

Studying the Effects of Deformation on Microstructure and Mechanical Behavior of Al-Cu Alloys

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Abstract

Aluminum alloys with a wide range of properties are used in engineering structures. Selecting the right alloy for a given application entails considerations of its tensile strength, density, ductility, formability, workability, weldability, and corrosion resistance, to name a few. Aluminum alloys are used extensively in aircraft due to their high strength-to-weight ratio. On the other hand, pure aluminum metal is much too soft for such uses, and it does not have the high tensile strength that is needed for airplanes and helicopters. Thus various alloying elements are added to aluminum to enhance the mechanical properties of aluminum. Copper has been the most common alloying element almost since the beginning of the aluminum industry, and a variety of alloys in which copper is the major addition were developed. The current research emphasizes establishment of relationship between microstructure and cold deformation behavior of aluminum copper alloys. Aluminum copper alloys with varying Cu% were casted and their chemical compositions were determined using Optical Emission Spectroscopy (OES). These alloys undergone cold deformation and their microstructures were examined using optical microscope. Finally the effects of deformation were studied by measuring the hardness of those alloys.

Keywords: Aluminum copper alloy, microstructure, cold deformation, hardness, CALPHAD.

1. Introduction

Aluminum alloys are alloys in which aluminum (Al) is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon and zinc. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable. About 85% of aluminum is used for wrought products, for example rolled plate, foils and extrusions. Cast aluminum alloys yield cost effective products due to the low melting point, although they generally have lower tensile strengths than wrought alloys. Aluminum alloys are widely used in engineering structures and components where light weight or corrosion resistance is required [1].

The most important cast aluminum alloy system is Al-Cu. The addition of copper as main alloying element (mostly range 3–6 wt. %, but can be much higher), with or without magnesium as alloying constituent (range 0–2 %), allows material strengthening by precipitation hardening, resulting in very strong alloys. Also the fatigue properties are very good for this series. In contrast, the presence of copper is detrimental for corrosion resistance [2]. Copper tends to precipitate at grain boundaries, making the metal very susceptible to pitting, intergranular corrosion and stress corrosion. These copper rich zones are more noble/cathodic than the surrounding aluminum matrix and act as preferred sites for corrosion through galvanic coupling. In addition, copper has unfavorable effect on anodizing of these alloys. Copper precipitates dissolve in the anodizing electrolytes (acid electrolytes for porous film formation) leaving holes in the oxide, and solute copper migrates under the high electric field towards the aluminum/oxide interface compromising the anodic film properties.

Up to 12 wt. % copper the strength of the alloy can increase through precipitation hardening, with or without the presence of magnesium; hardening is achieved through the precipitation of Al_2Cu or Al_2CuMg intermetallic phases during ageing process which leads to strengths second only to the highest strength 7xxx series alloys [2]. Above 12 wt. % Cu the alloy becomes brittle. Copper also improves fatigue properties, high-temperature

properties and machinability of the alloy. These alloys are used for high strength structural applications such as aircraft fittings and wheels, military vehicles and bridges, forgings for trucks, etc [2, 3]. Environmental legislation to reduce emission of greenhouse gases is forcing transportation industries to find out substitutes of steels—currently profoundly used in vehicle production. Aluminum, being lighter than steel, is considered as an exciting alternative material in such applications. Different aluminum alloys are being prototyped by varying composition and by developing suitable microstructure with different heat treatment schedules. The current study includes the microstructural effects on deformation of aluminum alloys. Aluminum alloys of specified composition were casted and homogenized at 400 °C for four hours. Afterwards microstructures of as cast and homogenized alloys were observed. Compression tests involving 10%, 20% and 50% deformations were performed on the homogenized samples. Finally the changes in microstructure and hardness due to deformation of aluminum alloys were studied.

2. Experimental Details

The investigated materials consists aluminum as a primary constituent and copper is the major addition varied with 2, 4, 6%.

2.1. Alloy Preparation

All experimental alloys were prepared by liquid metallurgy route using pure aluminum (99.8%) and electrolytic copper (99.9%). The metals were melted in an induction furnace at predetermined weight percentages. The molten metal was poured into a permanent metal mold made of cast iron with a dimension of 200 cm length, 50 cm width and 80 cm height. The die was preheated to 200 °C. The compositions of the alloys were determined using Optical Emission Spectrometer (Shimadzu PDA 700) as shown in Table 1. The samples were cut into small pieces for homogenization treatment at 400 °C for four hours in a BlueM Electric furnace. After holding for 4 hour samples were quenched in water to retain the precipitates. Then heat treated alloys were deformed by compression to 10%, 20% and 50% each.

Table 1: Chemical composition of as cast aluminum alloys

Alloy	Al	Fe	Si	Cu	Ni	Mg
Al-2%Cu	97.48	0.26	0.00	1.97	0.189	0.09
Al-4%Cu	96.06	0.07	0.08	3.69	0.00	0.06
Al-6%Cu	93.55	0.058	0.12	6.16	0.01	0.06

The experimental work was segmented into two phases. The first phase consists of specimen preparation such as melting, casting and heat treatment of samples with different compositions in the aluminum-copper system. The second phase includes mechanical characterization like compression and hardness and microstructural studies using optical microscope of as cast and heat-treated samples. For microstructural observation, specimens were cut into 25 mm³ size, and ground and polished using conventional metallographic sample preparation route. The microstructures were observed in un-etched condition using Optica B-600 MET trinocular upright metallurgical microscope and images of same resolution and of same RGB numbers were acquired using OpticaTM Vision Pro software package. CALPHAD method was used to predict the phases developed in these alloys [4-9].

2.2 Mechanical Tests

The casted alloys were undergone deformation by compression test. Each alloy was deformed to 10%, 20% and 50% in a Universal Testing Machine (UTM). The test was carried out at ambient temperature in accordance with ASTM E9-89a standard. Hardness of the specimens was measured by using a standard Rockwell Hardness testing machine in HRF scale with a 60 kg load and using 1/16” diamond indenter. 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

3.1 Effect of Heat treatment on Microstructure and Hardness

Fig. 1 shows hardness of as cast and homogenized aluminum alloys containing 2-6% Cu. It clearly reveals that hardness of aluminum alloys increases with Cu% in both as cast and homogenized condition due to the increase of Cu bearing phase Al₂Cu (obtained from CALPHAD analysis as shown in Fig. 2) in the microstructure. There is little decrease in hardness values after homogenization treatment. This may be due to the fact that some of these phases go into solution in the matrix as indicated by their microstructures (Fig. 3).

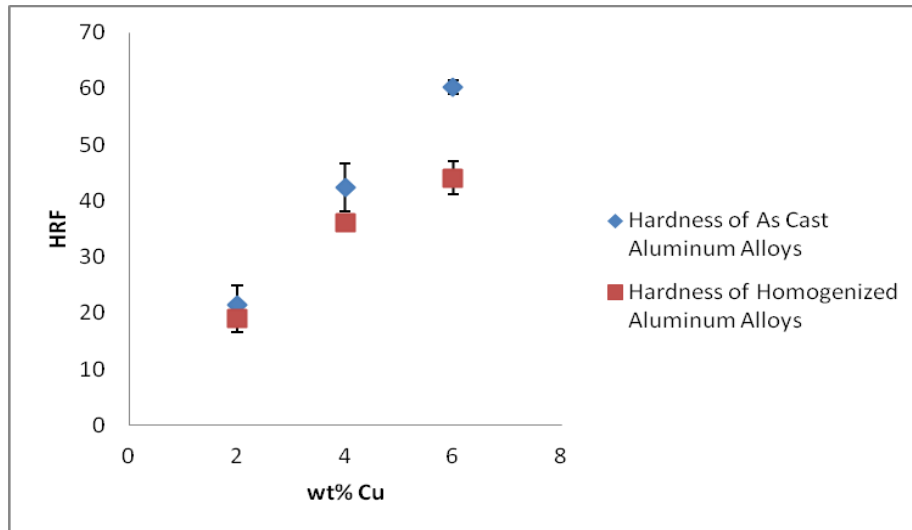


Fig. 1: Effect of Cu % and heat treatment on hardness of aluminum copper alloys

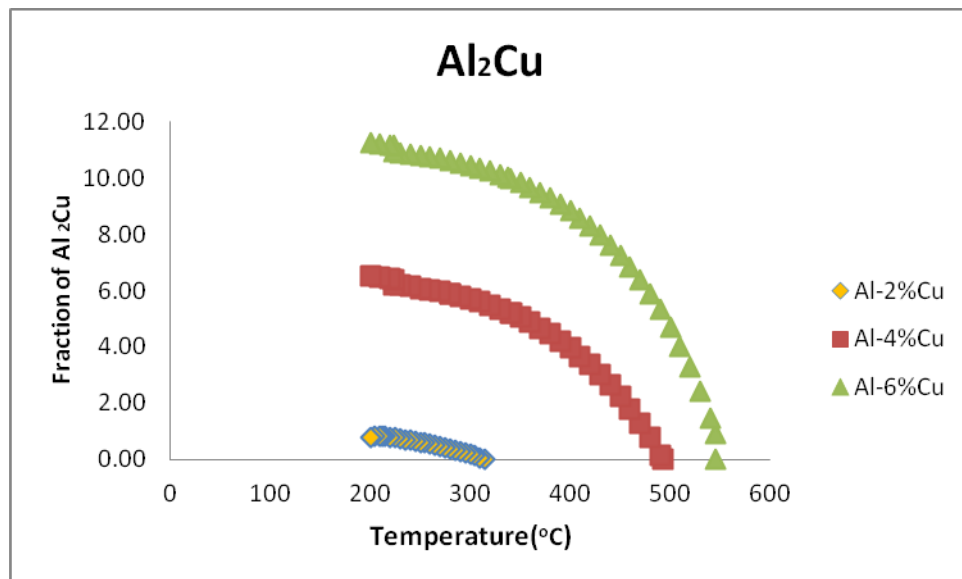


Fig. 2: Fraction of Al₂Cu in aluminum copper alloy with temperature

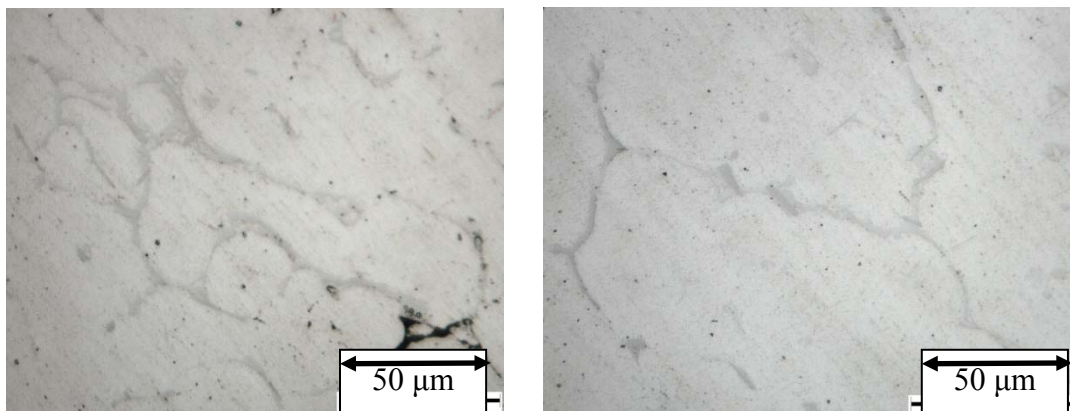


Fig. 3: Microstructure of Al-4% Cu alloys (a) As cast and (b) Homogenized

3.2 Effect of Deformation on Microstructure and Hardness

After deformation of the homogenized alloys to 10%, 20% and 50%, a large increase in hardness was evident. For each alloy, hardness was increased with increasing the amount of total deformation. Fig. 4 shows the effect of deformation on hardness. This increase in hardness is due to the presence of stored energy in the microstructure due to increase of dislocation density. Deformation increases the number of dislocations by interactions of dislocation during deformation and other defects, which cause an enhancement of hardness values [9-13]. Deformation also attributes a change in microstructure. It was observed that for each alloy the initial necklace like phases (Al_2Cu and $\text{Al}_7\text{Cu}_2\text{M}$) were destructed with the extent of deformation as shown in Fig. 5. As the amount of deformation increases, phases those provide an increase in hardness are no longer being in a continuous form, thereby have little significance in increasing hardness (Fig. 4).

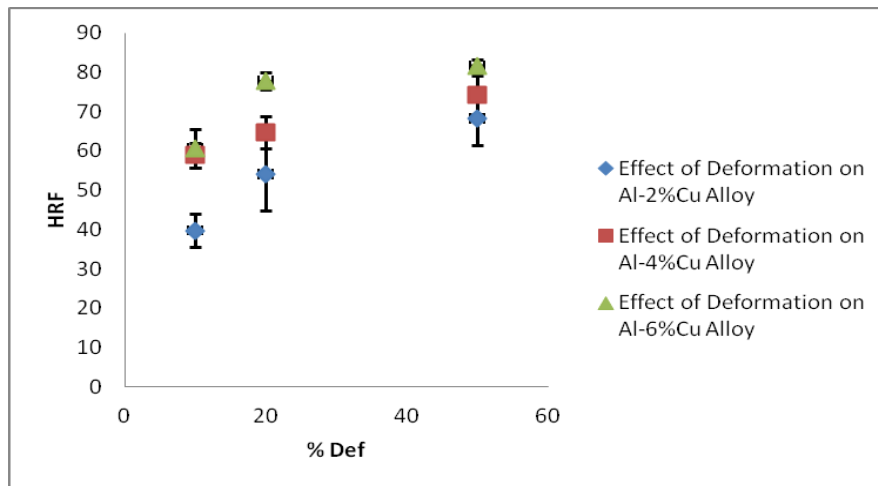


Fig. 4: Effect of deformation on hardness of aluminum copper alloys

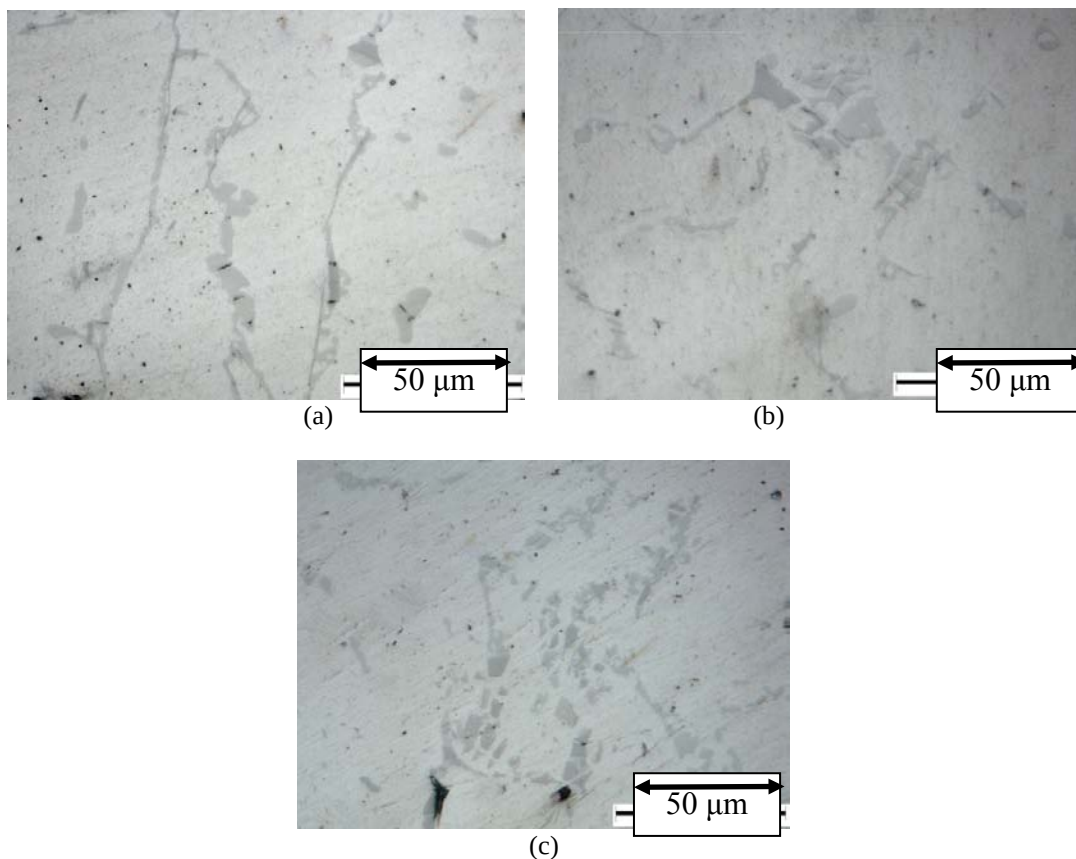


Fig. 5: Microstructure of Al-6% Cu (a) 10% (b) 20% and (c) 50% deformation

4. Conclusion

This study emphasizes the effect of deformation on microstructure and hardness of aluminum alloys with varying amount of copper. Results obtained from this study are summarized below:

- (i) Deformation causes an increase in hardness than non-deformed homogenized alloy due to changes in dislocation density. Deformation increases the number of dislocations by interactions of dislocation during deformation and other defects, which cause an enhancement of hardness values. High dislocation density results in a large number of dislocation interactions which results in high strength and hardness.
- (ii) With increasing amount of deformation, hardness continues to increase for different copper addition. Also, the higher the copper content, the greater the hardness.
- (iii) Deformation also changes the microstructure by destroying the necklace like shape of Al-Cu phases. For this reason, with larger amount of deformation, the increment of hardness may not be very significant.

5. References

- [1] Arnold, I. J. Polmear, *Light Alloys*, 1995
- [2] H.N. Girisha, K.V. Sharma, Effect of magnesium on strength and microstructure of aluminum, copper, magnesium alloys, *International Journal of Scientific Engineering and Research*, Vol. 3, issue 2, 2012.
- [3] A. Zhu, B. M. Gable, G. J. Shiflet, E. A. Jr. Starke, "Trace element effects on precipitation in Al-Cu-Mg-(Ag, Si) alloys: a computational analysis", *Acta Materialia* 52, pp. 3671–3679, 2004.
- [4] S. Zhang,*, Q. Han, Zi-Kui Liu, "Thermodynamic modeling of the Al-Mg-Na system", *Journal of Alloys and Compounds* 419, pp. 91–97, 2006.
- [5] N. Saunders, "The Modelling of Stable and Metastable Phase Formation in Multi-Component Al-Alloys", 9th International Conference on Aluminium Alloys, Brisbane, Australia, 2-5 August, 2004.
- [6] N. Saunders, Z. Guo, A.P. Miodownik and J-Ph.Schillé, "Modelling the Material Properties and Behaviour of Multicomponent Alloys", International Congress on FEM Technology with ANSYS CFX & ICEM CFD Conference, 22nd CAD-FEM Users' Meeting 2004.
- [7] T.E. Quested, A.T. Dinsdale, A.L. Greer, "Thermodynamic modelling of growth-restriction effects in aluminium alloys", *Acta Materialia* 53, pp. 1323–1334, 2005.
- [8] J. Lacaze and R. Valdes, CALPHAD-type Assessment of the Al-Mg-Si System", *Monatshefte für Chemie* 136, pp. 1899–1907, 2005.
- [9] S. O. Adeosun, O. I. Sekunowo, S.A. Balogun, L.O. Osoba, "Effect of Deformation on the Mechanical and Electrical Properties of Aluminum-Magnesium Alloy", *Journal of Minerals & Materials Characterization & Engineering*, Vol. 10, No.6, pp.553-560, 2011 jmmce.org
- [10] A. Abdulhaqq, P. Hamid, S. Ghosh,, O. Jain, and R. Subrata, "Processing, Microstructure and Mechanical Properties of Cast in-situ Al (Mg,Mn)-Al₂O₃(MnO₂) Composites" *Metallurgical and Materials Transactions A*, Vol. 36A, pp 221, 2005.
- [11] N. Roy, A. Samuel and F. Samuel, *Metallurgical and Materials Transactions*, Vol. 27A, pp. 415-429, 1996.
- [12] D. Lassance, M. Schmitz, F. Delannay and T. Pardoën, "Linking Microstructure and High Temperature Ductility in Aluminum alloys AA6xxx." Seminar paper available online at: www.hallf.kth.se/forskning/ecf15/ECF-proceedings/Lassance, 2002.
- [13] R. Valiev, N. Krashkov and K. Tsenev, "Plastic Deformation of Alloys with Submicron-grained Structure." *Materials Science and Engineering A*, Vol.153, Issue 3, pp.172-196, 1991.