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INFLUENCE OF NICKEL ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF ALUMINUM COPPER ALLOY

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ABSTRACT

This paper presents the results of Nickel component on the microstructure and mechanical properties of the aluminum-copper alloy. With the same heat treatment process (heated to 850oC quenching in water and tempering at 350oC in 2h) noticed: the sample was added nickel, it had phases of nickel with Al and Fe; these phases make sample's mechanical properties better than the non-nickel sample. The samples were added Nickel, the hardness is higher than those without Nickel (105HRB and 92HRB). The abrasion results show that the Nickel alloyed samples also exhibited better than those without Nickel.

KEYWORDS

aluminum-copper alloy, phases of nickel, microstructure.

1. INTRODUCTION

Aluminum in aluminum bronzes created inter-metallic phases with Cu such as $Cu_{32}Al_{19}$, $AlCu_3$... or other elements: Fe, Ni, Mn... In case these phases have proper morphology and distribution in the microstructure, alloy's mechanical properties will be improved [1-3]. Phase α: Solid solution of aluminum in copper. The solubility of aluminum in α increases if the temperature decreases (from 7.4% at 1035⁰C to 9.4% at 565⁰C). Phase α is ductile and good machinability [4-6].

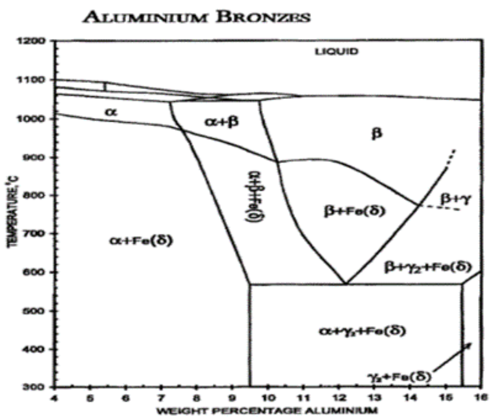


Figure 1: Phase diagram of Aluminium Bronzes

Phase β: Solid solution based on inter-metallic compound Cu_3Al with concentration rate Ce=3/2. At 565⁰, it occurs eutectoid reaction

$$\beta = [\alpha + \gamma]$$

Phase β has A2 crystal lattice, it is a disordered phase and also ductile, deformable [6]. Phase γ: Solid solution based on inter-metallic compound $Cu_{32}Al_{19}$, has complex cubic crystal lattice with concentration rate Ce= 21/13. Phase γ_2 is ordered, very hard and brittle [7]. In aluminum bronze, iron dissolves very little and almost creates inter-metallic phase Fe_3Al. In the case of Fe_3Al is fine, spherical and distributes homogeneously in the microstructure, the mechanical properties of alloy will be improved.

Iron affects to the heat treatment of alloy significantly. Its inter-metallic phase precipitated around α, within β and boundaries of β phase as well. It delays the decomposition of β phase, decreases the velocity of eutectoid reaction, therefore, that γ_2 phase is fine and it distributes homogeneously in the microstructure, increasing the strength and hardness, by that significantly improve the wear resistance for alloy [8-10]. There are many mechanism transformations in the copper alloy as spinodal decomposition, martensite transformation, created hardening phase… In this alloy, the phase of mechanism transformation is martensite [11-14].

Martensite phase transformation in aluminum bronzes can be described: During the cooling process by water-quenched, phase β has transformation without diffusion lead to form phase β'-martensite which has hexagonal crystal lattice. In contrast to martensite in steel (hard and durable), martensite in aluminum bronzes after quenching is softer than eutectoid. However, the hardening effect significantly after tempering because phase γ_2 precipitated is fine [15].

Nickel dissolves infinitely in copper but very little in aluminum. Nickel narrows α area on Cu-Al phase diagram when temperature decreases. It means that aluminum bronzes can be hardened by heat treatment. Nickel contributes to improving machining and mechanical properties of iron-aluminum bronze at room temperature and high temperature also. In addition, nickel can narrow solid solution α area when temperature decreases. It makes bronze alloyed by iron and nickel (Cu-10%Ni4%Fe) can be hardened after quenching and aging. For example, at annealing state (soft), Cu-10%Ni4%Fe has mechanical properties: σ_B = 650 MPa; δ = 35%; HB = 140; after quenching at 1080⁰C and aging at 400⁰C in 2 hours, hardness increases by HB=400 MPa.

Iron-aluminum bronzes are applied to produce a lot of parts: the corner of valves, guide section of the exhaust valve, bump parts, turbine parts, gears... Manganese is cheaper and can replace nickel to make manganese iron-aluminum bronze (Cu-3% Mn 4%Fe) which has good mechanical properties, anti-corrosion, machining properties [16]. This paper studied the effect of Nickel on the microstructure and mechanical properties of iron-aluminum bronze alloy.

2. MATERIALS AND METHODS

The chemical composition of samples is shown in below table

Table 1: Chemical composition of samples

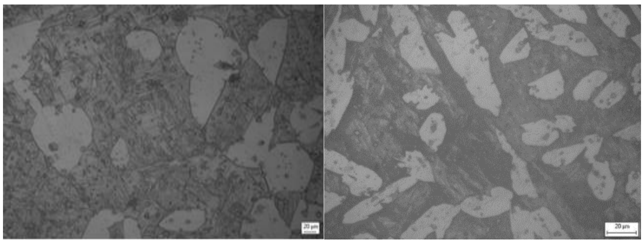
Sample	Al	Fe	Mn	Ni	Sn	Zn	Pb	Si	Cu
No1	9.05	3.86	0.11	0.14	0.27	0.96	0.22	0.21	Bal.
No2	9.41	4.98	0.15	2.44	0.04	0.49	0.07	0.07	Bal.

2.1 Heat treatment process

Samples were heat treated at 850^0 C→ soaked for 2 hours→ water cooled. In the next step, these samples were heat treated at 350^{0}C→ also soaked for 2 hours→ water cooled. The microstructure of samples was observed by an optical microscope Axiovert 25A which has maximum magnification 1000x with analysis software Ipwin31; SEM (scanning electron microscope), FESEM (Field Emission Scanning Electron Microscopy [17]. Using Mitutoyo durometer for testing the hardness and determining the mass losses of these samples by Tribotech (an abrasion testing machine).

3. RESULTS AND DISCUSSION

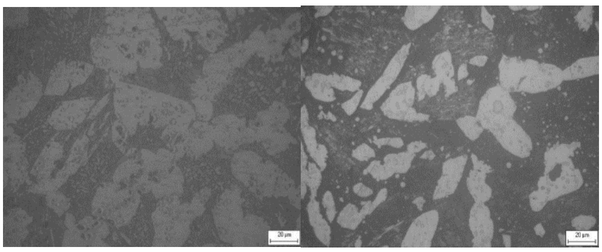
3.1 Microstructure



a) Sample 1 b) Sample 2

Through microstructure image of samples after quenching: With sample 1, in microstructure, it appeared needle phases corresponding to martensite phases after quenching [18]. In addition, it also can be seen the black dots of Fe-Al inter-metallic phases is finely dispersed. It will be proved more clearly by other analysis.

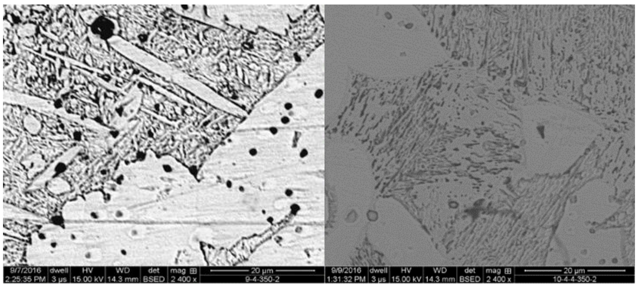
In sample 2, after heat treated and soaked at 850^{0}C, the microstructure α + (α+γ) changed to area of mixture two phases (α+β), light α phase area was narrowed, sharpness boundaries; appearing interlaced needle dendrites on cross-section that created isotropic or anisotropic lines, dark and thin parts were β martensite (Cu3Al) while light and large parts were α phases, black dots were finer



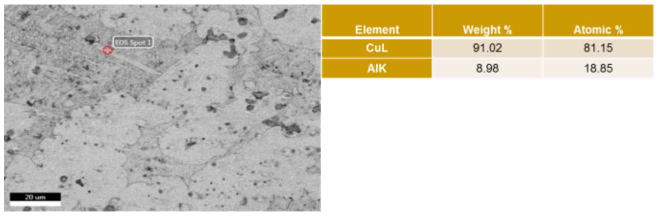
a) Sample 1 b) Sample 2

Tempering at 350^{0}C, β martensite (Cu3Al) transformed to β', also exist α phase (rich-copper solid solution) and γ2 in the microstructure [19]. In especially, CuAl9Fe4Ni2 alloy has interlace twin parallel martensite plates that sharpness and fine dispersed homogeneously in microstructure; the amount of α phase increased but finer and more dispersed homogeneously than as-cast samples. It proved that black dots were not impurity or oxidized, that result of precipitating inter-metallic phases which were fine dispersed homogenously in the microstructure.

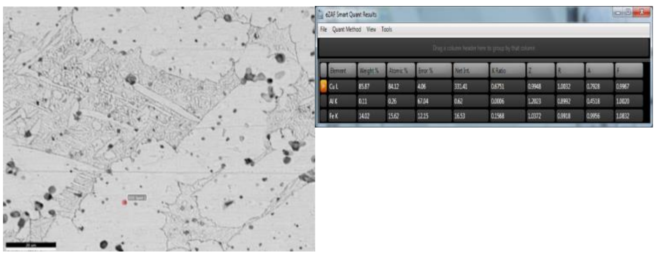
At CuAl9Fe4Ni2 alloy, nickel addition contributed to narrow α area, also fine and distributed homogenously more than that of CuAl9Fe4 due to the solubility of nickel in copper. After tempering, martensite precipitated aluminum, iron, nickel as inter-metallic phases based on Fe3Al, NiAl compound as well as the rich-copper solid solution (fcc) [20]. With Ni addition, the precipitated phases nuclear on martensite plates boundaries or previous rich-iron phases as inter-metallic phases (NiAl) that had high hardness but fine; therefore, they did not cause brittle phenomena and still ensure required hardness for alloy. BSED analysis clearly shows inter-metallic phases in both two alloys [21].



a) Sample 1 b) Sample 2



c) EDS 1



d) EDS 2

Figure 4: BSED and EDS of the sample after tempering

By EDS analysis, it can be seen that the appearance of inter-metallic phase Fe_3Al (spot 2). These phases distributed very homogeneously in the microstructure. They have the high hardness that contributes to improving wear resistance for the alloy in wear resistance working conditions.

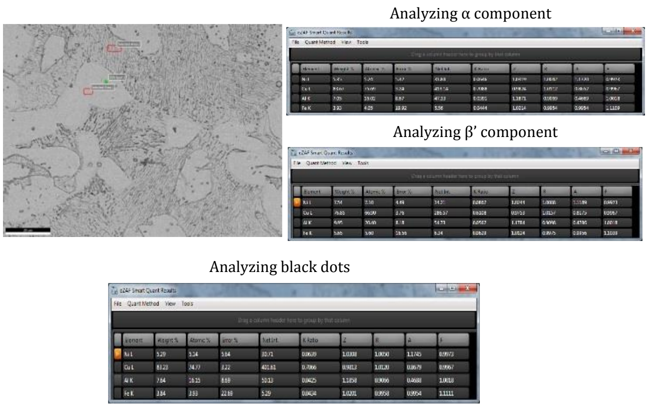


Figure EDS analysis_ Sample 350^0C in 2h **5:**

Also, by EDS analysis as image 5, it shows difference phases in the microstructure. However, at low magnification, it is very hard to determine exactly about phases component due to the effect of neighborhood phases).

3.2 Mechanical properties

Table 2: Hardness of samples

Sample	L1 (HRB)	L2 (HRB)	L3 (HRB)
CuAl9Fe4	91	92.5	93.5
CuAl9Fe4Ni2	105	104	105.5

Table 3: Mass loss of samples

Sample	Mass loss (g)
CuAl9Fe4	0.1239
CuAl9Fe4Ni2	0.1044

Hardness analysis result shows that Ni-alloyed samples have a higher hardness than that of non-Ni-alloyed samples. It proves that Ni addition improves mechanical properties for alloy. Mechanical properties analysis result clearly show microstructure and phases distribution in study alloy. The analysis of abrasive results shows that: The sample when added with Ni alloying gives less mass loss than the non-alloyed Ni sample. This result is perfectly consistent with the microstructure arguments above.

4. CONCLUSIONS

Through the microstructure and mechanical analysis of this alloys, it is shown that when adding Ni has increased the mechanical properties of this alloy system: The mechanical value after the above heat treatment process for hardness is about 92HRB for CuAl9Fe4 and 105HRB alloys for CuAl9Fe4Ni2 alloy. The anti-wear effect is also best with a value of 0.1239g for non-Ni and 0.1044g alloys for Ni alloys. Thereby, the phase transformation process has been identified; The structure of martensite is also identified but the structure of the inter-metallic phases is formed during heat treatment. After tempering, the β' phases were identified for alloy systems.

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