

Effect of Magnesium and Nickel on the Wear and Mechanical Properties of Casting Bronzes

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Abstract: Investigation on tribological properties of cast metals is a most attractive research subject in recent years. Aluminum-Bronze cast alloys demonstrate proper mechanical and wear properties for this application. In this research, the effects of magnesium and nickel on tribological properties of cast Aluminum-Bronzes have been investigated. After the casting, the samples were heat treated, quenching and aging. The wear test conducted by pin-on-disk apparatus and wear mechanisms and microstructure of the specimens were studied by a scanning electron microscopy. It was shown that addition of magnesium and nickel reduces the size of α and β' phases. Increasing the amount of magnesium and nickel to 10%, improves the mechanical and tribological properties of the alloys. When the alloying elements are low, the wear mechanism are lamination and abrasive. Increase alloying elements decrease these wear mechanisms.

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1. Introduction

Aluminum-bronze alloys are copper base alloys containing aluminum as the main alloying element. Other alloying elements such as Ni, Fe, Mn, Si improves other properties such as strength, toughness, resistant to corrosion, and magnetic behaviors (Meigh, 2000).

Aluminum-bronze alloys containing nickel (NAB) including 9-12% Al, 6% Fe and lot of Ni are important commercial aluminum bronze alloys. Presence of aluminum increase the mechanical properties of the alloy by the establishment a FCC phase, which could improve the casting and hot working properties of the alloy (G. Kear et al,2007). Other alloying elements improve the mechanical properties and modify the microstructure. Ni improves the corrosion resistance, whereas Fe is a grain refiner (J. A. Wharton et al, 2005).

Mechanical properties of bronze alloys are depend on their chemical composition, microstructure, production conditions and can be improve significantly by heat treatment. For example the tensile strength can be increase to 700 MPa by heat treatment. Improvement of mechanical properties in aluminum-bronze alloys containing 8-9.5% Al, when the amount of other alloying elements less than 2% is possible by heat treatment. (E. Derek et al1985). However, heat treatment is applicable on

aluminum-bronze alloy containing 9.5-11% Al, but, Ni, Fe and Mn can be added if it is not necessary (Z. Han et al,2002,C. Arthur,1991).

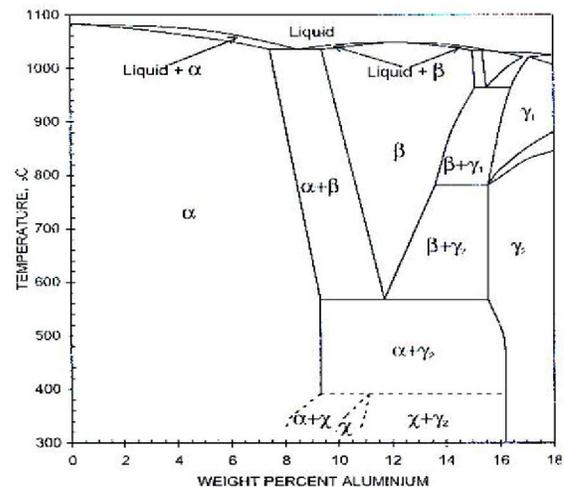


Figure 1. Equilibrium phase diagram of Cu-Al.

Aluminum-bronze alloys are proper selection for making gears at high stress conditions. Nevertheless, these alloys are also use in easier conditions, such as wear bands, bushes, valve ends, etc. When two surfaces are in contact and move against each other in

loading, wear occurs. In the most applications, one of the surfaces is not moveable. Based on the application of Bronzes, there are several types of wear conditions:

- A sliding action as in the case of plain rotary bearing or of various type of liner reciprocating machinery.
- A rolling action as in the case of wheels running along a track or of ball or roller bearing.
- A combination of both, as in gears (Meigh, 2000).

The equilibrium diagram of aluminum-bronze alloys is shown in Fig. 1. Depending on heat treatment process, alloys that contain 9.5-11% Al including α , β , γ_2 phases, forms with other phases. It is important to know that accelerate cooling could result in the formation of β' rather than $\alpha+\gamma_2$ phases. This phase is similar to martensite phase in steels (Meigh, 2000, R.Thomson et al, 1978).

Shi, study the Rotation-Sliding wear process in nickel aluminum bronzes alloys (Cu-10Al-5Ni-4Fe) without using lubricant agent in comparison with hardened EN19 steel and report adhesive wear and laminated wear mechanisms in these alloys (Shi et al, 1996).

2. Experimental

The aim of this work is to investigate the effect of adding 0, 2, 4, 6, 8, 10 % magnesium and nickel to the aluminum-bronze alloys, and research on their effects on mechanical and wear properties.

Commercially pure copper 99.99 wt, pure aluminum 99.7 wt, pure nickel 99.9 wt, ferromanganese (25-75, 90-10), pure manganese, and iron sheets were used as raw materials for melting process. In order to decrease gas absorption and porosity formation crucible gas fired furnace were used. The calculated amount of Cu, Ni, ferromanganese, and Fe were melted at 1200 °C and then the proper amount of pure Al was added to melt. In order to prevent segregation of elements, the melt was cast as billet in permanent molds. The chemical composition of specimens done are shown in Table 1. The tensile test samples were prepared according to the ASTM E8-03 standard, and wear test samples with the 5 cm length and 5 mm thickness were prepared. All the specimens were heated at 870 °C for 20 min, and quenched in water. Tempering treatment was conducted at 600 °C for 2 hours.

The alcoholic chloriferic etchant was used for etching the samples. Microscopic observations were done by scanning electron microscope (SEM) and tensile and hardness tests were done by standard procedures.

As shown in Fig. 2, pin-on-disk tests were used for wear tests using 52400 standard steel as the pin for 500 m. Specimens weight loss due to wear were measured by digital scale for the distances of 10, 20, 50, 100, 300, 500 m.

Table 1. Chemical composition of cast specimens.

EL \ Alloy	Cu%	Al%	Fe%	Mn%	Ni%
A	88.9	9.73	1.24	<0.050	<0.050
B	85.13	9.86	0.998	2.1	1.91
C	81.13	9.89	0.947	3.91	4.12
D	77.1	9.65	1.4	5.87	5.95
E	73	9.46	1.35	7.99	8.13
F	69.2	9.93	1.02	9.75	10.09

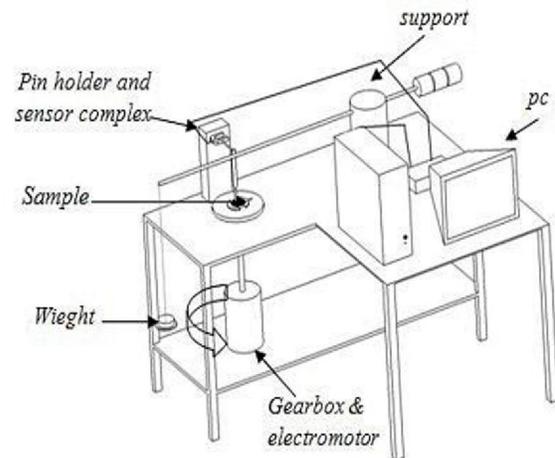


Figure 2. Schematic design of Pin-on-disk wear test

3- Results and Discussion

3-1- Microstructural

As can be seen in Fig. 3, β' phase (tempered β') is formed in adjacent of α phase, in all specimens. According the phase diagram it's expected to get β phase in the microstructure by heat treatment at 870 °C. Also, it's expected that by accelerate cooling, the

β to α phase transformation is prevented and β' phase is formed.

By tempering on 600 °C, β' is transformed to tempered β' and α . The growth of α phase in specimen A is accelerated due to absent of Ni and Mn elements. In this specimen, α grains are observed as a circle phases in the microstructure (Fig 3-a). In the presence of manganese and nickel, the formation of α phase in the specimens is prevented and finer α and β' phases are formed. This trend was continued by increasing alloying elements in the composition. That's why in the D, E, F specimens, the detailed microstructure is not observable in low magnifications. So, higher magnifications of these microstructures are shown in Fig. 3.

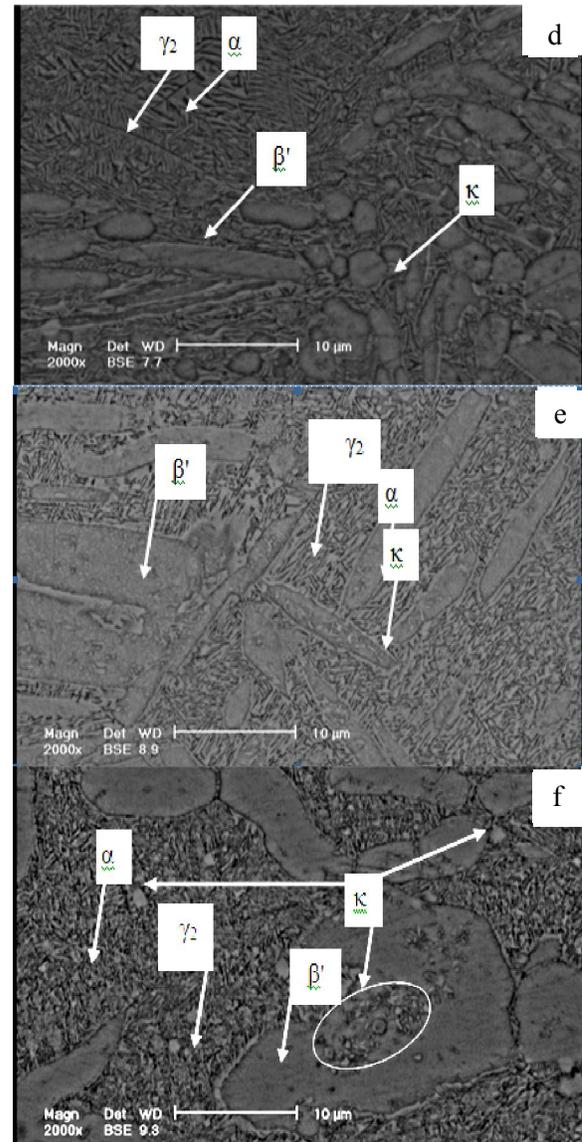
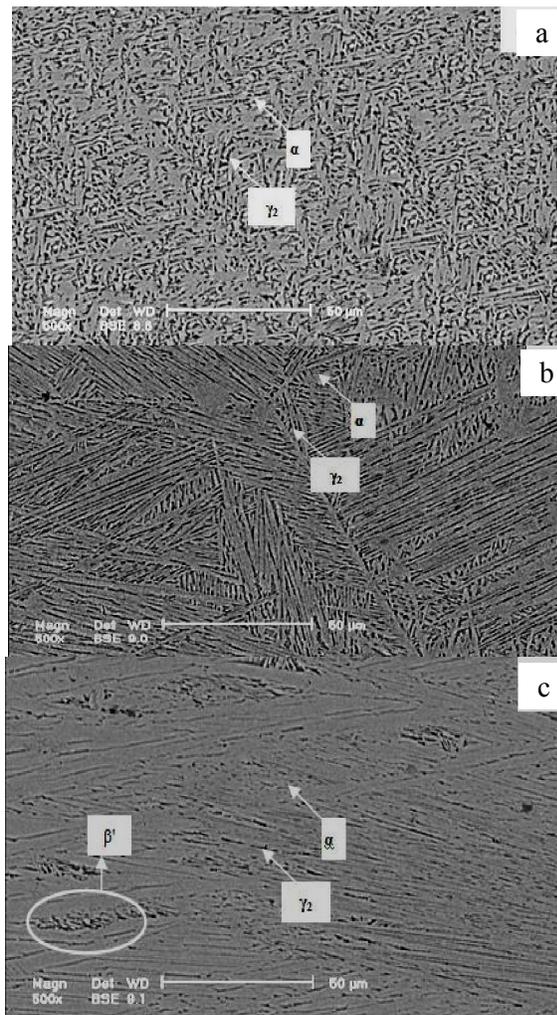


Figure 3. SEM microstructure images of the specimens contain different amount of Mn and Ni, (a) Specimen A, (b) Specimen B, (c) Specimen C. (d) Specimen D, (e) Specimen E, (f) Specimen F.

In specimens D, E, F, due to increasing in alloying elements and further changes in the equilibrium diagram, a little amount of α phase is remained in the casting microstructure. This phase is one of the adequate places for nucleation and growth of α phase during tempering treatment. Therefore by tempering, the microstructure is composed of combined α and β' phases. As a result, by increasing the alloying elements, due to their grain

refinement effects, the mechanical properties will be improve.

2.3 Investigation on mechanical properties

Figure 4 shows variations in hardness values of specimens before and after the heat treatment, as a function of Ni and Mn content of alloys. Fig. 5 shows the same conditions for tensile strength.

Concerning the figure 4, the alloy hardness increased after heat treatment. The reason for this behavior can be expressed as followings:

- In casting specimens, because of low cooling rates, in comparison of heat treatment specimens, the β phase is transformed to $\alpha+\gamma_2$ by eutectoid transformation, whereas, this transformation is prevented in heat treated specimens and β' phase is present in adjacent of α phase in the microstructure. The γ_2 phase is harder than β' phase and causes the hardness to increase (M. H. Sabzevar et al, 1990).
- In casting specimens, residual stresses are relatively high (due to casting and solidification conditions), whereas heat treatment caused these stresses to be released or decreased and consequently the hardness values decreased.

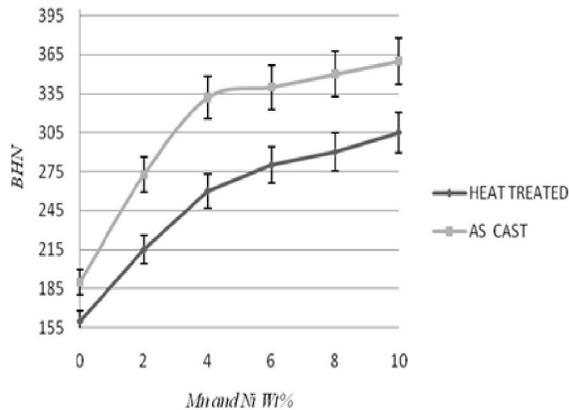


Figure 4. Effects of magnesium and nickel on the Hardness of samples

It can be seen in figure. 4 that the hardness increased by increasing alloying elements. Grain refinement effect of alloying element is responsible for micro structural changes (see also Figures. 1 and 3). The tensile strength of specimens also increased

by increasing alloying elements (figure. 5) caused the alloys in heat treated conditions have lower hardness values, better elongation, tensile and yield strengths in comparison with the cast condition.

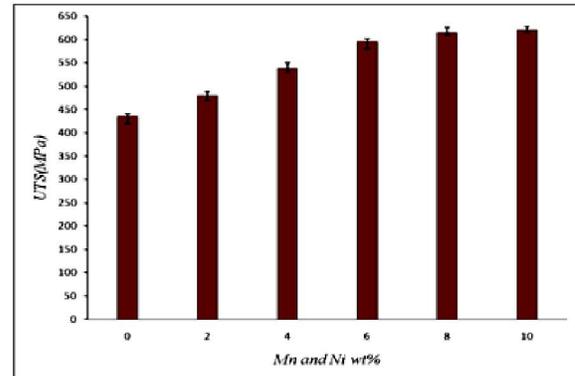


Figure 5. Effects of magnesium and nickel on tensile strength.

3.3 Wear behavior assessment

Figure 6 shows the weight loss of specimens in wear test. It can be consider that due to unstable wear in the first stage of wear test and absent of desired profile, the wear behavior of this stage is not so clear (N.P. Suh,1986). Therefore, in this research, discussions were made on 500 distances in wear test. As can be seen, by increasing the amount of alloying elements, weight losses of the specimens were declined. This phenomenon may be due to change in structure and formation of needle like microstructure of α and β' phases. The wear resistance of alloy increased by grain refinement. The highest wear resistance belonged to specimen F with the highest amount of alloying elements (Figure 6).

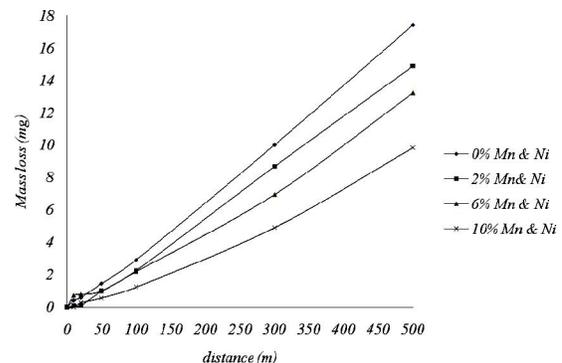


Figure 6. weight loss of specimens in wear test

Figure 7 shows the wear line in the specimens. It can be seen that in the absence of alloying elements such as manganese and nickel (specimen A), abrasive wear in addition to delamination wear are observable. By adding the alloying element, the delamination wear is decreased (Figure. 7-b). In specimen E and F the abrasive wear is almost eliminated and the delamination wear is the only abrasive wear mechanism. By comparing specimen E and F, it can be found that the wear abrasive depth decreased. This phenomenon is attributed to the increase in wear resistance of specimens. Thus, in the absence of alloying element, because of activation of both abrasive and delamination wear mechanisms, the weight loss is increased. These results are in consistent with the data shown in figure 6.

Figure 8 illustrates the variations in pin's weight at the wear test. It can be seen that by increasing the amount of alloying elements, the weight loss of pin increased. It shows that increasing the amount of alloying elements, and the hardness of specimens, could result in increase in weight loss of wearing specimens. These results are completely consistent with the data illustrate in figures 4 and 6.

Figure 9 shows the variation in wear coefficient of various specimens. By increasing the amount of alloying elements from specimen A to F, the wear coefficient is increased which could be due to increase in hardness value. This condition is result of increase in the pin's weight loss.

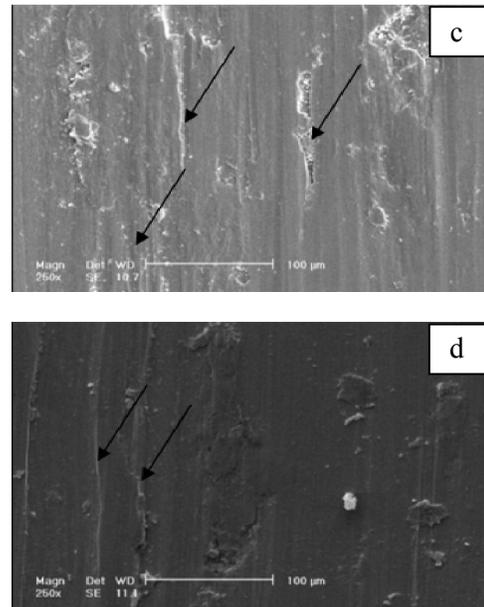
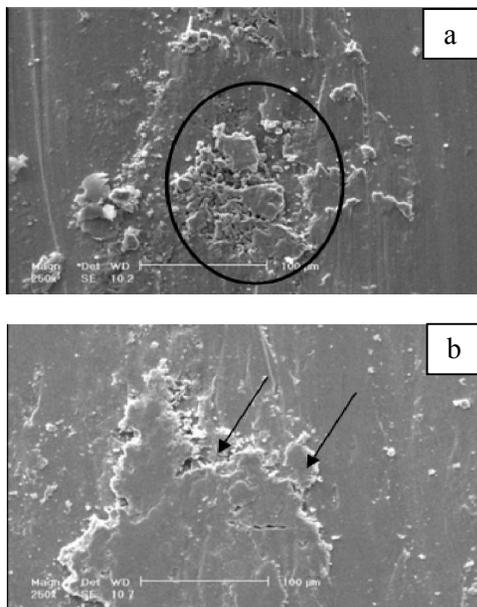


Figure 7. SEM images of wear lines in specimens with different amount of Ni and Mn : (a) Specimen A, (b) Specimen B, (c) Specimen D, (d) Specimen F.

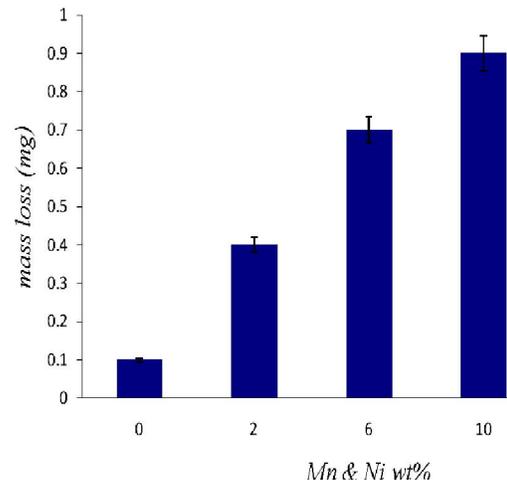


Figure 8. Pin Weight loss as a function of Ni and Mn content.

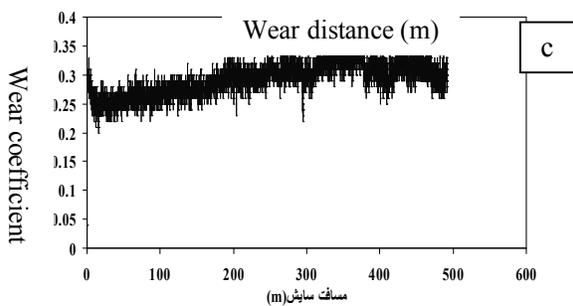
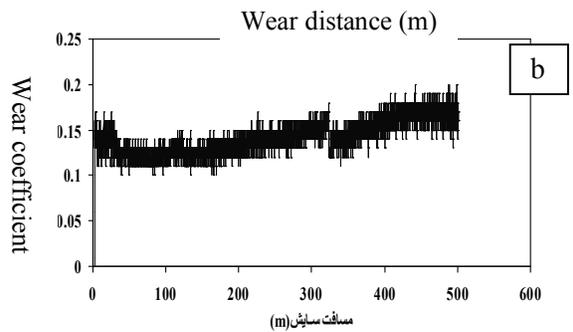
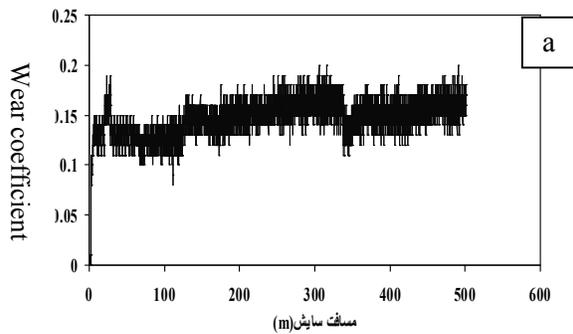
4. Conclusion

In this research, the effect of addition 0, 2, 4, 6, 8, 10 % nickel and Manganese to aluminum bronze alloy on mechanical and tribological properties has been investigated. The results are as follows :

- 1) The metallurgical structure after heat treatment included tempered β' and α phases. By increasing the amount of Ni and Mn elements, the mechanical and

tribological properties will be change due to grain refinement effects of alloying elements.

- 2) Increasing Ni and Mn content of alloy up to 10% will increase the tensile strength and hardness of the alloy.
- 3) By increasing the alloying elements, the wear properties will improves which attributed to change in metallurgical structure of the alloy. Also, in low amount of alloying elements, two wear mechanisms are activated, but by increasing the alloying elements up to 10%, abrasive and delamination wear mechanisms are disable.
- 4) By increasing alloying content, the wear rate will decrease.
- 5) Heat treatment, reduce hardness of samples.



Wear distance (m)

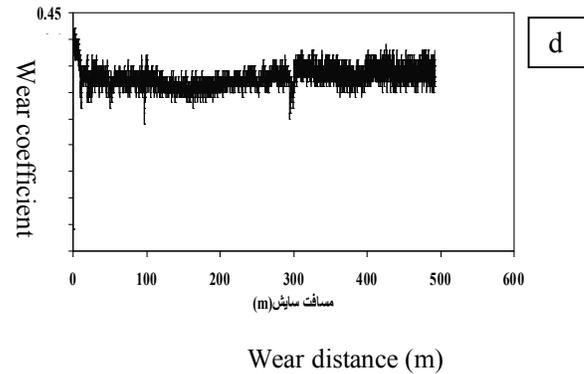


Figure 9. Evaluation of wear coefficient as a function of wear distance for different amount of Ni and Mn: (a) Specimen A, (b) Specimen B, (c) Specimen D, (d) Specimen F.

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