

# Effects of thermal-mechanical treatment on microstructure and properties of Cu-Zn-Fe alloy

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**Abstract.** In this paper the effects of thermal-mechanical treatment on microstructure and properties of Cu-Zn-Fe alloy have been studied by metallographic observation, SEM, hardness measurement and electrical conductivity measurement. The mechanical properties and electrical properties of Cu-Zn-Fe alloy are improved through hot rolling, cold rolling, annealing at high temperature, further cold rolling and annealing at low temperature. The optimum final annealing temperature is 200°C, and the optimum annealing time is 2 hours. The best comprehensive properties of the alloy can be reached at hardness of 194.83HV and conductivity of 37.2% IACS. Fe works as solute atoms in the alloy, and Fe can inhibit the growth of the grain during the process of deformation and heat treatment, thus improving the mechanical properties of the alloy. No precipitation strengthening phenomenon was observed during the process of annealing at 480 °C, which indicates the alloy is a working hardening alloy.

## 1. Introduction

As a kind of material with good electrical conductivity and thermal conductivity, brass is used more and more widely in industry nowadays [1]. The research on brass also developed rapidly, most of them mainly focus on improving the mechanical properties, corrosion resistance, machinability and electrical properties of brass [2-4]. The addition of trace elements in alloys, deformation and heat treatment are the common methods to research Cu alloy. Z.Y. Liu et al. [5] studied the effects of plastic deformation on Microstructure and properties of brass, shows that large plastic deformation can cause great improvement of mechanical properties of brass. The addition of Mg to Cu-40Zn [6] could form tiny particles in the phase boundaries, which can greatly improve the strength of brass. However, most studies have focused on the brass with high content of Zn; studies for brass with low Zn content are not many so far. N.P. Gurao et al. [7] studied the evolution of Cu-10Zn alloy during high strain deformation texture. S. Nestorović et al. [8] researched the influence of thermal cycling treatment on Cu-10Zn alloy, shows the thermal cycling treatment can improve the mechanical properties and electrical conductivity of the alloy. In this paper, trace Fe are added to Cu-10Zn, and the effects of Fe on the properties of Cu-10Zn alloy are studied; deformation and heat treatment are used on Cu-Zn-Fe alloy, to investigate the effects of thermal-mechanical treatment on microstructure and properties of Cu-Zn-Fe alloy.



## 2. Experimental section

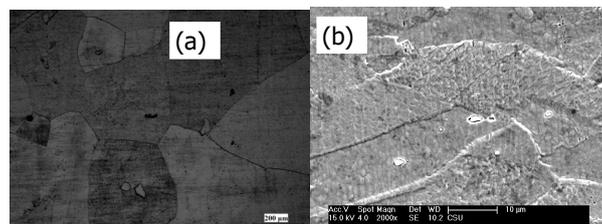
The alloy composition is Cu-10Zn-0.3Fe. After melting with medium frequency induction furnace, the alloy was casting to an ingot with size of  $4800 \times 400 \times 280$ mm. First of all, the metal was hot rolling from 280mm to 13.5mm at  $850^\circ\text{C}$ , then mill the surface into 12.5mm. Secondly, part of the alloy was subjected to cold rolling, making the thickness from 12.5mm to 3mm with the deformation rate of 76%. Thirdly, the material was annealing at  $480^\circ\text{C}$  for 4 hours in the bell type furnace after cold deformation. Lastly, following annealing at  $480^\circ\text{C}$ , the alloy was subjected to further cold rolling, reducing the thickness from 3mm to 0.92mm with the deformation of 69%. Thus three types of samples were manufactured, namely the hot rolled samples, the cold rolled sample, and further cold rolled samples.

Alloy of three states were investigated by the metallographic examination and SEM, to comparing the morphology characteristics of three kinds of samples. The cold rolled samples were annealed at  $480^\circ\text{C}$ , and use HV-5 small loads of Vickers hardness tester and 7501 type eddy current conductivity meter to measure hardness and electrical conductivity of the samples during the annealing process. Finally, the hot rolled samples, the cold rolled samples and the further rolled samples were subjected to annealing at low temperature, with annealing temperature of  $200^\circ\text{C}$ ,  $250^\circ\text{C}$  and  $300^\circ\text{C}$ , and annealing time range from 0.5-6 hours, then we measure and record the Vickers hardness and electrical conductivity.

## 3. EXPERIMENTAL RESULTS

### 3.1 Microstructure analysis

Fig. 1 shows the metallographic microstructure of as-cast sample and the SEM micrographs of the hot rolled sample, cold rolled sample and further cold rolled sample. In the microstructure of as-cast sample, alloy is a single-phase solid solution without obvious dendrite, and the crystalline grain is relatively large with size of approximately  $300\mu\text{m}$ , as shown in Fig. 1 (a). The grains of hot rolled sample are much finer than as-cast sample with size of approximately  $50\mu\text{m}$ , resulting from the dynamic recrystallization in hot rolling process. In addition, grains are elongated along the rolling direction, and twins can be obviously seen, as shown in Fig. 1 (b). After cold rolling, the microstructure turned to fiber tissues along rolling direction with elongated grains. It is easy to see the deformation is inhomogeneous, and the thickness of each grain is non-uniform in the direction perpendicular to the rolling direction, as Fig. 1 (c) shows. The microstructure of further cold rolled is shown in Fig. 1 (d), it is formed by fibrous tissue with grains more tiny than cold rolled sample, and the grains are homogeneous deformation, and thickness are uniform in the direction perpendicular to the rolling direction. The reason of this phenomenon is that complete recrystallization occurred when the cold rolled alloy anneal at  $480^\circ\text{C}$ , the microstructure turned into fine equiaxed grains, and Fe work as solute in the alloy, can inhibit the growth of the grains, so as to get the purpose of grain refinement strengthen, and then fine fibrous tissues with uniform deformation are achieved after further cold rolling.



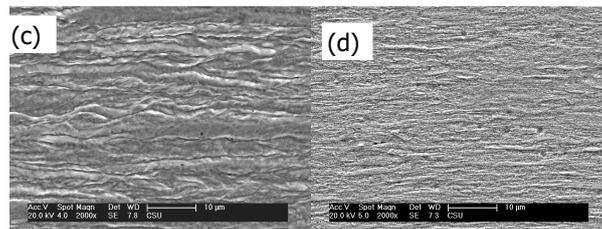


Figure 1. Microstructures of samples of different states. Metallographic microstructure of (a) as-casted alloy and SEM micrographs of (b) the hot rolled alloy, (c) the cold rolled alloy and (d) the further cold rolled alloy.

### 3.2 Aging treatment

Fig. 2 shows the Vickers hardness of cold rolled alloy on the process of annealing at 480°C. It can be seen from the figure that the hardness of the cold rolled alloy decrease quickly and decrease greatly. The hardness decreased 75HV only annealing for 1 hour, and it changed little during subsequent annealing. Recovery and recrystallization occurred in the process of annealing at 480°C, reduced the concentration of dislocations and stacking faults in the alloy, so that the working hardening cold rolled alloy be soften. Another reason causing the hardness decreases greatly is the alloy did not separate out second phase particle when annealed at 480 °C, thus no precipitation strengthening. Therefore the alloy belongs to the work hardening alloy.

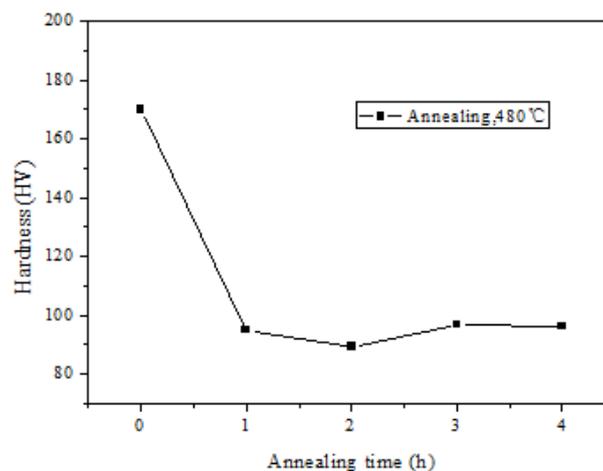


Figure 2. Hardness of the cold rolling sample after annealing at 480°C.

Fig. 3 describes the electrical conductivity of cold rolled alloy on the process of annealing at 480°C. As can be seen from the graph, the electrical conductivity of the alloy increases rapidly, it increases from 27.2HV to 35.8HV after an hour in the annealing process, and then the conductivity increased slightly in the subsequent annealing. The conductivity of metals is related to the

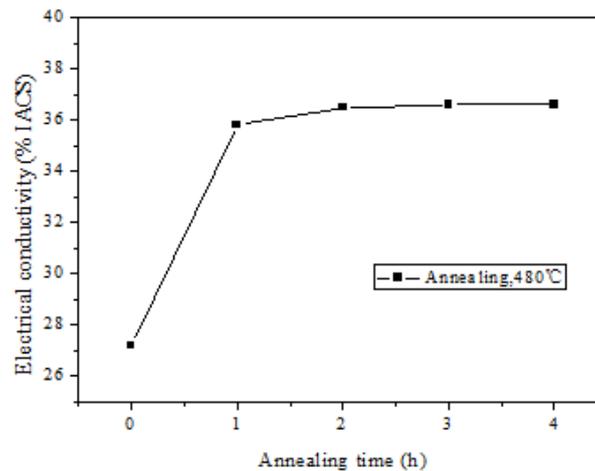


Figure 3. The trend of surface Vickers hardness of the A, B and C samples as a function of surface distance

crystal lattice. Cold deformation change interatomic spacing and structural defects cause lattice distortion, many become scattering center motion of the electron, which enhance electron scattering and reduce the electrical conductivity of the alloy. In the process of annealing at 480°C, the large concentration of dislocations and stacking faults of the cold rolled alloy, have been reduced because of dynamic recovery and recrystallization, and the distortion of lattice replied. Thereby great improvement of electrical conductivity of the alloy occurred.

Fig. 4 describes the Vickers hardness of the hot rolled samples, cold rolled samples and further cold rolled samples after annealing at 200°C, 250°C and 300°C. As can be seen from the graph, the hardness of hot rolled alloy changed just a little in the annealing process of each temperature, means the anneal treatment has little impact on the hot rolled alloy. The hardness of cold rolled alloy decrease when annealing at 300°C, and it decreases larger as annealing time expand. It is because the concentration of crystal defects decreased in the process of annealing at 300°C, and the working hardening tissues soften significantly, and the grains grew larger gradually. When annealing at 200°C and 250°C, the hardness cold rolled alloy was slightly increased, then decreased later, and the hardness of the cold rolled samples annealed at 200°C, which reached the peak value at 2h annealing, is higher than samples annealed at 250°C. The reason of the improvement of hardness of the cold rolled alloy is, in the process of annealing, the precipitates formed in rolling process, dissolved into  $\alpha$ -Cu solid solution, causing the lattice distortion, resulting in anneal hardening; at the same time, due to the annealing related with the recovery process, so that the concentration of defects reduced, thereby reducing the hardness of the alloys; and the grains grew large in annealing process, which can also make the decrease of hardness, so strengthening of the alloy is a comprehensive effects of solution strengthening, work hardening strengthening and refined crystalline strengthening. It is because in the process of annealing, the amount of increase of hardness caused by solution strengthening is larger than the amount of reducing of hardness caused by recovery and grain growth, thereby the hardness increase in the first 2 hours of annealing. As the annealing time prolonged, the amount of reducing of hardness caused by recovery and grain growth become larger than the amount of increase of hardness caused by solution strengthening, so that the hardness of the alloy decreased after 2 hours of annealing. Seen from the Fig. 4, the hardness of the further cold rolled samples are higher than the hot-rolled samples and the cold rolled samples. During annealing, the hardness trend of the further rolled samples is similar with the cold rolled samples. The hardness decreased as the increase of annealing time when annealing at 300°C, and the hardness increased at first and then decreased when annealing at 200°C and 250°C. The hardness of further cold rolled samples annealing at 200°C is higher than

annealing at 250°C., then rolled alloy The hardness reached the peak value of 194.83HV at 2 hours of annealing at 200°C. The strengthening principle of the further cold rolled samples in the process of annealing is also the comprehensive effects of solution strengthening, work hardening strengthening and refined crystalline strengthening.

Fig. 4 describes the electrical conductivity changes of the hot rolled samples, cold rolled samples and further cold rolled samples after annealing at 200°C, 250°C and 300°C. From the figure, the conductivity of further cold rolled alloy is much higher than the hot rolled alloy and cold rolled alloy. In the process of annealing, conductivity of the three kinds of alloys is increased at first and then tends to keep balance. The higher of the annealing temperature and the longer of annealing time is, the more conductivity of the three kinds of alloys rise. The reason for this phenomenon is that, in the annealing process, recovery occurs in the three kinds of alloys, reducing the concentration of defects density in the alloy, and reducing the effects of electrons scattering caused by distortion of lattice, thus improving the conductivity.

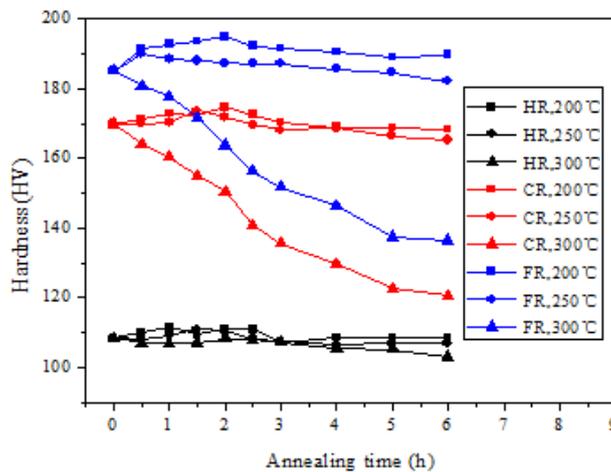


Figure 4. Hardness of the hot rolled (HR) samples, cold rolled (CR) samples and further cold rolled (FR) samples after annealing at different temperature.

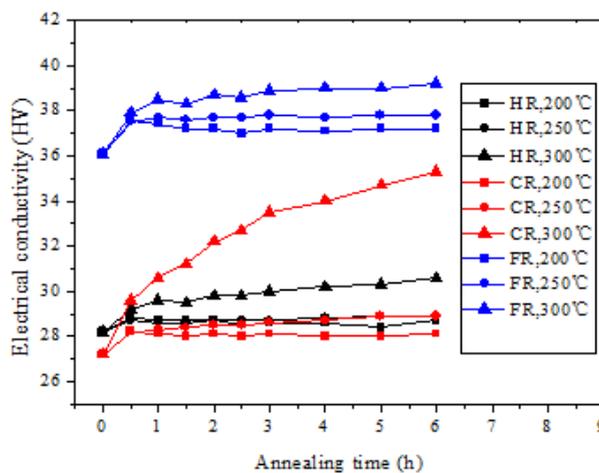


Figure 5. Hardness of the hot rolled (HR) samples, cold rolled (CR) samples and further cold rolled (FR) samples after annealing at different temperature.

#### 4. CONCLUSIONS

1. The hardness of the alloy decreased quickly, and conductivity increased quickly when annealing at 480°C. There is no second phase particle precipitation, and thus no precipitation strengthening, so the alloy belongs to the working hardening alloy.

2. Fe works as solute atoms in the alloy. Fe can inhibit the growth of the grain the alloy in the process of deformation and heat treatment, so as to achieve structure with fine grains, thus improving mechanical properties of the alloy.

3. The alloy turned into small uniform fiber tissues after hot rolling, cold rolling, annealing at 480 °C and further cold rolling. And the mechanical properties and electrical properties have been greatly improved. The hardness and electrical conductivity of further cold rolled alloy is higher than that of hot rolled alloy and cold rolled alloy. High hardness comes mainly from fine grain strengthening, working hardening, and annealing hardening.

4. The hardness and electrical conductivity of hot-rolled alloy have changed little in the final annealing. The annealing hardening effects of cold rolled alloy and further cold rolled alloy are getting weak as increases of annealing temperature. The optimum annealing temperature of the two kinds of deformed alloys is 200°C, and the optimum annealing time is 2 hours. The conductivity of the deformed alloys increased in the annealing process, and the higher of the annealing temperature, the higher conductivity increases.

5. After further cold rolled and annealing at 300°C, the conductivity of Cu-Zn-Fe alloy can reach peak value of 39.3% IACS, but the hardness of the alloy is low of 136.53HV at this status. The further cold rolled alloy can achieve the best comprehensive properties: hardness reaches the maximum value of 194.83HV and electrical conductivity of 37.2% IACS when annealing at 200 °C for 2 hours,. Therefore the best thermal-mechanical treatment system of the alloy: hot rolling, cold rolling, annealing at 480 °C for 4 hours, further cold rolled and annealed at 200°C for 2 hours.

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