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Effect of Secondary Aging of Copper-Chromium Alloys to Electrical Conductivity

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Abstract: Copper-chromium alloys are the most important spot-welding tips and disks; it is also used where high strength together with electrical conductivity is required. Electrical conductivity is also important for optimum energy consumption. It is obvious that if highly conductive materials are used, we need low electric current where today energy is a very precious thing. In our study due to the industrial requirement of highly durable and more consistent parts needs, secondary aging was used to obtain more efficient materials. Electrical conductivity is a must, therefore the copper chromium alloys were observed for their resistances for various processing conditions, like as cast, aged, and secondarily aged. The electrical resistance measurements for all conditions were done and compared. The aging heat treatment was done at 650 ^{o}C for 4 hours. Secondary aging heat treatment was done at 400 ^{o}C for 2, 4, and 6 hours. The lowest specific electrical resistivity was obtained from secondary aged at 400 ^{o}C for 2 hours as 0.0074 mΩ mm^2/mm. The resistance of as-cast copper-chromium alloy was measured as 0.078 mΩ mm^2/mm which is almost ten-fold resistive than secondarily aged sample therefore it can be said that the secondary aging heat treatment was found to have a favorable electrical conductance.

Keywords: Copper-Chromium Alloys, Aging, Microhardness, Electrical Conductivity

Introduction

Copper is an element that comes across in many areas, it is because of the properties that allow it to be used in many areas. Metals have been used in prehistoric times and at the beginning of the first uses of mankind. Copper was first used by people 10000 years ago. During the archaeological excavations, objects such as pendants, ornaments, containers were found. It is estimated that it was used around 8700 years ago. It is known that one of these substances is pure copper, which is obtained from ore. During the excavations carried out in Anatolia, the use of an alloy called a copper-tin alloy and the use of bronze this period, which began around the year B.C.7000, has been called the Bronze Age. In ancient times, there were findings obtained mainly in the direction of alloying techniques around Thailand. Bronze Age BC Technology transition and ended at 1200 iron experienced (C. A. D., 2010; Davis, 2001; Lipowsky, 2007; Schlesinger, 2011).

History uses copper as an element in terms of places from the past to the present, but it is one of them that has not transferred rare earth materials engineering. As copper can be used alone, different alloying elements can have very different properties with copper according to the purpose of use. Copper alloys, which are usually used and named after the added alloying elements, are divided into nine groups. (Davis, 2001; Lipowsky, 2007). These alloys differ in their strength, corrosion resistance, etc. to increase it is used for supports.

The Cu-Cr alloys we are considering here are alloys where it is desirable to have high mechanical strength without compromising electrical conductivity as much as possible. Applications of these alloys in the industry; Impact resistant connection with the use of electrical conductivity as a high end in spot welding machines, especially with non-sparking tools in the petrochemical industry (C. A. D., 2010; Davis, 2001; Ellis et al., 1995; Gao et al., 2003; Kim et al., 1995; Raghavan et al., 2017; Sun et al., 2001; Wang et al., 2009) the measure of electrical conductivity is measured according to the conductivity, or electrical resistance of annealed pure copper for all materials. The internationally recognized conductivity unit is recognized as 100% IACS (International Annealed Copper Standard) for annealed pure copper (C. A. D., 2010; Davis, 2001). The electrical conductivity of the Cu - 1% Cr alloy discussed here was measured as 85% IACS.

Copper-Chromium Alloy

Copper alloys containing chromium, classified as a concentration of 0.6-1.2% Cr by weight. Cu-Cr alloys are preferred because of their high strength, corrosion resistance, and electrical conductivity. The tensile strength of Cu-Cr alloys is higher than that of pure copper (221-455 MPa), which can be applied to their strength by precipitation hardening, i.e. aging, and as a result of aging heat treatment can increase to fractions (234-593 MPa). (Davis, 2001). The mechanism of hardening of Cu-Cr alloys occurs by precipitation of chromium from a solid solution, and these high-strength alloys can maintain their strength even at high temperatures. The corrosion resistance of Cu-Cr alloys is better than that of pure copper since chromium forms a protective oxide that protects the alloy from corrosion. Cu-Cr alloy has good cold formability and hot workability, as well as high strength. (Davis, 2001; Durashevich et al., 2002; Krishna et al., 2015).

Resistance welding electrodes, seam welding discs, gears, switches, electrical, electrode holding the jaws, cable connectors, current-carrying arms and rods, circuit breaker parts, arc and bridge components, patterns in electron tubes used Cu-Cr alloys, spot welding tips, copper conductors that require more strength and the electrical and thermal ignition key is used. It is important to use Cu-Cr alloys; resistance welding electrodes, seam welding drives, key electric gears, electrode holding jaws, cable connectors, current-carrying arms and rods, circuit breaker components, electron tubes arc welding lugs and the bridge point of the model components, copper electrical conductors and heat resistance that require more than the ignition key is used.

The Aging Heat Treatment of the Copper-Chromium Alloy

In Cu-Cr alloys that can be hardened by precipitation, the temperature drop reduces the solid chromium solution in copper. The slow-cooled Cu-Cr structure is a two-phase mixture of chromium and a-copper. Superior mechanical properties can be achieved by rapidly cooling Cu-Cr alloys from the annealing temperature, so Cu is saturated with a solid solution of chromium. The microstructure of the rapidly quenched Cu-Cr alloy is similar to that of unalloyed copper. Rapid cooling prevents the accumulation of chromium during solid-state transformation, so the cast structure consists of a single a-copper phase. The first material that begins to solidify is pure copper, which is followed by a eutectic mixture of single a-copper and chromium. a-copper and chromium form a eutectic phase, the plate-like structure is formed in the interdendritic zones. a-copper consists of twin grains in a solid solution. In general, Chromium is quickly cooled so that it remains in the a-copper solid solution. Aging disperses chromium precipitates along with the matrix (Chakrabarti et al., 1984).
Aging heat treatment;

1. Solid solution
2. Quenching to obtain an over-saturated solution
3. Aging to form second phase particles to obtain the desired properties

Materials and Method

The copper and chromium elements were obtained from Alfa-Aeser of high purity 99.99 %. The melting and casting were done in the Leybold-Heraeus vacuum induction melting furnace under an argon atmosphere. The ingots were homogenized at 1000 °C for 72 hours. The samples were solutionized at 950 °C for 4 hours and quenched in water at room temperature. Aging heat treatment was done at 650 °C for 4 hours and quenched in water. Secondary aging heat treatment was realized at 400 °C for 2, 4, and 6 hours. After completing the heat treatment procedure, the samples were polished and etched with 5 g $FeCI_3$ (ferric chloride), 50 ml HCI, and 100 ml H_20.

The microhardness testing was done by Futuretech make FV-800 instrument with 100 g load for 10 seconds. Electrical resistance measurements were realized by GW-Instek GOM-802 model D.C.Milli-Ohm Meter in auto mode.

Results and Discussion

The microhardness test results revealed that the secondary aging heat treatment improve the hardness. The hardness increases with aging time. The maximum value of hardness obtained in samples aged 650 °C for 4 hours and secondarily aged at 400 °C for 6 hours giving 75 H_v. This hardness value is 12% higher than the samples only aged at 650 °C for 4 hours. The trend in hardness differentiation was given in Figure 1.

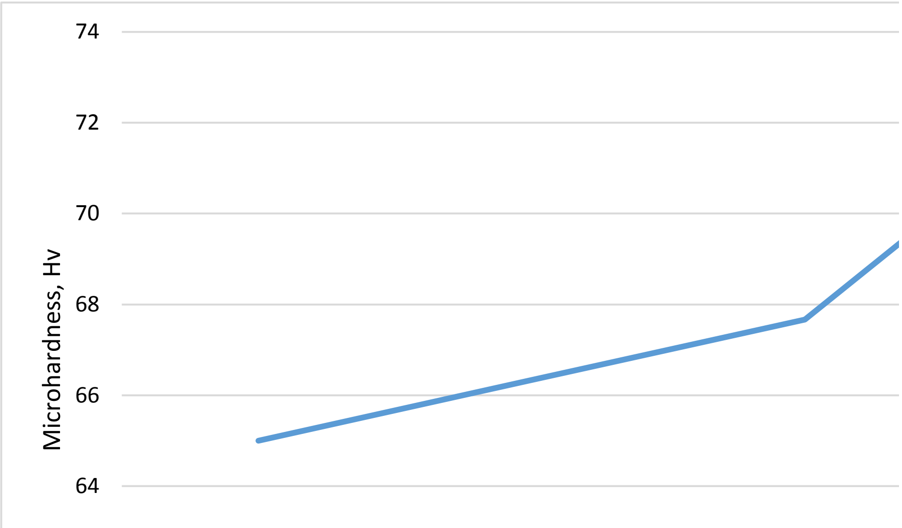


Figure 1. Microhardness change versus aging heat treatment

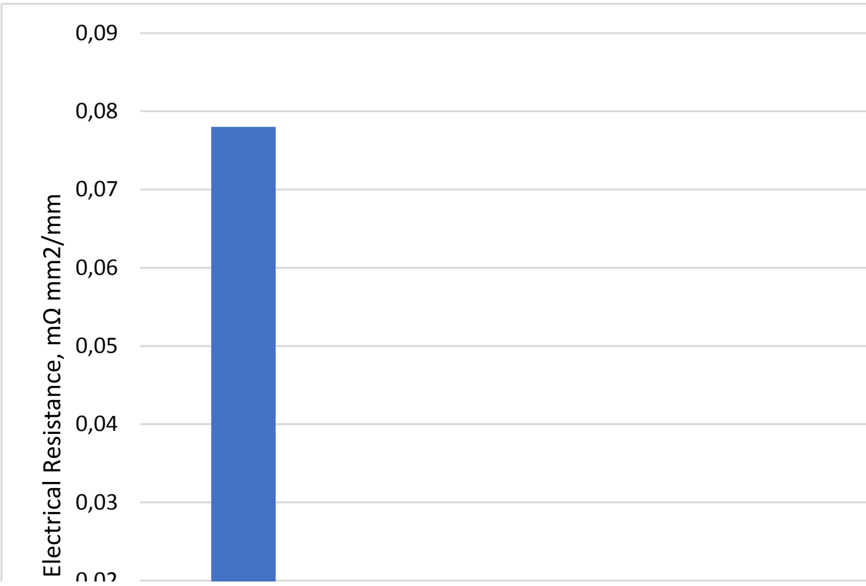
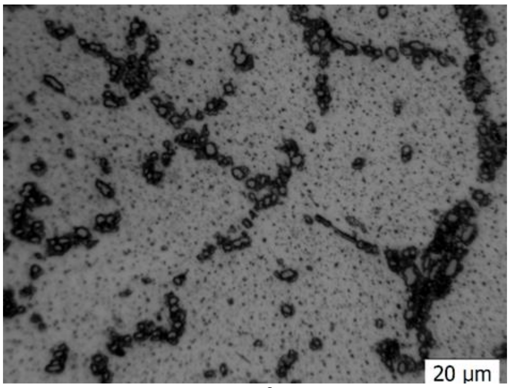
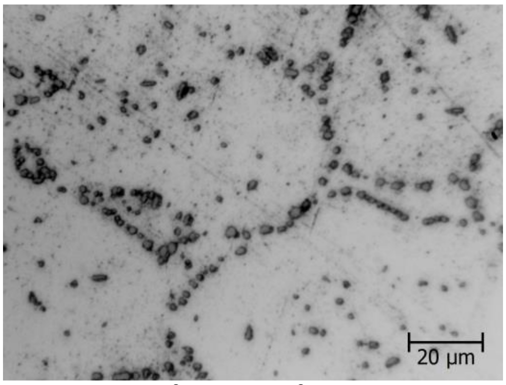


Figure 2. Electrical resistances of Cu-Cr alloys (SA notes the secondary aging)

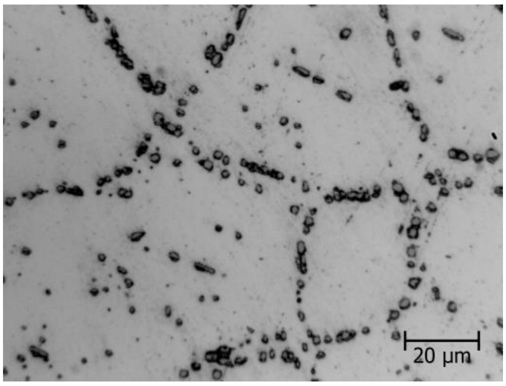
The electrical resistance of as-cast, aged, and secondarily aged samples showed that electrical resistance was increasing with secondary aging time increase (Figure 2). The electrical resistance is low than the aged and very low than the as-cast condition. The resistance slightly increases with secondary aging time, only 6 hours is higher than the aged sample, but this can be acceptable if the alloy strength and electrical resistance are taken into consideration together, 6 hours secondary aging time can be said preferrable with respect to aged one.



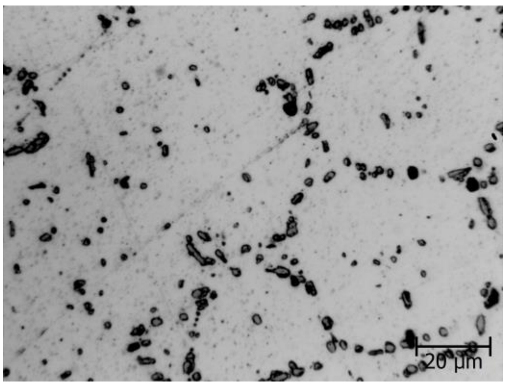
650 ^{o}C



650 ^{o}C and 400 ^{o}C 2 hrs



650-400- 4 hrs



650-400 6 hrs

Figure 3. Microstructures of the aged and secondarily aged samples

The electrical resistance of the as-cast sample was found 0.078 mΩ mm^2/mm, in the aged samples the resistance drops to 0.011 mΩ mm^2/mm, by applying secondary aging for 2, 4, and 6 hours the results are 0.0074, 0.0094, and 0.012 mΩ mm^2/mm respectively. The electrical resistance drops dramatically with aging heat treatment. Additionally, a secondary aging heat treatment increases the conductance 10, 8, and 6.5 times more than the as-cast condition. If the mechanical strength and electrical conductivity are evaluated together secondary aging heat treatment is highly favorable when working in a welding workshop.

The microstructures of aged and secondarily aged samples were given in Figure 3. The microstructures revealed that the grains were coarsening by increasing time in secondarily aged samples. The factors causing the hardness increase are the second phase particles that have precipitated. During aging, with the effect of temperature, alloying elements first begin to gather under edge dislocations. The GP regions, which are clusters of atoms, cause a certain amount of distortion as they create internal stress in the lattice, and at the same time cause the structure to harden even a little. As the aging continues, these clusters begin to form β precipitates compatible with the α matrix phase. These precipitates play a role in increasing hardness. As the aging continues, the sediments grow further and reach a critical height, it is seen from the trend of the graph in Fig.1 that the time and temperature limit required for excessive aging is not reached in the study. Since the experiment was not continued any longer, it was not clear at this stage whether the highest hardness zone was reached. At higher magnifications, the grain coarsening and fine precipitates were seen. As the aging time increases the fine precipitates dispersed very fine all over the matrix. The precipitates in the grain borders were also getting smaller and dispersed through the matrix which confirms the increase of the hardness.

This situation may be useful for the production of materials with higher strengths in tool manufacturing. Especially, it may be a more suitable solution in the production of spot-welding tips, non-sparking tools such as keys and hammers used in petrochemical plants.

Conclusion

The secondary aging heat treatment would be an advantageous production method for increasing the strength of age hardenable alloys. This may also increase the service life of age-hardened parts. But the most important concern should be electrical conductivity. Due to increasing energy costs and production costs, energy saving is very important, with the secondary aging heat treatment it is possible to increase the electrical conductivity. The effect of the secondary aging heat treatment on the electrical conductivity is very good, considering the different heat treatment times, it is seen that the electrical conductivity can be increased from 650% to 1000%. Therefore, we can say that a minimum 50 % energy saving can be made according to aged Cu-Cr alloys.

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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