value. This may be attributed to redistribution of the precipitates at the grain boundaries as can be seen in Figure 3 (b-c) (Olawaye, 2018).

The corrosion penetration rate of the precipitation treated and TSA anodized samples (Figure .4b) does not show uniform corrosion behavior at the initial of the exposure time, instead they show sharp raise and at a point become resistant due to passiveness. The passivity was at short period and later rise in corrosion penetration rate. But as the exposure time increases further, the corrosion penetration rate of the entire samples drop with the palm kernel treated and TSA anodized sample showing the least corrosion penetration rate. This result is in line with the claim of (Adeyemi, 2018).



**Figure 4: Observation of Variation of Corrosion Penetration rate with exposure time: (a) Precipitation treated samples, (b) Precipitation treated and TSA anodized samples**

## IV. Conclusion

The results obtained from this study indicates significant role of precipitation treatment, precipitation treatment and anodization on the corrosion resistance improvement of the cast AA 7050. Palm kernel oil has been used as a quenching medium and is suitable as alternative quench ant to petroleum based SAE 40 engine

oil for quenching aluminum alloys, without cracking or distortion. Based on the results presented, the following conclusions are made:

- i. The corrosive medium shows uniform initial step raise in corrosion penetration rate of the precipitation treated samples as the exposure time increases.
- ii. The precipitation treated and TSA anodized samples does not show uniform corrosion behavior at the initial exposure time, instead they show significant rising and at a point become resistant due to passiveness.
- iii. All the precipitation treated and TSA anodized samples recorded low corrosion penetration rate in 0.5 M NaCl solution, with palm kernel oil treated and TSA anodized sample showing the least corrosion penetration rate.
- iv. Precipitation hardness and TSA anodization improves corrosion resistance of cast AA 7050 alloy in 0.5 M NaCl solution by reducing the penetration rate by 22.05% and 17.86% respectively.

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