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Mechanical properties of Magnesium Inoculated 6063 Aluminium Alloy

Bodude, M. A, Ochulor, E. F, Ayoola, W. A. and Adeosun, S.O.

Department of Metallurgical and Materials Engineering. University of Lagos, Nigeria

Abstract: This study examined the effect of magnesium inoculation of 6063 Aluminium and normalizing temperatures on its mechanical properties. Conventional sand cast samples of 6063 aluminium alloy containing 0.48, 1.48, 2.48, 3.48, 4.48, 5.48, 6.48 and 7.48 % Mg were normalized at 25-27, 100-110, 200-210 and 400-410^{o}C for 1 hour. These samples were tested for hardness, impact resistance, ultimate tensile, yield and fracture strengths. Inoculation of structural aluminium alloy with magnesium followed by normalizing at 25-27^{o}C significantly increased the hardness (7.33-23.3 HR) and impact resistance (11-19 J). Inoculated samples with > 1.48%Mg showed increase in Ultimate tensile (UTS), yield and fracture strengths as compared to the control sample containing 0.48 %Mg. These properties are influenced by the presence of hard intermetallic compound of Mg_2Si precipitated in the matrix.

Keywords: Aluminium alloys, Mechanical properties, Normalizing, Magnesium, Magnesium silicide

1. Introduction

There are several properties that makes aluminium one of the most widely used element, these include non toxic, impervious, non sparking, decorative, easily formed, machined, strong, low density corrosion resistant, electricity conductor, non-magnetic, non-combustible highly reflective heat barrier and conductor, malleable and can be easily worked [1]. Depending on its purity, for example 99.996 per cent pure aluminium has a tensile strength of about 49 MPa, rising to 700 MPa following alloying and suitable heat treatment [2-5]. There are numerous other aluminium properties which are of particular use in a number of chemical and industrial applications. Al (6063) alloy has medium strength property, and is readily suited to welding, high specific strength and stiffness; improved high temperature property controlled thermal expansion resistance, and improved wear and attraction resistance [6].

Precipitation hardening of 6xxx aluminium alloy has resulted in its exceptional increase in strength [7]. The 6xxx aluminium alloy series which are known to have good extrudability, low density, good corrosion resistance, good weldability and low cost are used in construction and for automotive applications. The 6XXX series of Al-Mg-Si alloys are widely used as medium strength structural alloys which have the advantages of good weldability, corrosion resistance, and immunity to stress corrosion cracking [8-9]. The increased use of this aluminium alloy series in automobile and aircraft applications is hinged on their light weight (low fuel consumption), high resistance to atmosphere attacks and high thermal and electrical conductivities. In the aircraft application of this alloy, it can be used to manufacture the wing spars, fuselages, landing gear and the skin in plates [10].

In 6063 aluminium alloys, the contents of silicon and magnesium are commonly present in the range of 0.5-1.2wt%, with Si/Mg ratio larger than other elements [11]. Silicon content above this stated range in 6063 aluminium alloy will result in the formation of such phases as Al-Fe-Si and Al-Fe-Si-Mn apart from the secondary Mg_2Si phase [12]. The Iron in the above intermetallics is present as an impurity, and has low solubility in aluminium [13]. Solid solution strengthening or second phase hardening process has been used to improve the strength of these alloy series [7].

Mg_2Si (magnesium-silicide) is the primary hardening phase in these alloys, and the strength of the alloy is dependent on the size, volume fraction and distribution of magnesium-silicide precipitates. The hardening effects result from dislocation interaction with the precipitates acting as obstacles to the dislocation motion. Since volume fraction, chemical composition and morphology of intermetallic phases exert significant effect on the practical properties of 6xxx type Al alloys, it is also important to know where, when and what kind of intermetallic may form during solidification process [14].

Corresponding author: muideenbodude@yahoo.com (Bodude. M.A)

ICID: 1049208 (Index Copernicus)

This work discussed the magnesium addition (from 0.48 to 7.5wt %) on the microstructure and properties of 6063 Al alloy with a view to extending its engineering application.

2. Materials and Methods

2.1 Materials

The AA6063 aluminium alloy and magnesium ingot used for this work were obtained from Aluminium Rolling mills, Ota and Owode Onirin, Lagos, Nigeria respectively. The nominal chemical composition of the 6063 Aluminium alloy used is presented in Table 1.

2.2 Methods

The AA6063 aluminium alloy was melted in a low frequency induction furnace at 710^0 C, held for 15 minutes to attain homogeneity and tapped at 690^0 C. Subsequently, predetermined amount of magnesium was added to the molten aluminium alloy at 680^0 C in a preheated ladle. The weight percent mixing composition employed is presented in Table 2 where Si, Fe, Mn, Cu, Zn, Cr, Ca and Sr are the balance. The cast samples which were thirty-two made up 20 mm diameter rods and 150 mm in length. The sample was produced in green sand mould.

After shakeout and cleaning, the samples were heat-treated at 100-110, 200-210 and $400\text{-}410^0$ C in a muffle furnace for 1 hr and then cooled in air.

The heat treatment process was subsequently followed by mechanical and metallographic tests. The Rockwell hardness test for the cast samples was conducted on a 15 mm x 10 mm test pieces. Both grinding and polishing of treated samples were carried out starting with coarse filing and finishing using a motor-driven emery belt. A load of 100 kg was applied on the test piece for 15 seconds and the diameter of the impression measured. Tensile test pieces were prepared from the samples to ASTM E-8 standard and these were subjected to a 10 kN load from an Instron Universal tensile test machine. Impact test was carried out on 10 mm x 60 mm test pieces with a V notched angle of 45^o using a fully instrumented Avery Impact Testing Machine at 27^oC while maintaining a uniform striking velocity. A microstructural test piece of 30 mm x 30 mm x 30 mm was cut from each of the samples. These were successively ground using 80, 200 and 600 microns grades of emery papers. The ground surfaces were washed with water, polished on a rotating cloth pad with diamond paste and etched for 2 minutes in a solution containing mixture of 10g ferric chloride, 30 cm^3 HCl and 120 cm^3 distilled water. Photomicrographs of etched test pieces were taken using a digital metallurgical microscope at 100x magnification.

Table 1: Nominal Chemical Composition of AA6063 Aluminium Alloy

Element	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Zn**	**Cr**	**Ti**	**Ca**	**Sr**	**Al**
Wt%	0.441	0.199	0.000	0.022	0.482	0.003	0.0008	0.011	0.000	0.000	98.8

Table 2: Wt% of Magnesium in 6063 Aluminium Samples

Sample /Plate No.	**Wt%Mg/Wt%Al**
Control sample 1/Plate 1	0.48%Mg/98.838%Al
Sample 2/Plate 2	1.48%Mg/97.838%Al
Sample 3/Plate 3	2.48%Mg/96.838%Al
Sample 4/Plate 4	3.48%Mg/95.838%Al
Sample 5/Plate 5	4.48%Mg/94.838%Al
Sample 6/Plate 6	5.48%Mg/93.838%Al
Sample 7/Plate 7	6.48%Mg/92.838%Al
Sample 8/Plate 8	7.48%Mg/91.838%Al

3. Results and Discussion

3.1 Impact Energy and Fracture Stress

The influence of magnesium addition on impact energy absorption of AA6063 aluminium alloy at different heat treatment temperature is displayed in Figure 1. Impact energy values increased with increase in % composition of magnesium for all the heat treatment temperatures with the highest value of 13.55 J for both samples 7 and 8 at 25-27^{0}C. At this temperature, addition of 0.48 to 3.48 % magnesium caused increase in impact energy from 2.71 J to 16.26 J. Further increase in magnesium addition up to 5.48 % has no significant effect on the impact energy as its value remains 16.26 J. When the heat treatment temperature was increased to 110^0 C, appreciable increase in energy absorption from 8.1 to 12.2 J was observed as the magnesium addition increased from 0.48 to 3.48 % and above this the energy absorption remained 12.2 J up to 7.48 wt% Mg. Further increase in magnesium levels caused increase in energy absorption tremendously to saturation point before descending.

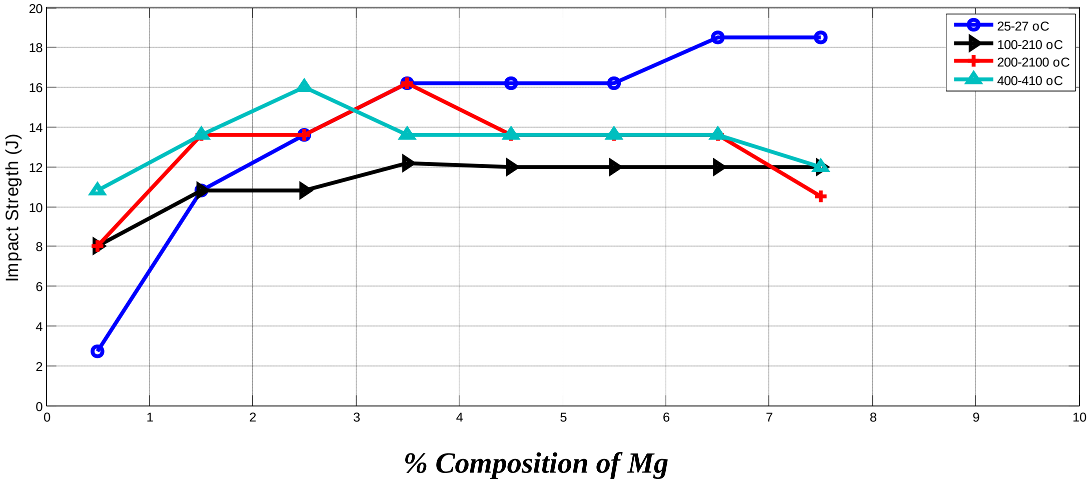

Figure 1: Impact strength against % Composition of Mg

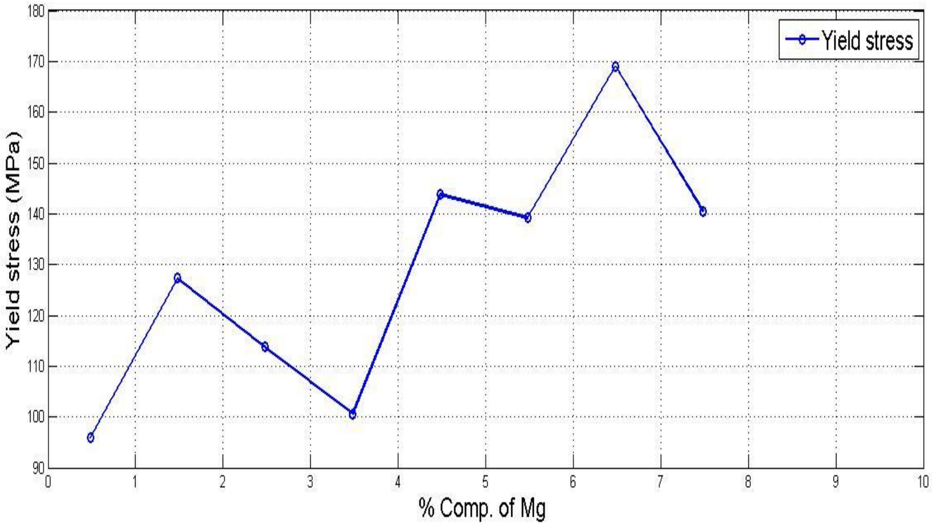

Figure 2: Yield Stress of Mg inoculated 6063 Aluminium Alloy

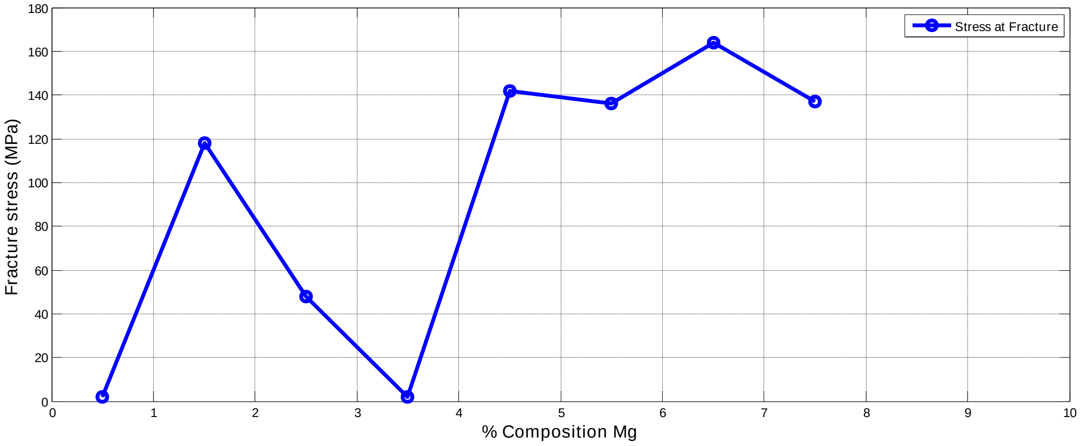

Figure 3: Stress at Fracture of Mg inoculated 6063 Aluminium Alloy

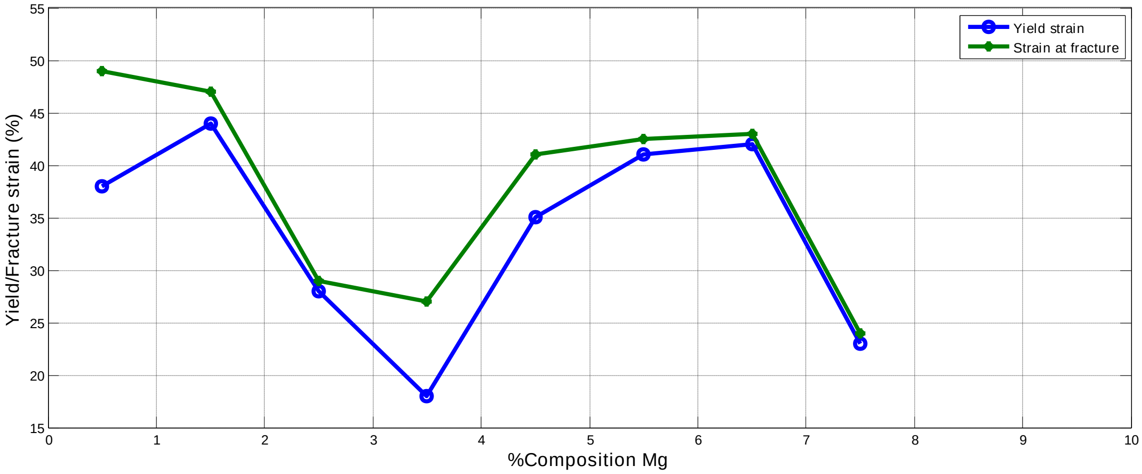

Figure 4: Yield/Fracture of Mg inoculated 6063 Aluminium Alloy

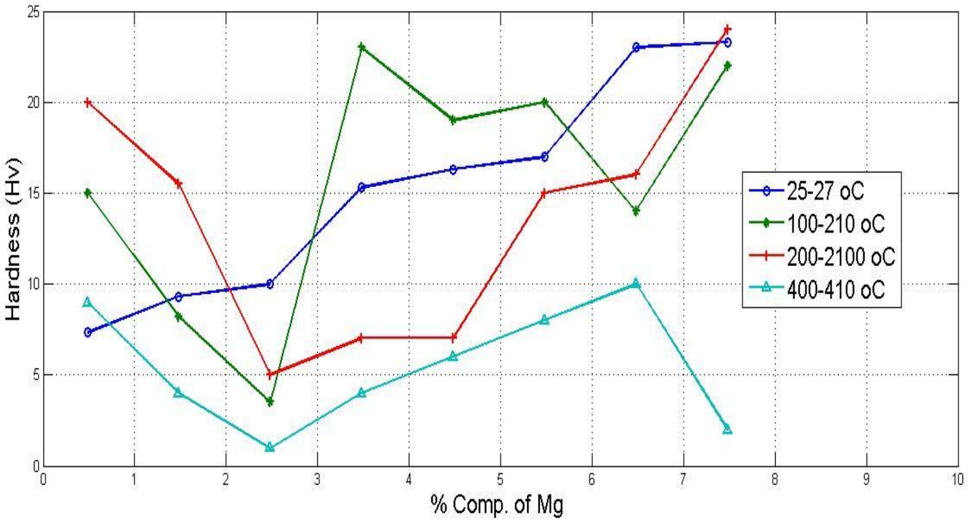

Figure 5: Hardness against % Composition of Mg

Figure 2 shows the yield stress variation with magnesium addition. From this figure, the peak yield stress of the aluminium alloy is about 169 MPa and achieved at 6.48% Mg addition. Furthermore, Figure 3 shows the peak stress at fracture to be 164 MPa which also occurs at this level of Mg addition. The fracture stress is also highest for sample 7, strain at yield and fracture are highest for sample 7 also, this shows that sample 7 gave the best mechanical properties. Figure 5 is the plot of hardness versus Mg addition, from this figure the hardness value was highest for sample 8 for all heat treatment temperatures except for at 400-410^{0}C.

3.2 Micrograph

The results of the microstructural analysis are shown in figures 6a to 6h. Figure 6a shows the α-aluminium white phase with the crystal being in the sample matrix while the second pronounced phase appears brownish and corresponds to distribute Al-Mg-Si intermetallic which is coarse form. The third phase is light green in color and other phases made up of the impurities present in the alloy are evident but not too pronounced. The dark spots on the sample matrix indicate the presence of voids.

The increase in the percentage of Mg addition hinders for the formation of the inter-metallic bonds between Aluminium and other impurities and in effect increases the tendency for bond between Al-Mg. This is shown by the decline in the brown phase with a corresponding increase in the light green phase (Figure 6b). This occurrence tends to increase in intensity up to 5.48% Mg addition with a fairly even distribution. At 6.48 and 7.48% Mg (Figure 6g and 6h) the microstructures show a balance distribution of phase between the brown and light green phase in the aluminium alloy matrix. A fine phase is observed in figure 6h where the composition of Mg is 7.48.

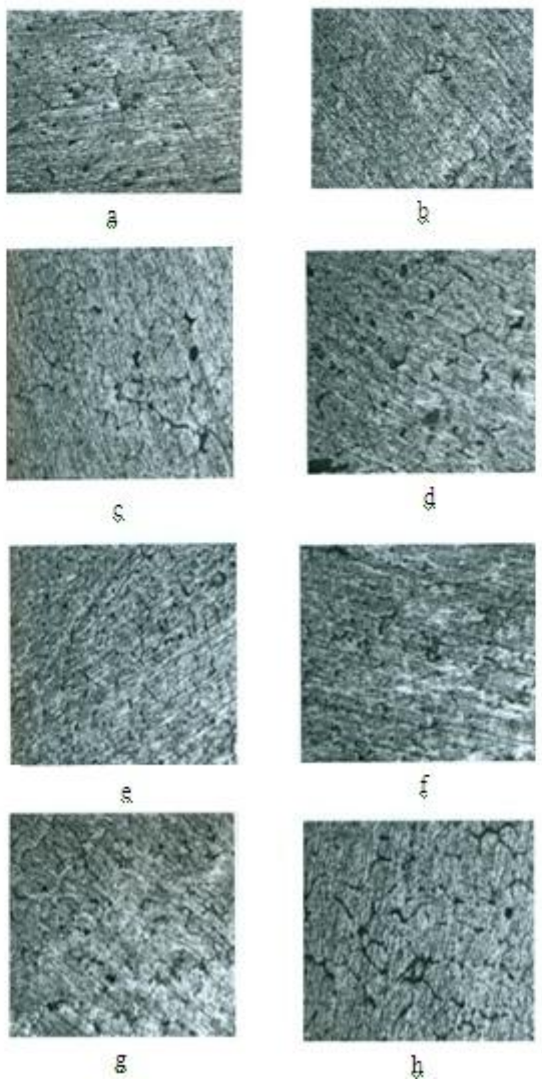

Figure 6: Morphologies of Mg inoculated 6063 aluminium alloy sample containing (a) Control, 0.48; (b) 1.48; (c) 2.48; (d) 3.48; (e) 4.48; (f) 5.48; (g) 6.48; (h) 7.48 percent Magnesium

4. Conclusion

The following can be concluded from this research work:

1. The mechanical properties of the alloy show an improvement with increase in percent addition of magnesium and its best properties obtained at 6.48% Mg.
2. It was observed from the study that as the temperature increased from room temperature there was corresponding decrease in hardness as compared to what was observed at the lower treatment temperatures despite the increase magnesium addition. This trend conforms to the fact that the high temperatures tend to soften the bonds between solute atoms and the matrix which gave rise to increased dislocation movement when the sample was under an applied load.
3. The extreme loss of hardness of the alloy at 400-410^{0}C could be attributed to proximity to the recrystallization temperature of the alloy (420-427^{0} C).
4. The results obtained from this study are useful for engineering purposes for temperatures not more than 410^{0} C.

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