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The Effect of Magnesium and Heat Treatment on the Hardness as well as Microstructures of Aluminium Copper Binary Alloys

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***Abstract:** Cast Al – Cu- Mg alloys have been widely applying in aircraft and aerospace industries since many years due to their extraordinary mechanical properties like super strength and super strength-to-weight ratio. In this research an intensive investigations have been made on their mechanical behaviors and microstructural changes due to casting magnesium and copper with mother Aluminium cast. The hardness profile indicates the great effect of magnesium and copper when doped with Aluminium cast. Heat treatment for 2 hours at 380^{0}C has been conducted for observing the mechanical properties changes and microstructural also. The effect of Magnesium and ageing on microstructure was analyzed by Scanning Electron Microscope (SEM) and optical microscope. Moreover, the chemical compositions were determined using Optical Emission Spectroscopy (OES) and EDS analysis.*

***Index Terms**: Aluminum-copper-magnesium alloys, effect of magnesium, heat treatment effect, Microstructural changes.*

I. INTRODUCTION

The best known characteristic of aluminum is its light weight. Aluminium alloys are used in engineering design chiefly for their light weight, high strength-to-weight ratio, corrosion resistance, and relatively low cost. Certain aluminium alloys have a better strength-to-weight ratio than that of high strength steels. They are also utilized for their high electrical and thermal conductivities, ease of fabrication and ready availability. An ultra-pure form of Aluminium is used for photographic reflectors to take advantage of its high light reflectivity and no tarnishing characteristics. Generally the metal castings have conventionally been cast iron. though, with a better importance on growing the effectiveness of the engine via weight decrease, producers have begun to seem for different alloys that are lighter than cast iron, which lead the manufacturing to move to aluminum alloys and other nonferrous alloys, such as magnesium which they consider can retaining the essential potency to carry on the same forces as cast iron The weight of a car influences fuel expenditure and performance, with more weight consequential in increased fuel consumption and decreased performance. According to a research conducted by Julian Allwood of the University of Cambridge, global energy use could be profoundly reduced by using lighter cars, and a common weight of 500 kg has been said to be well attainable. The majority of aluminum is utilized for car parts such as cylinder heads, pistons, radiators, car's body and wheel rims. It was been published that one kilogram of aluminum, used to substitute heavier materials in a car or light truck, has the prospective to get rid of 20kg of CO_2 over the life duration of the vehicle. The relation between vehicle mass and fuel consumption as a requirement for light weight automotive is mounting day by day, manufacturers are start seeking for lighter material than aluminum. In early 1990's, automobile industry has begun to endow in magnesium material where they showed the lightest of all the frequently used metals and thus, make it very good-looking for application in transportation. With a weight approximately 30% lighter than aluminum and 60% lighter than steel, magnesium confirmed that it is the lightest of the structural metals. Choosing the precise alloy for a given application entails considerations of its mechanical and other properties. These properties can be basically modified by shifting the alloy composition. Si, Cu, Zn and Mg are the most frequently used alloying elements in aluminium, which have adequate solid solubility. Aluminium alloys are second in use only to steels as structural metals. Structural components made from aluminium and its alloys are vital to the aerospace industry and are significant in other areas of transport and structural materials. The as-cast microstructure of cast Aluminium alloys normally displays considerable segregation and super saturation .For this, homogenization of aluminium alloys is frequently done to get better workability and mechanical properties by dissolving the non-equilibrium, brittle, inter-dendritic constituents and by given that a more homogeneous structure throughout the ingot .

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II. EXPERIMENTAL PROCEDURE

A. Materials

For making the master alloy some piston alloy products were taken and melt together. In the next step, some Cu wire and master alloy were used to change the alloy composition.

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Depending on the Spectrometry of the Master alloys the composition of the alloys is as below

Table 1: Composition of the Al alloys

Alloy	Al	Cu	Mg	Si	Fe	Mn	Zn
AlCu3	95.69	2.78	0.06	0.14	0.06	0.00	0.03
AlCu6	92.8	5.69	0.07	0.14	0.22	0.004	0.02
AlCu3Mg1	98.1	2.67	0.44	0.5	0.0007	0.00	0.03
AlCu6Mg1	93.13	6.01	0.57	0.09	0.17	0.00	0.024
AlMg1	97.39	0.00	1.58	0.34	0.28	0.00	0.002

B. Casting Procedures

The raw materials were melt into a Gas fired Crucible pit furnace and were cast in a sand mould in the shape of a long rectangular bar. For changing the alloy composition, again casting was done in Permanent metal mould of circular cross-section (Length- 170 mm, Diameter-17 mm). Before operation, the furnace was preheated. For both alloys, the melt was heated up to 8500C and poured at 8000C. Before adding Cu, the upper layers were skimmed off to get as pure melt as possible. Cu wires were added after the temperature of the melt was about 7000C to ensure better mixing. Before pouring, some degasser was used.

C. Sample Preparation

For OES analysis of the master alloy, small rectangular pieces were cut from the first casting, machined and polished. Primary cutting from main large casting was done using Oscillating Power Hacksaw and small cuts were done by hand hacksaw. For cold deformation of master alloy, cylindrical pieces were made by machining (Length- 50 mm, Diameter- 17 mm, maintaining the ratio L⁄(D=3), according to the ASTM Standard E9–89a). The next alloy of increased Cu content was initially cast in the form of cylindrical rods. Small pieces were cut, machined and polished for OES analysis and heat treatment. Samples for microstudy were prepared by firstly machining with saw and then grinding with grinding wheels. Then these were polished in progressively finer abrasive paper. Final polishing was done using Diamond or Al2O3 powder on velvet paper attached with a horizontally rotating wheel. Samples for hardness preparation were done in the same manner as for microstudy. For both microstudy and hardness measurement, samples were cut into same height of 1.5 cm to avoid any effect of variation.

D. Heat treatment of the Alloys

To get better properties heat treatment was carried out to the Al-Cu Binary alloys with 1% Mg. For this purpose we used the small crucible type furnace at the temperature of 380o C holding time was 2 hours. After passing the determined time 2 hours we quenched it directly in the plain water.

E. Quenching

This is a critical operation and must be carried out to precise limits if optimum results are to be obtained. The objective of the quench is to ensure that the dissolved constituents remain in solution down to room temperature. The speed of quenching is important and the result can be affected by excessive delay in transferring the work to the quench. The latitude for the delay is dependent on section and varies from 5 to 15 seconds for items of thickness varying from 0.4mm to 12.7mm. Generally, very rapid precipitation of constituents commences at around 450°C for most alloys and the work must not be allowed to fall below this temperature prior to quenching.

F. Hardness Testing

The hardness of the alloys at several steps was measured by Universal Testing Machine (Brinell hardness) and Rockwell Hardness Tester (in F scale). Then these values were converted into Rockwell B scale. For hardness test in Brinell scale, a 10 millimeters (0.39 in) diameter steel ball as an indenter with a 500 kgf (4.9 kN; 1100 lbf) force was used for 30 seconds, as it is the standard for softer materials. The indentation is measured and hardness calculated as

$$BHN = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})}$$

Where, P = applied force (kgf)
D = diameter of indenter (mm)
d = diameter of indentation (mm)

The Rockwell hardness test uses a direct-reading instrument based on the principle of differential depth measurement. For Rockwell F or HRF, 60 kgf loads with 1⁄16 inch diameter (1.588 mm) steel sphere indenter was used. Whereas, for Rockwell B or HRB, 100 kgf load is applied with same indenter. Both B and F scale are used for soft metals.

III. RESULT AND DISCUSSION

A. Hardness profile of Al alloys

Depending on the variation of the Cu, Mg in the Aluminium alloys the different Brinell hardness we got as below.

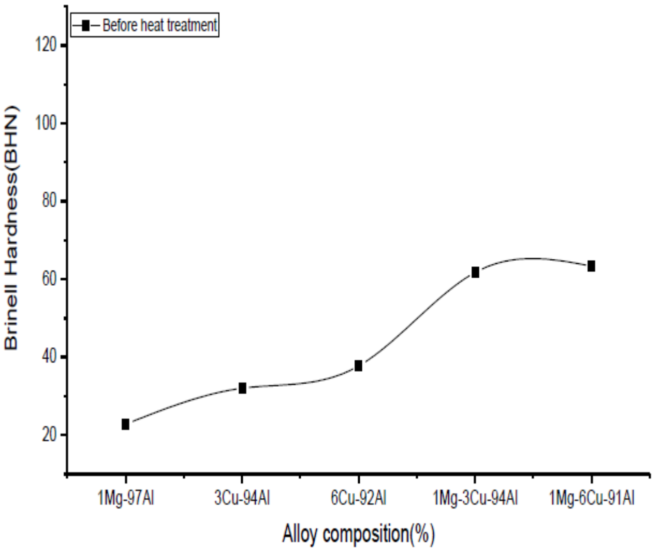

Fig 1: Hardness Profile of Al Alloys before Heat Treatment

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B. The Hardness of Aluminium Alloys after Heat treatment

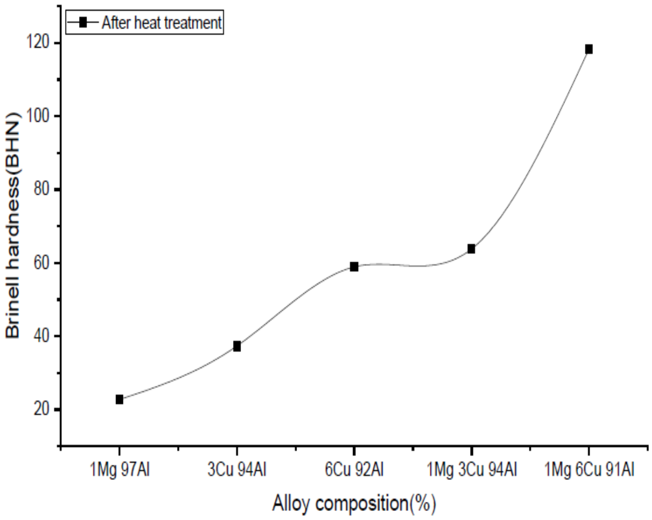


Fig 2: Hardness profile of Al alloys after heat treatment

C. Comparison between Hardness profile of before and after of Heat treatment

The hardness of Al-Cu Binary alloys with 1 % Mg changes due to heat treatment. Because of Heat treatment depending on the percentage of Cu precipitation hardening occurs. As a result the hardness of the Al-Cu Binary alloys with 1 % Mg changes and it has been observed that the hardness of the alloys of written above increases.

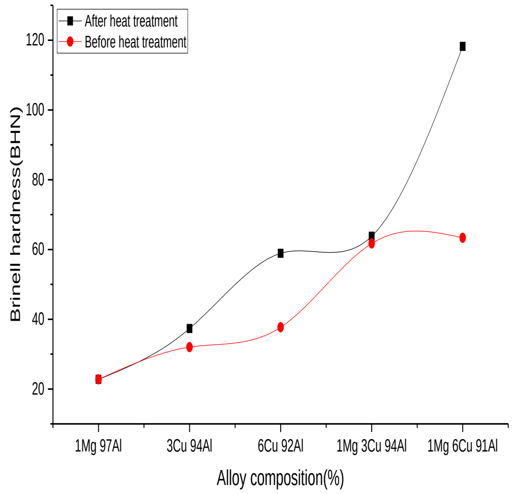


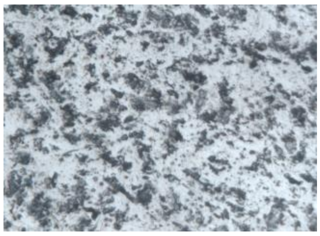
Fig 3: Comparison of Hardness Profile Between Before and After of Heat Treatment

D. Microstructure Analysis

The microstructure of AlMg1 alloys consisting of dendrites of Aluminium solid solution as a primary phase with a eutectic mixture filling the inter-dendritic spaces. The eutectic surrounding has a mixture of Aluminium and Magnesium phases. The second phases may be Al2Mg2 or Al3Mg2.

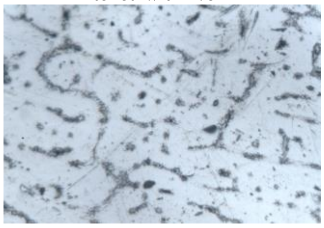
E. Micrographs (As cast)

(a) *AlCu3(0% Mg, 3%Cu), unetched*

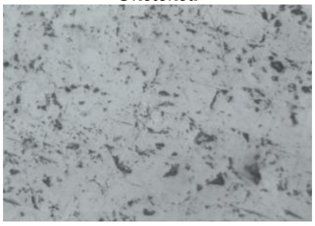


(b) *AlCu3 (0% Mg,3%Cu), Etched with 1%HF*

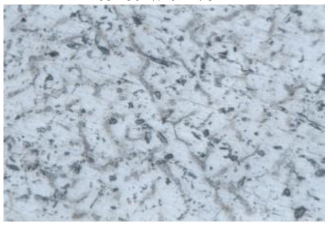
(c) *AlCu3Mg1 (1% Mg, 3%Cu), Unetched*



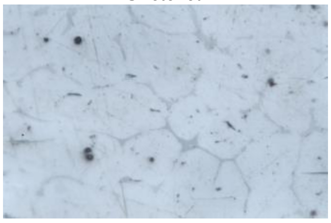
(d) *AlCu3Mg1 (1% Mg, 3%Cu), Etched with1%HF*



(e) *AlCu6 (0% Mg, 6%Cu), Unetched*

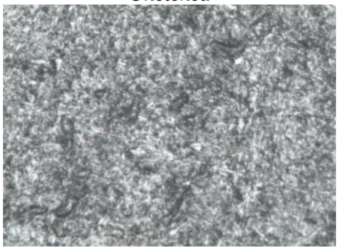


(f) AlCu6 (0% Mg, 6%Cu), Etched with 1%HF

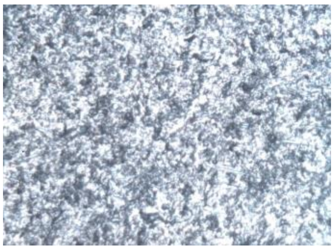


(g) AlCu6Mg1 (1% Mg, 6%Cu); Unetched

(h) AlCu6Mg1 (1% Mg, 6%Cu); Etched with 1%HF



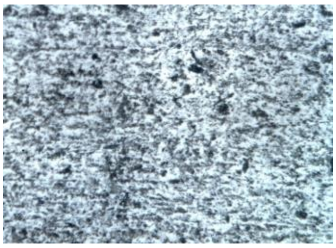
(i) *AlMg1 (1% Mg, 0%Cu); Unetched*



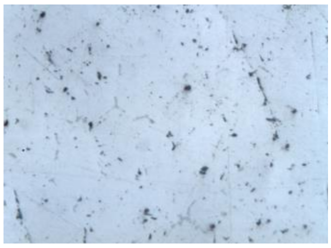
(j) AlMg1 (1% Mg, 0%Cu); Etched with 1%HF

Fig 4: Microstructure of different compositions of Al-Cu Alloys (a to j), all micrographs are in 500X magnification

F. Micrographs as Etched Condition (After Heat Treatment)



(a) AlCu3 (0% Mg, 3%Cu)



(b) AlCu3Mg1 (1% Mg, 3%Cu)

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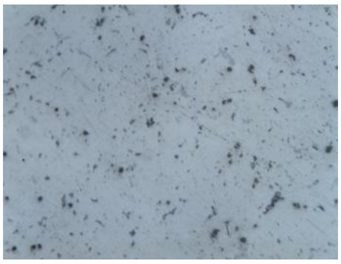
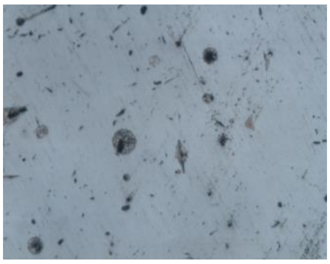
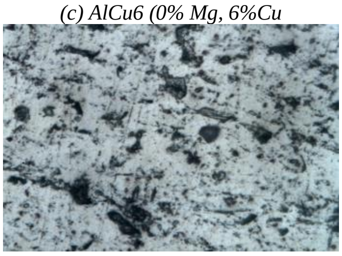


(c) AlCu6 (0% Mg, 6%Cu



(d) AlCu6Mg1 (1% Mg, 6%Cu)

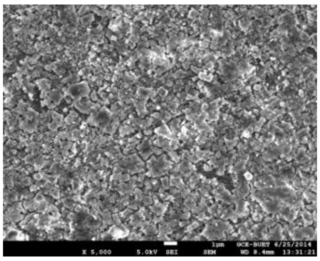


(e) AlMg1 (1% Mg, 0%Cu)

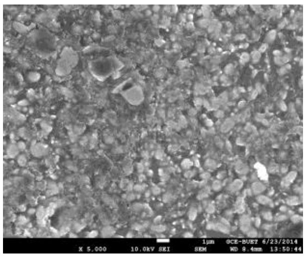
Fig 5: Microstructure of different compositions of Al-Cu alloys (a to e). All micrographs are in 500X magnification

G. Analysis by Scanning electron microscope (SEM)

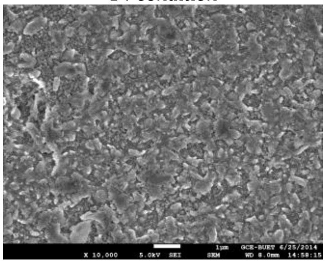
JEOL JSM-7600F, Field Emission Scanning Electron Microscope (FESEM) was used to characterize the surface morphology and grain size of the alloys.



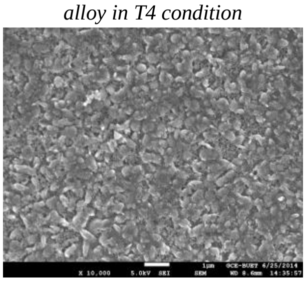
(a) Microstructure of AlCu3 alloy in T4 condition



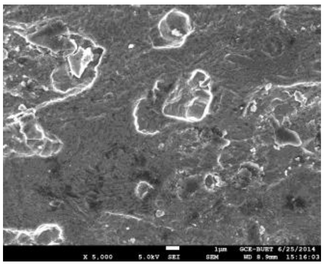
(b) Microstructure of AlCu3Mg1 alloy in T4 condition



(c) Microstructure of AlCu6 alloy in T4 condition



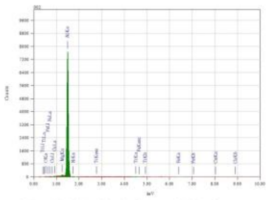
(d) Microstructure of AlCu6Mg1 alloy in T4 condition



(e) Microstructure of AlMg1 alloy in T4 condition

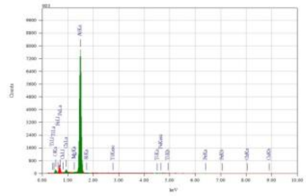
H. Analysis by Energy-dispersive X-ray spectroscopy (EDS)

In order to find out the different elements in the alloys the EDS was done successfully.



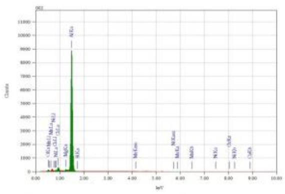
Element	(keV)	Mass%	Sigma	Atom%	Con
O K	0.525	0.74	26709.98	1.24	
Mg K	1.253	0.57	20243.58	0.64	
Al K	1.486	96.96	281802.00		97.0
Si K	1.739	0.45	26108.10	0.43	
Ti K	4.508	0.63	56685.23	0.36	
Fe K	6.398	0.56	104388.30		0.27
Cu L	0.930	0.08	6740.32	0.04	
Total		100.00		100.00	

(a) AlMg1 alloy



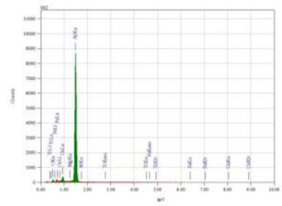
Element	(keV)	Mass%	Sigma	Atom%	Con
O K	0.525	6.84	0.16	11.18	
Mg K					
Al K	1.486	90.02	0.47	87.32	
Si K	1.739	0.23	0.06	0.21	
Ti K	4.508	0.30	0.11	0.17	
Fe K	6.398	0.73	0.29	0.34	
Cu L	0.930	1.88	0.07	0.77	
Total		100.00		100.00	

(b) AlCu3 alloy



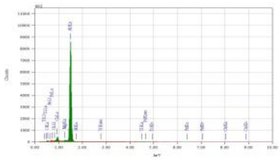
Element	(keV)	Mass%	Sigma	Atom%	Com
O K	0.525	2.63	0.10	4.44	
Mg K	1.253	0.46	0.05	0.51	
Al K	1.486	93.22	0.45	93.42	
Si K	1.739	0.00	0.05	0.00	
Mn K	5.894	0.33	0.20	0.16	
Ni L	0.851	0.90	0.18	0.41	
Cu L	0.930	2.47	0.08	1.05	
Total		100.00		100.00	

(c) AlCu3Mg1 alloy



Element	(keV)	Mass%	Sigma	Atom%	Cor
O K	0.525	4.33	0.13	7.23	
Mg K					
Al K	1.486	92.21	0.45	91.24	
Si K	1.739	0.11	0.06	0.10	
Ti K					
Fe K	6.398	0.41	0.23	0.20	
Cu L	0.930	2.95	0.08	1.24	
Total		100.00		100.00	

(d) AlCu6 alloy



Element	(keV)	Mass%	Sigma	Atom%	Compo
O K	0.525	1.96	1.21	3.34	
Mg K	1.253	0.42	0.50	0.47	
Al K	1.486	93.68	7.89	94.38	
Si K	1.739	0.21	0.50	0.20	
Ti K	4.508	0.04	0.41	0.02	
Fe K	6.398	0.16	1.59	0.08	
Cu L	0.930	3.53	1.27	1.51	
Total		100.00		100.00	

(e) AlCu6Mg1 alloy

Fig 7: Energy-dispersive X-ray spectroscopy (EDS) (a to e)

IV. CONCLUSIONS

From all experiments carried out, we understand the effect of Cu, the effect of homogenization in Al-Cu-Mg alloys. The mechanical behaviors of Aluminium alloy are strongly influenced by the test temperature and the exposure of the time at high temperature. Magnesium addition increases the hardness of the alloys both as cast and heat treated conditions. Heat treated Al-Cu-Mg alloys has improved mechanical properties when compared with as cast alloys. Heat treatment causes dissolution of low melting point phases in the matrix and also causes precipitations causes, thus increases hardness of aluminium alloys.

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