한국표면공학회지
J. Kor. Inst. Surf. Eng.
Vol. 42, No. 5, 2009.
<연구논문>

Effects of Alloying Element and Heat Treatment on Properties of Cu-Ti Alloys

Han-Gil Suk[a], Hyun Seon Hong[b*]

[a]Department of Materials and Metallurgical Eng., Kangwon National University,
Samcheok 245-711, Korea
[b]Plant Engineering Center, Institute for Advanced Engineering (IAE), Yongin 449-863, Korea

(Received October 6, 2009 ; revised October 28, 2009 ; accepted October 30, 2009)

Abstract

Cu-Ti alloys with titanium in the range of 0.5-6.0 wt% were developed to evaluate the effect of the titanium content and heat treatment on microstructure, hardness, and electrical conductivity. The hardness of the Ti-added copper alloys generally increased with the increase in titanium content and hardening was effective up to the 2.5 wt%-Ti addition. Microstructural examination showed that the second phase of Cu_4Ti started to precipitate out from the 3.0 wt% Ti-addition, and the precipitate size and volume fraction increased with further Ti addition. Aging of the present Cu-Ti alloys at 450°C for 1 h increased the hardness; however, the further aging up to 10 h did not much change the hardness. In the present study, it was inferred that in optimal Ti addition and aging condition Cu-Ti alloy could have the hardness and electrical conductivity values which are comparable to those of commercial Cu-Be alloy.

Keywords: Copper alloys, Metals and alloys, Hardness, Electrical properties

1. Introduction

Copper alloys with beryllium (Cu-Be alloys) have attracted considerable interest due to their good combination of high strength and high electrical conductivity. Cu-Be alloys are currently used in spring, wire, load cells and other parts that must retain their shapes. They are also used in current contacts for batteries and electrical interconnectors because of its electrical conductivity. Many studies have been done on age hardenable Cu-Be alloys, which have found their application in developing high strength springs and interconnectors. However, Cu-Be alloys are expensive and health hazardous and thus Cu-Ti alloys are considered as a prominent alternative. The mechanical properties of Cu-Ti alloys are comparable to commercially developed Cu-Be alloys[1-6)].

In the case of most precipitation hardenable alloys, a high strength is attained if the alloys are properly solution-treated and aged. It has been known that if Cu-Ti alloys were optimally heat-treated, the ultimate tensile strength exceeding 1000 MPa could be attained. However, systematic research on Cu-Ti alloys has not yet been carried out and scare literature exists regarding multi-alloying element systems and continuously cast alloys[7-10)].

The aim of the present study is to give a contribution to the understanding of the effects of titanium content and aging treatment on properties of Cu-Ti binary alloys and to provide fundamental data for designing of multi-alloying element systems such as Cu-Ti-x-y where x and y could be Ni, Co, Fe and so on, which will be presented in forthcoming companion paper. The present investigation includes: (a) the effect of the titanium content on hardness and microstructure; (b) the influence of heat treatment on hardness and electrical conductivity.

2. Experimental

Cu-Ti binary alloys were prepared by the arc

---

[*] Corresponding author. E-mail : hshong@iae.re.kr

Table 1. Chemical composition of the specimens (wt%)

Specimen No.	Nominal Composition
No.1	Cu - 0 Ti
No.2	Cu - 0.5Ti
No.3	Cu - 1.5Ti
No.4	Cu - 2.5Ti
No.5	Cu - 3.0Ti
No.6	Cu - 3.5Ti
No.7	Cu - 4.0Ti
No.8	Cu - 5.0Ti
No.9	Cu - 6.0Ti

melting. The ingot melting was carried out under argon gas atmosphere. The chemical composition of the ingot is listed on Table 1. The titanium content varied from zero to 6 wt%. After the ingot melting, the solid solution treatment of the samples was conducted at 920°C for 3 h and the aging treatments for the alloys were performed at 450°C for 1 h, 5 h and 10 h.

The metallographic samples of the titanium copper alloys were first mechanically wet ground using a #1200 SiC grit paper, then polished with 3 μm diameter Al_2O_3 powder, followed by etching in a mixture of nitric acid and hydrogen peroxide (5 m*l* HNO_3 + 15 m*l* H_2O_2 at 25°C). After etching, the specimens were cleaned with distilled water, and then dried in air. Subsequently, the specimen was examined in a scanning electron microscope (SEM).

The samples for hardness measurements were wet ground using #1200 SiC grit paper, then tested on the Rockwell hardness F scale. Electrical conductivity was measured according to ASTM E 1004 with a FISCHER's SMP-10 instrument.

3. Results and Discussion

Fig. 1 represents the variation of hardness of Cu-*x*Ti alloys as a function of titanium content. The hardness was measured by Rockwell F scale on the as-cast samples. As the Ti content increased from 0.5 wt% to 2.5 wt%, the hardness of the alloy increased from 29 H_f to 91 H_f. Further addition of the Ti content up to 6 wt% showed relatively slight increase in hardness. The value increased only by 25 H_f. Fig. 2 shows XRD patterns of the Cu-*x*Ti alloys as a function of titanium concentration. Up to the 2.5 wt%Ti-addition, the structure of the alloy remained as the fcc copper single phase, however, the second phase of Cu_4Ti started to precipitate out from the 3.0 wt% Ti-addition. This precipitation might reduce the effect of Ti-addition on hardness increase.

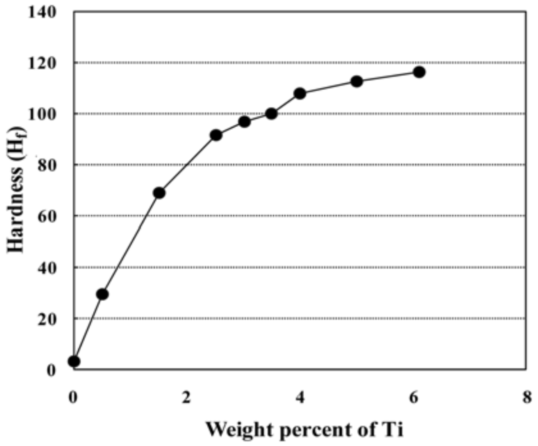

Fig. 1. Changes of hardness of Cu-*x*Ti alloys in as-cast condition.

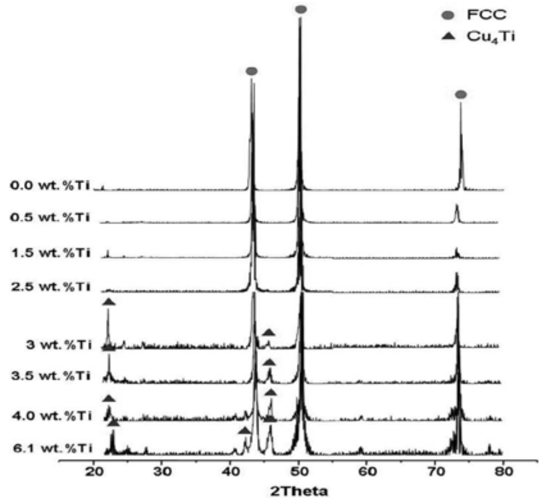

Fig. 2. XRD patterns of Cu-*x*Ti alloys in as-cast condition.

Although the phase diagram of the copper-titanium system has been studied, the solubility of titanium in copper at room temperature has not yet been clarified[11,12]. However, it can be estimated by using the terminal solubility equation, $C = C_0 \exp(-\Delta H/RT)$. The solubilities of silicon at 885°C and at 500°C are reported to be 8 wt% and 0.8 wt%, respectively. From these data the ΔH and the C_0 values can be determined, and the solubility of titanium at room temperature is calculated to be about 1.2×10^{-5} wt%. Therefore, the lowest titanium content (0.5 wt%) used in this study is considered to be far above the solubility limit of titanium at room temperature. Accordingly, it is considered that this supersaturated titanium could induce the increase in strength upon aging through titanium precipitates.

Fig. 3 shows the microstructural change of Cu-Ti

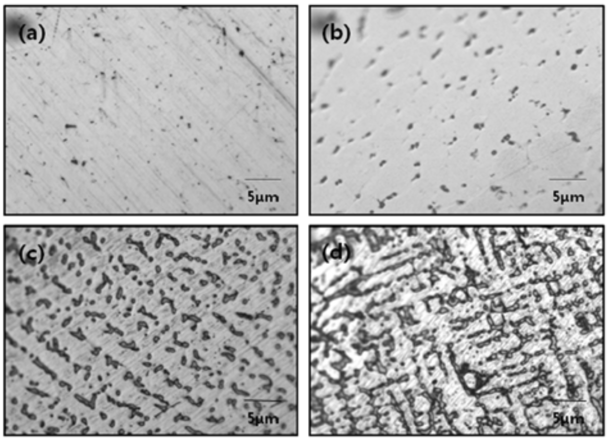

Fig. 3. Microstructural changes with varying Ti concentration; (a) 0.1 wt%Ti, (b) 1.0 wt%Ti, (c) 3.0 wt%Ti, (d) 4.0 wt%Ti.

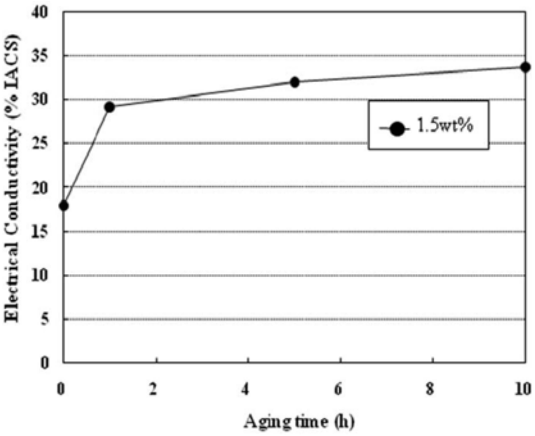

Fig. 5. Changes of electrical conductivity of Cu-1.5 wt%Ti alloy as a function of aging time.

alloys as a function of Ti content. As Ti content increased, the number of precipitates and the volume fraction of precipitates increased. It can be seen in the 3.0 wt% Ti sample that precipitates began to merge so the size of precipitates increased. It is thought that the precipitate Cu_4Ti formed, which was revealed from XRD examination, and merged from the 3.0 wt%Ti-addition thereby reducing the precipitate hardening effect.

In order to investigate the influence of aging on hardness enhancement, the as-cast samples were solid solution treated at 920°C for 3 h and then aged at 450°C for 1 h, 5 h and 10 h. The solid solution and aging temperatures were selected according the Cu-Ti phase diagram and literatures[1-3,11,12)] and the aging time was varied in order to see its influence. The aging experiment was conducted only on 1.5 wt% and 2.5 wt%Ti samples which showed good hardness results. Fig. 4 exhibits the relationship between hardness and aging time for the Cu-2.5 wt% Ti and Cu-1.5 wt% Ti alloys. In the case of the Cu-2.5 wt%Ti alloy, the hardness increased from 78 H_f to 110 H_f after the 1-h aging. Further aging to 5 h slightly increased the hardness to 112 H_f. It is to be noted that the hardness value of 112 H_f is comparable to that of commercial Cu-Be alloy, 119 H_f. The aging for 10 h did not much change the hardness. The Cu-1.5 wt% Ti alloy showed the similar results. The hardness increased for the first 1 h but the hardness remained the same up to the 10-h aging.

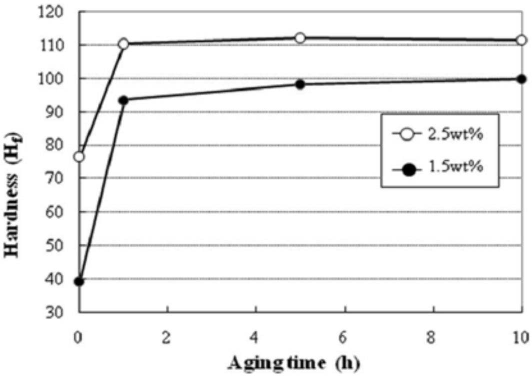

Fig. 4. Changes of hardness of Cu-1.5 wt%Ti and Cu-2.5 wt%Ti alloys as a function of aging time.

In order to be an alternative for Cu-Be alloys, Cu-Ti alloys should have good electrical conductivity. Fig. 5 shows the changes of electrical conductivity of the Cu-1.5 wt% Ti alloy as a function of aging time. The electrical conductivity of the solid solution treated specimen was 18%IACS. After aging at 450°C for 1, 5 and 10 h, the electrical conductivity increased to 29%IACS, 32%IACS and 34%IACS, respectively. At this aging temperature, the electrical conductivity increased with the aging time. It is to be noted that the electrical conductivity value of 34%IACS is comparable to those of Cu-Be alloys, 20-50%IACS.

5. Conclusions

For the Cu-Ti alloys with titanium in the range of 0.5-2.5 wt%, the addition of titanium was effective for producing age-hardenable alloys. The hardness of the Cu-2.5 wt%Ti alloy was almost three times higher than that of Cu-0.5 wt%Ti alloy in the as-cast condition. Aging of the Cu-2.5 wt%Ti alloy at 450°C for 5 h increased the hardness value to 112 H_f, which is comparable to the hardness of commercial Cu-Be alloy. In the present study, the aging longer than 5 h did not affect the hardness enhancement. In order to design the multi-alloying element systems as substitutes for Cu-Be alloys, the Cu-Ti binary alloy with titanium content less than 2.5 wt% could be used with a proper heat treatment.

Acknowledgment

This paper was supported by the Campus Research Fund, Kangwon National University, 2008.

References

1. A. A. Hameda, L. J. Blaz, Mater. Eng., A254 (1998) 83.
2. I. S. Batra, A. Laik, G. B. Kale, G. K. Dey, U. D. Kulkarni, Mater. Sci. Eng., A 402 (2005) 118.
3. S. Nagarjuna, Bull. Mater. Sci., 27 (2004) 69.
4. W. A. Soffa, D. E. Laughlin, Prog. Mater. Sci., 49 (2004) 347.
5. I. S. Batra, G. K. Dey, U. D. Kulkarni, S. Banerjee, Mater. Sci. Eng., A (2003) 360.
6. Y. J. Oh, J. W. Ahn, J. G. Ahn, M. S. Lee, J. Kor. Inst. Surf. Eng., 35 (2002) 158.
7. S. Nagarjuna, M. Srinivas, K. Balasubramanian, D. S. Sarma, Acta Mater., 44 (1996) 2285.
8. S. Nagarjuna, K. K. Sharma, I. Sudhakar, D. S. Sarma, Mater. Sci. Eng., A 313 (2001) 251.
9. S. Nagarjuna, M. Srinivas, Mater. Sci. Eng., A 335 (2002) 89.
10. R. Markandeya, S. Nagarjuna, D. S. Sarma, Mater. Sci. Eng., A 404 (2005) 305.
11. T. B. Massalski, Binary Alloy Phase Diagrams, 2nd ed., ASM, Ohio, 1990.
12. R. P. Elliott, Constitution of Binary Alloys, McGraw-Hill, New York, 1965.