Effects Of Magnesium Oxide (MgO) On The Structure And Mechanical Properties Of Al-4%Cu Alloy

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***Abstract*—Aluminium-four percent weight -copper (Al - 4%wtCu) alloy exhibits moderate strength as a result of brittle structure of the intermetallic compound ($Al_2Cu(\theta)$) formed as non-coherent precipitates as the alloy cools slowly to ambient temperature. Hence, this paper focuses on addition of Magnesium oxide (MgO) to melted Al-4%wtCu alloy, in order to refine the grain size and structure, thereby improving the mechanical properties of the alloy. The objective of this work is to study the extent to which each concentration of the oxide influenced the mechanical properties of Al-4%Cu alloy and the concentrations that improved the mechanical property suitable for engineering application. The experiment was carried out by adding MgO in concentrations of 0.75%, 1%, 1.25%, 1.5%, 1.75%, 2% and 2.25% by weight to melted Al-4%Cu alloy, stirred and sand cast. Mechanical tests and micro-examination were carried out and the results established that the MgO can be used to improve the microstructure and mechanical properties of Al-4%Cu alloy.**

Keywords—Refractory Oxide, Microstructure, Mechanical Properties and Al-4%Cu Alloy.

I. INTRODUCTION

Aluminium alloys have been utilized for more than a century. The combination of strength, low density, formability, corrosion resistance, conductivity and abundance nature makes the material ideal for a number of applications (Nnuka, 2002). The alloys have high strength-to-weight ratio and durability which makes them useful for foil and conductor cables (Kissel and Ferry, 1995). Both the automotive and aerospace industries benefit greatly from the high strength-to-weight ratio of aluminium alloys (Wang et al, 2004). The heterogeneous nature of aluminium alloys is most evident in members of the high strength alloys of the 2xxx, 6xxx, 7xxx and 8xxx and most particularly the 2xxx series alloys where alloy additions are required to obtain the high strength to weight ratio properties of these materials (Birbilis and Bucheit, 2005; Hatch, 1984; Castillo and Lavernia, 2000).
Al-4%Cu alloy is distributed in form of individual isolated inclusions between the dendrite cell and grain boundary (Nnuka, 1991). The increase in hardness and tensile strength is due to the interaction of the stress field around the particles with a moving dislocation and also due to physical obstruction by the hard particles to the moving dislocation (Nnuka, 2002). The extent to which strengthening is produced depends on the amount of the second phase particles, the characteristics and properties of the second phase, the particle size, shape and distribution (T. Lipinski, 2010).
Al-4%wtCu alloy being a 2xxx series alloy, exhibits moderate strength as a result of brittle structure of the intermetallic compound ($Al_2Cu(\theta)$) formed as non-coherent precipitates as the alloy cools slowly to ambient temperature (Nnuka,1991; Bourgeois et al, 2011). Hence, this paper focuses on addition of MgO to melted Al-4%wtCu alloy, in order to refine the grain size and structure, thereby improving the mechanical properties of the alloy. To produce Al-4%wtCu alloy with improved mechanical properties, the concentrations of Magnesia (MgO) was varied in the order of 0.75, 1.0, 1.25, 1.5, 1.75, 2.0 and 2.25%wt, in Al-4%Cu alloy.
The extent to which each concentration of MgO influenced the mechanical properties of Al-4%Cu alloy was studied and the concentrations that gave improved mechanical properties were established.

II. METHODOLY

The MgO was added in concentrations of 0.75%, 1%, 1.25%, 1.5%, 1.75%, 2% and 2.25% by weight to melted Al-4%Cu alloy, stirred and sand cast. Subsequently, specimens obtained from the casting were subjected to machining and mechanical properties such as ultimate tensile strength, hardness, yield strength, ductility and impact strength were determined for each specimen using Mansanto tensometer, Rockwel hardness tester and universal impact testing machine, respectively. The microstructure of the samples was also studied using metallurgical microscope with photographs taken.
The following steps were taken for micro-structural examination of the as-cast specimens:

A. Cutting

The specimens were cut to mounting size with the aid of a hack saw.

B. Mounting

The cut specimens were mounted on a thermosetting material.

C. Grinding

The mounted specimens were ground using P220C, P320C, P600C, and P800C grades of water-proof Silicon carbide grinding paper (sequenced from coarse to fine).

D. Polishing

The ground specimens were polished using ECOMET II polisher, after pouring diamond paste on the rotating polishing surface of the ECOMET II polishing machine. This was done to remove the fine surface scratches on the specimens in order to have mirror-like finish.

E. Etching

The polished specimens were etched with Keller's reagent to expose the specimens' surface for micro-structural examination. It was further rinsed in water and dried with METASER specimen dryer.

F. Micro-Structural Examination

The etched and dried specimens were finally subjected to micro-structural examination using an optical microscope, after which the micrographs of (×100) magnification were obtained with the aid of a digital camera linked to a computer, for a visual display of the snapshots.

III. RESULTS

Results on the effect of MgO of 0.75%wt - 2.25%wt concentrations, on mechanical properties of Al-4%Cu alloy are shown in table I.

Table I: The effects of MgO on mechanical properties of Al-4%Cu alloy.

Alloy composition	**UTS (MPa)**	**YS (MPa)**	**EL (%)**	**HB(*10) (MPa)**	**CHARPY IMPACT (J)**
Al-4%Cu	170	140	10.0	80	6
Al-4%Cu-0.75%MgO	150	104	15.6	84	18
Al-4%Cu-1.00%MgO	158	116	14.8	85	16
Al-4%Cu-1.25%MgO	165	126	14.0	86	14
Al-4%Cu-1.50%MgO	194	140	13.8	90	10
Al-4%Cu-1.75%MgO	200	148	12.7	94	8
Al-4%Cu-2.00%MgO	215	158	11.4	98	6
Al-4%Cu-2.25%MgO	222	164	10.1	103	4

Note: EL – Elongation, HB- Brinell hardness, UTS – Ultimate tensile strength and YS – Yield strength.

IV. DISCUSSION OF RESULTS

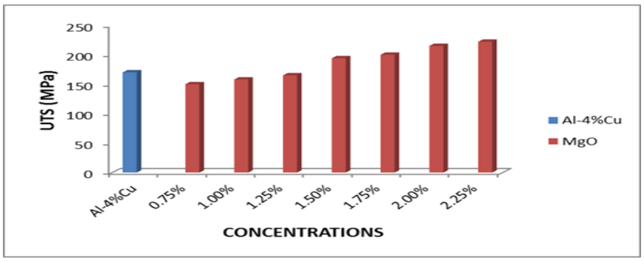

Fig.1.*The Effect of MgO Concentrations on Ultimate Tensile Strength (UTS) of Al-4%Cu alloy*

Figure 1 shows the effect of MgO concentrations on ultimate tensile strength of Al-4%Cu alloy. From Fig.1, addition of some of the concentrations of MgO such as from 1.5%-2.25%, improved the ultimate tensile strength of Al-4%Cu alloy. This was because beyond 1.25% concentration, the grains where refined giving rise to the formation of more grain boundaries which served as the precipitation site for Al_2Cu and Al_2Cu-MgO intermetallic phases. As these intermetallic phases formed and spreaded in the alloy matrix, the ultimate tensile strength of Al-4%Cu alloy was improved.

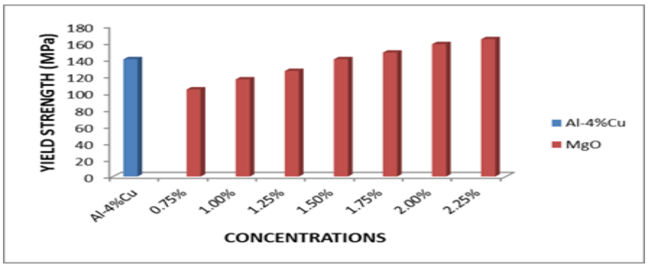

Fig.2. *The Effect of MgO Concentrations on Yield Strength of Al-4%Cu alloy.*

Figure 2 shows the effect of MgO concentrations on yield strength of Al-4%Cu alloy. Yield strength of Al-4%Cu alloy was improved by the addition of some of the concentrations of MgO such as from 1.75%-2.25% as shown in Fig. 2. This was because beyond 1.5% concentration, the grains sizes were more refined and the Al_2Cu and Al_2Cu-MgO intermetallic phases were evenly distributed in the alloy microstructure.

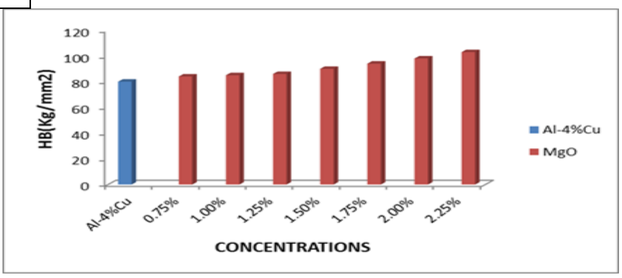

Fig.3.*The Effect of MgO Concentrations on Brinell hardness (HB) of Al-4%Cu alloy.*

Figure 3 shows the effect of MgO concentrations on hardness of Al-4%wtCu alloy. It was observed that the hardness of Al-4%Cu alloy improved reasonably by the addition of all concentrations of MgO and the degree of improvement appreciated as MgO concentrations increased. This improvement in hardness of Al-4%Cu alloy was due to the alloy's grains refinement as MgO concentrations increased in the alloy's matrix.

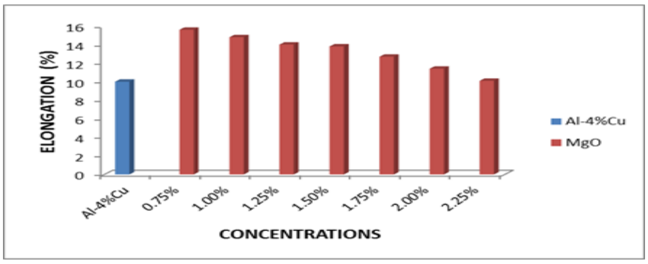

Fig.4.*The Effect of MgO Concentrations on Elongation (Ductility) of Al-4%Cu alloy.*

Figure 4 shows the effect of MgO concentrations on elongation or ductility of Al-4%Cu alloy. The elongation or ductility of Al-4%Cu alloy was improved by the addition of all concentrations of MgO as shown in Fig. 4. However, the impact of MgO decreased with an increase in its concentrations, because of the formation of fine grain sizes as well as Al_2Cu and Al_2Cu-MgO intermetallic phases.

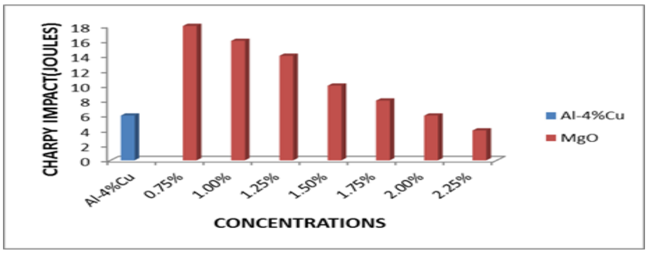

Fig.5. *The Effect of MgO on Impact Energy (Toughness) of Al-4%Cu alloy.*

Figure 5 shows the effect of MgO concentrations on the impact energy or toughness of Al-4%Cu alloy. It was observed that MgO with concentrations 0.75%-1.75% improved the toughness of Al-4%Cu alloy. The toughness of Al-4%Cu alloy decreased with an increase in MgO concentrations beyond 1.75%, because of the rapid formation and distribution of the Al_2Cu and Al_2Cu-MgO intermetallic phases in the Al-4%Cu alloy matrix. Moreover, there was grains refinement in the Al-4%Cu alloy microstructure as the concentrations of MgO increased. This further decreased the toughness of the alloy beyond 1.75%MgO.

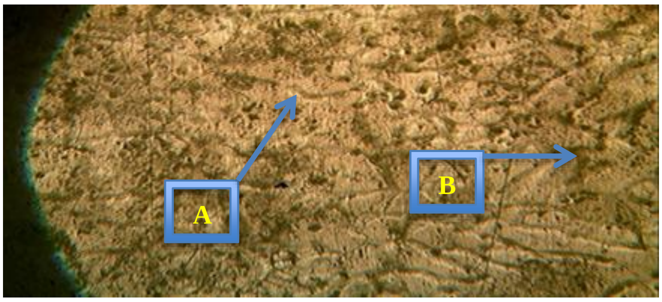

Plate 1: Al - 4%wtCu (X100)

Note: **A –** α-solid solution, **B –** intermetallic compound (Al_2Cu)

The micrograph of the control specimen (Al-4%wtCu) as shown in plate 1 reveals that the microstructure of the specimen comprised of the eutectic α-solid solution (the region where copper formed a solid solution with the aluminium matrix) and the intermetallic compound (Al_2Cu precipitates). The intermetallic compound existed in the form of coarse brittle precipitate from the α-solid solution by the grain boundaries.

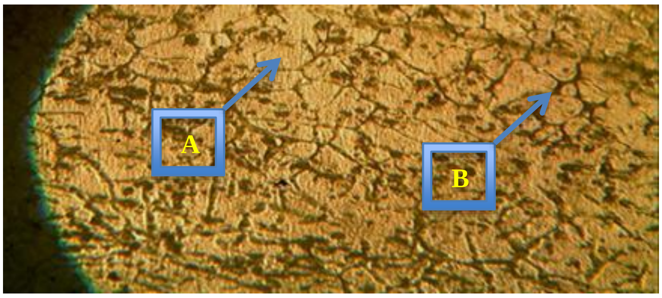

Plate 2. Al-4%Cu - 0.75%wtMgO (X100)

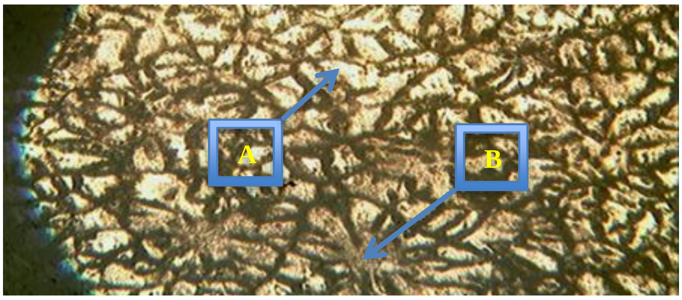

Plate 3. Al-4%Cu - 1%wtMgO (X100)

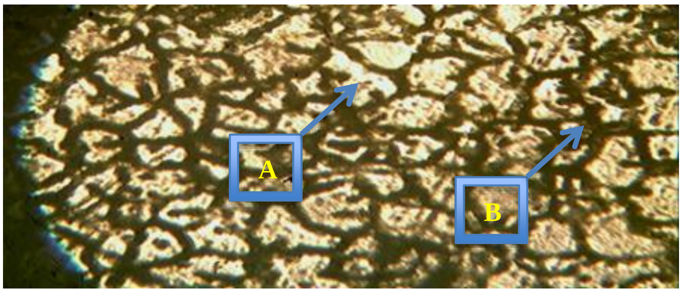

Plate 4. Al-4%Cu - 1.25%wtMgO (X100)

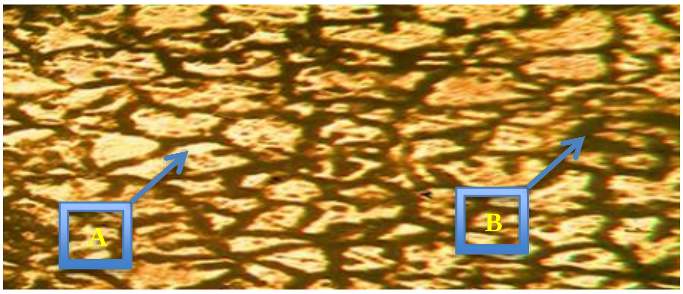

Plate 5. Al-4%Cu - 1.50%wtMgO (X100)

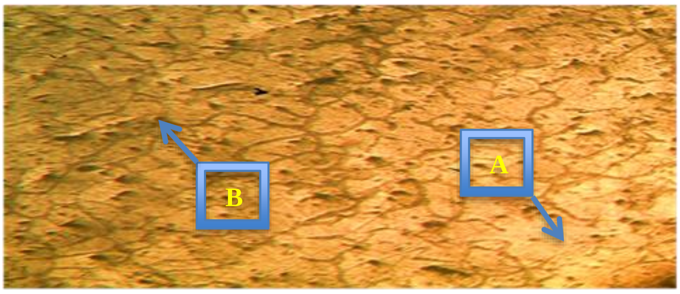

Plate 6. Al-4%Cu - 1.75%wtMgO (X100)

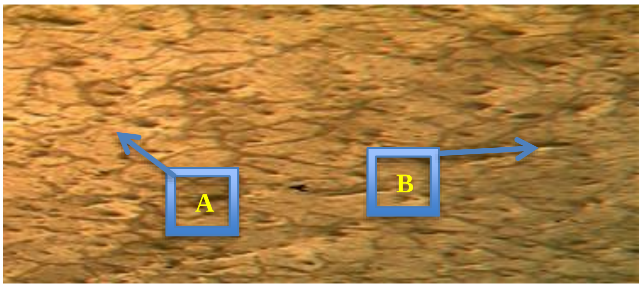

Plate 7. Al-4%Cu - 2%wtMgO (X100)

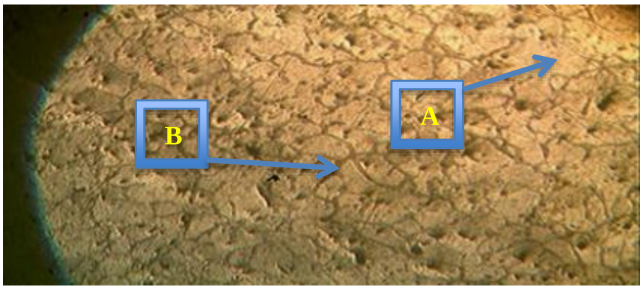

Plate 8. Al-4%Cu – 2.25%wtMgO (X100)

Note: **A** – α-solid solution, **B** – intermetallic compounds (Al_2Cu and Al_2Cu-MgO).

Plates 2-8 show the micrographs of Al-4%Cu alloy doped with 0.75%wtMgO to 2.25%wtMgO. The micrographs show dendrites of aluminium solid solution (α-solid solution) as the primary phase, with a eutectic mixture filling the interdendritic spaces. The second phase comprised of intermetallic compounds (Al_2Cu and Al_2Cu-MgO) which appeared in various amounts and at various locations in the microstructure, depending on the concentration of magnesium oxide. Plates 2-8 also show an increase in precipitates of the intermetallic phases formed and were dispersed evenly as the concentrations of magnesium oxide increased in the alloy matrix.

V. CONCLUSION

The results showed that the addition of the magnesium oxide (MgO) at certain concentrations, improved the mechanical properties of Al-4%Cu alloy. The mechanical properties were improved due to the alloy's grains refinement, the precipitation and distribution of intermetallic phases by the addition of some concentrations of MgO to the alloy.

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