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Effect of Zn/Cu Content on Microstructure and Mechanical Properties of Al-Zn-Cu Cast Alloys

Karjagi Kiran Suresh[1], S. Ilangovan[2], Sanjivi Arul[3], A. Shanmugasundaram[4]
Karjagi Kiran Suresh[1], S. Ilangovan[2], Sanjivi Arul[3], A. Shanmugasundaram[4],
M.Tech. Student[1], Department of Mechanical Engineering, Amrita School of Engineering
Associate Professor[2, 3], Department of Mechanical Engineering, Amrita School of Engineering
Assistant Professor[4], Department of Mechanical Engineering, Amrita School of Engineering
Amrita Vishwa Vidyapeetham, Coimbatore –641112, Tamilnadu – India
[2] s_ilangovan@cb.amrita.edu

Abstract

A binary Al-Zn and five ternary Al-Zn-Cu alloys were produced using stir casting process by varying the Cu contents from 0-5 wt. % and keeping Al content as constant value of 60 wt. %. It was found that the micro-hardness and the ultimate tensile strength of the alloys increases significantly with increasing Cu content up to 2 wt. % which is due to solid solution hardening of Cu content in Al-Zn alloy. Further increase of Cu content results in the formation of hard and brittle θ phase which weakens the inter-dendrite region and marginally increases the hardness and ultimate tensile strength of the alloy. The percentage elongation of the alloy system decreases continuously with addition of Cu content.

Keywords: Al-Zn-Cu alloys, Effect of Cu, Mechanical Properties.

Introduction

Al alloys are largely used due to its properties such as light weight, ductility, corrosion resistance, high strength to weight ratio [1] – [2]. Al-Zn alloys are the most commonly used alloys to replace non-ferrous (bronze/gun metal) and ferrous metals (cast iron) cost-effectively [3] – [6]. It is used to make components for tribological applications because of their superior wear properties. However, for most engineering applications the mechanical properties and creep strength of Al-Zn alloys are not suitable at elevated temperatures [7] – [9]. Hence a ternary alloying element like Cu, Si, Mg and Ni is added to improve the mechanical properties. Among these Cu has been found to be the most successful alloying element towards improving the mechanical properties [10].

In this work the effect of Cu content on the mechanical properties of 60Al-Zn-Cu alloys was studied.

Experimental Procedure

A. *Alloy Preparation*

Six different types of alloys are prepared from the commercially available pure elements. They are melted using stir casting machine [Fig. 1] and casted in to preheated metallic die [Fig. 2] to get the required alloy samples. The selected alloy compositions and the spectrometric results of the alloy compositions are reported in Tables [1, 2] respectively. The casted alloy blocks are shown in Fig.3. The various alloys are designated as Alloy Numbers 1-6.

Figure 1: Stir Casting Setup

Figure 2: Mild Steel Permanent Mould

Table 1: Alloy Compositions

Alloy Number	**Composition (wt. %)**		
	Al	**Zn**	**Cu**
1	60	40	0
2	60	39	1
3	60	38	2
4	60	37	3
5	60	36	4
6	60	35	5

Table 2: Spectroscopic Result of Alloy Compositions

Alloy Number	**Chemical Composition**		
	Al	**Zn**	**Cu**
1.	59.89	39.93	-
2.	60.12	38.78	1.02
3.	59.73	38.18	1.98
4.	59.50	37.25	3.15
5.	60.08	35.96	3.88
6.	59.85	35.20	4.90

Figure 3: As Casted Specimen

B. Microscopic Examination

To reveal the microstructure, microscopic examination was performed for all six alloy compositions. Carl-Zeiss make metallurgical microscope was used with the magnification of 100×. The microscopic images were recorded with the help of a CCD camera which is attached to the microscope. The alloy specimens were polished and etched as per metallographic standards. The etchant used was Keller's Reagent recommended for Al alloys.

C. Micro Hardness Testing

An average hardness value was estimated by using a Mitutoyo make micro-hardness tester [Fig. 4].Readings are taken at various locations to assess the effect of alloy composition on micro-hardness for each alloy specimens. ASTM E384 standard was used to conduct the hardness test.

Figure 4: Micro Hardness Testing Equipment

D. Tensile Testing

Fig. 5 shows the experimental setup of the computerized Tinius Olsen make (UK) universal testing machine. The test was conducted to predict the Ultimate Tensile Strength (UTS) of different alloy compositions. ASTM - E4 standard specimens were used for the tensile test. Figure 6 represents the dimensions of the tensile test specimen.

Figure 5: Universal Testing Machine

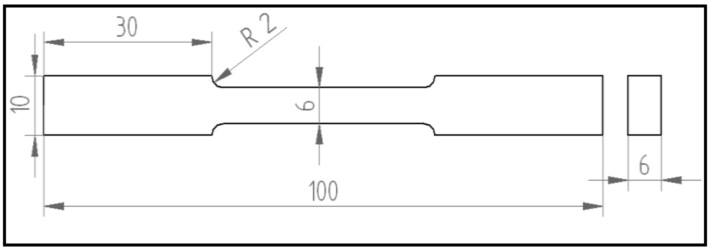

Figure 6: Tensile Test Specimen Dimensions

Results and Discussion

Fig. 7 shows the microstructure of Al-Zn alloy without Cu addition which shows (i) cored zinc-rich α dendrite structure and (ii) α+η phase. Fig. 8 to Fig. 11 shows the typical microstructure of Al-Zn-Cu alloys with 1 wt. % to 4 wt. % Cu content. The addition of Cu in Al-Zn alloy leads to the formation of inter-metallic stable θ ($CuAl_2$) phase in the inter-dendrite region of the Al-Zn-Cu alloys. This θ phase is shown in Fig. 12. By increasing Cu content in Al-Zn-Cu alloy, increases the size and volume fraction of the θ phase [11].

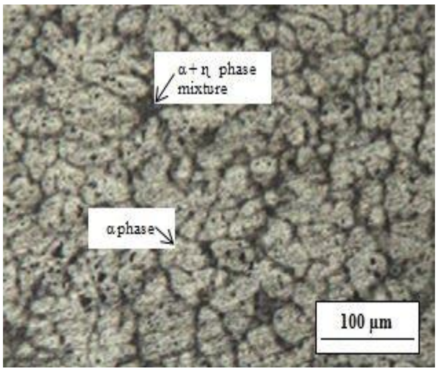

Figure 7: Microstructure of as Cast 60Al-40Zn Alloy

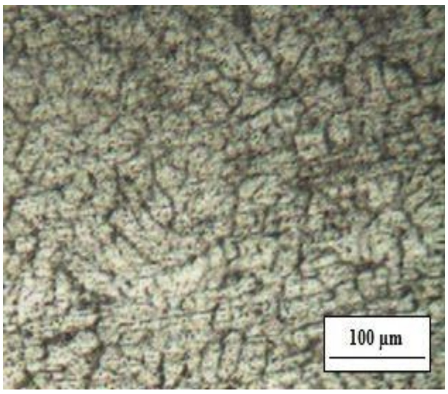

Figure 8: Microstructure of as cast 60Al-39Zn-1Cu Alloy

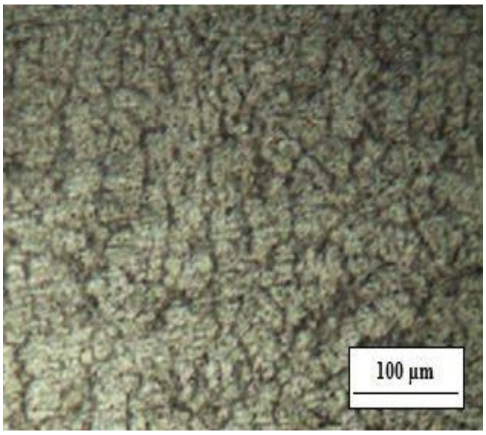

Figure 9: Microstructure of as Cast 60Al-38Zn-2Cu Alloy

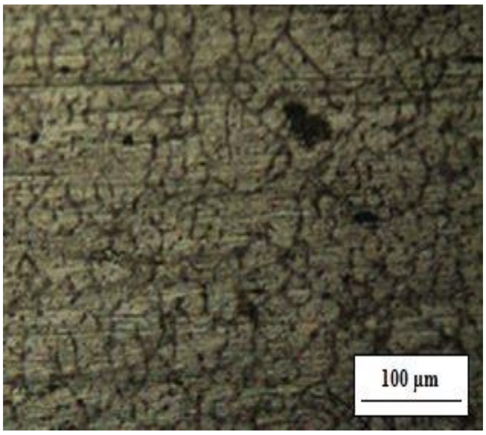

Figure 10: Microstructure of as Cast 60Al-37Zn-3Cu Alloy

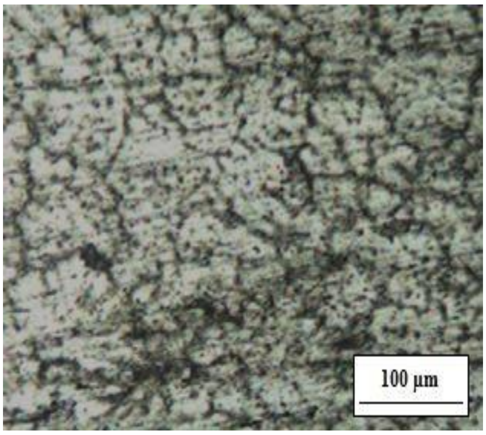

Figure 11: Microstructure of as Cast 60Al-36Zn-4Cu Alloy

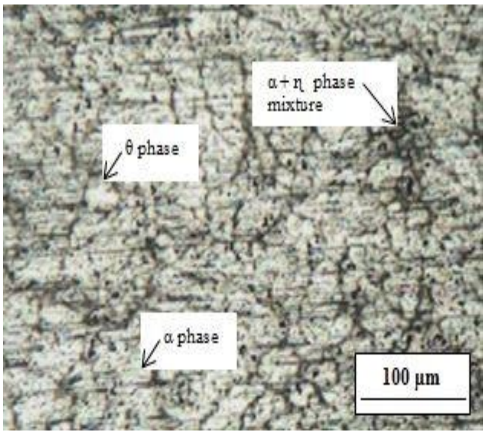

Figure 12: Microstructure of as Cast 60Al-35Zn-5Cu Alloy

Fig. 13 represents the variation of hardness with Cu content (alloy number). It is observed from the plot that the increase in hardness of the alloy is significant till the Cu content reaches up to 2 wt.% (alloy numbers:1-3) in Al-Zn alloy. This is due to solid solution hardening of Cu in Al-Zn alloy matrix and forming a Cu-rich θ phase [9] – [11]. However, further addition of Cu content (above 2 wt. %) results in a marginal increase in hardness. It is reported that the formation of θ phase is hard and brittle. This θ phase also weakens the inter-dendrite regions of the alloys [11]. But as stated in earlier research work the solid solution hardening is the dominant mechanism for the ternary alloys containing up to 2 wt. % of Cu content [11]. Beyond 2 wt. % of Cu content the weakening effect of θ phase dominates and marginally increases the hardness as shown in the Fig. 13 from alloy number: 3-6. The similar behavior was observed in the plot of UTS versus alloy number as shown in Fig. 14.

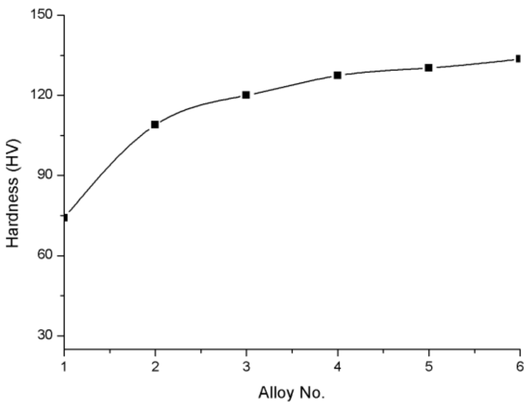

Figure 13: Hardness versus Alloy Number

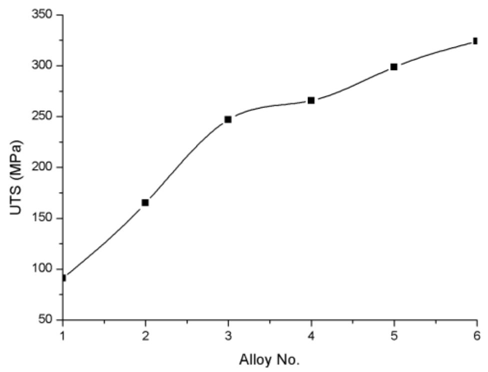

Figure 14: Ultimate Tensile Strength versus Alloy Number

The percentage elongation of the Al-Zn-Cu alloy decreases continuously with increase in Cu content in Al-Zn alloy as shown in Fig. 15. This is due to change in micro structural features.

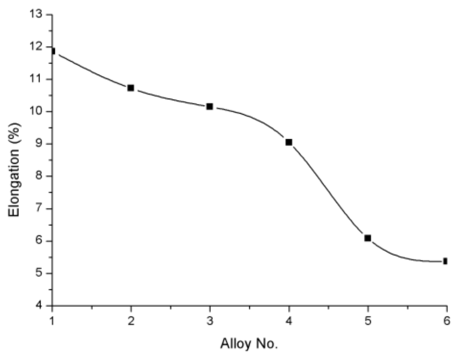

Figure 15: Percentage Elongation versus Alloy Number

Conclusions

The following are the conclusions based on the investigation of Al-Zn-Cu alloys.

- The microstructure of Al-Zn alloy without Cu addition consists of the cored zinc-rich α dendrite structure and α+η phase.
- In the inter-metallic regions, θ phase ($CuAl_2$) is formed on addition of Cu content.
- The rapid increase in micro-hardness of the alloy up to 2 wt. % of Cu content is due to solid solution hardening.
- The marginal increase in hardness is due to the formation of hard and brittle θ phase which weakens the inter-dendrite regions of the alloys.
- The behavior of UTS of the Al-Zn-Cu alloy system is similar to the hardness variation.

- The percentage elongation of the alloys continuously decreased with increasing Cu content.

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