The Effects of Magnesium Content and Porosity on the Mechanical, Microstructural and Corrosion Properties of (1xxx) Aluminium Alloy

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Abstract

The effects of alloying elements on the mechanical, microstructural, and corrosion properties of Aluminum have been investigated. This investigation was done by fabricating alloys of Aluminum and Magnesium, with magnesium concentrations of 0.0, 0.1, 0.4, 0.8, 1.2, 1.5, and 1.8 weight percent. Subsequently, the mechanical properties of the samples were tested. Optical microstructural examinations were carried out on each of the samples, and the corrosion properties in a 0.2M H_2SO_4 solution were determined using the coupon testing method. The results obtained show that Magnesium does not just affect the mechanical, microstructural, and corrosion properties of Aluminum, but these properties are also dependent on the relative content of Aluminum and Magnesium. It was observed that 70 (RHB) was the maximum hardness obtained, and it occurs at 0.8 wt% Mg, after which the hardness becomes negatively affected. Magnesium addition was also found to increases the corrosion rate of (1XXX) aluminum in 0.2M H_2SO_4. It was also observed from the micrographs of the alloys that there was a uniform dispersion of Magnesium in the matrix of Aluminum.

Keywords: Al-Mg Alloy; Ultimate Tensile Strength (UTS); Hardness; Engineering Fracture Strength (EFS); *%Elongation; %Reduction; Microstructure; Corrosion rate; Porosity.*

1.0 Introduction

Pure metals are not often used for engineering and material fabrication applications, except where high electrical conductivity, high ductility or any other specific properties are required [7] [9] [17] [14]. A close look at the numerous pure metals will reveal that they possess properties in limited amount. These properties possessed may not be adequate to meet the material requirement for the manufacture of a particular product. In view of this, alloying elements to change the properties of the material to desirable properties becomes necessary.

The applicability of any metal or alloy for a specific purpose is determined by its properties. These properties can be varied within limits by several methods, which include; mechanical working, grain size control, heat treatment and alloying elements [12] [4]. Alloying elements such as Magnesium, tin, zinc, and other alloying elements are added with a view to give aluminium and other metals some desirable properties. Also, a variation in the concentration/amount of these elements has a significant impact on the mechanical properties of the resultant alloy [3]. Some of these properties are to increase or improve the mechanical strength, such as yield strength, tensile strength and hardness [19] [2]. This occurs as a result of the alloying element in the structure changing the properties of the alloy by preventing the metal ions from sliding over each other. It happens when substitution solute atoms are mixed in the molten state with that of another metal (solvent), and thus stress fields are created around each atom in the solid state. These stress fields interact with dislocations and limit their movement; thus, the resultant solid solution or alloy becomes stronger and tougher than the pure or parent metal [6] [19].

More than 90% of metals currently in use are in the form of alloys [13]. They represent a large family of engineering materials that provide a wide range of products with useful properties. Actually, the main objective of forming an alloy is to provide a metallic substance with physical, mechanical and or chemical properties and characteristics that are different from those of its individual components [18].

Aluminium, also known as Aluminum, with atomic symbol, Al, and atomic number, 13, is a P-block, Group 13, Period 3 element on the periodic table with an atomic weight of 26.9815386. It is the third most abundant element in the earth's crust and the most abundant metallic element. It is light with a density 2.7g/cm^3 and nonmagnetic. It is the second most malleable metal, and sixth most ductile metal. Today, aluminium and aluminium alloys are extensively used in many industrial applications where strong, light, easily constructed materials are required, such as in the production of cans, foils and kitchen utensils, as well as parts of airplanes. It is used in electrical transmission lines because of its relatively high electrical conductivity and light weight. Pure Aluminum is soft and lacks strength, but when alloyed with small amounts of copper, silicon, manganese, Magnesium, or other elements, it possesses a variety of useful properties [1] [5] [10] [11] [15]. The addition of alloying element to aluminium is the principal method used to produce a selection of different materials that can be used in a wide area or assortment of structural application. In the present study, the effect of addition of Magnesium of varying concentrations to aluminium is investigated.

2.0 Materials and method

2.1 Preparation of Aluminium alloy

Commercially pure Magnesium was used for the present study. Similarly, the aluminium used is the high purity aluminium (1XXX) series, gotten in sheet form having a thickness of about 0.25mm from Charles Aluminium Company Port Harcourt factory. Table 1 below gives the composition of the aluminium used for this present study.

Table 2.1. Composition of the Aluminium used for the present study

Element	Si	Fe	Cu	Mn	Ni	V	Al
Composition (wt %)	0.11248	0.00010	0.02945	0.09272	0.08526	0.03975	99.56000

The above composition was determined from the spark analysis of the aluminium sheet, carried out at First Aluminium Nigeria Plc Port Harcourt, using a spectrometer. Aluminium having the above composition was alloyed with Magnesium to produce seven samples of Aluminium-Magnesium alloys, with Magnesium ranging from 0.0 to 1.8 weight percent, at a scale of 200g. The aluminium was heated to a temperature of around 725^{0}c, and then the Magnesium in powdered form was added and the mixture was stirred to obtain homogeneity and the casting was then done after oxide impurities and coagulants have being removed, on a green sand mould, which was prepared using the normal mould preparation procedures. After pouring, the resultant samples were allowed to solidify and cooled in normal room temperature. A Blacksmith hearth furnace which uses charcoal as its fuel with mild steal crucible was used for melting the metals.

2.2 Preparation of the samples for mechanical test

Part of each cast sample was machined to tensile configuration for tensile test. The samples were prepared to have the following dimensions (Fig. 2.1):

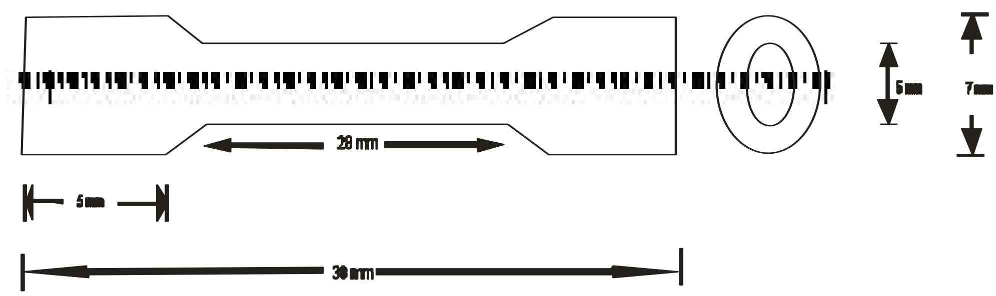


Fig. 2.1 Specimen for tensile test

Similarly, square like specimen of about 8x8mm^2 were produced from each cast and the microstructures were revealed after the normal metallographic procedures were followed. Also, cylindrical coupons were prepared from each sample, for the corrosion test.

Hardness test was done using the Macro Rockwell hardness tester. Tensile testing was done using a Monsanto tensometer. The microstructure of the samples where revealed, using metallurgical microscope with camera attachment and computer interface.

2.3 Preparation of the Corrodant

The media environment was prepared from a concentrated Sulphuric Acid obtained from Fin Laboratory, Owerri. Its description is as follows: Chemical Formula: H_2SO_4, Molecular Weight: 98.07g/mol, Percentage Purity: 98.0%, Manufactured By: Guanghua Chemical Factory Company Limited, Shatau, Guandghau, China.

The corrosion test was carried out to determine the corrosion rate of the various samples in 0.2M H_2SO_4 solution, dipped for 48 hours, using coupon testing method. The corrosion rate in miles/year was calculated using the following relation [16] [17].

$$C_R = K\left(\frac{W_i - W_f}{\rho A t}\right) \quad (2.1)$$

Where:

C_R is the rate of corrosion (mills/year)

W_i and W_f are the weight of specimen before and after corrosion (g)

A is exposed area of specimen (cm^2)

t is the time of exposure (in hours), ρ is specific gravity of metal (g/cm^3) and

K is a constant, whose value is 3.45 X10^6 (mills/year) [16].

For cylindrical specimen, the following formula given below, holds;

$$\text{Area}(A) = 2\pi r l \quad (2.2)$$

$$\textbf{Volume } (v) = \pi r^2 l = \frac{\pi D^2 l}{4} \quad (2.3)$$

Where π = constant ≈ $\frac{22}{7}$, r = radius of the cylinder, l = slant height of the cylinder, D = diameter of the cylinder.

While the density is calculated from the formula given by;

Density = $\frac{mass}{volume}$ **(2.4)**

3.0 Results and Discussion

3.1 Hardness Test Result

The macro-hardness testing was carried out using Rockwell Hardness testing machine and the type is Rockwell Hardness B. The following table 3.1 shows the result of the hardness test performed on the samples.

Table 3.1. Hardness Test Results

S/N	Wt % Mg (%)	Hardness (RHB)
1	0.00	64
2	0.10	66
3	0.40	67
4	0.80	70
5	1.20	65
6	1.50	61
7	1.80	62

Figure 3.1 below shows the variation of hardness (Rockwell hardness B) with percentage Magnesium in the Aluminium–Magnesium alloys.

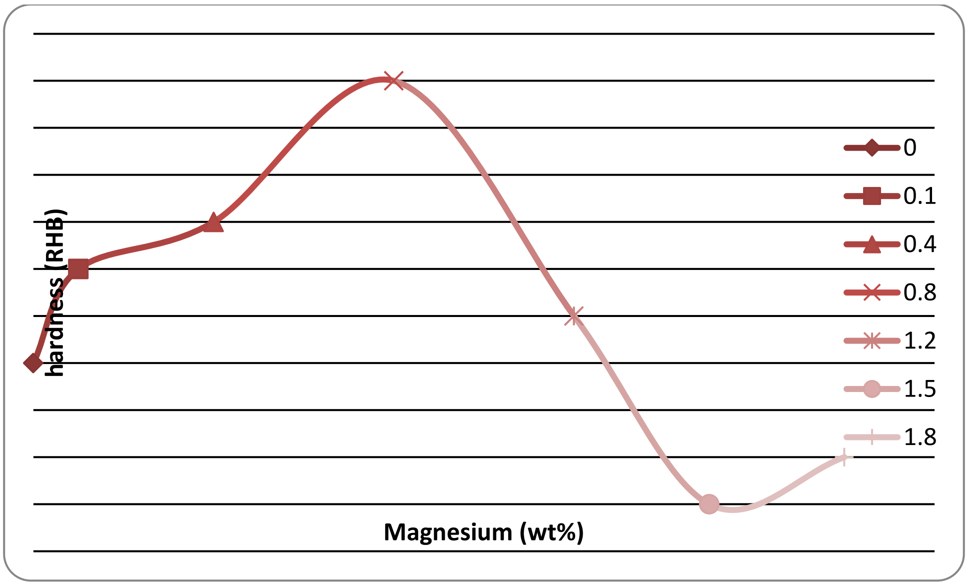


Figure 3.1. Hardness against percentage Magnesium

As can be observed from fig. 3.1, the hardness of the aluminium alloys increases initially with an increase in magnesium content up to a maximum of 70 RHB at 0.8 Wt% Mg after which it begins to decrease with further addition of Magnesium up to a minimum of 61RHB at 1.5 Wt% Mg and thereafter it tends to increase slightly. This shows that when magnesium content exceeds about 0.8 Wt%, it results to a negative impact on the hardness of the alloy, which is in agreement with [3]. Thus, less hard materials can be obtained for an Al-Mg alloy by forming the alloy with Magnesium ranging from either 0 to 0.1 Wt% or from 1.2 to 1.8 Wt%, whereas hard materials can be obtained by alloying with about 0.8 Wt% magnesium.

3.2 Tensile Test Results

Deductions and computations for the Ultimate Tensile Strength (UTS), Engineering Fracture Strength (EFS) and the Ductility in terms of percentage elongation (% EL) and percentage reduction in cross-sectional area (% RA) for each sample are presented in table 3.2 below.

Table 3.2. Values of UTS, EFS, % EL, % RA, for the samples

S/N	Wt % Mg (%)	Ductility (%)		UTS (KPa)	EFS (KPa)
		% EL	% RA		
1	0.00	3.57	15.73	53468	60427
2	0.10	18.93	19.36	61106	50518
3	0.40	9.29	10.70	71290	62725
4	0.80	1.79	2.43	43238	41734
5	1.20	7.68	4.55	73836	53348
6	1.50	10.36	6.88	70272	54684
7	1.80	13.79	28.94	73836	71659

Figures 3.2, 3.3, 3.4 and 3.5 respectively give the variation of UTS, EFS, % EL, % RA, with percentage Mg.

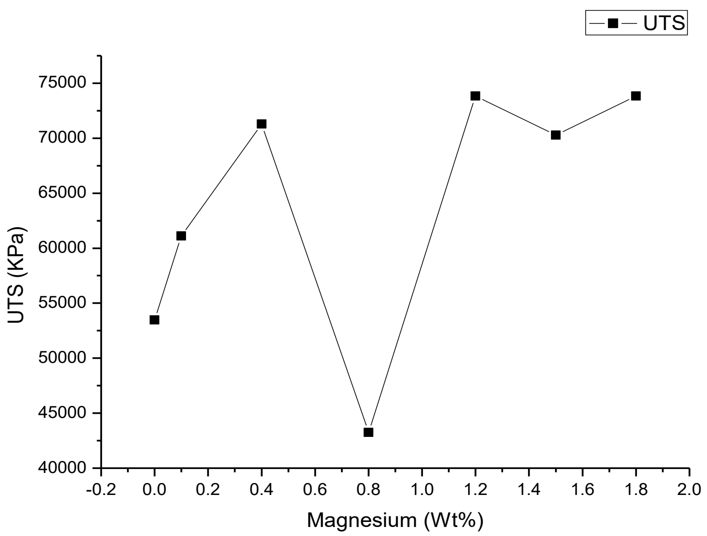


Figure 3.2. Plot showing variation of UTS with percentage of Magnesium

As observed above (fig. 3.2), the ultimate tensile strength of the alloys increases with the addition of Magnesium, but at 0.8 Wt% magnesium, it decreased to its minimum value and after which it increases further. The decrease may be due to the fact that the tensile test specimen for 0.8 Wt% magnesium sample fractured close to the edge of the gauge length during the test, which may result from non-uniform machining of that sample or due to the presence of impurities. Hence Magnesium has a positive impact on the UTS of the alloys, which also is in agreement with [3].

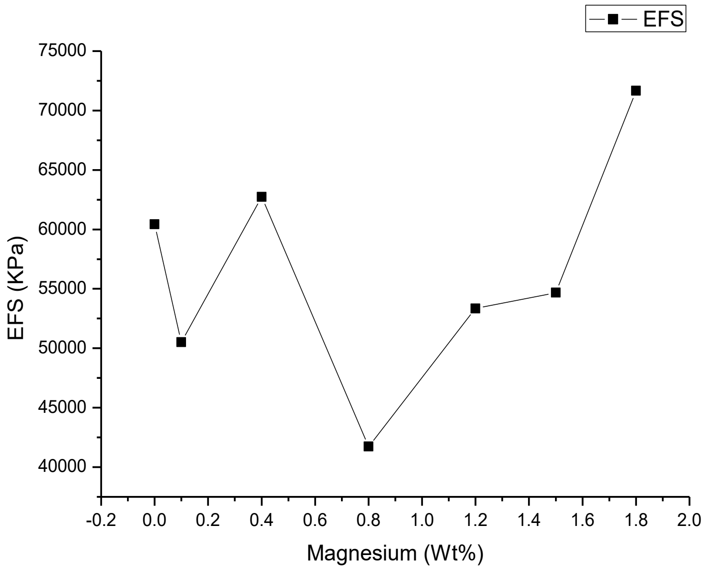


Figure 3.3. Plot showing variation of EFS with percentage of Magnesium

From fig. 3.3 above, the engineering fracture strength (EFS) decreased initially with an addition of Magnesium, and on further addition of Magnesium it increased. Furthermore, when more Magnesium is added, it decreased to its minimum value at 0.8 Wt% Mg and thereafter increased continually with further addition of Magnesium. Thus, the EFS of the alloy does not give any definite pattern of variation with magnesium addition and ranges between the minimum value of 41734KPa at 0.8 Wt% Mg to a maximum value of 71659KPa at 1.8 Wt% Mg.

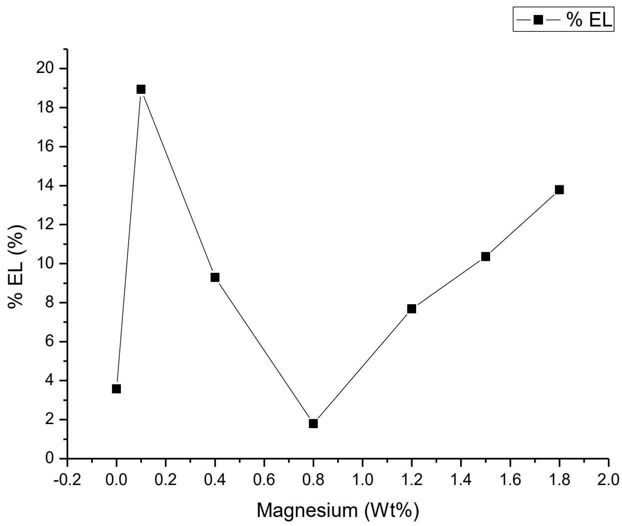


Figure 3.4. Plot showing variation of % EL with % Magnesium

From the plot above (fig. 3.4), Percentage Elongation increased drastically with an addition of 0.1 Wt% Mg, after which it starts decreasing up to a minimum value of 1.79% at 0.8 Wt% Mg and thereafter increased continuously with further increase in percentage magnesium. Thus, magnesium addition increases elongation in Aluminum except for the case of 0.8 Wt% Mg.

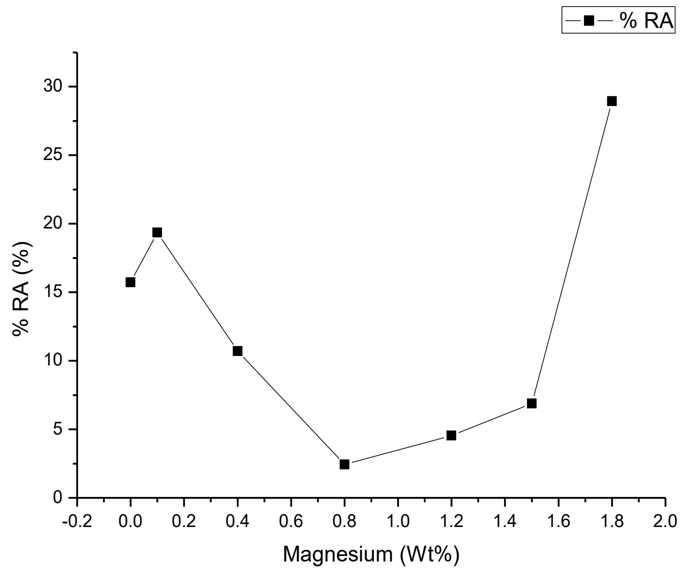


Figure 3.5. Plot showing variation of % RA with percentage of Magnesium

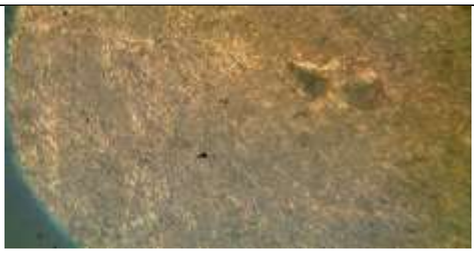
The above fig. 3.5 shows that the reduction in area initially increased slightly when 0.1 Wt% Mg was added, and then decreased with increase in magnesium content. It becomes minimum at 0.8 Wt% Mg, before it begins to increase again. In fact, between 0.6 Wt% and 1.5 Wt% Mg is the region of proper compartment of the constituent elements.

3.3 MICROSTRUCTURE RESULT

The Metallurgical microscope images of the seven samples being studied are shown below in fig. 3.6.

0.00 Wt% Mg

0.10 Wt% Mg



0.40 Wt% Mg

0.80 Wt% Mg

1.20 Wt% Mg

1.50 Wt% Mg

1.80 Wt% Mg

Fig. 3.6: Micrograph of the samples (x100)

From the microstructures of the alloys we see that there was a uniform dispersion or distribution of Magnesium throughout the samples and the formation of AlMgSi precipitate which causes strengthening of the alloy through precipitation strengthening. And the dark portion of the first sample could be due to sand inclusion in the cast sample.

3.4 Corrosion Test Results

The results of the corrosion test carried out for the different samples are recorded below.

Table 3.3 Data for corrosion test carried out in 300cm^3 of 0.2M H_2SO_4 for 48 hours.

S/N	Weight % Magnesium (%)	Mass (g)	Volume(cm^3)	Density (g/cm^3)	Total surface area (cm^2)	Initial weight (g)	Final weight (g)	Weight loss (g)	Corrosion rate (miles/year)
1	0.00	7.0557	3.0310	2.3278	11.5469	7.0557	7.0366	0.0191	35.730
2	0.10	7.2013	2.9417	2.4480	11.4240	7.2013	7.1798	0.0215	55.257
3	0.40	8.0001	3.6571	2.1876	12.6107	8.0001	7.9818	0.0183	47.678
4	0.80	10.4145	4.0703	2.5587	15.5058	10.4145	10.3808	0.0337	61.051
5	1.20	7.0099	2.6756	2.6199	10.4926	7.0099	6.9865	0.0234	61.182
6	1.50	6.5928	2.6406	2.4967	10.6693	6.5928	6.5726	0.0202	54.504
7	1.80	5.3187	2.0234	2.6286	7.6645	5.3187	5.3017	0.0170	60.648

The environment that the samples were exposed to is 300cm^3 of 0.2M H_2SO_4 solution and the time of exposure was 48 hours. The method employed for the corrosion test carried out is the coupon testing method.

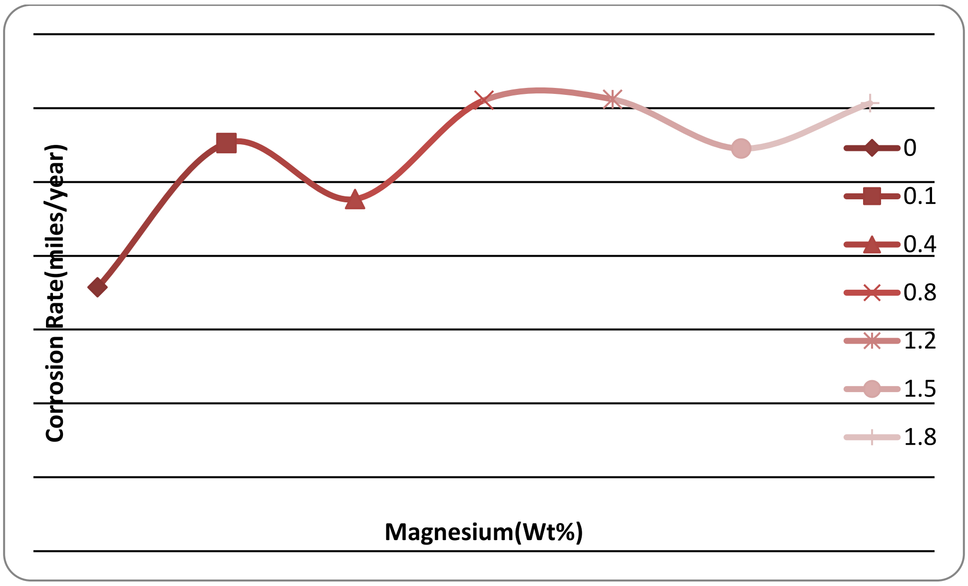


Figure 3.7. Variation of Corrosion Rate (CR) with percentage Magnesium

As evident above (fig. 3.7), the corrosion rate of the alloy increased initially (from 35.730 to 55.257 m/y) with the addition of 0.1 wt% Mg and then it decreased to 47.678 m/y at 0.4 wt% Mg, and with further addition of about 0.8 to 1.2 wt% Mg, the corrosion rate increased to a relatively constant value of about 61.1m/y. When 1.5 wt% Mg was added, there was a decrease from the initial value, and at 1.8 wt% Mg the corrosion rate increased to 60.648 m/y. Hence magnesium addition increases corrosion rate of 1xxx aluminium alloy.

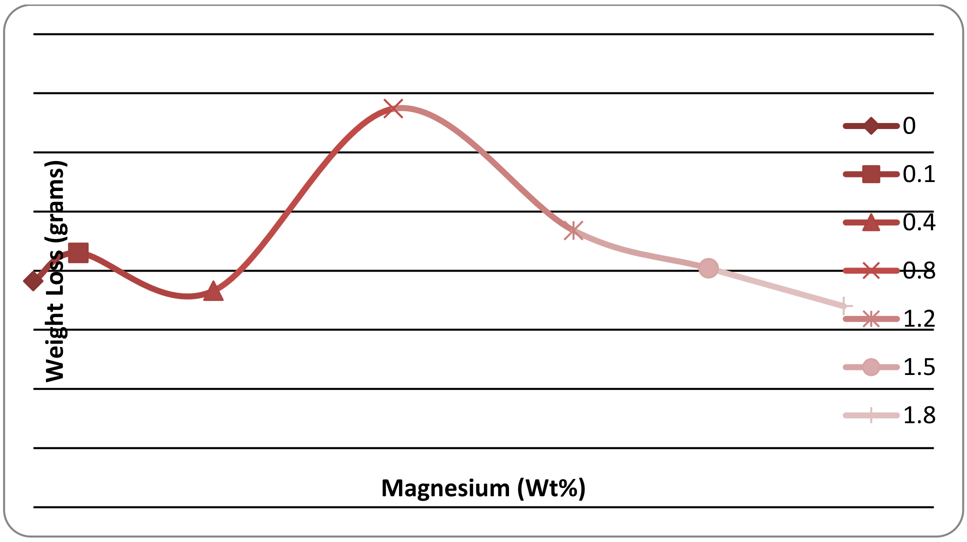


Figure 3.8. Variation of weight loss with percentage Magnesium

From fig. 3.8 above, it is evident that, the weight loss is drastically affected by the amount of magnesium present. When 0.1 Wt% Mg was added, the weight loss slightly increased and then decreased when 0.4 wt% Mg was added after which it increased until gets to its maximum value of 0.0337g at 0.8 Wt% Mg and thereafter decreased continuously with further addition of Magnesium.

3.5 Comparison of The Plots Above

From the plots above, it is evident that;

1. As the hardness of the alloy increases, the corrosion rate increases and as the hardness decreases the corrosion rate also decreases, except for the case of 0.4 Wt% Mg and 1.2 Wt% Mg. Thus, the hardness is directly proportional to the corrosion rate.

2. The plots of weight loss (fig. 3.8) and EFS (fig. 3.3) against weight percent magnesium are directly opposite in nature. That is, they are inversely proportional to each other.

3. Percentage elongation and percentage reduction in area are interrelated and are partly proportional, having their minimum values occurring at 0.8 Wt% Mg.

4. Except for the corrosion rate for 1.2 Wt% Mg, the hardness, weight loss and corrosion rate all have their maximum values at 0.8 Wt% Mg, whereas the UTS, EFS, %EL and %RA all have their minimum values at that same 0.8 Wt% Mg.

CONCLUSION

In this study the effects of the addition of Magnesium on the mechanical, microstructural and corrosion properties of 1XXX (99.56 %) Aluminium has been investigated. The result of the research shows that:

1. The hardness of the aluminium alloys became negatively affected when magnesium content exceeds about 0.8Wt%, which is in agreement with literature [3].

2. Percentage Elongation increased drastically with an addition of 0.1 Wt% Mg, after which it starts decreasing up to a minimum value of 1.79% at 0.8 Wt% Mg and thereafter increased continuously with further increase in percentage magnesium.

3. The reduction in area initially increased slightly when 0.1 Wt% Mg was added, and then decreased with increase in magnesium content. It becomes minimum at 0.8 Wt% Mg, before it begins to increase again. In fact, between 0.6 Wt% and 1.5 Wt% Mg is the region of proper compartment of the constituent elements.

4. Magnesium has a positive impact on the UTS of the alloys, which also is in agreement with literature [3].

5. The microstructures of the alloys reveal that there was a uniform dispersion or distribution of Magnesium throughout the samples.

6. Magnesium addition increases corrosion rate of (1xxx) aluminium in 0.2M H_2SO_4 solution.

7. The mechanical properties, microstructural properties and corrosion properties of aluminium alloys depend on the content of Magnesium and also on the stoichiometric ratios of the elements present.

8. Further study is ongoing to examine the microstructural properties of these alloy samples, using scanning electron microscope (SEM), transmission electron microscope and x-ray diffraction techniques.

Conflicts of Interest

All authors declare no competing interest regarding this work.

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