Effect of magnesium on strength and microstructure of Aluminium Copper Magnesium Alloy

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Abstract: Cast Al – Cu- Mg alloys have widely used in aircraft, aerospace, ships and boat making, 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 the literature in terms of enhancing the mechanical properties.
The objective of this paper was to investigate the influence of magnesium on microstrructural changes and mechanical properties such as tensile strength and hardness of the Al4Cu alloys. The modifications of Al4Cu by adding Mg of 0.5 to 2 % 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 5 hr at 175°C. The effect of Mg and ageing on microstructure was studied by using optical microscope with image analysis software for measuring grain size and dendrite arm spacing. The mechanical properties such as tensile strength and hardness were studied using universal testing machine and Brinell hardness tester respectively. The micro-structural analysis result shows the 2 % addition of Mg reduces the 20% grain size and 21.52% dendrite structure. The tensile strength and hardness increasing with % of Mg. The addition of 2% Mg increases tensile strength 57.9% and hardness of 25%. Aging specimens showed that 1% of Mg influence more on grain refinement and mechanical properties due to smaller the grain size.

Keywords: Al-Cu-Mg alloy, Dendrite arm spacing (DAS), Grain size, Hardness, Tensile strength.

1. Introduction

Aluminium alloys are used in advanced applications because of their combination of high strength, low density, durability, machinability, availability and the cost is also very attractive compared to competing materials[1]. Due to excellent strength vs. density ratio, formability and corrosion resistance, AlCuMg alloys are potential candidates for a numerous industrial applications [2]. 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 [3].
Magnesium increases the strength and hardness of the alloys, but especially in castings, this is accompanied by a decrease in ductility and impact resistance [4]. 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 [5] and confirmed in our earlier unpublished work.
In this paper investigation was done on the as cast structure of AlCuMg system over a wide range of magnesium contents in order to know the effect of magnesium content on the microstructure and mechanical properties of AlCuMg alloys. Depending on the alloy composition (Cu contents and Cu/Mg ratio), different phase distributions and consequently different AlCuMg alloys having a copper content of 4wt% and Cu/Mg ratio 4: 2, 4: 1.5, 4:1, 4:0.5 respectively, is done by quantitative microstructure analysis and hardness and tensile strength determination.

2. Experimental details

The investigated materials consists aluminum as a primary constituent and copper is the major addition with magnesium 0-2wt% varied in steps of 0.5wt%.

2.1 Alloy preparation

All experimental alloys were prepared by liquid metallurgy route using pure aluminium (99.8%), electrolytic copper (99.9%), and magnesium.
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 having 200 mm long. Die was preheated to 200°C. The composition of the alloy was determined using Optical Emission Spectrometer.
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 aluminum-copper-magnesium system. The second phase includes mechanical characterization like hardness and ultimate tensile strength and microstructural studies using optical and electron microscope of ascast and heat treated samples.

2.2 Mechanical Tests

Mechanical Tests such as Tensile and Hardness were conducted as per the ASTM standards. In the present study, the tensile test was conducted to using a standard 40 ton capacity Servo-hydraulic universal testing machine of model UTES-40. The test was carried out at ambient temperature and in accordance with ASTM A370 standards. Three specimens were tested and average values of the Ultimate Tensile Strength are reported.

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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. Five 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. 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 the developed alloys (Wt%)

Type of sample	% Al	%Fe	%Si	%Cu	%Mg	%Ni	%Ti
$AlCu_4Mg_0$	95.59	0.135	0.100	4.134	0.000	0.023	0.014
$AlCu_4Mg_{0.5}$	94.87	0.135	0.100	4.434	0.424	0.024	0.014
$AlCu_4Mg_{1.0}$	94.73	0.131	0.100	4.154	0.845	0.023	0.015
$AlCu_4Mg_{1.5}$	93.84	0.139	0.100	4.378	1.311	0.023	0.014
$AlCu_4Mg_{2.0}$	93.22	0.168	0.100	4.563	1.920	0.021	0.013

Table.2. Grain size and dendrite arm spacing (DAS) of Aluminium-copper-magnesium alloys.

Alloy	Average grain size, μm		DAS, μm	
	As cast	5Hr Heat treatment	As cast	5Hr Heat treatment
$AlCu_4Mg_0$	198.50	171.30	42.32	33.26
$AlCu_4Mg_{0.5}$	187.62	165.75	37.77	31.02
$AlCu_4Mg_{1.0}$	176.60	156.25	35.88	28.23
$AlCu_4Mg_{1.5}$	165.87	170.00	34.45	31.58
$AlCu_4Mg_{2.0}$	159.25	174.00	33.21	33.26

Table.3: Experimental results of developed alloys

Alloy	Ultimate tensile strength (MPa)		BHN	
	As cast	5Hr Heat treatment	As cast	5Hr Heat treatment
$AlCu_4Mg_0$	103.52	113.94	71.68	89.7
$AlCu_4Mg_{0.5}$	106.48	133.61	72.75	91.0
$AlCu_4Mg_{1.0}$	118.74	216.79	89.7	91.3
$AlCu_4Mg_{1.5}$	121.09	138.94	89.88	83.2
$AlCu_4Mg_{2.0}$	163.48	113.23	89.88	91.0

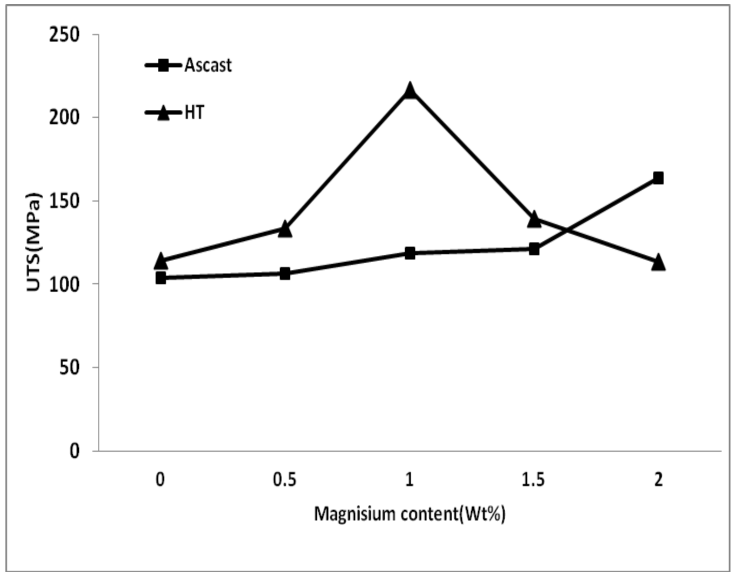

Fig 1: UTS Vs Wt % Mg

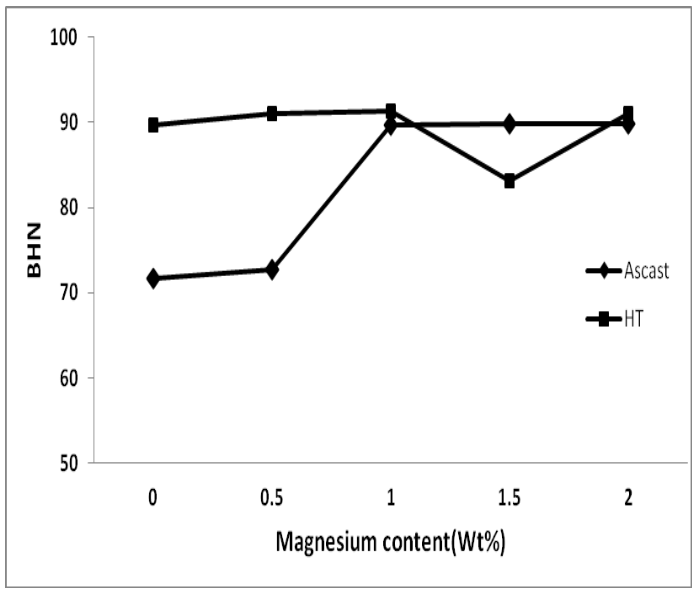

Fig 2: BHN Vs Wt % Mg

3.1 Mechanical properties

The Brinell hardness and the tensile strength are shown in the table 3. The change in the chemical composition of the alloy causes changes in the structure that are reflected on Brinell hardness and the tensile strength. By increasing the content of magnesium hardness and the tensile strength also increases with reference to ascast condition. Fig.1 & 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.

The constituents formed in the alloys containing only one or more of copper, magnesium etc, are soluble ones. In $AlCu_4Mg_{0.5}$ 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 AlCu4Mg1, $AlCu_4Mg_{1.5}$ and $AlCu_4Mg_2$ 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 Microstructure

Optical microscope was used for microstructural studies of the as-cast and heat treated alloys. The specimens were polished and etched 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 548^0C. These investigated AlCuMg alloys have dendrite-cellular structures. Micrographs show the 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 and 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.

The Figs. 3&4 shows the microstructure of the prepared alloy consists of eutectic grey phase and Al-rich phase, while the eutectic surrounding has a mixture of copper and magnesium phases. The dark regions are intermetallics like Al_2Cu and Al_2CuMg (ε).

3.2 Quantitative microstructure analysis

Using automatic image analysis grain size, dendrite-DAS has been measured. Dendrite arm spacing is measured by the intercept method, in the same manner as that of grain size measurement. Dendrite arm spacing is an important consideration in cast aluminum – copper magnesium alloy microstructures. From the experimental results it is clear that the finer dendrite arm spacing imparts higher the strength to the alloy.

The reduction of grain size and dendrite arm spacing, and also improvement in structure uniformity is as shown in table 2. The addition of magnesium has significant effect on the size and shape grains & DAS. As the amount of magnesium increases in the alloy, the average values of the dendrite arm spacing and grain size decreased, results in a fine and uniform grain structure as shown in micrographs. Also it found influence of heat treatment reduces both grain size and DAS when magnesium content approaches 1%, beyond it increases.

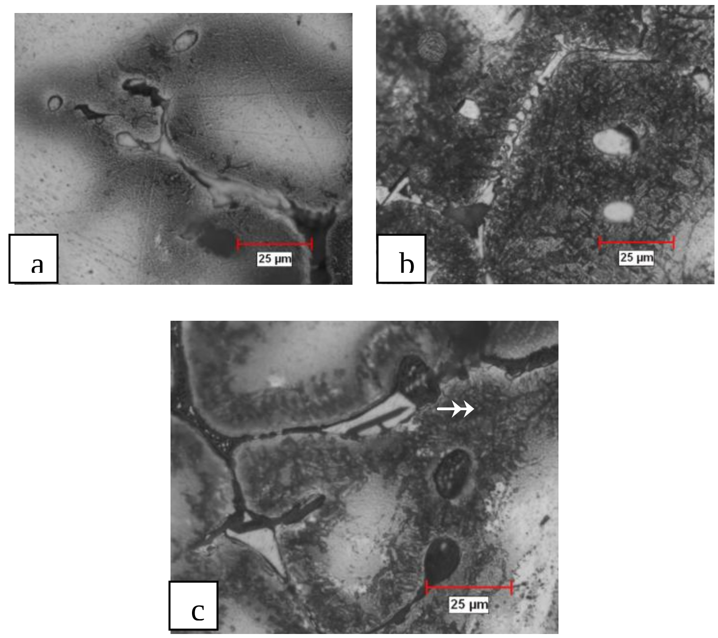

Fig 3: Sample Optical micrographs of Ascast Al4Cu alloy: (a) 1% magnesium, (b) 1.5% magnesium, (c) 2% magnesium
Double arrow: eutectic Phase

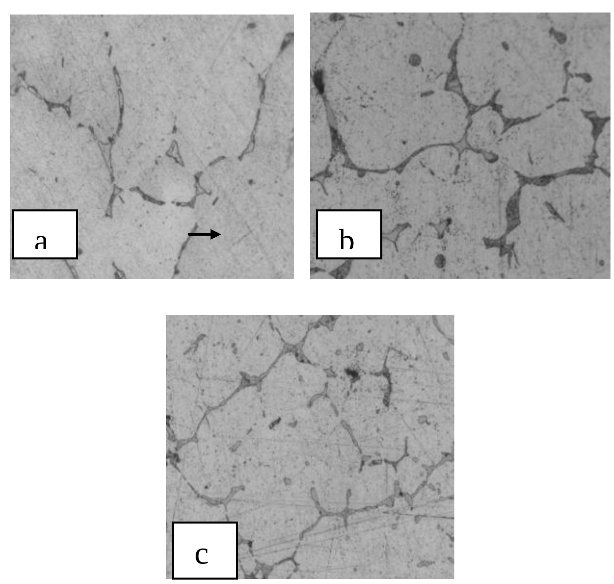

Fig 4: Sample Optical micrographs of Heat treated Al4Cu alloy: (a) 1% magnesium, (b) 1.5% magnesium, (c) 2% magnesium
Single arrow: Aluminium rich phase

ISSN 2229-5518

4. Conclusions

1. It has been observed that the tetragonal intermetallic compound Al2Cu and orthorhombic intermetallic compound Al2CuMg formed across the whole range of Mg additions.
2. With increased amount of magnesium in the alloy, the average values of the dendrite arm spacing and grain size decreased in as cast condition.
3. Brinell hardness and the tensile strength increase with the increase of magnesium content in as cast condition.
4. Fine grain size and dendrite arm spacing obtained at AlCu4Mg1.0 at 5 hr ageing heat treatment.
5. In the range of magnesium additions tried, the sample containing 1% is seems to be a most favorable alloy in terms of tensile strength and hardness both in as cast and heat treatment condition.

4. References

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