

# Effect of Heat Treatment on Mechanical Properties of Al-1.5Cu-9.5Zn-3Mg Rapidly Solidified Alloy

El Said Gouda<sup>1,2</sup>, Emad Makboul Ahmed<sup>1</sup>, Nabih Lotfi Tawfik<sup>1</sup>

<sup>1</sup>Metal Physics Lab., Solid State Physics Department, National Research Center, Dokki, Egypt; <sup>2</sup>Physics Department, Faculty of Science, Jazan University, Jazan, K.S.A.  
Email: [gouda.el73@yahoo.com](mailto:gouda.el73@yahoo.com)

Received April 29<sup>th</sup>, 2010; revised June 17<sup>th</sup>, 2010; accepted June 18<sup>th</sup>, 2010.

## ABSTRACT

Ribbons with the composition Al-1.5Cu-9.5Zn-3Mg were prepared by melt spinning technique. Microhardness and tensile strength were measured. The melt spun hardness and ultimate tensile strength values were as high as 291 HV and 660 MN/m<sup>2</sup>, respectively. Hardness values are relaxed to lower values on prolonged thermal annealing to around 50%. X-ray diffraction lines corresponding to Cu, Zn and Mg were disappeared for the as melt spun ribbons, which indicates a complete solubility of these element in Al matrix. On prolonged thermal annealing these alloying elements were precipitated.

**Keywords:** Microhardness, Rapid Solidification, UTS, Tensile Strength

## 1. Introduction

The study of the material strength is an important subject because it is the first characteristic comes in mind when used in industrial applications specially that subjected to shock loading. Steel is a good example for the most strength materials, but its high density restricts its uses. Aluminum alloys are increasingly employed in many important manufacturing areas, such as the automobile industry, aeronautics and the military [1]. Currently, it offers the greatest potential for cost effective weight savings in automotive body structures and closures. With a density of only 33% of that of steel and a greater strength to weight ratio, there is the possibility for a weight savings of 40% to 50%. Also, Mg alloys are very attractive materials for producing lightweight components for automobiles because they have densities that are 66% of Al alloys and 22% of steel. With their lower density and moderate strength, Al-Mg alloys are well suited for a number of applications, ranging from steering wheels and instrument panels to engine and transmission components. The mechanical properties of the Al-Mg plastically processed alloys depend on the content of magnesium in the alloy. With an increase of magnesium from 0.5 to 5% the properties increase; this rise is greater

when magnesium increases from 3 to 6% [2]. There are many studies characterize the strength and mechanical properties of Al-based and Mg-based alloys with different elements [3-8]. The present paper aims to characterize hardness and tensile strength of the quaternary alloy Al-1.5Cu-9.5Zn-3Mg as an example for a high strength material.

## 2. Experimental

Al-1.5Cu-9.5Zn-3Mg alloy was prepared from 99.75 wt.% pure Al, 99.9 wt.% pure Cu, Zn and Al-10 wt.%Mg master alloy. The required quantities were weighted out and melted in electrical resistance furnace then thermally agitated to ensure the homogenization. The molten alloy was casted into graphite moulds to produce rods of 25 mm length and 4 mm diameter. A stream of the molten alloy at 850°C was ejected by argon gas at a gauge pressure of 1.5 atm., from a silica tube with 0.5 µm orifice diameter. The melt jet fell on a copper wheel of the melt spinning apparatus fixed at 2950 r/m. The estimated cooling rate was about 10<sup>5</sup> K/s. The resulting alloys are in ribbons form of about 50 µm thickness and width 2 mm. X-ray diffraction analyses was performed to identify the structure of the ribbons using a 1390 Philips X-ray Diffractometer with Cu radiation. The ribbons

were tensile tested with a gauge length of 5 cm at strain rate of  $1.66 \times 10^{-5} \text{ s}^{-1}$ , at room temperature. Measurements of hardness were done with the specimen placed against a glass slide with a load of 150 gm and indentation time of 10 s. Tests were done for the as melt-spun ribbons and for fully aged ribbons.

### 3. Results and Discussion

#### 3.1. X-Ray Diffraction

The cooling rates of the melt spinning process exceed  $10^5 \text{ }^\circ\text{C/s}$  was high enough to retain the high concentrations of the alloying elements in solid solution with the Al-1.5Cu-9.5Zn-3Mg alloy. This was confirmed by the presence of Al reflections only in the X-ray diffraction pattern of the as melt-spun ribbons as illustrated in **Figure 1**. For aged ribbon, the Al-Cu compound and the alloying elements start to precipitate and crystal growth starts to be exist, so additional X-ray diffraction peaks were formed for the aged ribbons as illustrated in **Figure 2**. The additional diffraction lines were corresponding to pure Mg, Zn and  $\text{Al}_2\text{Cu}$  phases.

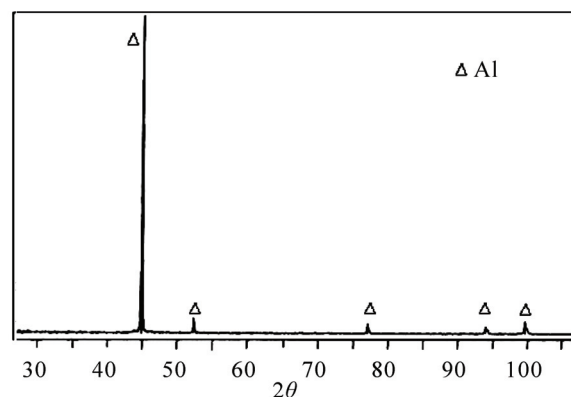
#### 3.2. Tensile Test

Samples for the tensile test were chosen such that, a minimum variation in width and thickness has been obtained. The stander deviation in cross sectional area for each sample is  $\pm 5\%$ . Samples with gauge length 5 cm were tested. **Figure 3** shows the load-elongation curves for as melt-spun and annealed ribbons. Each curve can be divided into two regions. The first region is a linear and ends at strain ratio  $\varepsilon/\varepsilon_f$  about 80% and 30%, for the as melt-spun and annealed samples, respectively,  $\varepsilon_f$  is the fracture strain. The second region is slightly curved due to yielding near the end of the test. Slope of the straight line in the first region represents Young's modulus of the as melt-spun sample. The ultimate tensile strength (UTS) for the as melt-spun sample was  $660 \text{ MN/m}^2$ . This value decreased by annealing at  $300^\circ\text{C}$  for 5 h to  $442 \text{ MN/m}^2$ . Also, toughness, which is expressed as the area under the load-elongation curve until fracture, was calculated. It was  $3.98 \text{ MN/m}^2$  for the as melt-spun samples and  $3.39 \text{ MN/m}^2$  for the annealed sample.

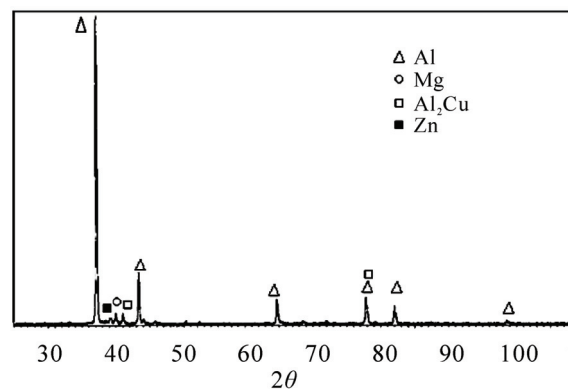
#### 3.3. Microhardness

Hardness of the as melt spun Al-1.5Cu-9.5Zn-3Mg alloy is  $291 \text{ MN/m}^2$  and decreases to  $145 \text{ MN/m}^2$  by thermal ageing at  $220^\circ\text{C}$  for 5 h. This decrease takes place in two stages as illustrated in **Figure 4**. An initial fast stage follows by slow stage in which a slight decrease in hardness can be observed. The as-cast rod with the same composition gives the value of  $141 \text{ MN/m}^2$ . By comparing the two values, it is noticed that, the as melt-spun ribbon

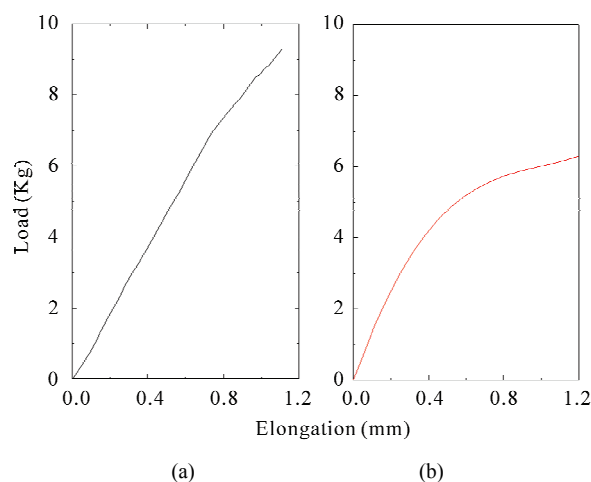
has a much higher value than that of the as cast rods, which agreement with other results [9] for alloy rapidly solidified at different cooling rates. On thermal aging, the



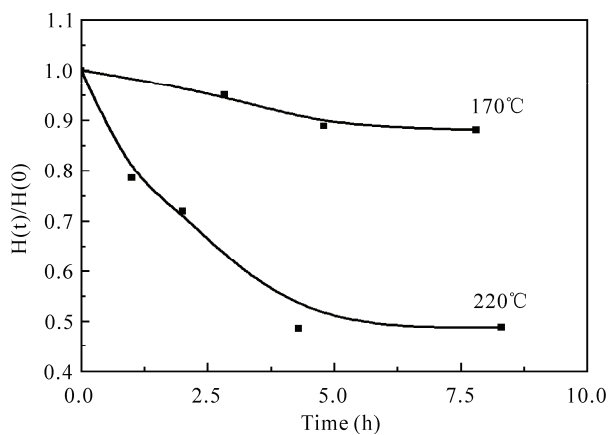
**Figure 1.** X-ray diffraction pattern of the Al-1.5Cu-9.5Zn-3Mg melt spun ribbon.



**Figure 2.** X-ray diffraction pattern of the Al-1.5Cu-9.5Zn-3Mg annealed ribbon.



**Figure 3.** Load versus elongation for Al-1.5Cu-9.5Zn-3Mg melt spun ribbons (a) as melt spun and (b) aged for 5 h at  $300^\circ\text{C}$ .



**Figure 4. Variation of Vickers hardness ratio  $H(t)/H(0)$  at 170 and 220°C with aging time.**

hardness decreases to reach limiting values of 50% of the as melt-spun values. It was observed that the hardness relaxation during isothermal ageing is much slower than that of resistivity relaxation at the same temperature. This behavior can be explained as that, hardness is closely related to size of precipitates. Also the electrical resistivity is sensitive to point defects which are usually the first properties to recover. On the other hand, the hardness depends more on line imperfection which may require higher temperatures for recovery. So, rapid solidification has a significant effect on increasing the hardness. The higher value of hardness for the as melt spun state can be attributed to the effect of the solute atoms upon the solvent lattice and the nature of the lattice forces operative owing to the interaction of different atomic species.

#### 4. Conclusions

The effects of rapid solidification and thermal heat treatments on the mechanical properties of quaternary Al-1.5Cu-9.5Zn-3Mg melt spun alloy were studied. A maximum solid solubility value of 9.5 wt.% Zn in  $\alpha$ -Al was obtained for the as melt-spun alloy, 3% Mg and 1.5% Cu were also obtained as solid solutions in Al-matrix. The existence of the alloying elements as solid solution in  $\alpha$ -Al significantly enhances microhardness, ultimate ten-

sile strength U.T.S values. After aging the values relaxed to lower values as a result of the  $Al_2Cu$ , Zn and Mg precipitations. Hardness and U.T.S were as high as 291 HV and 660 MN/m<sup>2</sup>, respectively.

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