

Corrosion Response of Cast Aluminium Alloy for Extension Clamp Fabrication

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Abstract Aluminium and its alloys are materials of special interest due to their availability and unique properties. Hence, they are widely used in many areas. Aluminium alloy A, was prepared by melting aluminium cans (17kg) together with ferro-silicon (1kg), ferro-manganese (0.5kg), lead (20g) and zinc (10g) inside a 40kg crucible furnace. When the mixture was completely molten at 720°C, it was stirred for 30 seconds, held for 5 minutes and poured into the prepared moulds and allowed to solidify by cooling after which they were removed from the moulds. The experiment was repeated for additional three times, varying the quantity of ferro-silicon of alloys B, C and D to obtain four samples. The corrosion response in terms of mass loss of the cast aluminium alloys in different media (1M hydrochloric, sulphuric and nitric acid solutions and 1M sodium hydroxide solution) for 15, 30, 45 and 60 minutes at room temperature was studied by chemical technique. Sulphuric acid had higher corrosive effect on the test samples than hydrochloric and nitric acids and sodium hydroxide at 15 and 30 minutes soaking time as the weight percentage of silicon content in the cast increased. At 45 and 60 minutes soaking time, sodium hydroxide had higher corrosive effect on the test samples than sulphuric and hydrochloric acids as the weight percentage of silicon increased.

Keywords Corrosion response, Aluminium alloy, Fabricate, Chemical technique, Corrosive media, Extension clamp

1. Introduction

Corrosion is the gradual destruction of materials, (usually metals), by chemical reaction with its environment. In the most common use of the word, this means electrochemical oxidation of metals in reaction with an oxidant such as oxygen. Rusting, the formation of iron oxides is a well known example of electrochemical corrosion. This type of damage typically produces oxide(s) or salt(s) of the original metal. Corrosion can also occur in materials other than metals, such as ceramics or polymers, although in this context, the term degradation is more common. Corrosion degrades the useful properties of materials and structures including strength, appearance and permeability to liquids and gases. Many structural alloys corrode merely from exposure to moisture in air but the process can be strongly affected by exposure to certain substances. Corrosion can be concentrated locally to form a pit or crack, or it can extend across a wide area more or less uniformly corroding the surface [1]. When a metal corrodes in water, the atoms lose electrons and become ions that move into the water. This is called an anodic reaction, and for the corrosion process to proceed there must be a corresponding cathodic reaction that

absorbs the electrons. The process can be stopped by isolating the metal from the water with an impermeable barrier [2]. The corrosion of metals is more of a problem than that of other materials. Corrosion is also defined as the wearing away due to chemical reactions, mainly oxidation-reduction. It occurs whenever a gas or liquid chemically attacks an exposed surface, often a metal, and is accelerated by warm temperatures and by acids and salts. Normally, corrosion products (e.g., rust, patina) stay on the surface and protect it. Removing these deposits re-exposes the surface and corrosion continues. Some materials resist corrosion naturally while others can be treated to protect them by coating, painting, galvanizing, or anodizing [2].

Aluminum is the most abundant metallic element in the earth's crust. After oxygen and silicon by mass, it is the third most abundant of all elements in the earth's crust. It constitutes approximately 8% of the earth's crust by mass [3]. After iron, aluminium is the second most widely used metal in the world. It is a material of special interest because it has a unique combination of attractive properties; low weight, high strength, superior malleability, easy machining, excellent corrosion resistance and good thermal and electrical conductivity are amongst aluminium's most important properties and it is also very easy to recycle. Because of these unique properties, it is used in five major areas: building and construction, containers and packaging, transportation, electrical conductors, machinery and equipment [4, 5]. Aluminium alloys are alloys in which

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aluminium (Al) is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon and zinc. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable. About 85% of aluminium is used for wrought products, for example rolled plate, foils and extrusions. Cast aluminium alloys yield cost effective products due to the low melting point, although they generally have lower tensile strengths than wrought alloys. The most important cast aluminium alloy system is Al-Si, where the high levels of silicon (4.0% to 13%) contribute to give good casting characteristics. Aluminium alloys are widely used in engineering structures and components where light weight or corrosion resistance is required [6].

The most important alloying elements used to impart particular properties to aluminium are Silicon (Si), Magnesium (Mg), Manganese (Mn), Copper (Cu) and Zinc (Zn). Other alloying elements often used in combination with one or more of the major alloying elements include Bismuth (Bi), Boron (B), Chromium (Cr), Lead (Pb), Nickel (Ni), Titanium (Ti) and Zirconium (Zr). These elements are usually used in small amounts (<0.1 per cent by weight, although B, Pb and Cr may comprise up to 0.5 percent) to tailor alloys for special purposes by imbuing them with properties such as castability, machinability, heat-resistance, corrosion-resistance, tensile strength etc [7]. Untreated aluminium has very good corrosion resistance in most environments. This is primarily because aluminium spontaneously forms a thin but effective oxide layer that prevents further oxidation. Aluminium oxide is impermeable and, unlike the oxide layers on many other metals, it adheres strongly to the parent metal. If damaged mechanically, aluminium's oxide layer repairs itself immediately. This oxide layer is one of the main reasons for aluminium's good corrosion properties. The layer is stable in the general pH range 4 – 9 [8].

No metal is immune to corrosion in all environments, but through monitoring and understanding the environmental conditions that are the causes of corrosion, changes to the type of metal being used can also lead to significant reductions in corrosion. Metal corrosion resistance data can be used in combination with information on the environmental conditions to make decisions regarding the suitability of each metal. The development of new alloys, designed to protect against corrosion in specific environments are constantly under production. In this study, the corrosion response of cast aluminium alloy for extension clamp fabrication is experimentally investigated and presented.

2. Experimental Procedure

2.1. Materials

The materials used for the casting of an extension clamp

and test bars are: Used Aluminium Beverage Cans (17kg), Ferro-Silicon (1kg), Ferro-Manganese (0.5kg), Lead (20g), Zinc (10g), Dilute Hydrochloric, Sulphuric and Nitric acids, Sodium Hydroxide Pellet and Distilled Water. All were sourced locally in Lagos.

2.2. Preparation of Corrosive Media

86ml of concentrated HCl was diluted with 914ml of distilled water for 1M solution of HCl. 56ml of concentrated H₂SO₄ was diluted with 944ml of distilled water for 1M solution of H₂SO₄. 63ml of concentrated HNO₃ was diluted with 937ml of distilled water for 1M solution of HNO₃. 40g of NaOH was dissolved in 1000cm³ of distilled water for 1M NaOH. The HCl, H₂SO₄, HNO₃ and NaOH used as corrosive media were from Analar grade and bi-distilled water was used for their preparation.

2.3. Sample and Extension Clamp Preparation

The design of the three prong clamp pattern was done with Autodesk Inventor Professional software. The pattern was fettled and machined to the precise dimension and shape after casting with aluminium. In order to overcome wooden pattern defects, aluminium metal was utilised for the fabrication of the pattern. Sand mould was used for the casting of extension clamps, while mild steel split-die mould was used for the test rods. Alloy A was prepared by melting aluminium cans (17kg) together with ferro-silicon (1kg), ferro-manganese (0.5kg), lead (20g) and zinc (10g) inside a 40kg crucible furnace. When the mixture became completely molten at 720°C, it was stirred for 30 seconds, held for 5 minutes and poured into the moulds and then allowed to solidify by cooling after which they were removed from the moulds. The experiment was repeated for additional three times, varying the quantity of ferro-silicon of each constituent of the mixture to obtain four samples for both extension clamp and test rod. The quantities of ferro-silicon used for alloys B, C and D are 2.43kg, 3.56kg and 5.13kg respectively. The cast (test) rods have dimensions (length 30cm and diameter 30mm). The extension clamps and test rods were fettled with hacksaw. Wire brush, warding file and grinding machine were used on them for finishing. The extension clamps were machined to finished size using drilling machine (Fobco Model), milling machine (Adcock-Shipley, Model 2E), and pedestal grinding machine (Peugeot Model). The composition of four different cast samples was analysed using Bench Top Arc Spectrometer (Model 120971/06). All samples were machined to dimension (length 5cm and diameter 20mm) for the corrosion test. Both Acidic and Basic (Chemical) corrosion tests were carried out by soaking the cast rods in 1M of hydrochloric (HCl), sulphuric (H₂SO₄) and nitric (HNO₃) acids and 1M of sodium hydroxide (NaOH) respectively for 15, 30, 45 and 60 minutes. Metallographic test was carried out on the test rods using computerised optical microscope (Model: CETI, 0703552). Microstructural characterisation was done in etched

condition and etching was done using the Keller's reagent 1 volume part of hydrofluoric acid (48%), 1.5 volume part of hydrochloric. These tests were done at room temperature (25°C).

3. Results and Discussion

In this study, ferrosilicon is used as a source of silicon. It is also used for manufacturing corrosion-resistant and high-temperature resistant ferrous silicon alloys [9]. Aluminium is alloyed with silicon for ease of casting and silicon is good in metallic alloys used for casting because it increases the fluidity of the melt, reduces the melting temperature, decreases the contraction associated with solidification and is very cheap as a raw material. Silicon has a low density (2.34 gcm^{-3}), which may be an advantage in reducing the overall weight of the cast component. Silicon has a very low solubility in aluminium; it therefore precipitates as virtually pure silicon, which is hard and hence improves the abrasion resistance [10]. Ferrosilicon has many properties essential to a metal or alloy powder that is to be used as a heavy medium of which some are (a) resistance to abrasion, (b) resistance to corrosion, (c) high specific gravity, (d) magnetism, which allows easy magnetic recovery with subsequent easy demagnetization and (e) low cost [11]. Figures 1, 2 and 3 show the macrographs of the used aluminium beverage cans, ferro-silicon and ferro-manganese respectively.

Table 1 shows the spectrometric composition of the elements present in the control sample (extension clamp) and the cast Al-Si alloys A, B, C and D. Apart from Aluminium present in the control sample, other elements that contributed to the brittleness of control sample are Copper, Zinc, and Lead. The presence of Silicon in prepared alloys improves flow rate of melt into the prong parts of the extension clamp,

and prevents the formation of cementite at the surface of products. The more the silicon during casting, the better the flow characteristics of melt to tiny parts of the extension clamp. Table 2 shows the dimensional specification of the fabricated three-prong extension clamp. A cast rod sample and fabricated three-prong extension clamp are shown in figures 4 and 5 respectively.



Figure 1. Macrograph of used Aluminium Beverage Cans (17kg)



Figure 2. Macrograph of Ferro-Silicon (1kg)

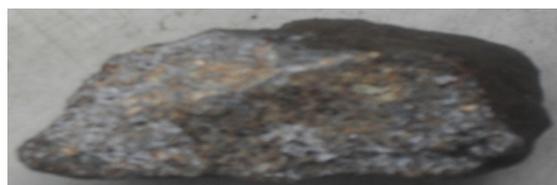


Figure 3. Macrograph of Ferro-Manganese (0.5kg)

Table 1. Alloy composition in weight of elements (%)

Element(s)	Control (Clamp)	Alloy A	Alloy B	Alloy C	Alloy D
Al	85.405	94.658	93.226	92.205	90.199
Si	1.720	0.940	2.280	3.350	4.820
Fe	0.005	1.100	1.180	1.210	1.300
Cu	6.350	0.226	0.232	0.227	0.248
Mn	0.070	0.830	0.820	0.800	0.800
Mg	0.472	1.520	1.460	1.400	1.350
Cr	0.053	0.021	0.031	0.026	0.035
Zn	5.160	0.468	0.540	0.510	0.930
Ti	0.012	0.016	0.027	0.016	0.024
Bi	0.103	0.001	0.001	0.001	0.001
Co	0.161	0.001	0.002	0.001	0.001
Pb	0.285	0.208	0.186	0.241	0.276
Sn	0.209	0.011	0.015	0.013	0.016

Table 2. Dimensional specification of fabricated three-prong extension clamp

Clamp			Maximum Grip Size (mm)	Mass (g)	Clamp Extension			Overall	
Jaw size (mm)					L (mm)	Ø (mm)	Mass (g)	L (mm)	Mass (g)
L (mm)	W (mm)	Th (mm)							
24	9	4	90	91.9	142	8	19.9	240	111.8



Figure 4. A cast rod sample

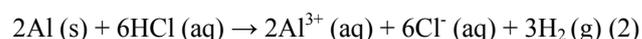
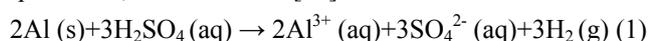


Figure 5. Fabricated three-prong extension clamp

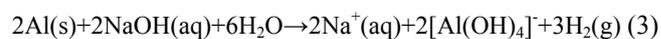
Table 3. Corrosion Test Result of Test Samples

Samples			Alloy A	Alloy B	Alloy C	Alloy D
Mass Loss (g)	15 Minutes	HCl	0.1321	0.1426	0.1867	0.1971
		H ₂ SO ₄	0.2341	0.2542	0.3124	0.3304
		HNO ₃	-0.0662	-0.0634	-0.0893	-0.0913
		NaOH	0.0130	0.0241	0.0505	0.0591
	30 Minutes	HCl	0.1977	0.2046	0.2238	0.3757
		H ₂ SO ₄	0.2874	0.3136	0.3814	0.4092
		HNO ₃	-0.0575	-0.0498	-0.0642	-0.0647
		NaOH	0.1654	0.2299	0.3191	0.3528
	45 Minutes	HCl	0.2528	0.2771	0.3505	0.6647
		H ₂ SO ₄	0.3703	0.3863	0.4768	0.5069
		HNO ₃	0.0833	0.0788	0.0939	0.0683
		NaOH	0.4151	0.4443	0.5585	0.6168
	60 Minutes	HCl	0.3079	0.3496	0.4772	0.9537
		H ₂ SO ₄	0.4033	0.4127	0.4961	0.5417
		HNO ₃	0.0235	0.0214	0.0490	0.0264
		NaOH	0.6587	0.6648	0.7979	0.8808

Corrosion test result reveals the reaction of test samples soaked in 1M hydrochloric (HCl), sulphuric (H₂SO₄), nitric (HNO₃) acid solutions and sodium hydroxide (NaOH) solution at different times (15, 30, 45 and 60 minutes). As shown in table 3 and the corresponding line diagrams in figures 6, 7, 8 and 9 respectively, sulphuric acid has higher corrosive effect on the test samples than sodium hydroxide, hydrochloric and nitric acid at both 15 and 30 minutes soaking time in terms of mass loss with respect to increase in silicon weight percentage of test samples. At 45 and 60 minutes soaking time, sodium hydroxide has higher corrosive effect on test samples than sulphuric and hydrochloric acids as silicon weight percentage of test samples increases. While test samples soaked for 15, 30, 45 and 60 minutes in nitric acid increased in mass with respect to the increase in silicon weight percentage. Part of the cast dissolved in dilute sulphuric acid to form solutions containing the aqueous Al (III) ions together with hydrogen gas, H₂. The corresponding reaction with dilute hydrochloric acid also forms the aqueous Al (III) ions while the cast sample in nitric acid got passivated. These are shown in equations 1, 2 and 3 below [12].



Part of the sample dissolved in sodium hydroxide with the evolution of hydrogen gas, H₂, and the formation of aluminates of the type [Al(OH)₄]⁻.



The optical micrographs of transverse cross section of the samples are shown in figures 10, 11, 12 and 13. All the microstructures show the silicon flake structure (dark regions) in the matrix of the aluminium phase, characteristics of unmodified eutectic solidification. In the minor phase, silicon dominates crystallographically. In figure 10, the silicon flakes are finer and evenly distributed within the aluminium phase. In figures 11 & 12, the silicon flakes are coarser than those in figure 10, more connected and are also less evenly distributed within the aluminium matrix. This is due to increase in silicon content of the composition. In figure 13, silicon grains are scattered and more evenly distributed within the aluminium matrix. Some clusters of free silicon particles are visible also within the aluminium matrix. This is due to increase in silicon content of the composition.

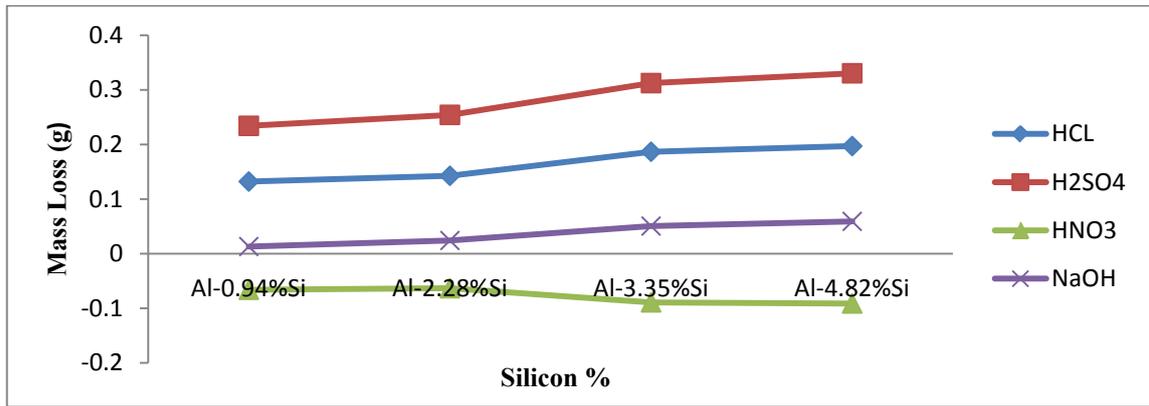


Figure 6. Variation of Corrosion effect (mass loss) with Silicon percentage at 15 minutes

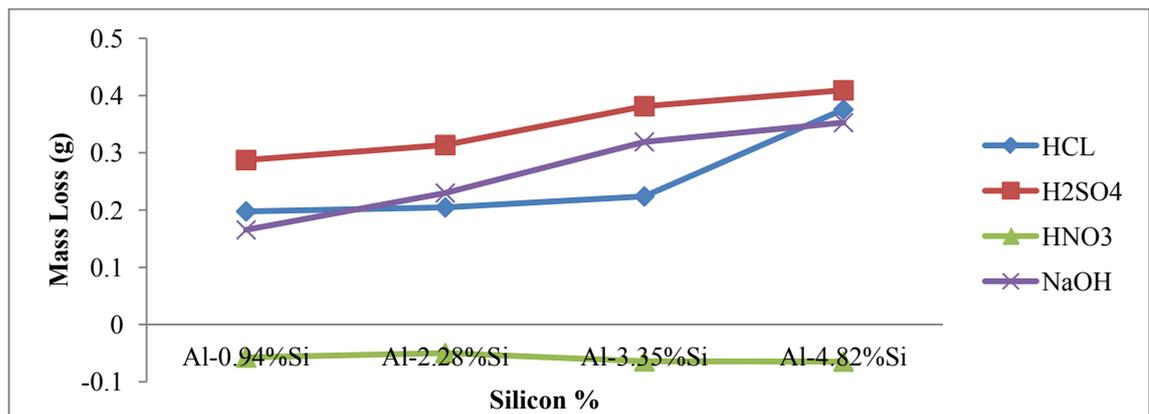


Figure 7. Variation of Corrosion effect (mass loss) with Silicon percentage at 30 minutes

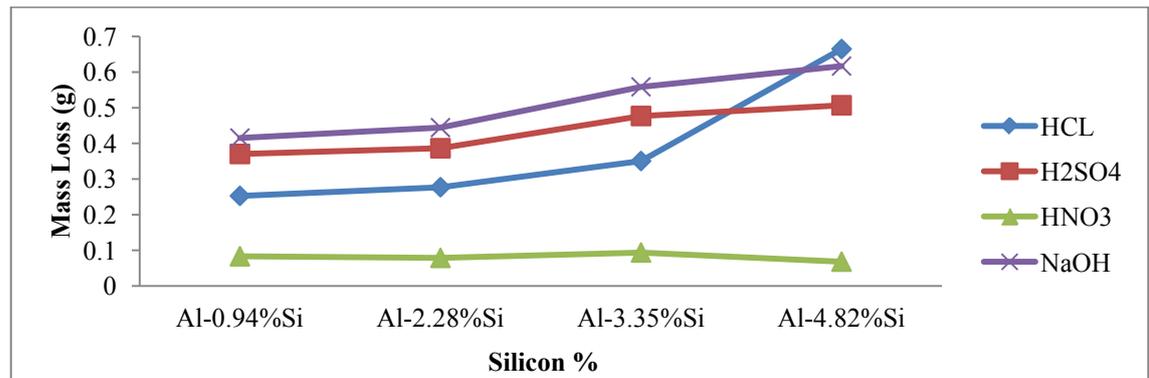


Figure 8. Variation of Corrosion effect (mass loss) with Silicon percentage at 45 minutes

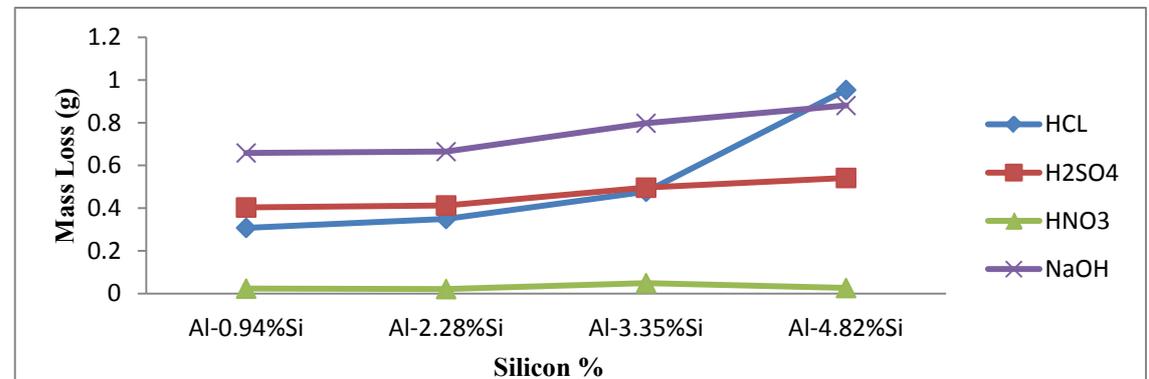


Figure 9. Variation of Corrosion effect (mass loss) with Silicon percentage at 60 minutes



Figure 10. Microstructure of Al-0.94% Si

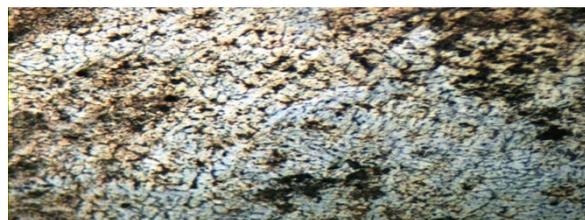


Figure 11. Microstructure of Al-2.28% Si

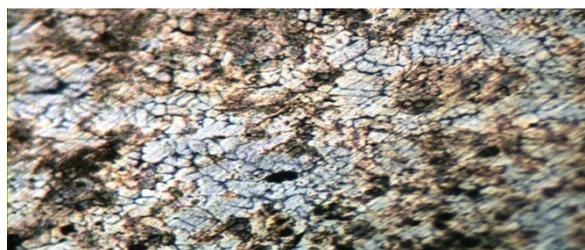


Figure 12. Microstructure of Al-3.35% Si

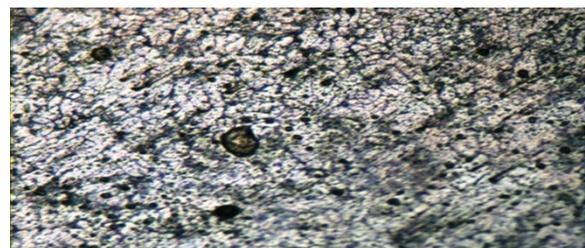


Figure 13. Microstructure of Al-4.82% Si

4. Conclusions

Corrosion rate of test samples in sulphuric acid, hydrochloric acid and sodium hydroxide increases with the increase of weight percentage of silicon. Inhibition efficiency of nitric acid on test samples increases with the increase of weight percentage of silicon. Evaluation of the fabricated extension clamp functionality at laboratories shows that the fabricated extension clamps perfectly hold

burette, round bottom flask, dropping funnel, separating funnel, thermometer, split cork among others during experiments in Chemistry and physics laboratories.

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