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THE EFFECT OF DIFFERENT COPPER CONTENT ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF Zn–40Al AND Al–40Zn ALLOYS

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ABSTRACT

The alloys of different weight percentage of Cu–namely, 1, 2, 3, 4 and 5 wt.% are produced by conventional melting and mould casting route. The effect of different Cu–weight percentage on the tensile properties, percent elongation, hardness and wear behavior of the alloys is investigated. It was observed that the hardness of the alloys increased continuously with increasing copper content up to 5 wt.%. The tensile strength increased and the wear loss decreased with increasing Cu–content up to 2 wt. % for Zn–40Al but up to 3 wt. % for Al–40Zn. However, the coefficient of friction and temperature were found to be less for the copper containing alloys than the ones without copper.

KEYWORDS: Zn–Based Alloy, Al–Based Alloy, Ultimate Strength, Hardness, Friction Coefficient and Wear

INTRODUCTION

As a result of extensive research work carried out over the past, a number of Zn–based commercial alloys having eutectic (Zn–5Al), eutectoid (Zn–22Al) and Monotectoid (Zn–40Al) compositions have been developed. The alloys showed better performance than either bronze or cast iron used in engineering and tribological applications [1, 2]. These alloys are mainly based on Zn–Al eutectic, eutectoid or monotectoid compositions. The Zn–Al monotectoid alloys were found to have higher strength and wear resistance than either eutectic or eutectoid alloys [3–7]. It has been shown that the addition of alloying elements including copper, silicon, magnesium and nickel can improve the mechanical and tribological properties of Zn–Al alloys [8–12]. A few studies have been carried out on the evaluation of mechanical and tribological properties of Al–based ternary alloys containing zinc and small amounts of copper [11, 12]. According to the results of these investigations, hardness, tensile strength and wear resistance of the Al–based ternary alloys increased with decreasing zinc and increasing copper contents [11, 12]. This indicates that the binary Al–40Zn alloy can be taken as the basis for preparing and investigating ternary Al–Zn–Cu alloys. Copper was found to be the most effective alloying addition towards improving mechanical and tribological properties of these alloys [8, 9]. However, the effects of copper content on friction and wear properties of these alloys have not been fully established. Zn–based monotectoid alloys containing copper and silicon have been found to be superior to the alloys based on either eutectic or eutectoid compositions, as far as their mechanical and tribological properties are concerned [10, 11].

EXPERIMENTAL METHODS

Materials Selection

The alloys were produced from high purity zinc (99.9%), commercially pure aluminum (99.7%) and electrolytic copper (99.9%).

Preparation of Test Specimens

The alloys were melted in a crucible using an electrical furnace and poured at a temperature of approximately 630 °C into a steel mould at room temperature. The mould had a conical shape with length 196 mm, internal diameter at the bottom 60 mm, and internal diameter at the top 72 mm. The microstructure of the alloys was examined using scanning electron microscopy (SEM). Tensile tests were performed on round specimens having a diameter of 8 mm and a gauge length of 40 mm at a strain rate of $4.5x10^{-3}$ s^{-1}.

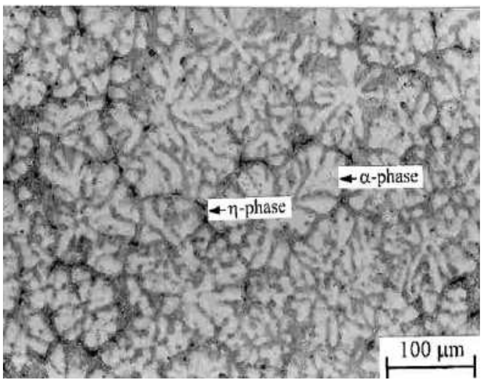
Tensile properties of the alloys were analyzed by carrying out test on the universal testing machine. Three specimens were used to determine the tensile strength of each alloy. Brinell hardness of the alloys was measured using a load of 62.5 kgf and a 2.5 mm diameter ball as an indenter. Vickers microhardness of the alloys was also measured at a load of 5 gf. The macro hardness and microhardness of the alloys were determined by taking an average of five and ten readings respectively.

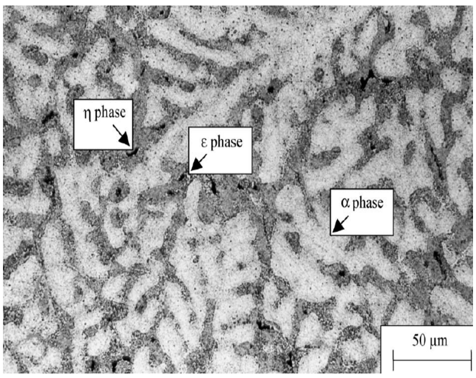
Computerized pin–on–disc wear test machine was used for the wear and friction tests of alloy samples under different loads from 10 N to 100 N and linear speed of 0.65 ms^{-1} for one hour. Wear resistances are measured by a weight loss using a four digital microbalance. Each wear sample is ultrasonically cleaned and weighed before the wear test using a balance with an accuracy of 0.01 mg. Three samples for each condition are tested and the average of the weight loss measurements is used for calculation of the wear property.

RESULTS AND DISCUSSIONS

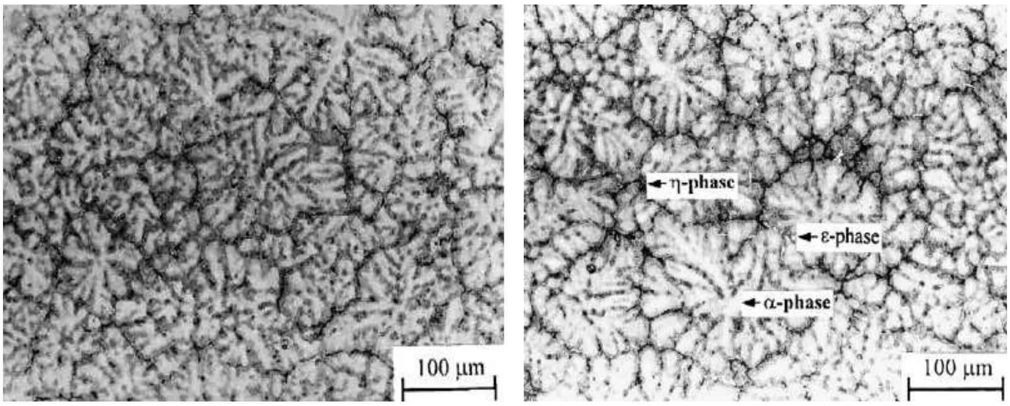
The Microstructure

The microstructure of the Zn–40Al alloy basically comprise a mixture of two phases, namely dendrites α–Al rich phase and interdendritic η–Zn rich phases as shown in Figure 1(a). Addition of copper resulted in the formation of ε–Cu rich intermetallic ($CuZn_4$) phase in the interdendritic regions of the alloys. This can be seen in the microstructures of the alloys containing 3 and 5% copper, Figure 1(b–d). The number and size of the ε–phase particles increased with the copper content of the alloys. This type of microstructure seems to be ideal for bearing materials, ε–phase acts as a load–bearing phase, produces hardening effects and offers wear resistance in the alloys [13–18].





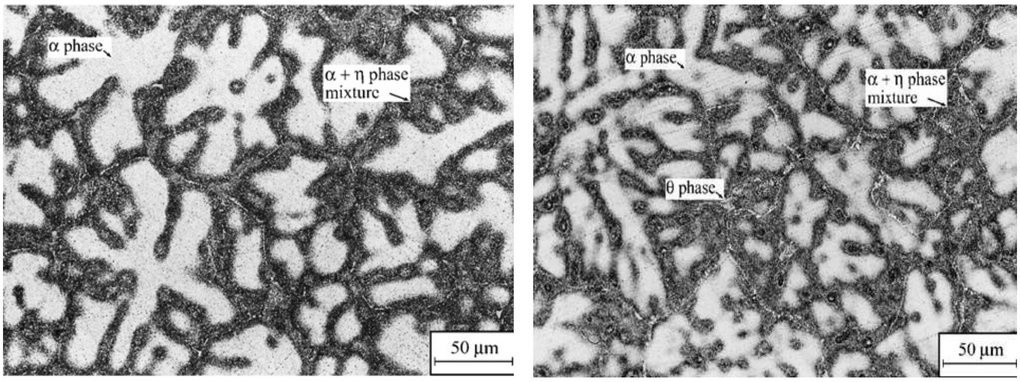
(a) **(b)**



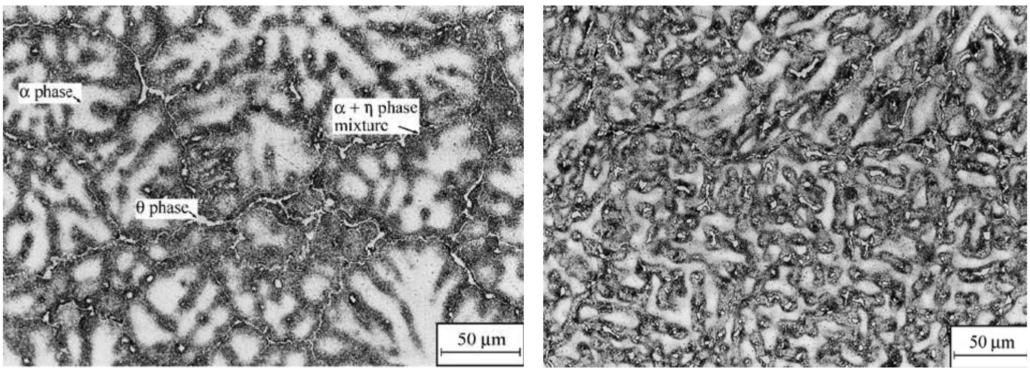
(c) (d)

Figure 1: Microstructures of the Alloys: (a) Zn–40Al, (b) Zn–40Al–2Cu, (c) Zn–40Al–3Cu and (d) Zn–40Al–5Cu

While the microstructure of the Al–40Zn alloy consists of α–Al rich phase dendrites surrounded by eutectoid α+η phase, Figure 2 (a). In addition to these phases, θ–($CuAl_2$) particles formed in the interdendritic regions of the ternary Al–40Zn–Cu alloys (Figure 2b–d). The θ–particles coarsened with increasing copper content of the alloy system.



(a) (b)



(c) (d)

Figure 2: Microstructures of (a) Al–40Zn, (b) Al–40Zn–1Cu, (c) Al–40Zn–3Cu and (d) Al–40Zn–5Cu Alloys

It appears that replacing zinc with aluminum in Zn–Al–Cu system results in the formation of θ–phase in place of ε–particles. These observations are in agreement with the results of previous investigations and can be related to Al–Zn, Al–Cu and Al–Zn–Cu phase diagrams [13–18].

Mechanical Properties Results (Tensile Strength, Percent Elongation and Hardness)

The variation of hardness, tensile strength, percent elongation and microhardness of the test alloys as a function of copper content are shown in Figs. 3–6.

Hardness and Percentage Elongation

It was found that, the hardness of the alloys increased almost continuously with increasing Cu–content up to 5 wt.% (Figure 3) results from the solid solution strengthening [8, 9]. Addition of copper to the binary Zn–40Al alloy, ε–phase is a hard phase and its formation increases the overall hardness of the alloys (Figure 3). However, formation of the ε–phase results in a reduction of the copper content of the α–phase which is the matrix of the alloys and hence reduces the effect of solid solution strengthening [19, 20]. While, Addition of copper to the binary Al–40Zn alloy results in solid solution strengthening of the α–phase and formation of copper–rich θ–phase. Solid solution strengthening effect (solution of copper in α) causes an increase in both hardness and tensile strength of the ternary alloys. But, the percentage elongation of the alloys decreased continuously with increasing Cu–content (Figure 4).

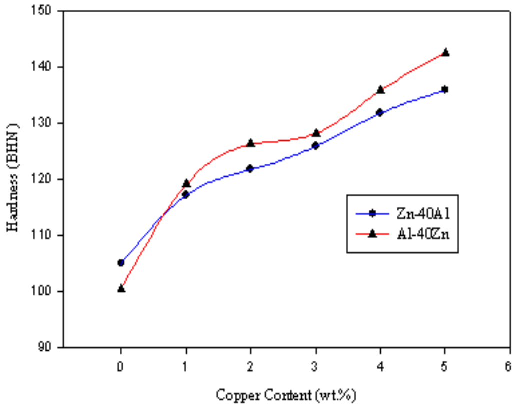


Figure 3: The Effect of Copper Content on the Hardness of Zn–40Al–Cu and Al–40Zn–Cu Alloys

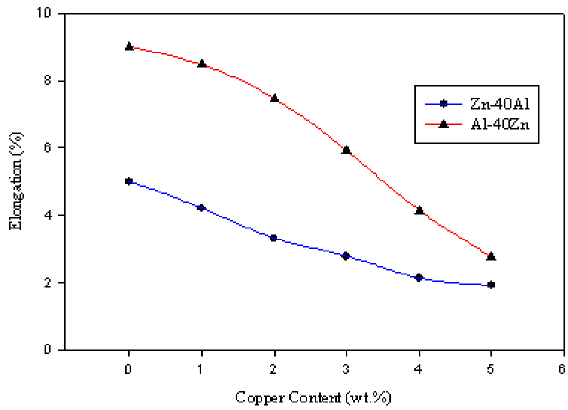


Figure 4: The Effect of Copper Content on the Percentage Elongation of Zn–40Al–Cu and Al–40Zn–Cu Alloys

Tensile Strength

It was found that, the tensile strength of the alloys increased with increasing Cu–content up to 2 wt.% (in Zn–40Al alloys) and up to 3 wt.% (in Al–40Zn alloys) above which the trend reversed, while their hardness increased continuously over the entire range of Cu–content (Figure 5). However, the decrease observed in the tensile strength of the alloys containing more copper may be explained in terms of microstructure. It is known that, when the Cu–content of the Zn–Al–Cu alloys exceeds a certain level (1–2 wt.%), formation of the ε–phase results in a reduction of the copper content of the α–phase which is the matrix of the alloys and hence reduces the effect of solid solution strengthening, also increase the cracking tendency of the alloys [8–11, and 21]. But, when the Cu–content of the Al–Zn–Cu alloys exceeds 3 wt. %, formation of hard and brittle θ–phase weakens the interdendritic regions of the alloys and gives rise to cracking tendency. The microhardness of the α–phase of the alloys increased with increasing Cu–content up to 2 wt. % (in Zn–40Al alloys) and up to 3 wt.% (in Al–40Zn alloys) and became constant above this level (Figure 6).

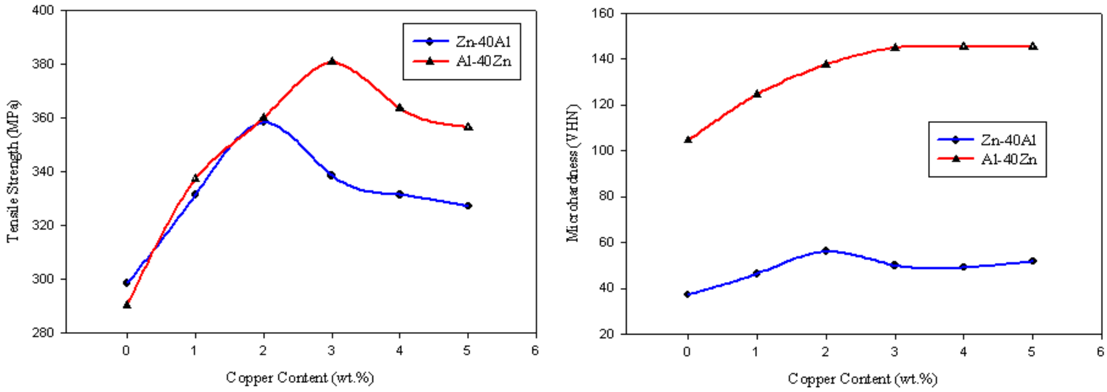


Figure 5: The Effect of Copper Content on the Tensile Strength and Microhardness of the α–phase of Zn–40Al–Cu and Al–40Zn–Cu Alloys

Wear Test Results

Wear loss of the alloys is plotted as a function of sliding distance in Figure 6. It was found that the wear loss of the alloys decreased with increasing Cu–content up to 2 wt.% (in Zn–40Al alloys) and up to 3 wt.% (in Al–40Zn alloys). However above this level, the positive effect (i.e. reduced wear rate) of increased hardness was outweighed by the negative influence (high wear rate) of decreasing strength. This is probably why when the Cu–content exceeded, marginal increase in wear loss was observed in the alloys. After a certain range of sliding distance and wear loss of the samples become almost constant. These observations may be explained in terms of microstructure and mechanical properties of the alloys. The hardness and tensile strength of the alloys have a strong effect on their wear resistance.

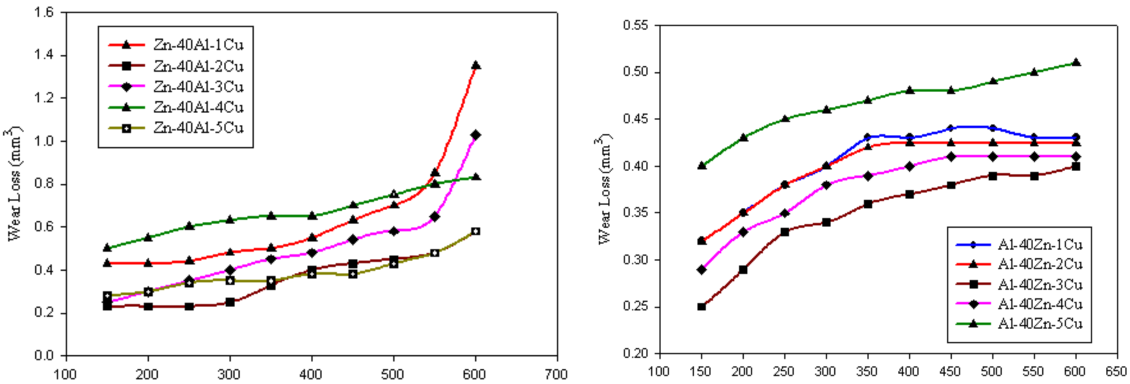


Figure 6: Effect of Copper Content on Wear Loss of Zn–40Al–Cu and Al–40Zn–Cu Alloys

CONCLUSIONS

- When the Cu–content increased, new phases like ε–phase formed in Zn–40Al and θ–phase formed in Al–40Zn in the interdendritic regions of the copper containing ternary alloys.
- Hardness of the alloys increased continuously with increasing Cu–content, but percentage elongation showed a reverse trend.
- Microhardness of α–phase and tensile strength of the alloys increased with increasing Cu–content up to 2 wt.% for Zn–40Al and up to 3 wt.% for Al–40Zn, but above this level it decreased as the Cu–content increased. The wear loss of the alloys was found to be inversely proportional to their tensile strength.

- As the sliding distance increased, the friction coefficient and wear loss of alloys reached constant levels following an initial decrease in friction coefficient and only an initial increase in wear loss.
- Tensile strength and hardness are very effective towards controlling the wear behavior, but microhardness of α–phase has the strongest influence on their wear resistance.
- Among these alloys, the highest tensile strength and wear resistance (inverse of wear loss) were attained by the Zn–40Al–2Cu alloy and Al–40Zn–3Cu alloy.

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