The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2024

Volume 32, Pages 101-105

IConTES 2024: International Conference on Technology, Engineering and Science

Research of Combined Copper Processing Technology Including Heat Treatment and Radial-Shear Rolling

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Abstract: This paper is devoted to the study of the influence of a combined technology, including both pre-heat treatment and deformation on a radial-shear rolling mill, on changes in the mechanical properties of M1 grade copper. The conducted studies have shown that after preliminary heat treatment, namely quenching at a temperature 500°C, and subsequent deformation of billets at temperatures of 20 and 200°C on a radial-shear rolling mill, an increase in the strength properties of copper is observed with a decrease in its plastic properties within the normal range. Also, according to the results of the conducted studies, it was found that the cross-section of the obtained copper bars shows a spread of microhardness values, which fully correlates with the data on the formation of areas with different microstructures after radial shear rolling in this cross-section.

Keywords: Combined technology, Pre-heat treatment, Radial shear rolling, Copper, Mechanical properties, Microhardness

Introduction

Currently, three-roll radial-shear rolling mills are widely used in the production of solid rolled bars of circular cross-section made of non-ferrous and ferrous metals and alloys. The main feature of the radial-shear rolling process is the ability to control the scheme of the stress-strain state of metal in a sufficiently wide range, which ensures the production of high-quality round rolled products with the necessary structure and a given level of mechanical properties. Currently, there are many scientific papers devoted to the study of the influence of radial-shear rolling on the evolution of microstructure and changes in the mechanical properties of not only various ferrous and non-ferrous metals, but also modern composite materials. Here are some of these scientific papers Gamin et al. (2021), Lezhnev et al. (2021), Arbuz et al. (2023), Akopyan et al. (2018), Gamin et al. (2023), Sheremet’ev et al. (2019), Lezhnev et al. (2023), Naizabekov et al.(2020). The authors of these works proved that using radial shear rolling, it is possible to produce high-quality bars of different sizes in diameter

- Selection and peer-review under responsibility of the Organizing Committee of the Conference

from various materials that will have a gradient ultra-fine-grained structure and a given level of mechanical properties.

It has also long been proven that heat treatment can also achieve additional grain refinement in various materials, if the correct modes of its implementation are chosen, which also has a positive effect on the properties of metal products subjected to heat treatment. Including in several scientific works, it was proved that combining into a single technological process pre-heat treatment in different modes and different methods of metal forming allows achieving better results in refining the initial grain of various materials (Lezhnev et al., 2014).

Based on the analysis of the above works, as well as several other works in this area of research, we have previously conducted studies of the effect of combined processing technology for M1 grade copper, including pre-heat treatment, namely quenching from a temperature of 500C and radial-shear rolling at temperatures of 20°C and 200°C, on evolution of the structure of this material. The results of these studies are given in Naizabekov et al. (2023). However, we did not study the effect of the combined technology considered in this paper on the change in the mechanical properties of M1 grade copper. Therefore, the purpose of this work is to study the combined technology of processing M1 grade copper, including heat treatment and radial-shear rolling, for changing the mechanical properties of this material.

Method

To achieve this goal, we conducted a physical experiment. As initial blanks, copper (M1 grade copper) blanks with a diameter of 25 mm and a length of 150 mm were taken. Which, based on the results previously obtained in Naizabekov et al. (2023), were subjected to preliminary heat treatment, namely, quenching from a temperature of 500C. Further, these billets were deformed on a radial shear rolling mill RSP 10-30 at two temperatures: 20 and 2000C. The blanks were deformed to a diameter of 16 mm and 12 mm with an absolute compression step of 3.0 mm in diameter when deformed to a diameter of 16 mm and 2.0 mm when deformed to a diameter of 12 mm (i.e. ∅25→∅22→∅19→∅16→∅14→∅12 mm) according to the standard deformation scheme, shown in Figure 1.

To determine the mechanical characteristics of the obtained M1 grade copper bars after preliminary heat treatment and multi-transition deformation at a radial-shear rolling mill, it was decided to conduct tensile tests and measure the microhardness distribution over the cross-section of the bars.

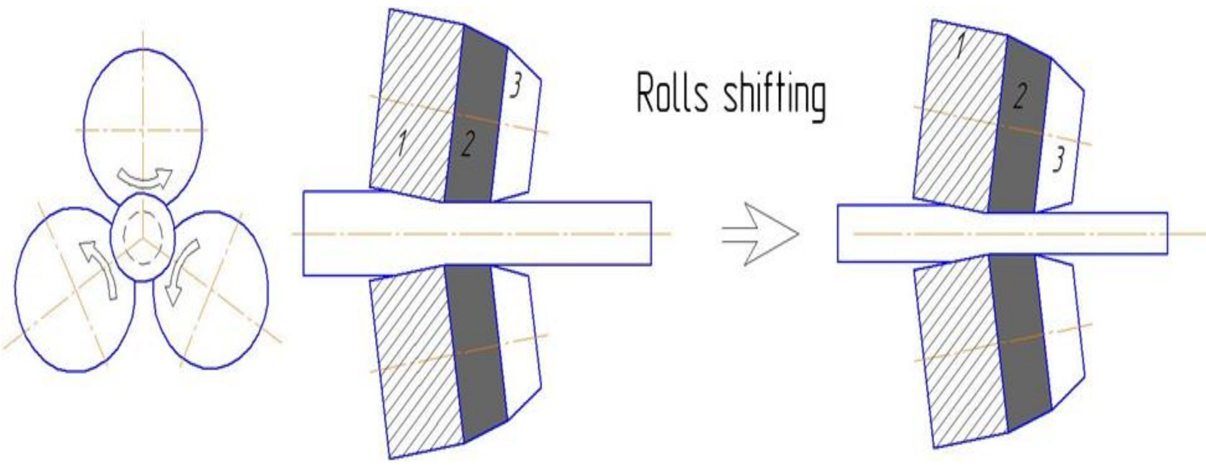


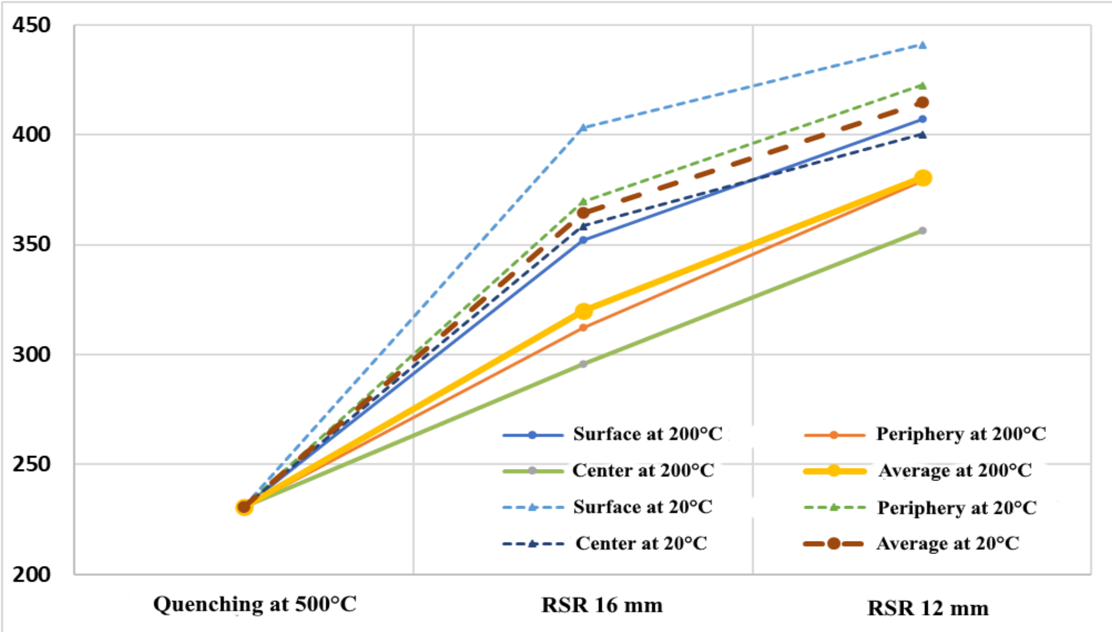
Figure 1. Scheme of billet deformation at the RSR 10-30 mill

To perform tear tests, test samples were cut from all deformed bars (both up to a diameter of 16 mm and 12 mm) on a high-precision automated cutting machine GTQ-5000 in the form of strips with dimensions h×b×l=0.3×3×30 mm. These strips were cut in the longitudinal direction of the bar from the surface, intermediate and the central zone. Similar samples were also prepared to determine the mechanical properties of M1 grade copper after preliminary heat treatment. The prepared samples were tested on a two-column digital tensile testing machine with a force of 1000 kN from Qingdao Guangyue Rubber Machinery Manufacturing Co., Ltd (China). At the same time, the tests for each material were duplicated three times to avoid errors.

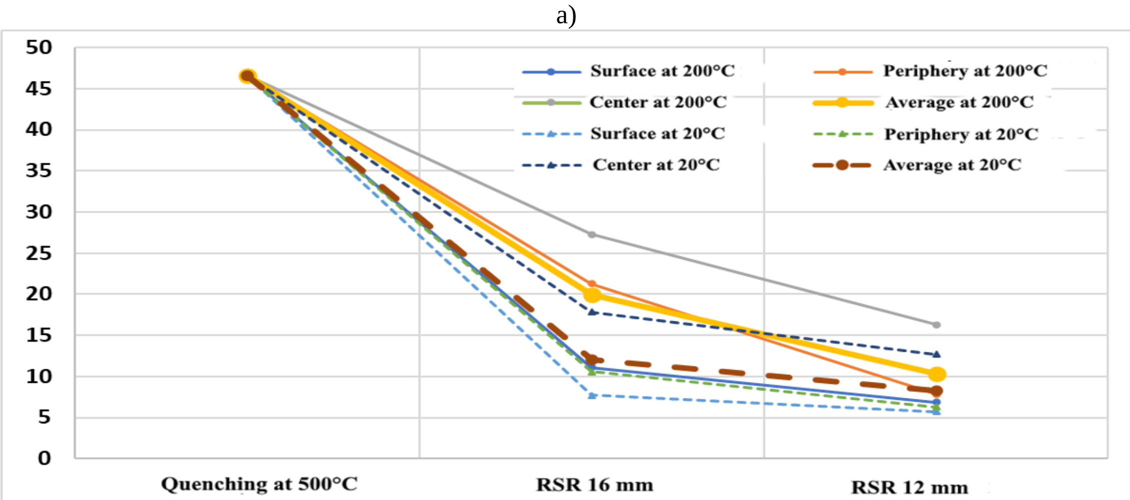
Results and Discussion

Based on the obtained and statistically processed data of tensile tests, the average value of mechanical properties was determined and the corresponding graphs of the dependence of the ultimate strength σ b and the relative elongation δ on the type of processing were plotted (Figure 2). Analysis of the results of mechanical tests shown on the graphs of the dependence of the ultimate strength σ b and the relative elongation δ on the type of processing (Figure 2) showed that in the process of radial-shear rolling, the strength properties of M1 grade copper previously subjected to heat treatment according to the selected mode increase, both in the surface and in the intermediate and central regions of the deformed bar, and the value of the relative elongation, which characterizes the plastic properties of these materials, on the contrary, decreases. Moreover, the greater the compression, the greater these changes.

In addition, the graphs shown in Figure 2 show that the deformation temperature directly affects the change in mechanical properties. Thus, at the deformation temperature at the RSR mill equal to 200°C there is a smaller increase in the tensile strength and, accordingly, a smaller drop in the relative elongation for M1 grade copper compared to its deformation at a temperature of 20°C.



a)



b)

Figure 2. Mechanical properties of M1 grade copper: A-ultimate strength σ; b - relative elongation δ

Also, from the graphs shown in Figure 2, the highest values of tensile strength and the lowest values of relative elongation are observed in the surface layers of the workpiece. Conversely, the highest values of relative elongation and the lowest values of ultimate strength are observed in the central layers of the workpiece. This is fully consistent with the previously reported results of studying the evolution of the microstructure of M1 grade copper during their deformation in a radial-shear rolling mill, which showed that a gradient structure is formed in these materials along the bar cross-section during the RSP process (Naizabekov et al., 2023). Also, from the obtained results of studying the mechanical characteristics of M1 grade copper, at the first stage of deformation, i.e. up to a diameter of 16 mm, the values of mechanical properties (strength and plastic) in the intermediate region are closer to the values of the same mechanical properties in the central zone of the deformable bar. With further deformation of these bars, the values of mechanical properties in the intermediate region become closer to the values of the same mechanical properties in the surface region of the deformable bar. This is also fully consistent with the results of the study of the evolution of the microstructure of various materials, which are also given in the works Gamin et al. (2021) Lezhnev et al. (2021) Arbuz et al. (2023) Akopyan et al. (2018) Gamin et al. (2023) Sheremet'ev et al. (2019) Lezhnev et al. (2023) Naizabekov et al. (2020). Namely, with the fact that during radial-shear rolling, with increasing compression, the number of elongated grains in the intermediate zone decreases and at the same time they become misoriented. A further increase in compression leads to the fact that the surface zone of deformable bars, as it were, absorbs the intermediate zone and an equiaxially fine-grained structure is formed in it, while preserving a small number of misoriented elongated grains.

To clarify the gradient of changes in the mechanical properties of M1 grade copper and compare it with the established features of the evolution of the microstructure gradient over the cross-section of the sample as it is modified by radial-shear rolling, microhardness distribution over the cross-section of 20°C to diameters of 16 and 12 mm was studied. Microhardness measurements were carried out on a microhardness meter "Micromet-II" with a load of 50 g according to GOST 9450-76. Analysis of the obtained results of microhardness studies over the cross-section of a copper bar showed that in general, they are consistent with the studies of microstructure evolution previously conducted in Naizabekov et al. (2023). So, in both cases (i.e., in a bar with a diameter of 16 mm, and in a bar with a diameter of 12 mm), a gradient distribution of microhardness over the cross-section of the bar is observed. The maximum values of microhardness for copper subjected to RSR are observed in the surface layers, and the minimum values are observed in the central zone, respectively. Thus, the maximum microhardness value in the surface layer of a bar with a diameter of 16 mm reached 940 MPa, and a diameter of 12 mm-1240 MPa (at the initial microhardness value of 545 MPa, i.e. after quenching from a temperature of 500°C). In the central layer of M1 grade copper deformed at the RSP mill, the average microhardness value was in a bar with a diameter of 16 mm – 765 MPa, and in a diameter of 12 mm-960 MPa.

Conclusion

Studies of the mechanical properties of M1 grade copper have shown that in the process of radial-shear rolling, the cross-section-averaged strength properties of these materials previously subjected to heat treatment under the selected modes increase, while the plastic ones, on the contrary, fall. Thus, for M1 grade copper, the cross-section-averaged value of the tensile strength after radial shear rolling at 200 ° C to a diameter of 12 mm increased by 65% compared to the value of this indicator after quenching at 500°C, and after RSR at a temperature of 20°C the same diameter by 80%. The average value of the relative elongation, which characterizes plastic properties, in a bar decreased by 78% after RSR to a diameter of 12 mm at a deformation temperature of 200°C and by 83% after RSR at a deformation temperature of 20C. The reduction of the plastic characteristic, namely the relative elongation, for M1 grade copper during radial shear rolling is within the normal range for this material subjected to severe plastic deformation during the implementation of various pressure processing methods. Microhardness studies have shown that the cross-section spread of microhardness values is observed in the copper bars obtained by the RSR, which is completely correlated with the data on the formation of areas with different microstructures in the cross-section of the bars after radial shear rolling.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Acknowledgements

* This article was presented as a poster presentation at the International Conference on Technology, Engineering and Science (www.icontes.net) held in Antalya/Turkey on November 14-17, 2024.

* This research was funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant № AP14869128).

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To cite this article:

Pishchikov, V., Kuzmin, S., Chigirinsky, V., Marukov, A., Naizabekov, A., & Volokitina, I. (2024). Research of combined copper processing technology including heat treatment and radial-shear rolling. *The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 32,* 101-105.