

# Effect of the Addition of Al and Cu on Magnesium Processed by Powder Metallurgy Route

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## Abstract

**Objectives:** Magnesium being HCP structured has the disadvantage of having poor deformation properties at room temperature making it difficult to work below recrystallization temperature. Hence it is necessary to improve the properties of Mg such as hardness and ductility etc. The present work aims to fabricate Mg-3Al-0.3Cu, Mg-3Al-0.6Cu, Mg-6Al-0.3Cu and Mg-6Al-Cu alloys by powder metallurgy route. **Methods/Statistical Analysis:** The effect of both Al and Cu on the mechanical properties of pure Mg was evaluated. The elemental metal powders of Mg, Al and Cu are blended to make homogenized mixture and compacted at 300 MPa pressure to a 30mm diameter billets. The compacted samples were sintered using microwave furnace. The sintered samples are then subjected to microstructural and micro-hardness testing using optical microscope and microhardness tester respectively. **Findings:** Results of microstructural and mechanical tests suggest that the Al and Cu have significant effect on the hardness of Mg by the formation of Mg<sub>2</sub>Cu and Mg<sub>17</sub>Al<sub>12</sub> phases. Based on the observations the optimum percentage of Al and Cu was found to be Mg-6Al-0.6Cu for better hardness. **Application/Improvement:** The systematic investigation of the effect of Al and Cu on the sintered magnesium alloys is reported for the first time.

**Keywords:** Magnesium Alloys, Material Characterization, Mg-Al-Cu Alloys, Microhardness, Optical Microscopy, Powder Metallurgy

## 1. Introduction

Though corrosion is one of the limiting factor for the wide spread usage of the magnesium, recent developments such as coatings allow it to be more attractive than ever<sup>1</sup>. Due to the remarkably low density of magnesium (about 1.7 g/cm<sup>3</sup>), which is about one third of aluminum, besides having high specific strength, and high damping properties, magnesium alloys are of engineering importance in the applications such as automobiles and aerospace where the weight is to be minimized without compromising on the other structural properties<sup>2</sup>. However, magnesium, being HCP structured material, has the disadvantage of having low strength, ductility and mechanical properties at room temperature making it difficult to work below the recrystallization temperature. So there is a need for the

magnesium alloys with improved mechanical properties. Mg-Al-Cu alloys have the potential to enable building of the vehicles for the automotive and aerospace applications that are significantly fuel efficient due to their low density, high strength to weight ratio, coupled with good ductility. For instance, it was reported that the weight of an engine block made of cast iron can be reduced by about 65% when the same engine block is made by adopting magnesium based alloys<sup>3,4</sup>. It is difficult to obtain uniform microstructure in the products made by the regular die casting technique due to the chilling effect of the mold walls. Further, it is difficult to make products with complex shape by die casting techniques. The mechanical behavior of the light alloys with relatively low strength such as magnesium can be enhanced by adopting unconventional processing routes<sup>5</sup>. Materials produced by the powder

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consolidation techniques were reported to exhibit better strength properties due to their refined microstructures<sup>6</sup>. Magnesium components made by powder metallurgy find many applications including the biomedical implants<sup>7</sup>. It is possible to process magnesium alloy components of complex geometry by powder metallurgy route with the added advantages such as uniform microstructure, uniform mechanical properties due to the absence of any possible micro-segregation of the alloying constituents<sup>8</sup>. Powder metallurgy also has the advantages of high dimensional accuracy, desired surface finish, and longer life of components due to enhanced microstructure and lack of defects. Thus, in present paper, various Mg-Al-Cu alloys (Mg-3 Al-0.3 Cu, Mg-3 Al-0.6 Cu, Mg-6 Al-0.3 Cu, Mg-6 Al-0.6Cu) are prepared by using powder metallurgical route and characterized for their hardness.

## 2. Materials and Methods

### 2.1 Processing

Powders were mixed using the mortar and pestle process which is a traditional hand mixing method. The mortar was cleaned using ethanol, and then the powders of magnesium, aluminum and copper are taken according to their respective compositions. The mixed powders were then compacted using zinc stearate as die lubricant. Pressure of 300 MPa is applied to make cylindrical compacts of 30mm diameter and 10mm height. Sintering was carried out by using microwave sintering at a temperature of 450°C for 15 minutes with the ramping rate of 5°C/sec.

### 2.2 Microstructural Characterization

The sintered samples were polished using progressively higher grit numbers per the standard metallographic practice and subsequently on disc polisher using alumina abrasive powder. Samples are then etched with the help of 0.5% v/v HF solution in distilled water. The microstructures of the specimen were observed using optical microscope at the magnification of 200x.

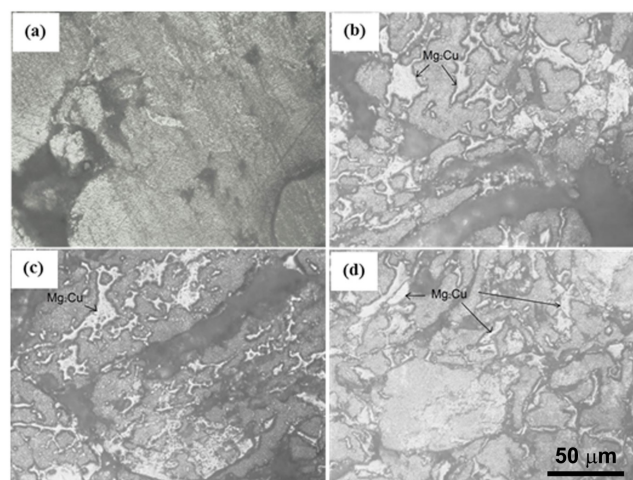
### 2.3 Microhardness Test

The hardness measurements were conducted on the prepared samples using microhardness tester (Shimadzu, Model no. HMV-G 20S) with the applied load of 100 gm. Five readings were carried out for each of the sample and taken average.

## 3. Results and Discussion

### 3.1 Microstructure

The microstructure of the alloys viewed in the optical microscope are shown in Figure 1(a-d). Pores are observed on all the samples as the Mg powder used for the study is coarse. Among all the samples, Mg-3Al-0.3Cu alloy was observed to have more porosity. The presence of Mg<sub>2</sub>Cu phase was also evident from the microstructures. When the sintering temperature exceeds above 400°C, Mg reacts with Cu to form an intermetallic phase of Mg<sub>2</sub>Cu which is mostly observed on the grain boundaries<sup>5</sup>. The Cu rich phase helps in the process of densification by moving to either the grain boundaries or the interparticle boundaries. Hence, in the sample Mg-6Al-0.6Cu, less porosity has been observed which is evident from Figure 1.



**Figure 1.** Microstructure of the alloys processed in the present study: (a) Mg-3Al-0.3Cu, (b) Mg-3Al-0.6Cu, (c) Mg-6Al-0.3Cu and (d) Mg-6Al-0.6Cu.

### 3.2 Microhardness

The room temperature micro hardness values for the alloys are depicted in Table 1. It can be observed that, as the composition of Al and Cu increases, the hardness value also gets increased. This can be attributed to the solid solution strengthening effect due to the formation of intermediate phase of Mg<sub>2</sub>Cu. The Mg<sub>2</sub>Cu phase interacts with the dislocations and makes it difficult for the dislocations to move effectively, increasing the hardness of the alloys. With the increase in the alloy, addition of the copper, more volume fraction of the Mg<sub>2</sub>Cu is likely to present. This increased amount of Mg<sub>2</sub>Cu will hinder

the movement of dislocations, further improving the hardness of the alloys. Further, the hardness of the Mg<sub>2</sub>Cu phase as such is relatively high and it directly influences the enhancement of hardness of the alloys.

**Table 1.** Room temperature microhardness of Mg-3Al-0.3Cu, Mg-3Al-0.6Cu, Mg-6Al-0.3Cu and Mg-6Al-0.6Cu alloys

Sl.No	Composition	Hardness (HV)
1.	Mg-3Al-0.3Cu	25.5
2.	Mg-3Al-0.6Cu	31.54
3.	Mg-6Al-0.3Cu	29.55
4.	Mg-6Al-0.6Cu	33.56

It was reported that, in case of Mg-Al binary alloy system, magnesium reacts with aluminum to form Mg<sub>17</sub>Al<sub>12</sub> intermetallic phase. Moreover, Mg<sub>17</sub>Al<sub>12</sub> intermetallic phase increases hardness by hindering dislocations<sup>9,10</sup>. It is also observed that the hardness of Mg-3Al-0.6Cu and Mg-6Al-0.6Cu alloys is much higher than other compositions under study. This could be due to the presence of more amount Mg<sub>2</sub>Cu phase as compared to the other alloys. It has been already reported that Mg<sub>2</sub>Cu phase increases the strength and hardness of Mg alloys.

## 4. Conclusions

From the present study, following conclusions were drawn.

- The porosity decreased with increase in the percentage of Al and Cu in Mg, possibly due to the increase in the volume fraction of Mg<sub>2</sub>Cu and Mg<sub>17</sub>Al<sub>12</sub> phases.
- Mg-6Al-0.6Cu alloy exhibits highest hardness as compared to other alloys under study which was attributed to the presence of more amount of Mg<sub>2</sub>Cu phase besides Mg<sub>17</sub>Al<sub>12</sub> phase.
- The Mg<sub>2</sub>Cu phase was observed to contribute more than Mg<sub>17</sub>Al<sub>12</sub> phase to the increase in strength and hardness of Mg.

## 5. Acknowledgement

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