Effect of cold rolling process on microstructure and properties of T1 Copper sheet

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Abstract. The 8mm thick T1 state copper plate was cold rolled into 3mm, 2mm and 1mm thin plate sections, and its microstructure and texture were analyzed by optical metallographic microscope and X-ray diffraction (XRD). The mechanical properties were tested by cupping machine and micro-hardness tester. The results show that with the increase of cold rolling deformation, the grain size decreases and a strong (220) diffraction surface texture appears. The highest tensile strength is 421.76MPa, and the microhardness is 129.9HV, all of which are greatly improved, but the elongation decreases from 40% to 5%, and the fracture morphology changes from ductile fracture to quasi cleavage fracture.

1. Introduction
Copper has excellent conductivity, thermal conductivity, good plasticity, easy to process, but at the same time, it has low strength, soft surface, easy to scratch and other defects [1-4]. As a common processing method, cold rolling is easy to operate and low in cost. Cold rolling improves the strength and hardness by changing the crystal structure, but reduces the toughness and plasticity, which is easy to generate residual stress, so it can only be used for ordinary parts [5-8]. In daily life, the demand for copper is mostly thin, but the cost of thin copper plate is high, so the copper can be processed by cold rolling to meet the use demand.

In this paper, the mechanical properties of T1 copper sheet under different cold rolling conditions are tested, and the effect of different cold rolling processes on the mechanical properties of T1 copper sheet is studied. The effect of rolling texture on the structure and properties of T1 copper was studied by XRD⁹, and the reference for the use and reprocessing of sheet and section was provided.

2. Material preparation and experimental research methods

2.1. Preparation of experimental materials
The annealed T1 pure copper sheet with thickness of 8mm was selected in the experiment. The rolling process parameters are as follows: temperature 20°C, initial width 40mm, rolling speed 0.65m/s, final rolling thickness 3mm, 2mm and 1mm respectively.

2.2. Experimental method

2.2.1. Metallographic sample preparation and microstructure analysis. Different copper samples were cut into standard samples with sample cutting machine. The contact surface between the sample
and the roller of the rolling mill was selected as the observation surface. 180#—1400# sandpaper was used for grinding in turn, and then polished on the polishing machine. The polishing agent was chromium oxide polishing paste. The polished sample was corroded with 3% FeCl₃ + 10% HCl + 87% H₂O solution for 10s. The microstructure of the sample was observed by Shang Guang 4XC metallographic microscope.

2.2.2. Mechanical property test and fracture observation. The tensile property of the material was tested on WDW-50m microcomputer controlled electronic universal testing machine. The tensile speed at room temperature was 2mm/min, and the sample size was prepared according to GBT228-2002. JSM-6490LV scanning electron microscope was used to analyze the fracture morphology.

2.2.3. Hardness sample preparation and hardness test. Choose the contact surface with roller as microhardness test, then use 180#—1400# sandpaper to grind and polish. The hardness was measured by HV-1000Z micro-hardness tester. The pressure was 500N and the holding time was 15s.

2.2.4. Sample preparation and XRD test. Using D8 ADVANCE X-ray diffractometer to test the material, the specific parameters are: scanning angle 20° ~ 95°, scanning mode is step scanning, step length 0.04, scanning speed 0.1661 °/s.

3. Results and analysis

3.1. Microstructure analysis of alloy

![Microstructure Images]

Figure 1. Metallographic microstructure (a) Original specimen in non rolled state; (b) Rolling thickness of 3mm; (c) Rolling thickness of 2mm; (d) Rolling thickness of 1mm; It can be seen from Figure 1 (a) that the grain shape in the non rolled (annealed) state is close to the equiaxed state. When cold rolling from the initial 8mm thickness to 3mm thickness, as shown in Figure 1 (b), the grains are elongated along the rolling direction (RD), resulting in rolling deformation band. With the increase of rolling deformation (2mm thick), as shown in Figure 1 (c), the angle between deformation band and RD direction decreases, the grain is obviously refined, the grain is severely compressed laterally, and the grain boundary becomes blurred. When cold rolling to 1mm thickness, as shown in Figure 1 (d), though the grain boundary becomes unrecognizable, the microstructure becomes obviously finer.
3.2. Mechanical properties of copper plate with different rolling deformation

![Tensile stress-strain curve of T1 copper under different rolling conditions](image)

Figure 2. Tensile stress-strain curve of T1 copper under different rolling conditions

It can be seen from Figure 2 that the tensile strength of T1 state copper increases with the increase of cold rolling deformation, the elongation decreases greatly, and its elastic modulus increases. This is precisely because the cold-rolled plastic deformation material appears work hardening, that is, the strength increases and the plasticity decreases \(^{[10]}\). When the copper plate is cold rolled to 2mm thick, the maximum value of its ultimate tensile strength reaches 421.76MPa, which is 42.9% higher than the original T1 state copper tensile strength value of 295MPa.

![SEM appearance of tensile fracture](image)

Figure 3. SEM appearance of tensile fracture: (a) T1 original specimen; (b) 3mm thick; (c) 2mm thick; (d) 1mm thick;

According to Figure 3, the tensile fracture of copper is ductile fracture. As shown in Figure 2, with the increase of cold rolling amount, the strength of T1 state copper increases and the elongation decreases. Figure 3 (a) shows that there are obvious elongated dimples on the tensile fracture surface
of unrolled (annealed) copper, and the dimples are similar and large. When cold rolled to 3mm (as shown in Figure 3 (b)), the dimple size becomes smaller. When the cold rolling amount increases to 2mm (as shown in Figure 3 (c)), the dimple is getting smaller and smaller. When cold rolled to 1mm (as shown in Figure 3 (d)), the number of dimples decreased significantly, and the cleavage surface of brittle fracture appeared, which changed from ductile fracture to quasi-cleavage fracture.

3.3. Effect of different rolling conditions on hardness

![Graph showing microhardness and cold rolling capacity of T1 copper](image)

Figure 4. Relationship between microhardness and cold rolling capacity of T1 copper

Figure 4 shows the relationship between the microhardness of the original T1 copper sample and the thickness of the cold rolled sheet. It can be seen from Fig.4 that after cold rolling plastic deformation, the microhardness of pure copper increases with the increase of cold rolling amount. After cold rolling, the samples show different degree of work hardening. When rolled to 1mm thick, the microhardness value reaches 129.9HV, which is 23.7% higher than the original T1 microhardness value of 104.4HV [11].

3.4. Analysis of X-ray diffraction results

![XRD spectra of copper plates with different rolling thickness](image)

Figure 5. XRD spectra of copper plates with different rolling thickness: (a) Thickness of 1mm; (b) Thickness of 2mm; (c) Thickness of 3mm; (d) T1 state copper.

According to the analysis of the X-ray diffraction pattern results in Figure 5, the diffraction peaks of the phase are clear and complete. By using Jade 5.0, the main diffraction peak data in the figure is compared with the Cu (PDF#04-0836) standard diffraction peak data in the JCPDS card, and the four diffraction peaks can be accurately calibrated to coincide with the pure Cu phase. However, the (220) peak strength increases after forming with different rolling deformation, and the (111) diffraction peak reaches the lowest value at the 2mm thick sample, and increases with the increase of deformation, which shows that after cold deformation, obvious texture appears on the (220) crystal surface. When the deformation increases, the proportion of texture structure increases, and the diffraction peak strength increases, which is consistent with the face centered cubic crystal structure \{111\} \langle110\>
slip system characteristics [12-13]. This is also in accordance with the microstructure of Figure 1 and Figure 3. When the rolling thickness reaches 1mm, the microstructure and fracture morphology change obviously.

4. Conclusion
At the initial thickness of 8mm, the T1 state copper plate was rolled at the speed of 0.65 m/s, and the cold rolled plates were 3mm, 2mm and 1mm. The grain size decreased with the increase of rolling deformation, (220) surface texture increased, and (111) surface texture decreased. The highest tensile strength along the rolling direction is 421.76MPa, 42.9% higher, and the microhardness is 129.9HV, 23.7% higher. However, the elongation decreased obviously, and the fracture morphology changed from ductile fracture to quasi-cleavage fracture.

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