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Effect of Cu and Zn Addition on the Mechanical Properties of Structural Aluminum Alloy

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Abstract: *The effect of independently adding Cu and Zn on the mechanical properties of 6063 aluminium alloy has been examined. In this study, sand cast samples of aluminum alloy containing Cu/Zn (0-20 vol %) and homogenized at 510^{0}C for 1hr are analyzed for ultimate tensile strength (UTS), hardness, elongation and impact energy. Addition of more than 15 vol % Zn to structural aluminum alloy raised its hardness and elongation. Copper additions above 4 vol % lowered the UTS, elongation and impact energy. However, the hardness increases with percent addition of Cu. These properties are functions of evolving microstructure. The intermetallic compound of Zn-Al has structure and crystal orientation similar to Mg_2Si in the matrix with its influence on the aluminum alloy similar to that of Mg_2Si. This occurrence is the reverse of the effect of Cu on the alloy. The addition of zinc to structural aluminum will improve the homogeneity of the matrix. The impact energy and hardness of the matrix are enhanced when Cu addition is within 2-4 vol %.*

Keywords: *Mechanical properties, Microstructure, Zinc, Copper, Structural Aluminum.*

INTRODUCTION

Strength and ductility are two of the most important mechanical properties for structural materials. A material may be strong or ductile but rarely both strong and ductile at the same time (Valiev, 2002). The effect of Cu additions on the structural features and mechanical properties of Al-Si-Cu alloy have shown that Cu additions increase the strength of these alloys due to its influence on the precipitation behavior of the aluminium during the age-hardening treatment (Dobrzanski, 2007; Mrowkwa-Nowotnik, 2007; Wierzbinska, 2006; Backerud, 1986, Backerud, 1992 and Backerud, 1992). Yield stress, hardness and microhardness increase with increase in the Cu content regardless of the alloy composition and increases of Cu content to 2 wt % lead to changes of the α -AlSi eutectic structure resulting in increase of the UTS and ductility (Dobrzanski, 2007).

One of the main advantages of Al-Zn-Mg alloy in comparison with their Aluminium base alloy is their high strength combined with their high ductility. For instance a typical 0.2% proof strength of alloy AA7108.70 is approximately 400 MPa while elongation to fracture is approximately 12% in the T6 conditions. This alloy contains typically 5.4% Zn, 1.2% Mg and 0.15% Zr. The high strength of this alloy makes it very suitable for structural applications where high strength and low weight are required. An example of these is the bumper beam in

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cars which can be made of hollow or semi-hollow hot extruded pipes. However, the disadvantage of these alloys is that their high room-temperature strength is accompanied with a high deformation resistance at hot work temperature and this is attributed to the presence of Mg, Cu, Cr, and Zr (Venkata, 2008).

Wrought aluminum alloys for automotive and structural applications e.g. AA5754, AA6111 and AA6063 contain various intermetallics. Some of these intermetallics may dissolve during subsequent heat treatment but usually a considerable fraction of these phases remain intact after the sheet fabrication process. These particles are brittle and reduce the formability of the aluminum alloy.

The development of aluminum sheet alloys which can respond well to forming operations is of paramount concern to the automotive industry. These materials will be light in weight and provide alternatives to steel sheet in structural and closure panel applications. Currently the formability of aluminium alloy sheet is hindered by the presence of relatively brittle intermetallic compounds, which are distributed throughout the matrix. These particles can induce damage and premature failure in a wide variety of sheet forming and bending operations. This study therefore seeks to overcome these problems by adding selected metals like Cu and Zn to the current generation of structural and automotive aluminum alloys hopefully to produce more ductile phases with superior forming properties.

EXPERIMENTAL METHODOLOGY

The chemical analysis of the AA6063 aluminum alloy, copper and zinc ingots used for this study are shown in Tables 1 and 2. An oil-fired crucible furnace model LO2 MAN was used for the melting of these metals. The amount of copper and zinc added separately to aluminum alloy varied between 0-20 vol %. Cylindrical shaped samples of length 180 mm and diameter 15 mm were cast using a sand mould. To cast Al-Cu alloy, Cu was melted first and aluminum was added later as Cu has a higher melting temperature than aluminum.

Table 1
Chemical Composition of Aluminum Alloy

Element	*Si*	*Fe*	*Cu*	*Mn*	*Mg*	*Zn*	*Cr*	*Ti*	*Ca*	*Al*
% weight	0.444	0.203	0.012	0.013	0.571	0.006	0.003	0.008	0.003	98.738

Table 2
Chemical Composition of Cu and Zn

Element		*Cu*	*Zn*	*Sn*	*Pb*	*Fe*	*Cd*	*Al*
%weight	Cu	95.0	4.0	1.0	-	-	-	-
	Zn	0.002	99.99	0.001	0.003	0.003	0.003	0.002

The crucible used for the melting process was emptied and cleaned after each melt to avoid contamination from previous melting process. A total of 39 samples were produced with nineteen (19) each for Al-Cu and Al-Zn groups and one AA6063 alloy serving as control.

Each sample was cast and homogenized at 510°C for 1 hour and air cooled to achieve the properties of as-extruded alloy. The cast samples were machined to tensile configuration using BS 18 standard with the tensile bar gauge length of 25.25 mm and diameter of 5.05 mm. Tensile testing was carried out on an Otto Wolpert Werke tensometer at test rate of 50 mm/min with scale variation up to 2000 N.

The hardness of the samples was determined on a Brinell hardness tester with hardened steel ball (indenter) of diameter 10 mm and load 500 Kg. The average diameter of impression (indentation) was measured with a low power portable microscope fitted with scale.

Impact strength of the samples was determined using Charpy test with 2 mm notch at the centre. The results of all these tests are displayed in Figures 1-5.

Microstructural analysis was carried out on the samples through sequential grinding using emery paper grade 80, 220, 320 and 600 micron in succession, while lubricating with water to obtain a scratch-free mirror surface. Samples were etched for 20 seconds in a mixture of Nitric acid (68%), hydrofluoric acid (30%), and sodium hydroxide (2%) diluted with water. The microstructure of the samples were examined on a digital metallurgical microscope and photographed at a magnification of 100 (see Plates 1-2).

RESULTS AND DISCUSSION

Mechanical Properties

In Figure 1, the UTS of the aluminum alloy increases from 100 MPa to a maximum of 120 MPa for Cu addition from 0-3 vol %, while the UTS correspondingly decreases from 100 MPa to a minimum of 75 MPa between 0-4 vol % Zn addition. Beyond this range, the UTS decreases slowly as Cu addition is in excess of 4 vol%. The continuous addition of Cu decreases the precipitation of intermetallics which are noted for strength increases. Conversely the presence of Zn above 4 vol % does not depress the precipitation of intermetallics in the matrix of the alloy. At Zn additions in excess of 4 vol %, the UTS increase steadily. Thus above 8 vol % Zn, the alloy has superior strength than that offered by Cu additions and specifically above 18 vol % the strength value of over 130 MPa can be achieved. Above 8 vol %, Cu addition decreases the precipitation of strength-improving intermetallics while Zn increases its formation in AA6063 aluminum alloy.

Figure 2 shows the variation of yield stress with Cu and Zn addition. The behavioral pattern is similar to that in Figure 1. The maximum yield stress of 6063 aluminum alloy with Cu addition occurs at 2 vol % Cu addition (108 MPa). The reverse is the case with Zn additions where yield stress of aluminum increases after 4 vol % Zn addition.

In Figure 3, the hardness effects of both Cu and Zn addition on aluminum alloy 6063 are comparable and similar. However above 3 vol % addition, the hardness of the resulting aluminum is higher with Cu addition than with Zn addition. It should be noted that below 3 vol % additions, the hardness of both alloys is the same as Cu in the matrix is within permissible limit where its influence on the precipitation of the intermetallics is negligible.

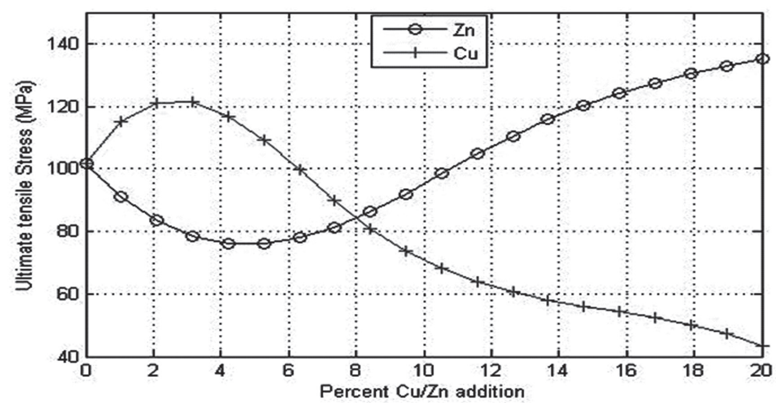

Figure 1: Ultimate Tensile Stress Against Per cent Cu/Zn Addition in Aluminum

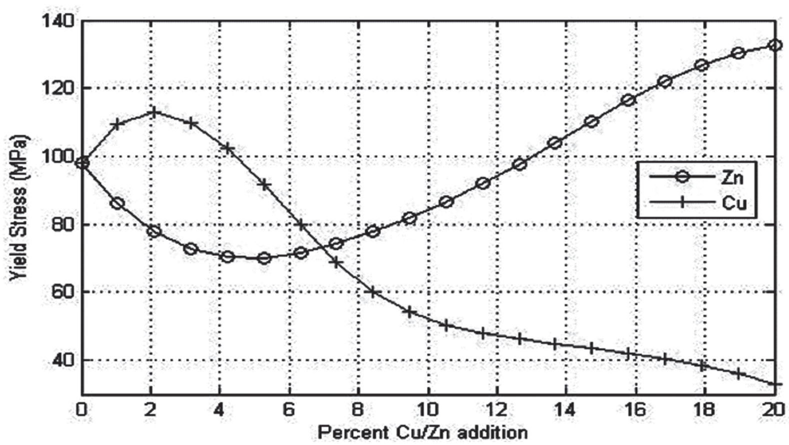

Figure 2: Yield Stress Against Per cent Cu/Zn Addition in Aluminum

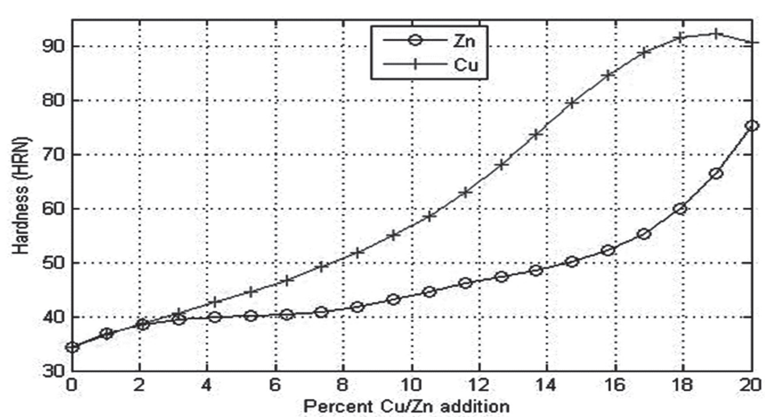

Figure 3: Hardness Against Per cent Cu/Zn Addition in Aluminum

The variations of impact energy of aluminum 6063 alloy with independent additions of Cu and Zn metals are shown in Figure 4. The maximum impact energy of about 28 J is obtained at about 5 vol % Cu additions in the alloy. Above this percent Cu addition, the impact energy decreases steadily as the formation of hard $CuAl_2$ particles at grain boundaries increases. For Zn addition the minimum impact energy occurred in the aluminum around 5 vol % additions before it increases slowly. However with the range of elemental additions considered, the impact energy of Cu addition is much better than that for Zn addition due to the formation of coarse crystals of Cu in the matrix.

The effects of Cu and Zn additions on elongation of the structural aluminum alloy are shown in Figure 5. In this case Zn addition has a better improvement on the elongation of 6063

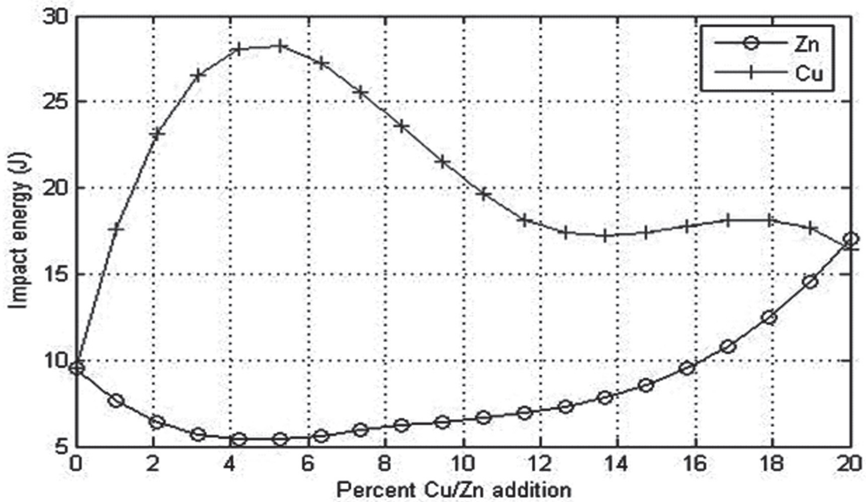

Figure 4: Impact Energy Against Per cent Cu/Zn Addition in Aluminum

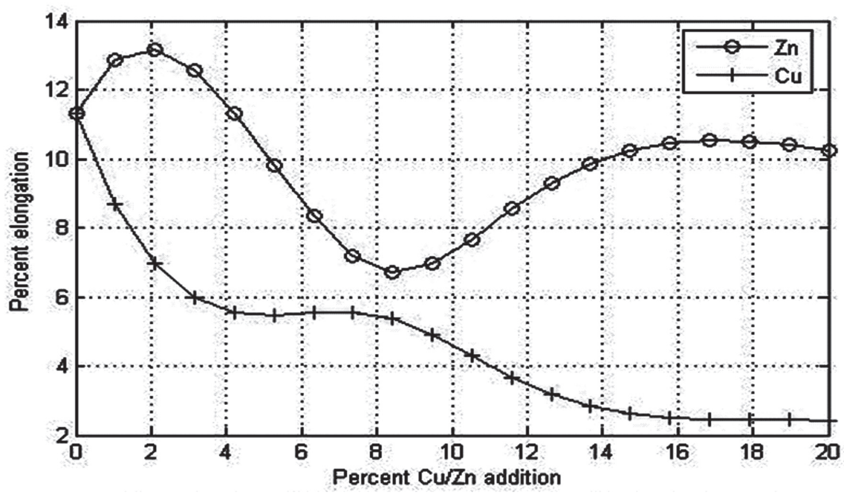

Figure 5: Per cen Elongation Against Per cent Cu/Zn Addition in Aluminum

aluminum than Cu addition. The addition of Zn resulted in an early peak of 13% elongation at 2 vol %. Elongation then falls gradually to a minimum of 7 vol % around 8 vol % before rising up again with further Zn addition. Cu addition promotes a rapid fall in ductility between 0-3 vol % as a result of the presence of $CuAl_2$ at grain boundaries. An optimum percent Cu addition with significant effect on the strength, hardness, impact energy and elongations occurred at 4 vol % content. The continued presence of hard $CuAl_2$ at grain boundaries caused decrease in strength, impact and ductile characteristics with attendant increases in hardness as Cu addition increases beyond 4 vol %. Thus Zn addition above 2 vol % offers better results for elongation, hardness and impact energy in 6063 aluminum alloy when desired without necessarily depressing the strength effect of Mg_2Si in the matrix.

Microstructure

Al –Cu alloy

The matrix of 6063 aluminum alloy shows fine crystals of α-aluminum surrounded by crystals of Mg_2Si fairly distributed in the matrix (see Plate 1a). In plate 1b the matrix of the Al-Cu alloy consist essentially fine α-aluminum crystals with Mg_2Si at grain boundaries in the matrix. At 12 vol % Cu addition there is significant increase in volume fraction of precipitated intermetallics at grain boundaries in the α-aluminum matrix (see Plate 1d). When the amount of Cu increases to 20 vol %, an increase in the number of grain boundaries and its constituents is observed in the microstructure (see Plate 1e).

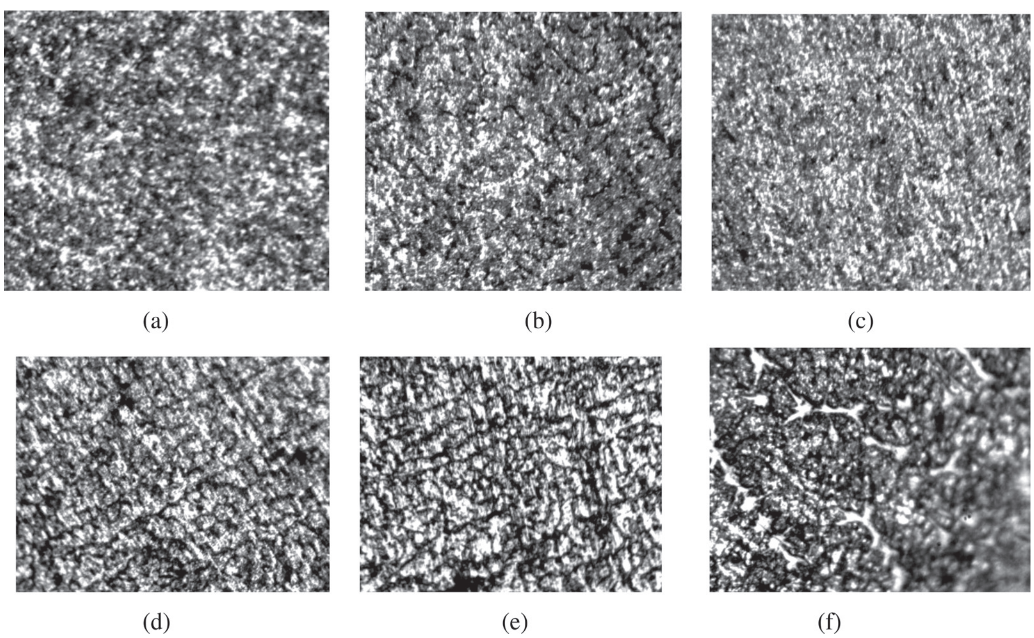

Plate 1: Shows Al-Cu sample microstructure at various Cu additions after normalizing (a) Unalloyed, (b) 4%Cu (C) 8%Cu (d) 12%Cu (e) 16%Cu (f) 20%Cu

Al -Zn alloy

The matrix consists of α-aluminum crystals, Mg_2Si and other intermetallics, with Mg_2Si crystals at the grain boundaries. At 4 vol % Zn addition the intermetallic crystals are sparsely dispersed in the matrix (see Plate 2b). There is an increase in amount of intermetallic phases precipitated as Zn addition increases to 8 vol %. However this does not affect the amount of Mg_2Si crystals precipitated in the aluminum matrix as well as the volume fraction of primary aluminum phase (see Plate 1c). At 12 vol % Zn addition there is a depression in the amount of Mg_2Si crystals precipitated. Plate 2e of samples containing 16 vol % Zn indicates a considerable absorption of Mg_2Si into the matrix as a result of the increase in amount of Zn added to the aluminum alloy. Further increase of Zn additions to 20 vol % increase the fineness of α-aluminum phase with precipitation of high intensity volume fraction of Mg_2Si that is well distributed in the matrix.

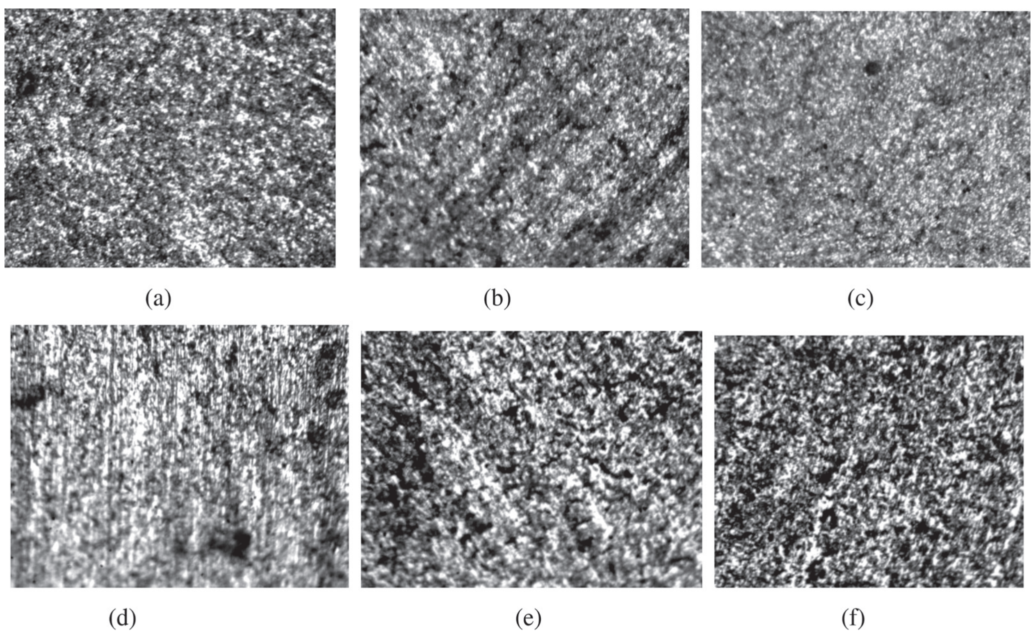

Plate 2: Shows Al-Zn Sample Microstructure at Various Zn Additions After Normalizing (a) Unalloyed, (b) 4%Zn (C) 8%Zn (d) 12%Zn (e) 16%Zn (f) 20%Zn

CONCLUSION

The study has revealed that the yield stress, UTS and hardness of Aluminum 6063 alloy can be greatly improved with addition of 14-16 vol % of Zn. Above 16 vol % Zn addition, impact energy is significantly improved. For structural purposes the addition of Zinc above the allowable Zn content in 6063 aluminium alloy will improve the strength, yield stress, impact energy and elongation responses. The ductility of the alloy depends on the amount of Mg and Si in the solid solution and on the size and distribution of the particles of the Mg_2Si (Ref 10).

The addition of Cu in the matrix significantly depresses the precipitation of other intermetallics in the matrix surface resulting in increase in both UTS and yield stress. At 8 vol % Cu addition, the volume fraction of Mg_2Si phase precipitated are reduced with increase in precipitation of other intermetallics in the matrix leading to reduction in UTS and yield stress with increase hardness. Cu addition in the range of 2-4 vol % will increase the tensile strength and impact energy without diminishing the hardness. This is a way to make brittle intermetallics embedded in FCC matrix ductile and would be of interest to the auto industry.

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