The structure and capability of hot deformation Cu-1.2Cr-0.2Zr in aging state

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Abstract. Cu-Cr-Zr alloy belongs to precipitation-enhanced, high-strength and high-conductivity copper alloys. The volume fraction of specimen deformation was 25% and the deformation rates were 0.01~1 s⁻¹ with the deformation temperature ranged from 500 °C to 800 °C at Gleeble-1500 thermal simulator. The results state that the rheological stress of Cu-Cr-Zr alloy decreases with a rising temperature at a same deformation quantity. Along with the increasement of the strain rates and the temperatures during hot deformation, the grains of Cu-Cr-Zr alloy were elongated perpendicularly to the direction of compression. When the deformation temperature was 600 °C, some of fine recrystallized grains appeared.

1. Introduction
Copper and copper alloys have the most important characteristics of high electrical conductivity and thermal conductivity. With the exception of silver, copper is the most conductive in all metals, which determines its widely application and high consumption. In addition, copper and copper alloys possess excellent corrosion resistance, anti-bacterial effect, easy processing, the preparation of various alloys, etc. Copper alloys are mainly used in electronics, electric power, chemical industry, communication, machinery, marine engineering, transportation, aerospace, building decoration and other fields [1-3]. Cu-Cr-Zr alloy is a precipitation-enhanced high-strength and high-conductivity copper alloy. Many researches in the heat treatment process have been studied before, such as room temperature mechanical properties, electrochemical properties, precipitation microstructure, hot deformation behavior, processing map, etc [4-5]. However, the study of the structure and capability of hot deformation Cu-Cr-Zr alloy was less.

2. Experimental
The composition of materials used in the experiment was Cu-1.2Cr-0.6Zr alloy rolled rod with diameter of 20 mm. The raw materials were cut into a cylindrical with φ8mm × 12mm. The specimens were heated 450 °C in vacuum atmosphere, kept for 4 hours, and air cooling for aging. Hot deformation was carried out at the Gleeble-1500 thermo-mechanical simulator with parameters of table 1. The samples were polished and etched with a solution of FeCl₃(5g)+HCl(10ml)+H₂O (100ml).
The phase composition were tested using Rigaku D/max/2500PC X-ray diffraction. And the microstructures were observed using XJP100 metallographic microscope and QUANTA FEG 250 field emission scanning electron microscope. Moreover, energy dispersion spectrum were proved the phase and component of materials discussed here. In addition, micro-hardness indicated the ability of metal materials to resist local deformation, especially plastic deformation. It is also the basis of material hardness, which represents the deformation resistance of materials.

3. Results and discussion

3.1 Thermal Deformation Analysis of Cu-Cr-Zr Alloy

Hardening and strengthening will be occurred by the recovery and recrystallization taken place in plastic deformation during the annealing. Table 1 shows the flow stress of Cu-Cr-Zr alloy at a deformation volume fraction of 25% with different deformation temperatures and strain rates. It was clear that the flow stress was decreased while the deformation temperature was increased for the growing kinetic energy. The point defect is activated and the activation energy of the cutting edge dislocation increased. The corresponding kinetic energy of the metal atom is also strengthened. The critical shear stress between the atoms is reduced, when the dislocation motion is relatively easy to occur. And the dynamic softening effect is obtained, which reduces the flow stress of Cu-Cr-Zr alloy.

Table 1. Peak stress under different temperature and strain rate with 25% deformation of the Cu-Cr-Zr alloy

| Temperature | Strain rate 0.01 s⁻¹ | Strain rate 0.1 s⁻¹ | Strain rate 1 s⁻¹ |
|-------------|----------------------|---------------------|------------------|
| 800 °C      | 56.52                | 77.01               | 100.8            |
| 700 °C      | 96.54                | 134.9               | 167.9            |
| 600 °C      | 239.7                | 289.6               | 306.7            |
| 500 °C      | 344.7                | 365.3               | 379.1            |

3.2 XRD analysis of Cu - Cr - Zr alloy

The only peaks of Cu, absent of Cr and Zr peaks, state low content in the samples (Figure.1). Besides, it is seen that the peaks of specimens shifted to left for Cr dissolved into the Cu matrix during solution[6]. After hot deformation of the samples, thermal compression actually, the crystallinity declined and the grain size decreased for peaks broad taken on these pictures.

![Figure1. XRD spectrum of Cu - Cr - Zr alloy with rolling state (a) and thermal deformation conditions: 800°C, deformation rate: 1s⁻¹, deformation:25%(b)]](image)

3.3 SEM and EDS analysis of Cu - Cr - Zr alloy
In order to determine the structure, morphology, phase, composition of the alloy, SEM and EDS analysis were shown in Figure 2. The main components of the alloy were Cu, Cr, Zr.

![Figure 2. SEM and EDS spectrum of Cu-Cr-Zr alloy](image)

3.4 The microstructures of Cu-Cr-Zr alloy after thermal deformation

The microstructures of Cu-Cr-Zr alloy at 800 °C with different strain rates (0.01 s⁻¹, 1 s⁻¹, 1 s⁻¹) were shown in Fig. 3. The grain size was decreased clearly with a high strain rate for lacking enough recrystallizing time. At a large strain rate, there are not enough time for the dislocations in Cu-Cr-Zr alloy to slip while the proliferation and entanglement of dislocations were occurred, which resulting in inhomogeneous deformation, local rheological deformation and shear band. When the strain rate was 0.1 s⁻¹, the dislocations cross-slip were taken place and the grains of Cu-Cr-Zr alloy were elongated perpendicularly to the direction of compression.

![Figure 3. SEM at the thermal deformation conditions: 800 °C, deformation rate: (a) 0.01 s⁻¹ (b) 0.1 s⁻¹, (c) 1 s⁻¹ when deformation: 25%](image)

The microstructures in different thermal deformation temperature of 800°C, 700°C, 600°C, 500°C at a strain rate of 0.01 s⁻¹ were shown in Fig. 4. At 500°C, obviously, the grains of the Cu-Cr-Zr alloy were compressed to fibrous structure along with the compression direction. However, recrystallization was not occurred for the absence of nucleation grains. When the deformation temperature was 600 °C, some of fine recrystallized grains appeared near the original grains, which indicated that the dynamic recrystallization was generated. When the deformation temperature reached to 700°C or 800°C, the
recrystallization grains enlarged obviously, which indicated that the Cu-Cr-Zr alloy underwent dynamic recrystallization. In general, there were indications that both of the grain size of the alloy and the quantity of recycled grains increase with a rising deformation temperature. Recrystallization plays a leading role in this process.

![Figure 4](image1.png)

**Figure 4.** Metallographic at the deformation rate: 0.01 of different temperature: (a) 800 °C (b) 700 °C (c) 600 °C (d) 500 °C

3.5 *The micro-hardness of Cu-Cr-Zr alloy after thermal deformation*

![Figure 5](image2.png)

**Figure 5** The change of the hardness value at the different temperature when the deformation conditions: (a) 25% (b) 50%

Micro-hardness refers to the resistance to local deformation especially to the plastic deformation, indentation or scratch. It is the basis of characterizing the hardness and deformation resistance of the materials. Figure 5 shows the values of hardness at different temperatures and deformation rates. It can be seen that the hardness decreases with the increase of the deformation temperature. The effect of dynamic recovery, dynamic recrystallization and work hardening of Cu-Cr-Zr alloy at different temperatures are distinct. With gradually increasing deformation temperatures, the deformation resistance is reduced and the dynamic recrystallization occurs, which are beneficial to softening.
4. Conclusions
(1) After hot deformation of Cu-Cr-Zr alloy the crystallinity declined and the grain size decreased.
(2) The grain size was decreased clearly with a high strain rate for lacking enough recrystallizing time.
(3) Recrystallization begins at 600°C. And some of fine recrystallized grains appeared near the original grains. When the deformation temperature reached to 700°C or 800°C, the recrystallization grains enlarged obviously.
(4) With gradually increasing deformation temperatures, the values of the micro-hardness decreased.

References
[1] Ding Z, Jia S, Zhao P, et al. Hot deformation behavior of Cu–0.6Cr–0.03Zr alloy during compression at elevated temperatures[J]. Materials Science & Engineering A, 2013, 570(5):87-91.
[2] Zhang S.J, Li R.G, Kang H.J, et al. A high strength and high electrical conductivity Cu-Cr-Zr alloy fabricated by cryorolling and intermediate aging treatment[J]. Materials Science & Engineering A, 2017, 680: 108-114.
[3] Fu H.D, Xu S, Li W, et al. Effect of rolling and aging processes on microstructure and properties of CuCr-Zr alloy[J]. Materials Science & Engineering A, 2017, 700: 107-115.
[4] Joo H.S, Kim Y.N, Hwang S.K, Im Y.T. The effect of wire drawing and aging on mechanical and electrical properties of Cu-Cr-Zr alloy[J]. Procedia Engineering, 2017, 207: 1129-1134.
[5] Liu Y.L, Zhou P, Liu S.H, Du Y. Experimental investigation and thermodynamic description of the Cu-Cr-Zr system[J]. CALPHAD: Computer Coupling of Phase Diagrams and Thermochemistry, 2017, 59: 1-11.
[6] Zhou J.M, Zhu D.G, Tang L.T, et al. Microstructure and properties of powder metallurgy Cu-1%Cr-0.65%Zr alloy prepared by hot pressing[J]. Vacuum, 2016, 131:156-163.

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