

Influence of Magnesium Addition on Mechanical Properties and Microstructure of Al-Cu-Mg Alloy

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Abstract: The influence of Mg addition on mechanical properties and microstructure of Al-Cu-Mg alloy was investigated. Cast Al – Cu- Mg alloys have widely been used in aircraft, aerospace, industrial and architectural applications for their good mechanical properties, high strength-to-weight ratio. An intensive study of these cast aluminium family has been found in many literature as a source for enhancing the mechanical properties and microstructure of aluminium alloys. The main objective of this paper was to investigate the effect of magnesium on mechanical properties and microstructural changes of Al₄Cu alloys. The modifications of Al₄Cu by adding Mg of 0.5 to 2.5 % in the interval of 0.5% mixing with stirrer and casted by gravity die casting, subsequently the specimens were subjected T6 type heat treatment for 6 hr at 180^oC. The effect of Mg and ageing on microstructure was studied by using optical microscope. The mechanical properties such as tensile strength and hardness were studied using universal tensile testing machine and Brinell hardness tester respectively. It was observed that the tensile strength and hardness increased with increase of percentage of Mg. The addition of 2.5% Mg increases the tensile strength by 69.9% while hardness increased by 22%. Samples that were aged showed that with addition of 1% of Mg had effect on grain refinement and mechanical properties of the alloy because of smaller grain size.

Keywords: Al-Cu-Mg alloy, Grain size, Hardness, Tensile strength, microstructure.

1.0 Introduction

Aluminium alloys are used in automotive, aerospace, construction, and shipbuilding industry because of their combination of high strength, low density, durability, machinability, availability and the cost is also very attractive compared to competing materials (Mondolfo). Because of the excellent strength vs. density ratio, formability and corrosion resistance, Al-Cu-Mg alloys are potential candidates for a numerous industrial applications (Yang, Hunt, Edmonds, 1993). Even though, due to their high specific strength, they are mainly considered as a substitute of iron-based on mentioned metallic system are now being considered and developed (Zlucicanin, et al (2003).

Magnesium increases the strength and hardness of the alloys, but especially in castings, this is accompanied by a decrease in ductility and impact resistance (Garg, Howe, 1992). Standard industrial aluminium-copper alloys solidify with the formation of a dendrite structure, however, a tendency to form with a globular structure at higher copper contents was reported (Muhammad Riaz Khan, et al, 2008).

This paper present an investigation that was done on the as-cast structure of Al-Cu-Mg system over a wide range of magnesium contents in order to know the effect of magnesium content on the microstructure and mechanical properties of Al-Cu-Mg alloys. Depending upon the alloy composition (Cu contents and Cu/Mg ratio), different phase distributions and consequently different Al-Cu-Mg alloys having a copper content of 4wt% and Cu/Mg ratio 4:2.5, 4: 2, 4: 1.5, 4:1, 4:0.5 respectively, is done by quantitative microstructure analysis and hardness and tensile strength determination. The materials investigated consist of aluminium as a primary constituent and copper is the major addition with magnesium 0-2.5wt% varied in steps of 0.5wt%.

2.0 Methodology

2.1 Alloy Preparation

The material used for this work was purchased in Kaduna from aluminium construction company (NOCACO) and were prepared according to the normal process (melting Al plus Mg). The compositions were melted in an electrical resistance furnace, using graphite crucible. The molten metal was poured into permanent cylindrical die of diameter 25 mm with 200 mm long. Die was preheated to 185^oC. The composition of the alloy was determined using Optical Emission Spectrometer at Nigerian Foundry plc.

The experimental work was divided in two phases. The first phase consists of specimen preparation such as melting, casting and ageing heat treatment of samples with different compositions in the aluminium-copper-magnesium (Al-Cu-Mg) system. The second phase includes mechanical characterization like ultimate tensile strength, yield strength, hardness and microstructural studies using optical microscope of as-cast and heat treated samples.

2.2 Mechanical Tests

Mechanical Tests such as Tensile and Hardness were conducted according to ASTM standards. In the present study, the tensile test was conducted to using a standard 30 ton capacity Servo-hydraulic universal testing machine of model UTES-30. The test was carried out at room temperature and in accordance with ASTM A370 standards. Three specimens were tested and average values of the Ultimate Tensile Strength are reported. In the present study, hardness of the specimens was measured by using a standard Brinell hardness testing machine. The hardness test was conducted in accordance with ASTM E10 standards. Six readings were taken for each specimen at different locations to circumvent the possible effect of any alloying element segregation and the average value was considered.

3.0 Results and Discussion

The Chemical composition test was carried by Optical Emission spectrometer. Table 1 shows the chemical composition of the developed alloys.

Table 1. Chemical composition of developed Al-Cu-Mg alloys

Mg content (%)	Type of alloy	% Cu	% Mg	% Fe	% Si	% Mn	% Ti	% Zn	% Al
0.00	AlCu ₄ Mg	4.25	0.00	0.26	0.24	0.3	0.02	0.04	Bal.
0.50	AlCu ₄ Mg	4.30	0.79	0.26	0.24	0.3	0.04	0.04	Bal.
1.00	AlCu ₄ Mg	4.38	0.98	0.28	0.24	0.4	0.05	0.06	Bal.
1.50	AlCu ₄ Mg	4.30	1.50	0.28	0.24	0.4	0.05	0.06	Bal.
2.00	AlCu ₄ Mg	4.75	1.97	0.28	0.24	0.4	0.05	0.06	Bal.
2.50	AlCu ₄ Mg	4.89	2.28	0.30	0.24	0.40	0.06	0.07	Bal.

Table 2. Mechanical properties of developed Al-Cu-Mg alloys

Mg content (%)	Type of alloy	Tensile strength (MPa) As cast alloy	Tensile strength (MPa) Heat treated alloy	Yield strength (Mpa). As cast alloy	Hardness (BHN) As cast alloy	Hardness (BHN) Heat treated alloy
0.00	AlCu ₄ Mg	101.89	110.80	86.69	72.20	90.20
0.50	AlCu ₄ Mg	105.80	134.02	92.40	73.50	91.00
1.00	AlCu ₄ Mg	120.04	139.50	100.60	90.20	92.00
1.50	AlCu ₄ Mg	122.50	219.40	103.20	90.80	96.80
2.00	AlCu ₄ Mg	159.98	140.10	125.60	90.90	90.00
2.50	AlCu ₄ Mg	172.06	110.05	136.00	94.20	92.00

3.1 Mechanical properties

The mechanical properties of the different form of samples with various compositions were studied. The tensile properties of the Al alloys under investigation were determined using universal tensile testing machine as observed in Table 3 and Figures 1 and 2. It was clear that the tensile strength increases with increase of % Mg. the hardness values are shown in Table 2. As we can observed, that the hardness behaviour of these materials follow the same trend as the tensile strength, where the change in the chemical composition of the alloy causes changes in the structure that are reflected on the hardness and the tensile strength. By increasing the content of magnesium, hardness and the tensile strength also increases with reference to as-cast condition. Fig.1 and Fig 2 shows that for 1% of magnesium the alloy exhibits maximum strength in terms of UTS and hardness this is may be due to smaller the grain size. Figure 3 shows standard schematic tensile test sample as stipulated by ASM

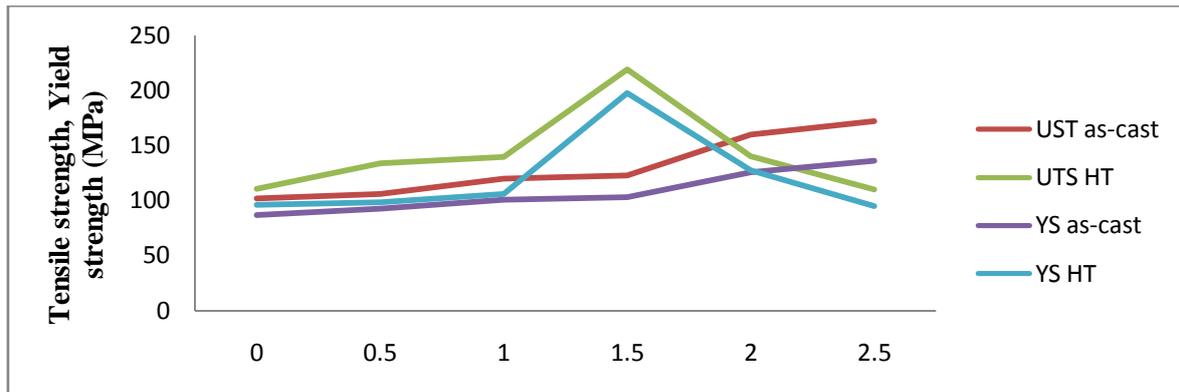


Fig. 1. Tensile properties versus Mg content

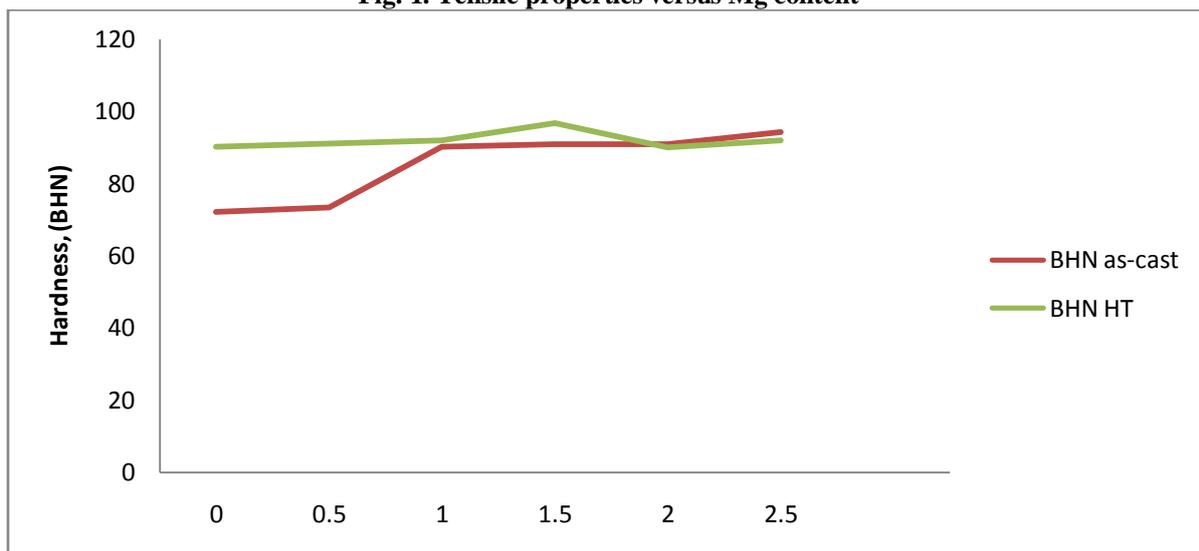


Figure 2. Hardness versus magnesium content

The constituents formed in the alloys containing only one or more of copper, magnesium etc, are soluble ones. In $\text{AlCu}_4\text{Mg}0.5$ alloy in which the copper; magnesium ratio is in the range 8:1 to 4:1 the main hardening agents are Al_2Cu and Al_2CuMg both are active. In $\text{AlCu}_4\text{Mg}1$, $\text{AlCu}_4\text{Mg}1.5$, $\text{AlCu}_4\text{Mg}2$ and $\text{AlCu}_4\text{Mg}2.5$ alloys in which the Cu/Mg ratio is in the range between 4:1 and 1:0.5 Al_2CuMg controls the properties.

3.2 Microstructural analysis

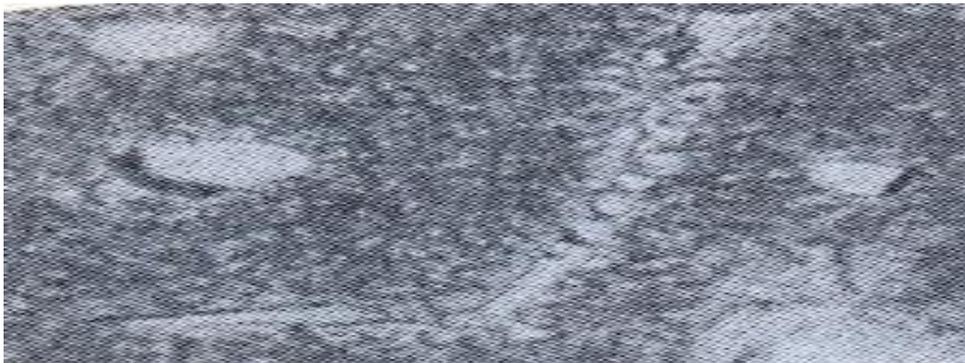
Optical microscope was used for microstructural studies of the as-cast and heat treated alloys of Al-Cu-Mg alloys. The specimens were grinded with emery paper of different sizes, polished with polishing agent and etched with Keller's reagent for metallographic analysis.

The copper content in the standard AlCuMg alloys was up to 4 wt% that represents the maximum solid solubility of copper in aluminium at the eutectic temperature of 548°C . As we have observed that these investigated AlCuMg alloys have dendrite-cellular structures. Figure 4 (a, b), shows the micrographs in as-cast condition consisting of dendrites of aluminium solid solution as the primary phase, with a eutectic mixture filling the interdendritic spaces. The second phase can be an intermetallic compounds that contain aluminium with one or more alloying elements (Al_2Cu and Al_2CuMg) intermetallic compounds that do not necessarily contain aluminium (Mg_2Cu or MgCu_2) or alloying elements, such as copper or magnesium, depending on the composition of the alloy. This was in agreement with Girisha and Sharma (2012) who concluded that Figures 4 and 5 show the microstructure of the prepared as-cast and heat treated alloy consisting of eutectic grey phase and Aluminium-rich phase, while the eutectic surrounding has a mixture of copper and magnesium phases. The dark regions showed intermetallics like Al_2Cu and Al_2CuMg (ϵ).

a)



b)



c)

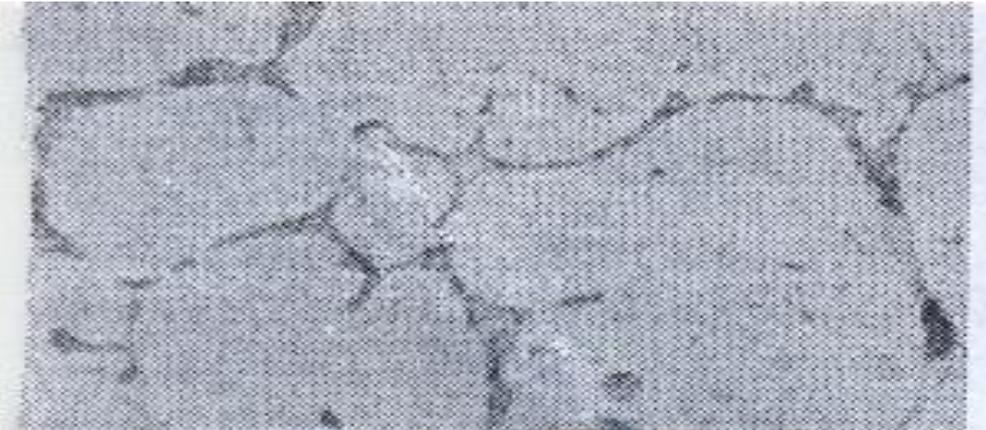


Figure 4. Micrographs of as-cast samples of Al₄Cu alloy: a) 1% Mg, b) 2% Mg, c) 2.5% Mg

a)



b)



c)



Figure 5. Micrographs of heat treated sample of Al₄Cu alloy: a) 1% Mg, b) 2% Mg, c) 2.5% Mg

4.0 Conclusions

1. Magnesium addition increases the hardness, tensile and yield strength of the alloys in castings but with decrease in ductility of cast alloys.
2. In the range of magnesium additions tried, the sample containing 1.5% is seems to be a most favourable alloy in terms of tensile strength, yield strength and hardness both in as cast and heat treatment condition.
3. Heat treated Al- Cu-Mg alloys had improved mechanical properties when compared with as-cast alloys.
4. Addition of magnesium to Al-Si alloys beyond 1.5% Mg causes decrease for both the strength and hardness of the alloys. However, heat treated samples with composition of Mg from 0.1-1.5% have shown an improvement on mechanical properties as compared to as-cast alloys.

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