# Corrosion Resistance of Aluminum Plates in Lime Solution.

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## ABSTRACT

The corrosion resistance of aluminum plates was investigated in lime solution. The lime solution was prepared with different molarities of 0.5, 1.0, 1.5, and 2.0. The aluminum samples were cut into 5x5 cm pieces. Sixteen samples of aluminum plates were produced from each thickness which was further sub divided into four thicknesses (0.6 mm, 0.9 mm, 1.2 mm and 1.5 mm). Each group was then immersed into different solutions of lime for different time intervals. The samples were first weighed before and after immersion with a Miller weight balance. Weight losses were calculated for all samples. The corrosion rate of 6.875 mm/yr was obtained for the 0.6 mm sample of aluminum at 72 hours while the rate of corrosion decreased to 1.079 mm/yr at 288 hours. The photo micrographs of the aluminum samples both soaked and un-soaked were taken. It was observed that corrosion rates of the aluminum samples decreased with increase in thickness of samples. The rates of corrosion also decreased with time of immersion. The study also recommends that further research should be carried on other media such as sodium chloride solution.

(Keywords: corrosion, resistance, weight loss, Al, lime water, aluminum, aluminium, $CaOH_2$, hydrated lime)

## INTRODUCTION

Aluminum compounds have proven to be useful for thousands of years. Around 5,000 B.C., Persian potters made their strongest vessels from clay that contained aluminum oxide. Ancient Egyptians and Babylonians used aluminum compounds apart not only for making vessels but also for cosmetics, fabric dyes, and medicines. However, it was not until the early nineteenth century that aluminum was identified as an element and isolated as a pure metal.

In 1886, two 22-year-old scientists independently developed a smelting process that made economical mass production of aluminum possible. Known as the Hall-Harcourt process after its American and French investors, the process is still the primary method of aluminum production today [1] .

Aluminum compounds occur in aluminum types of clay, but the ore that is most useful for producing pure aluminum is bauxite. Bauxite consists of 45.60% aluminum oxide, along with various impurities such as sand, iron and other metals.

Aluminum metal is a soft, lightweight, malleable metal with an appearance varying from silvery to dull gray, depending on the surface roughness. Its light in weight and its flexibility has made it a good material for domestic use in making cooking utensils and others items such as containers, appliances, and building materials [2].

As a result of the good thermal and mechanical properties, aluminum is often used in making cooking pots. Aluminum pots have a rounded-bottom shape that provides good thermal efficiency. It has much better hear-transfer characteristics and provides an improved and uniform thermal dispersion into the substance being cooked. This has actually helped and attributed important economic considerations, where fuel is both scarce and expensive.

Calcium hydroxide is also known as hydrated lime, slaked lime, lime water, and calcium hydrate [3]. Certain properties of calcium hydroxide which are crystals or soft, odorless granules or powder are: 1) it has a slightly bitter, alkaline taste [4]; 2) it readily absorbs carbon II oxide from air, forming calcium oxide and it is slightly soluble in water; 3) a solution of lime water is a medium to strong base, and reacts violently with acids; and 4) It attacks many metals in the presence of water forming flammable explosive hydrogen gas.

Calcium hydroxide is used as liming in agriculture, particularly when a rapid change in pH is needed and majorly in water treatment. Calcium hydroxide dissolves in water to form $Ca^{++}$ and $OH^{--}$. Aluminum has a special reaction that is called amphoteric which exhibits both acidic and basic reactions. Aluminum loses its electrons by reacting with the dissolved ions of calcium hydroxide and this attack leads to reduction in weight of the aluminum cooking pot termed corrosion. Corrosion means the breaking down of essential properties in a material due to chemical reactions with its surroundings and the loss of electrons of aluminum metal react with water and oxygen. The corrosion can be generally concentrated locally to form pits and cracks, or it can extend across a wide area to produce general deterioration [5].

The major percentage of domestic (kitchen and restaurant) utensils used today are made up of aluminum. The question then arises as to how durable are these aluminum utensils are related to incessant replacement due to perforations and wear caused by corrosion. Since aluminum cooking pots are common household utensils for cooking, the study of its reaction with lime (calcium hydroxide) is of importance as reactions occur between the cooking pots and water or soup which are major source of lime contacts.

The investigation of the durability of aluminum plates in lime water is the broad objective of this study. As a result of the problems mentioned above, the specific objectives of the study are to:

- investigate the corrosion rates of aluminum at different times of immersion and different pH levels of lime

- examine the corrosion rate of different thickness of aluminum plate in the solution of lime

- investigate the effect of temperature on the pitting of aluminum cooking pots

- investigate the effect of different concentrations of lime solution on corrosion rates of aluminum.

## MATERIALS AND METHODS

The four thicknesses of aluminum specimens used for the study were been obtained from the Aluminium Rolling Mills Sango- Otta, Ogun State, Nigeria in form of flat sheets. The two aluminum cooking pots used were made from Aluminium Rolling Mills with 1.5 mm thickness, diameter of 153 mm and a height of 84 mm.

Sixteen (16) different 5 cm X 5 cm were cut from each of the four thicknesses, making a total of sixty- four (64) samples. These samples were cut from the parent materials with the help of shears, while a steel rule and scriber were used for the dimensioning.

The four different concentrations of lime solutions (calcium hydroxide, [$CaOH_2$]) were prepared from Chemistry Department's Laboratory, University of Agriculture, Abeokuta. The four different concentrations of lime were prepared with distilled water a week before starting the experiment. These solutions were stored in four different plastic kegs. The four lime concentrations were 0.5 molar, 1.0 molar, 1.5 molar and 2.0 molar. Each of the measured samples was inserted into the identified plastic containers and different concentrations of lime were been poured as each was labeled.

## EXPERIMENAL DETAILS

The chemical compositions of each of the four different thicknesses of aluminum samples were analyzed by a Quatometer/Metal Analyzer from the Quality Control Department of Aluminium Rolling Mills Sango-Otta. These compositions are shown in Table 1 with aluminum thickness of 1.55 mm, 1.2 mm, 0.9 mm, and 0.6 mm. The total surface area of the samples exposed was 5 cm x 5 cm (25 $cm^2$).

**Table 1:** Chemical Composition of Aluminum Samples.

| Al samples | Fe | Si | Mn | Cu | Ti | Al |
|---|---|---|---|---|---|---|
| 0.6mm | 0.561 | 0.155 | 0.023 | 0.012 | 0.006 | 99.19 |
| 0.9mm | 0.493 | 0.194 | 0.005 | 0.004 | 0.150 | 99.27 |
| 1.2mm | 0.454 | 0.183 | 0.032 | 0.035 | 0.011 | 99.17 |
| 1.55mm | 0.397 | 0.221 | 0.011 | 0.011 | 0.016 | 99.32 |

The sixteen sub-samples from each of the four samples were first weighed as the initial weights by mean of weigh balance. The weighed samples were inserted into each of the separate plastic containers. The first numbered one to sixteen plastic containers contained the same aluminum thickness of 0.6 mm. The first sixteen plastic containers were then divided into four groups with four plastic containers in a group. In each of the four groups different concentrations of lime solutions were poured. The pH values of each of the four solutions and the initial temperature were determined by using pH meter and thermometer. These were repeated for other samples making a total of sixty- four (64) samples.

The aluminum cooking pot was filled with 0.5 molar concentration of lime solution (calcium hydroxide) with a pH of 12.55. The pot filled with lime solution was placed on a heater. This was boiled to 100$^{o}$C, as measured by a thermometer and was held for another 30 minutes (until the pot boiled dried).

The pot was then soaked in water for some days in order to wash and remove the lime that had reacted with the pot during the heating process. This could not be removed by detergent, due to aluminum oxide being formed. A 6 molar solution of hydrochloric acid (HCl) was added which remove all of the attack of the lime solution.

One sample was taken out from each of the four a single sample. Each sample of the four concentrations of lime solutions were timely labeled. The first 3 days (72 hours), the samples were removed by using tongs. The aluminum samples were firstly washed with distilled water in order to remove the un-dissolved lime attached to the samples. The samples were then cleaned with tissue paper, rinsed with acetone solution, dried under a ceiling fan and re-weighed for the final weight. An electronic digital weighing balance of 100 g and of four decimal places was used for measuring both initial and final weight of the samples.

After some days of soaking the cooking pot with 2.0 molar lime solutions, the pot developed many pitting corrosion spots. Since the pitting was relatively great, a square 5 mm x 5 mm portion was dimensioned, within the covered area. The number of pits was counted and this was calculated in response to the total surface area of the experimental pot.

## EXPERIMENTAL RESULTS AND DISCUSSION

The results obtained were contained in Tables 2 and 3. High purity aluminum samples with minute percentages of aluminum impurities were analyzed using Quantometer/Metal Analyzer.

**Table 2:** The pH Values of Corroding Medium.

| CM g/dm3 | pH 0 H | pH 72 H | pH 144 H | pH 216 H | pH 288 H |
|---|---|---|---|---|---|
| 0.5 | 12.71 | 12.69 | 12.65 | 12.61 | 12.6 |
| 1.0 | 12.7 | 12.67 | 12.65 | 12.61 | 12.6 |
| 1.5 | 12.69 | 12.68 | 12.65 | 12.6 | 12.6 |
| 2.0 | 12.67 | 12.64 | 12.64 | 12.6 | 12.58 |

**Table 3:** The Corrosion Rate of the Aluminum Samples (mm/y).

| CM (g/dm3) | Al samples (mm) | CR 72 H | CR 144 H | CR 216 H | CR 288 H |
|---|---|---|---|---|---|
| 0.5 | Al 0.6 | 6.875 | 2.806 | 2.007 | 1.079 |
| 1.0 | | 8.654 | 3.562 | 2.588 | 1.525 |
| 1.5 | | 9.337 | 1.605 | 1.202 | 0.095 |
| 2.0 | | 10.817 | 1.397 | 0.683 | 1.242 |
| 0.5 | Al 0.9 | 7.214 | 4.121 | 2.825 | 1.796 |
| 1.0 | | 7.199 | 2.275 | 2.072 | 1.609 |
| 1.5 | | 7.98 | 3.143 | 2.377 | 1.78 |
| 2.0 | | 9.212 | 2.616 | 1.827 | 1.444 |
| 0.5 | Al 1.2 | 4.272 | 4.413 | 2.943 | 2.21 |
| 1.0 | | 4.54 | 3.261 | 1.733 | 1.712 |
| 1.5 | | 7.614 | 3.562 | 2.435 | 1.885 |
| 2.0 | | 9.613 | 1.812 | 1.777 | 1.479 |
| 0.5 | Al 1.55 | 3.272 | 5.344 | 3.68 | 2.818 |
| 1.0 | | 4.968 | 3.235 | 2.916 | 2.408 |
| 1.5 | | 6.401 | 4.33 | 2.94 | 2.389 |
| 2.0 | | 7.181 | 3.223 | 2.232 | 1.749 |

The analysis exhibited that 1.55 mm thickness of aluminum has the highest percentage of aluminum purity while the least is 1.2 mm thickness.

The first 72 hours of all the samples in respective of the lime concentrations and samples thickness have the highest corrosion rates compared to the longest duration of 288 hours.

The tables also showed that the corrosion rates of the same sample that is, the same thickness, depended majorly on the level of lime concentrations. The corroding medium of 2.0 g/dm$^3$ (molarity) has the highest corrosion rate compared to the lower lime solutions.

The graphs (Figures 1 to 3) show the corrosion rate against time of immersion in different concentration of lime solutions (molarities). The sample that was immersed in highest molarity had the highest corrosion rate due to high level of the aggressive interaction between the aluminum samples and the molarity.

The weight loss per area showed a decreasing trend with immersion time as shown in Figure 1. The highest value was observed for 1.5 mm aluminum plate at 72 hours of immersion while the lowest value was obtained for 0.6 mm aluminum at an immersion time of 288 hours.

Aluminum samples of 0.6mm thickness showed the highest corrosion rate compared to other thicknesses. Pitting of an aluminum cooking pot was observed when soaked in lime solution and the pot heated to 100$^0$C and held for 30 minutes.

The corrosion rates of all of the samples decreased drastically with increase in period (duration) of immersion in respect of thickness and the concentration of the corroding medium (molarities).

Both the level of lime concentrations and the thickness of the samples played a significant role in the level of corrosion rate. For example, a sample of 0.6 mm thickness has the highest corrosion rate of 0.6875 mm/yr been immersed in 0.5 g/dm3 of lime solution while the sample immersed in 2.0g/dm3 of lime solution had an highest corrosion rate of 1.0817 mm/yr which has a difference of 0.3942 mm/yr as shown in Table 2.

The first 72 hours of the corrosion rate of 0.6 mm is 0.6875 mm/yr while the corrosion rate of 1.55 mm sample immersed in the same corroding medium (molarity) has a corrosion rate of 0.3272 mm/yr.

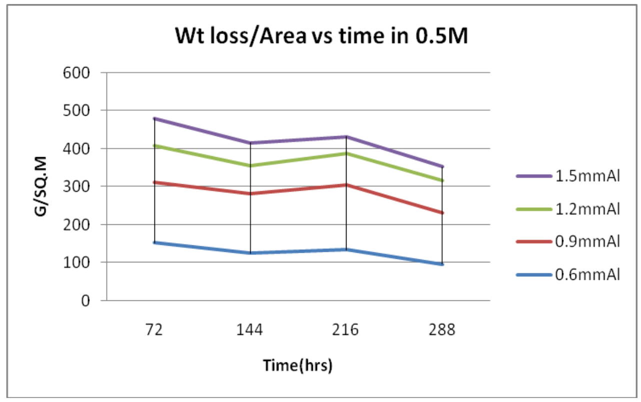


**Figure1:** Plot of Weight Loss per Area against Immersion Time.

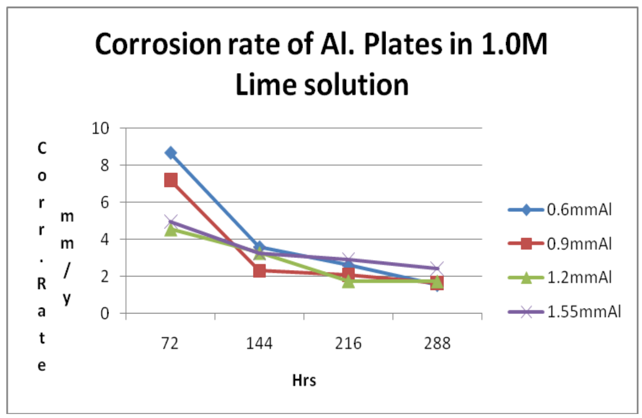


**Figure 2:** Plot of Corrosion Rate of Aluminum Plates against Immersion Time.

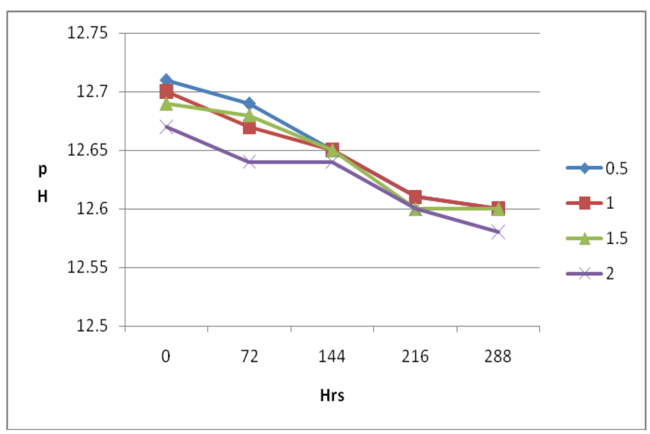


**Figure 3:** Plot of  pH of Lime Solution against Immersion Time.

Plate 1: 0.9mm Aluminum Sample (Un-soaked), X400, 2% Nitric Acid and 98% Ethyl Alcohol.

Plate 2: 0.9mm Aluminum Sample (Soaked), X400, 2% Nitric Acid and 98% Ethyl Alcohol.

**Figure 4:** Photomicrographs of Aluminum Samples.

## CONCLUSIONS

The results obtained from this study indicate the negative but significant effect of lime solution (calcium hydroxide [$CaOH_2$] on aluminum plates. The general reaction is known as corrosion effect which led to a reduction in the weight and thickness of aluminum cooking pots.

The highest corrosion rate of all the aluminum samples were observed in the first three days (72 hours) of immersion while the lowest was in the last 12 days (288 hours). The corrosion rate was also observed at the highest concentration of calcium hydroxide (2.0g/dm$^3$) and the lowest pH value.

The thinnest of the aluminum samples also gave the highest corrosion rate while the thickest aluminum sample (1.55mm thickness) gave the least corrosion rate.

Another critical effect observed during the course of the experiment was the attack of lime on the aluminum cooking pots which led to pitting corrosion on the aluminum.

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