Investigation of the influence of deformation temperature on the radial shear rolling mill on the microstructure evolution of copper

Abdrakhman Naizabekov[1], Kadyrgali Dzamanbalin[2], Irina Volokitina[1], Alexandr Arbuz[3], Sergey Lezhnev[1],
Evgeniy Panin[4], Andrey Tolkushkin[1]

[1]Rudny Industrial Institute, Rudny, Kazakhstan
[2]Kostanay Social-Technical University named after academician Zulkharnai Aldamzhar, Kostanay, Kazakhstan
[3]Nazarbayev University, Astana, Kazakhstan
[4]Karaganda Industrial University, Temirtau, Kazakhstan
naizabekov57@mail.ru

Abstract: *One of the effective ways to control the properties of copper is to refine its structure to a nano- or ultrafine-grained level, and primarily with the help of severe plastic deformation. At the same time, radial-shear rolling is one of the promising methods for obtaining long-length rods with a gradient ultra-fine-grained structure. It is known from a number of scientific works that one of the main factors influencing the possibility of obtaining an ultrafine-grained structure in various ferrous and non-ferrous metals and alloys is the deformation temperature of these metals and alloys. The aim of the work is to study the influence of the deformation temperature at the radial-shear rolling mill on the microstructure evolution of copper. The following deformation temperatures of copper rods were selected for the planned studies: 20°C, 100°C and 200°C. The conducted studies have shown that the implementation of radial-shear rolling at ambient temperature compared with rolling at temperatures of 100°C and 200°C made it possible to achieve more intensive refinement of the initial structure. And first of all, this is due to the fact that with radial-shear rolling of copper, realized at ambient temperature, there are no dynamic return processes.*

KEYWORDS: *RADIAL-SHEAR ROLLING, TEMPERATURE, COPPER, MICROSTRUCTURE, GRAIN SIZE.*

1. Introduction

Copper is one of the most common non-ferrous metals. It has high anti-corrosion properties, both under normal atmospheric conditions, and in fresh and sea water and other aggressive environments. In the presence of atmospheric oxygen, a patina film forms on the surface of the copper product, which protects the metal from corrosion.

Copper is easy to process by pressure and soldering. Having low casting properties, copper is hard to cut and poorly welded. In practice, copper is used in the form of rods, sheets, wire, tires and pipes.

Due to its high thermal conductivity, copper is used for the production of current conductors and electrical products, refrigerating units, elements of thermal pipelines, heating and gas supply systems, as well as CCM crystallizers. Since copper is resistant to the influence of aggressive chemicals, rolled products from it are used in the oil, gas and chemical industries and for the manufacture of cryogenic equipment. Copper products have a very long service life, and throughout this period the products retain their appearance, strength and physical integrity.

Impurities have a great influence on the properties of copper, which are divided into three groups according to the method of exposure:

1) Impurities forming solid solutions with copper – nickel, antimony, aluminum, zinc, iron, tin, etc. Reduce the electrical and thermal conductivity of copper. In this regard, copper with a limited content of arsenic and antimony (0.002 As and 0.002 Sb) is used as current conductors. Antimony also reduces the ability of the alloy to hot plastic deformation.

2) Impurities that practically do not dissolve in copper – bismuth, lead, etc. Practically do not affect the electrical conductivity of copper, but worsen its pressure treatment.

3) Impurities forming brittle chemical compounds (sulfur, oxygen). Oxygen significantly reduces the strength of copper and reduces electrical conductivity. Sulfur improves the machinability of copper by cutting.

Another effective way to control the properties of copper, as well as other ferrous and non-ferrous metals, is to refine its structure to a nano- or ultrafine-grained level, and primarily with the help of severe plastic deformation [1]. Radial-shear rolling is one of the promising methods for obtaining long-length bars with a gradient ultrafine-grained structure [2-3]. At the same time, it is known from a number of scientific papers, including [4-7], that one of the main factors influencing the possibility of obtaining an ultrafine-grained structure in various ferrous and non-ferrous metals and alloys is the deformation temperature of these metals and alloys. To obtain an ultrafine-grained structure, the deformation process must be carried out at a temperature not exceeding the threshold for the beginning of recrystallization, since with an increase in the temperature of the deformation beginning, the probability of dynamic collective recrystallization during hot deformation increases, leading to undesirable grain enlargement. Therefore, the choice of the temperature regime is based on the fact that in the process of hot deformation, the primary recrystallization takes place completely, and the collective one is suppressed.

Since within the framework of the grant topic "Development of technology for obtaining ultrafine-grained structure in copper and its alloys by radial-shear rolling and structure control by ultrasonic processing", at the first stage we are faced with the task of obtaining ultrafine-grained structure by radial shear rolling in copper and its alloys, the purpose of these studies is to study the influence of such a technological factor deformations on the radial-shear rolling mill, as the rolling temperature, on the microstructure evolution of copper.

2. Experimental part

For the laboratory experiment, rods with a diameter of 25 mm and a length of 300 mm made of M1 grade copper were used. The choice of M1 grade copper as the starting materials is justified by its wide application in various industries, including medicine, mechanical engineering, instrumentation, cable industry, etc.

The following bar deformation temperatures were selected for the planned studies: 20°C, 100°C and 200°C.

At the first stage, a 25 mm diameter copper rod was deformed at room temperature on the SVP-08 radial shear rolling mill according to the reverse scheme shown in Figure 1. Rolling was carried out in four passes, up to diameters of 23 mm, 21 mm, 19 mm and 17 mm. At the second and third stages, copper rods with a diameter of 25 mm were heated in a Nabertherm tubular furnace to a temperature of 100°C and 200°C, respectively, with an exposure time of 25 minutes before deformation on the SVP-08 radial-shear rolling mill. After that, these bars were deformed on a radial shear rolling mill to a diameter of 17 mm also in four passes with an absolute compression step of 2 mm in diameter according to the above scheme.

Samples were cut from the initial bar and bars after the 2nd and 4th passes using the BRILLANT 230 cutting machine and slots were made for metallographic studies in the longitudinal section.

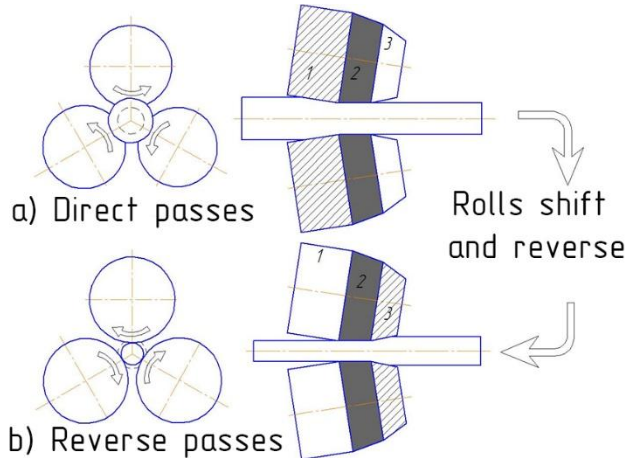


Fig. 1. *Scheme of reversible radial-shear rolling: 1 – crimping section for direct passes; 2 – calibration section for all passes; 3 - crimping section for reverse passes*

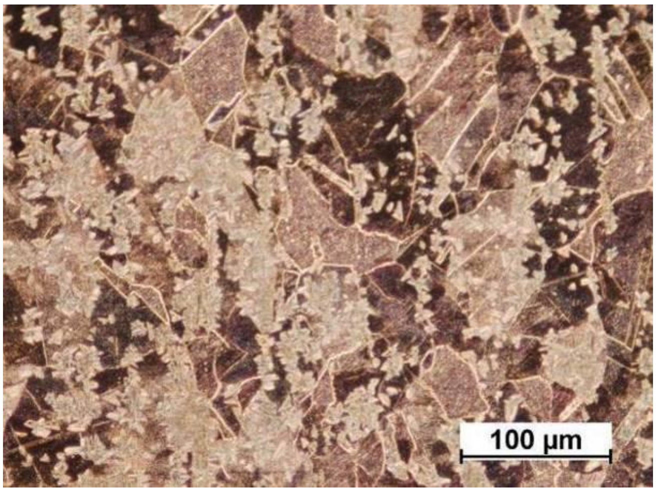
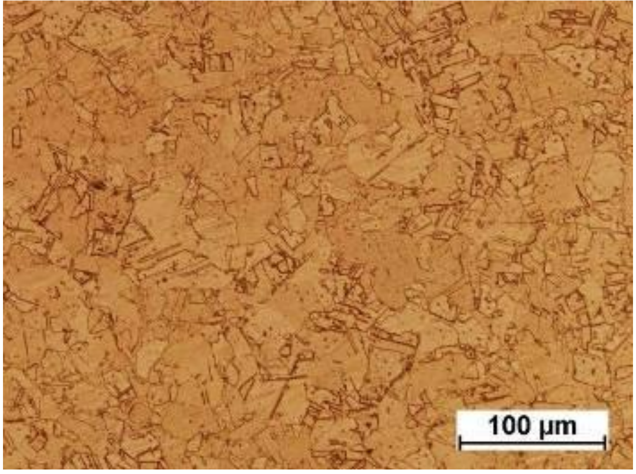


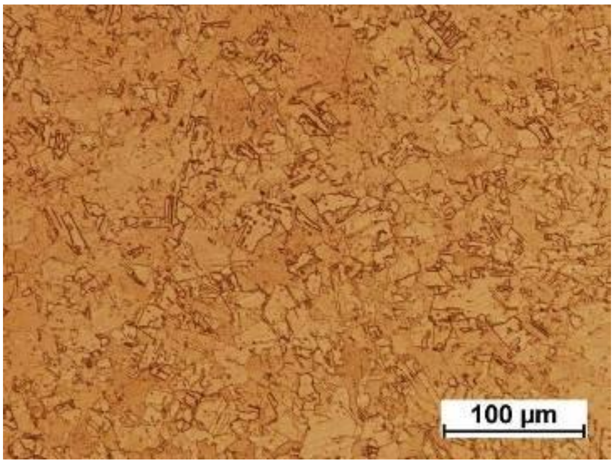
Fig. 2. *Initial structure of copper*

a)

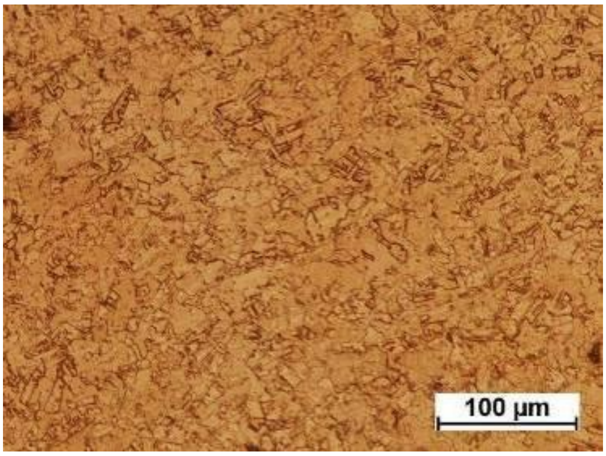


The microslips were prepared on a SAPHIR 520 grinding and polishing machine. To identify the microstructure , the polished surfaces of the samples were degreased with toluene and etched by wiping for 10-20 seconds with cotton wool with a solution of the following content: 75% saturated solution of $K_2Cr_2MnO_4$, 10% HHO_3, 10% HCL, 5% H_2SO_4. To increase the contrast, additional etching was carried out by immersion of the strip for 2-4 seconds in a solution of 10% HCL; 90% saturated $Cu_2(SO_4)_3$ [8].

Microstructure studies were carried out on a Leica DM optical microscope. Figure 2-3 shows optical photos of the microstructure before and after the 4th deformation cycle.



b)



c)

Fig. 3. *Microstructures of copper after 4 deformation passes on a radial-shear rolling mill at temperatures of 200°C (a), 100°C (b) and 20°C (c), respectively*

3. Results and discussion

Metallographic analysis of copper (Figure 3, 4) after radial-shear rolling showed that at all deformation temperatures, grain refinement occurs after each deformation pass. But at the same time, it has also been proved that when implementing radial-shear rolling at ambient temperature, the grain structure of copper rods is worked out more intensively. So at this temperature, the minimum average grain size after the fourth deformation pass on the radial-shear rolling machine was 6.0 microns, while the minimum grain size was 3.1 microns. The advantage of deforming copper samples on a radial-shear rolling mill at ambient temperature is primarily due to the fact that there are no dynamic return processes in this case.

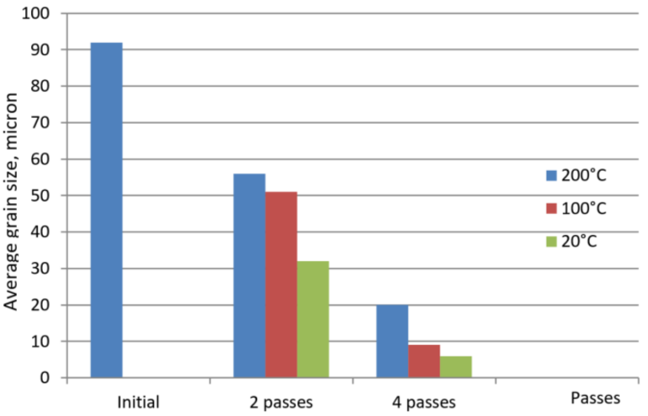


Fig. 4. *Average copper grain size by passes*

4. Conclusion

Based on the obtained results of metallographic studies, it can be concluded that the deformation temperature has a significant effect on the possibility of obtaining an ultrafine-grained structure in M1 grade copper when it is deformed on a radial shear rolling mill, which allows severe plastic deformation to be realized in the metal.

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