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EFFECT OF COPPER ADDITION ON THE MECHANICAL BEHAVIOR, MICROSTRUCTURE, AND MICROHARDNESS OF Zn-21% Al CAST ALLOY

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ABSTRACT

In this study the literature related to Zinc-Aluminium cast alloy was reviewed and discussed. Few works have been published on the effect of Copper addition on the mechanical behaviour, hardness, and microstructure of the obtained alloys. The effect of 4% Cu addition to Zn-21Al on the mechanical behaviour and microhardness was investigated. It was found that the addition of 4% Cu resulted in 18.3% enhancement in microhardness where the mechanical characteristics were reduced (softening) by 14.5% at 0.2 strain. It has been found that after upsetting test, the microhardness was enhanced by 53.3 % and 42.7 % for Zn-21Al and Zn-21Al-4%Cu respectively.

Keywords: Zinc, aluminium, copper, mechanical properties, microhardness, microstructure.

INTRODUCTION

Zn-based alloys have a number of advantages over traditional bearing materials (Murphy and savaskan, 1984; savaskan and Murphy, 1987; Lee *et al*., 1987). These advantages can be summarized as high resistance to wear, excellent castability, and low cost (savaskan *et al*., 2002; Prasad *et al*., 1996; Prasad *et al*., 2001; Savaskan and Aydiner, 2004; Purcek *et al*., 2002). Among the monotectoid-based alloys, the best mechanical properties and wear performance were obtained with the Zn–40Al–2Cu alloy (Savaskan *et al*., 2004; Savaskan *et al*., 2003). Zinc-based alloys have been found to be promising energy and cost effective substitute to conventional bearing bronzes under heavy load and slow-to-medium speed applications (Grevais *et al*., 1980; Apelian *et al*., 1981).

The basic emphasis of the present work is to investigate the copper addition at a rate of 4% on the mechanical characteristics of some Zinc-aluminium alloys, namely, ZA-21Al, in addition, the effect of upsetting process on both alloys are presented and discussed.

MATERIALS AND METHODS

Materials

Zinc, commercially pure aluminum, and pure copper were used in the preparation of the two Alloys; Zn-21%Al and Zn-21%Al-4%Cu. In this work Zn-21%Al will be reviewed as ZA21.

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Zinc and Aluminum

Zinc is a bluish, lustrous, diamagnetic metal with HCP structure of density 7.14 g cm^{-3} and melting point of 419.5 °C. Zinc powder of 99.9 % purity was used to prepare the two casted Alloys. The commercially pure aluminum of 99.98 % was used.

Casting Alloy (ZA-21) and ZA-21- 4%Cu

The chemical analysis of the prepared alloys ZA-21 and ZA-21-4%Cu are shown in table 1 and table 2 respectively. The density of ZA-21 is 6.23 gm. cm^{-3} and the melting point ranges between (380-386) °C.

Copper

Pure copper is used extensively as cable, wire, and pure powder. The density of copper is 9.95 $gm.cm^{-3}$ and the melting point is 1080°C. Copper has many important advantages; its corrosion resistance, easily fabricated, high electrical and thermal conductivity. Copper of 99.99% purity was used.

Equipment

The following set of machines and equipment were used throughout the experimental work:

1. An electric resistance furnace (Carbolite) with 0-1100°C.
2. XRF Model 1800- shemadzu, Japan
3. Digital microhardness tester (model HWDM-3).
4. Universal Testing Machine with 100KN capacity (Quasar 100).
5. Microscope type NIKON 108.
7. CNC lathe machine (Boxford).
9. Casting mould

Table 1. Chemical analyses of ZA21 alloy wt.

Element	Al	Mg	Fe	Pb	Cd	Sn	Zn
%, Wt	20.3-21.3	0.03-.08	0.1	0.005	0.004	0.003	Bal

Table 2. Chemical analyses of ZA-21-4% Cu alloy wt.

Element	Al	Cu	Mg	Fe	Pb	Cd	Sn	Zn
%, Wt	20.3-21.3	4	0.03-.08	0.1	0.005	0.004	0.003	Bal

Experimental Procedure

Preparation of test specimens

The ZA-21%Al alloy (in weight) was prepared by melting 99.99% Zn and 99.99% Al, where ZA-21%Al-4%Cu alloy was prepared as the first alloy just adding the predetermined amount of copper powder into molten ZA-21%Al at 550 °C under flux (aluminum florid and calcium florid). A graphite crucible and graphite rod were used in stirring the molten metal. The temperature was kept constant for five minutes and the alloy was stirred for five minutes before pouring it into brass mould. A number of cylinder specimens of 11mm diameter and 65 mm length mm from each ZA-21%Al and ZA-21%Al-4%Cu alloy were prepared for upsetting and microhardness tests. In addition, several specimens of 10 mm diameter and 10 mm height (h/D = 1) were prepared for investigating the mechanical behavior on compression test.

Compression Test

The prepared cylindrical specimens were subjected to compression test using Quasar 100 Universal Testing Machine with 100 KN capacity at $1*10^{-3}$/s strain rate. The load-deflection curve was obtained for each type of the prepared alloy from which the true stress-true strain curve was determined. Three tests were carried out on each ZA-Cu alloys where the average was calculated. The compressed work piece is shown in figure1.

Fig. 1. Compression test specimen.

Microhardness and Microstructure Tests

Microhardness test was carried out using HWDM-3 microhardness tester at 500 gm force on each ZA-Cu alloys. Finally, metallurgical examination was carried out on ZA-21 and ZA-21-4%Cu alloys to determine the effect of copper addition on its microstructures,50 % natal and 50% ethanol solution was used in etching process.

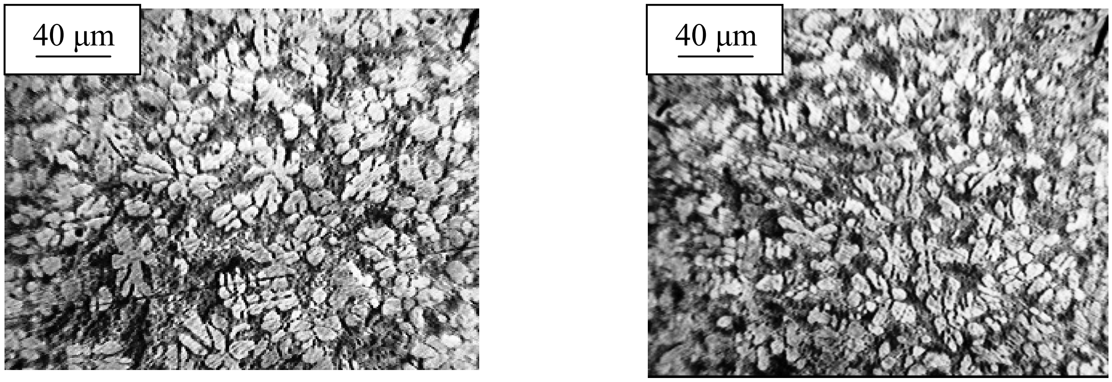
RESULTS AND DISCUSSION

In this section, the effect of copper addition on the microstructure, microhardness, and mechanical characteristics of ZA alloys will be presented and discussed.

Effect of copper addition on the microstructure of ZA21 cast alloy

Figure 2 shows the optical micrographs of ZA21 and ZA21-4 % Cu before upsetting (as casted). It is clearly shown that the microstructure consists of primary aluminium-rich **α** zinc-rich **η** and copper-rich **ε** phases. It is worth to mention that these results are consistent with those of El-Tayeb *et al.* (2006). Their results indicated that the microstructure of the ternary Zn–40Al–2Cu alloy consists of aluminium-rich **α** zinc-rich **η** and copper-rich **ε** phases.

Other studies pointed out that the microstructure of the binary monotectoid alloy (Zn-40Al) consists of aluminum-rich **α** dendrites and zinc-rich **η** phase in the interdendritic regions. Addition of copper produced copper-rich ε phase particles, but had no effect on the dendritic structure of the alloys. It was observed that the **ε** phase was formed in the interdendritic region of the alloys containing more than 2% Cu. This type of microstructure seems to be ideal for bearing materials which usually have two phases, one of which is hard and the other one is soft (Savaskan, 1980). In zinc-aluminum-copper alloys, the aluminum-rich **α** phase having a face-centered cubic (FCC) crystal structure that exhibits excellent ductility (Purecek *et al*., 2002; Pandey and Prasad, 1997; Prasad *et al*., 1997). The zinc-rich **η** phase having a hexagonal-close-packed (HCP) crystal structure with a large (c/a) ratio.



a) Za21 b) Za21-4% Cu

Fig. 2. Photomicroscan of a) ZA21 and b) ZA21-4%Cu at 250x.

Effect of copper addition on the microhardness of ZA21 cast alloy

It is obviously shown in figure 3 that the addition of 4% copper resulted in 18.3% enhancement in microhardness . The results are consistent with those of Joong *et al.* (2007). They observed that the hardness of the alloys increased continuously with increasing copper content up to 5%. Microhardness of the aluminium-rich **α** phase was also affected by the copper content in a manner similar to that of the tensile strength. It was found that the wear loss of the alloys decreased with increasing copper content and reached a minimum at 2% Cu for a sliding distance of 700 km. However, the coefficient of friction and temperature due to frictional heating were found to be generally less for the copper containing alloys than the one without the element. Furthermore, they explained the effect of copper on the wear behaviour of the alloys in terms of their microstructure, hardness, tensile strength, percentage elongation, and microhardness of the phase.

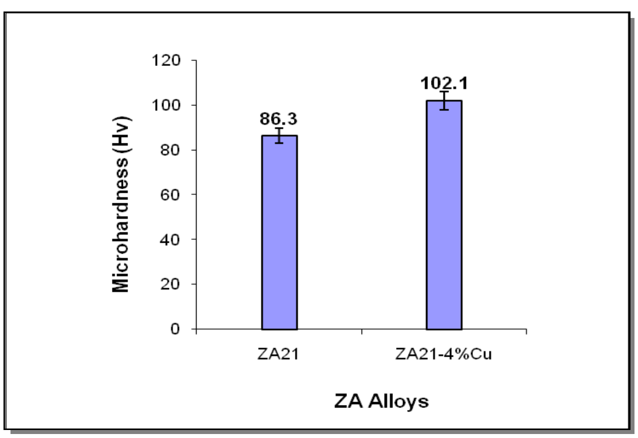


Fig. 3. Microhardness of ZA alloys (as casted).

Effect of copper addition the microstructure of ZA21 after upsetting

It can be seen from figure 4 that the interdendritic areas are decreased where the dendritic areas were increased.

Effect of Upsetting on the microhardness of ZA21 and ZA21- 4%Cu cast alloys

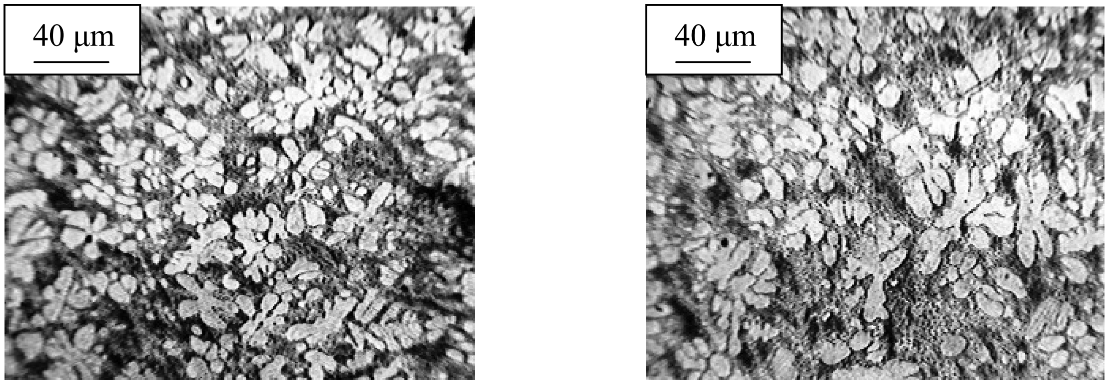
As illustrated by figure 5, there is an enhancement in microhardness after the upsetting test. A 53.3% enhancement in microhardness of ZA21 alloy and 42.7% enhancement in ZA21- 4%Cu were achieved.

Effect of copper addition on the mechanical characteristics of ZA21 cast alloy

As shown in figure 6, the mechanical properties after 4% Cu addition were deteriorated, however the structure become softer, the maximum reduction is about 14.5% at 0.2 strain. This result is consistent with that of El-Tayeb *et al.* (2006) where their result indicated that the tensile strength increased with increasing copper content up to 2%, but above this level the strength decreased as the copper content increased further.

Upon the work of structural softness due to morphological change of (**α+η**) phases from fine lamellar structure to coarse equiaxed grains (Joong *et al.*, 2007). According to hall-pitch equation, the strength of microstructure with lamellar or equiaxed grains morphology is inversely proportional to the grain size or interlamellar spacing.

On the other hand, the softness is related to two opposite defects; solid solution hardening of α phase and weakling effect through cracking tendency to ε phase, where the later is more effective at copper counted beyond 3% addition (Yasin and Savaskan, 2009).



a) Za21

b) Za21-4% Cu

Fig. 4. Photomicroscan of a) ZA21 and b) ZA21-4%Cu after upsetting process at 250x.

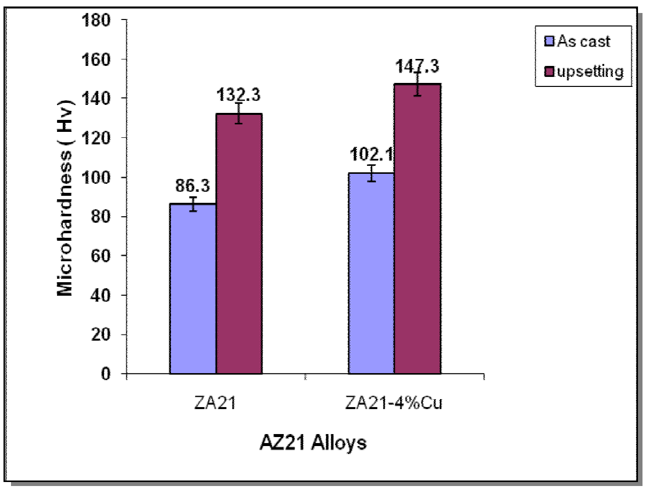


Fig. 5. Microhardness of ZA alloys before and after upsetting.

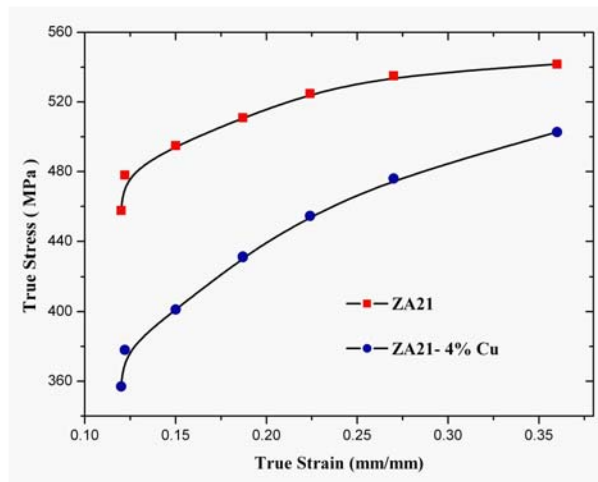


Fig. 6. True stress- true strain for ZA21 and ZA21- 4% copper.

CONCLUSION

The mechanical strength and the microhardness of ZA21 and ZA21-4%Cu have been investigated. The mechanical strength was decreased at 4% copper addition, and the structure become softer. On the other hand, the microhardness increased at 4% copper addition and this could be attributed to the new intermetalic compounds Al_2Cu which has been produced. Furthermore, after the addition of 4%Cu to ZA21 cast alloy, the structure of the produced alloy become softer, so this will reduce the press capacity during the forming processes. This study has thrown many questions in need. The machinability, the corrosion resistance, and wear resistance of these new alloys can be investigated. Further investigation into mechanical strength and microhardness for different alloys with different additives is strongly recommended.

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