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Effect of Alloying on the Microstructure and Strength of the Ni Bronzes

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Abstract: In this study, Al was added to the Cu15Ni8Sn Ni-bronze alloy. The effects of the added amount of Al on the microstructure and strength of the alloy were investigated. As an approach, the Sn element has been replaced by Al. The element Al was added at 2, 4, 6, and 8 wt. %. Alloys were melted in a graphite crucible by induction melting and poured into a graphite mold. No heat treatment was applied to the cast alloys. The microstructure of the alloys was studied under a light optical microscope (LOM) and scanning electron microscope (SEM). Mechanical characterizations were made by hardness measurement and tensile tests. Metallographic studies showed that the microstructure was not changed with the amount of Al added. Chemical composition changes in the phases were reflected in the mechanical properties. It was determined that the composition with the highest hardness and strength among the alloys was the composition containing 15Ni, 4Sn, and 4Al wt.%. The alloy with the highest ductility and toughness is Cu15Ni8Al.

Keywords: Ni-bronze, High strength, Alloying, Hardness

Introduction

Copper and copper alloys, which have the best conductivity after silver, are the oldest metals used by humanity. Copper can form solid solutions with many elements, so many copper alloys are homogeneous. Copper alloys attract the attention of researchers due to their very good properties such as electrical and thermal conductivity, corrosion resistance, strength, ductility and wear resistance (Yin et al. 2011).

It is known that the change in the microstructure has a great effect on the mechanical properties of the alloy. Microstructure also primarily depends on the chemical composition. In Cu-Ni-Sn alloys that can decompose spinodally, the mechanical properties can also be changed by microstructure (İlangovan et al. 2016, Zhao et al. 1998).

Cu15Ni8Sn alloy, commercially known as C72900, is an alloy that hardens spinodally and exhibits very good bearing properties in dry and lubricated environments. These alloys are widely used as bearing materials especially in aviation and mining applications due to their very good properties. (Singh et al. 2007). In addition, due to its high strength and electrical conductivity, it also provides opportunities for use in the machinery and electrical/electronic industries (Peng et al. 207, Hoang et al. 2018).

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The properties of Cu-Ni-Sn alloys can also be changed by heat treatment. These alloys are alloys in which the aging process can be applied. (Ilangovan et al. 2016, Peng et al. 2017, Sato et al. 1988, Lopez et al. 1999). There are also studies on the use of these alloys as coatings (Huia et al. 2010, Hunnik et al. 1992).

The effects of alloying elements are investigated to improve the mechanical and physical properties of these alloys. Luo et al. (2019) reported that by adding 0.5 Si to Cu-Ni-Sn alloy with low tin content, the strength of the alloy decreased slightly while its ductility increased. On the other hand, Lei et al. (2013) studied the effects of Aluminum on the microstructure and properties of Cu-Ni-Si alloys. A slight increase in yield and tensile strengths was achieved with the addition of a small amount of Al.

When the studies in the literature are examined, no study has been found on how the properties of Cu-Ni-Sn spinodal alloys change with the systematic addition of a second alloying element. In this study, the effects of Al added by systematically increasing amounts of Al to Cu15Ni8Sn spinodal alloy on the microstructure, hardness and tensile strength of the alloy were investigated. As an approximation, Al has been added instead of Sn element.

Method

Elements with the purity of 99.9%Cu, 99.65%Ni, 99.7%Al, 99.8%Sn were used in the preparation of alloys. The elements prepared according to the alloy composition were melted in a graphite crucible by an induction melting furnace. After melting, the alloys were poured into a graphite mold and allowed to cool in the air. Thus, 10mm diameter rods were produced.

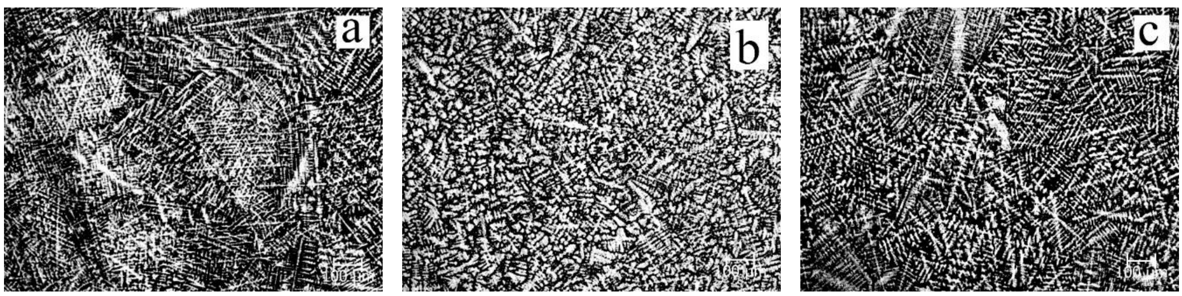
Commercial Cu15Ni8Sn alloy was taken as the basis for alloy selection. In this alloy, Aluminum element has been systematically added instead of Tin at increasing rates. For this purpose, Cu15Ni2Al6Sn, Cu15Ni4Al4Sn, Cu15Ni6Al2Sn, and Cu15Ni8Al alloys were cast. No treatment (thermal/mechanical) was applied to the alloys after casting.

Sections were taken from the cast alloys and the surfaces were sanded and polished with a 3-micron diamond paste. The microstructures of the alloys were studied under optical light microscope (LOM) and scanning electron microscope (SEM).

The hardness of the alloys was measured by Vickers hardness measurement by applying 0.5kgf load for 15 seconds. The tensile test samples were prepared from the bars by machining. Tensile tests were carried out in a universal testing device at room temperature and with a jaw speed of $5 mmmin^{-1}$. The effects of the change in alloy composition on alloy hardness, ductility, tensile strength, and toughness were revealed.

Results and Discussion

The optical microstructure images of the alloys at low magnifications are given in Figure 1. From the microstructure images, Cu15Ni8Sn alloy has a microstructure consisting of long dendrites. Dendrites are randomly oriented. It is considered that this structure is a result of rapid cooling as a result of casting into a cold graphite mold. There is no significant change in the microstructure of the alloys with Al added either. It can be said that the dendrites are shortened and expanded with the addition of Al. In the alloy containing no Tin (Fig. 1e), the detrites were formed in an even longer form.



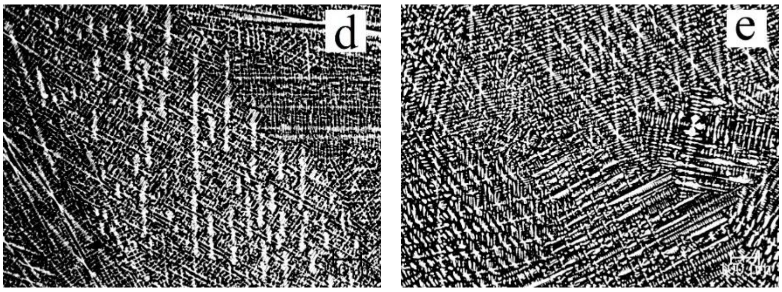


Figure 1. The light optical microstructure of the alloys at low magnification. a) Cu15Ni8Sn, b) Cu15Ni2Al6Sn, c) Cu15Ni4Al4Sn, d) Cu15Ni6Al2Sn, and e) Cu15Ni8Al

Microstructure images at high magnifications (Fig. 2) show that the structures usually contain 3 phases. It is seen in Figure 2a that the phase, which appears as a precipitate in the form of very small grains, grows with the addition of Al. The Cu15Ni8Al alloy, which does not contain any Tin, is seen as two-phase (Figure 2e)

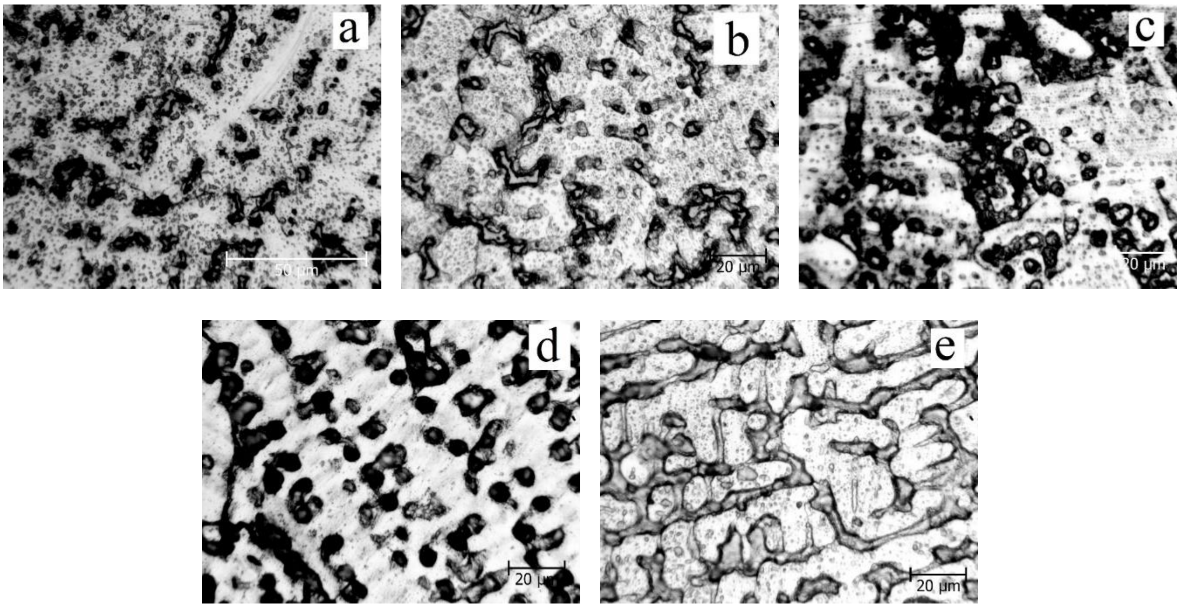
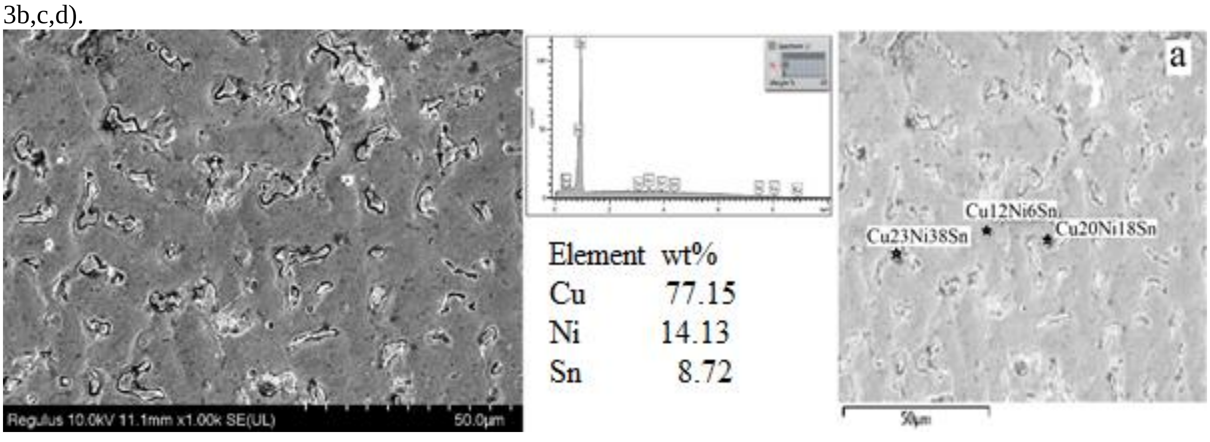


Figure 2. The light optical microstructure of the alloys at high magnification. a) Cu15Ni8Sn, b) Cu15Ni2Al6Sn, c) Cu15Ni4Al4Sn, d) Cu15Ni6Al2Sn, and e) Cu15Ni8Al

In Figure 3, SEM microstructure images of alloys and SEM energy dispersive spectroscopy (EDS) composition analyzes taken from certain points are given. From the general composition analyzes made, it is seen that the alloys have compositions very close to their nominal compositions. The Cu15Ni8Sn alloy, determined as the base alloy, contains the tin-rich-phase and the Cu-Ni matrix phases. The Sn content of the matrix phase is much less than that of the precipitate particles. The tin content increases at the boundary between the matrix phase and the precipitate phase (Figure 3a). With the addition of Al to the alloy, Aluminum also entered the precipitate phase, and while the Tin ratio in this phase decreased, the Aluminum and Nickel ratios increased (Figure 3b,c,d).



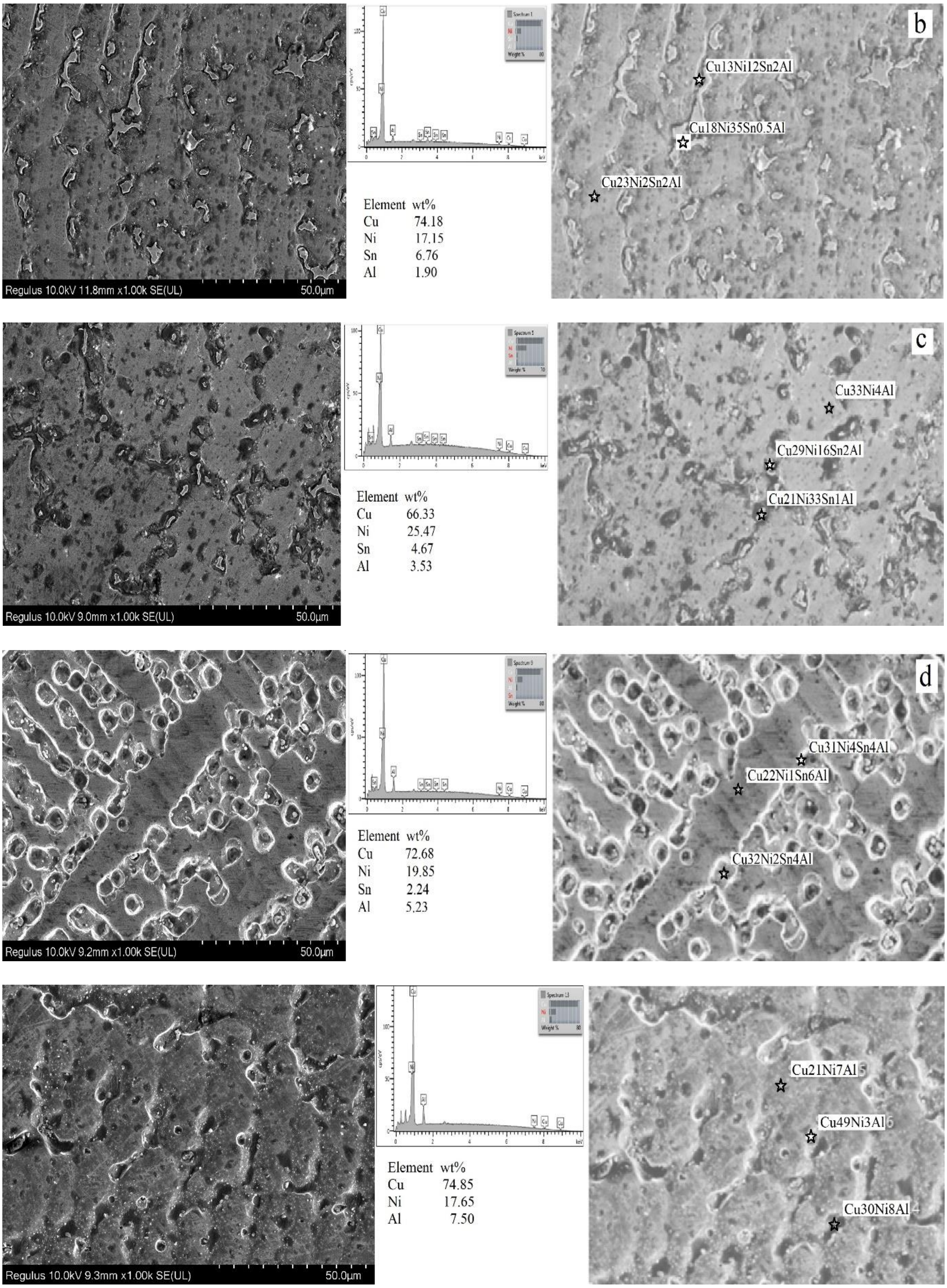


Figure 3 shows the tensile curves of cast alloys. It is clearly seen from the curves that Cu15Ni4Al4Sn alloy has the highest strength, on the other hand, Cu15Ni8Al alloy exhibits the highest ductility and toughness.

In the tin-free alloy, the precipitate phase is in the nickel-rich Cu-Ni composition (Figure 3e). Tin content in the matrix phase decreased with the addition of Al. No Tin was found in the matrix phase of the alloy where the Tin and Aluminum contents were equal. This composition is the composition with the highest hardness and strength.

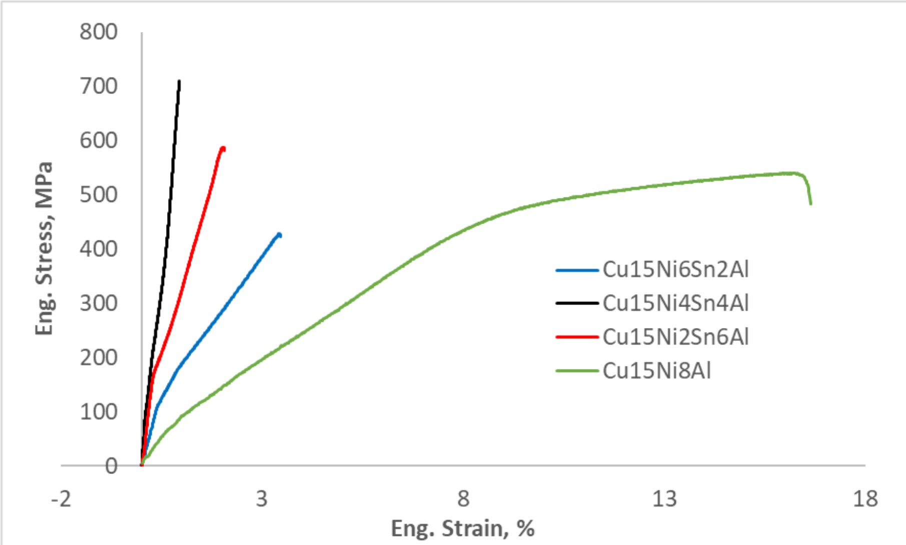


Figure 4. Tensile diagrams of the alloys.

Table 1 summarizes the mechanical properties of cast alloys. Al-containing alloys have higher hardness than Cu15Ni8Sn alloy. When the Al and Sn content of the alloy are equal, the hardness and strength take the maximum value. If the amount of Al is more than Sn, there is a decrease in strength but an increase in ductility.

Table 1. Mechanical properties of the alloys

Alloy	Hardness, HV0.5	Ductility, %	Tensile Strength, MPa	Toughness, $Nmmmm^{-3}$
Cu15Ni8Sn	140			
Cu15Ni2Al6Sn	214	3.46	424	8.7
Cu15Ni4Al4Sn	310	0.94	711	3.13
Cu15Ni6Al2Sn	229	2.06	581	6.83
Cu15Ni8Al	195	16.63	541	62.9

Conclusion

The cast microstructure of the Cu15Ni8Sn alloy chosen as the base alloy has a dendritic structure as a result of rapid cooling. Adding aluminum to the alloy at increasing rates did not cause a significant change in the casting microstructure of the alloy. While the change in the composition did not cause a change in the phase structure of the alloys, it created differentiation in the composition of the phases, which was reflected in the mechanical properties of the alloy. The highest hardness and strength were observed in the composition containing 4% Al and Sn. In this composition, the composition of the precipitate particles is similar to other alloys, while the matrix phase does not contain any Tin. In the alloy containing no Tin, the composition of the precipitate and matrix phases is similar. It has been determined that the strength is high in the alloys containing tin, but the strength decreases slightly in the alloy containing only Al, but the ductility and toughness increase significantly. It has been evaluated that the most responsible for this effect is the composition of the matrix phase.

Recommendations

1. The alloys should be heat treated including aging to determine the microstructural evaluations and mechanical properties.
2. The friction and wear behavior of the Al added alloys should be investigated.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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