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Investigation of the Effect of Combined Thermomechanical Processing on the Microstructure Evolution of CuZn23Mn7Fe4 Brass

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Abstract: The article investigates the effect of combined thermomechanical processing, including pre-heat treatment and radial-shear rolling on the microstructure evolution of CuZn23Mn7Fe4 brass. The conducted studies have shown that the most optimal pre-heat treatment for CuZn23Mn7Fe4 brass before deformation on a radial-shear rolling mill is annealing at a temperature of 500°C. As a result of subsequent deformation of workpieces with an initial diameter of 30 mm, subjected to pre-annealing at a temperature of 500°C, a gradient ultrafine structure was formed in this brass alloy on a radial-shear rolling mill up to a diameter of 18 and 12 mm. Thus, in the surface layer of the deformed rod, a structure with an average grain size of 7 μm was obtained when rolling it to a diameter of 18 mm, and 3 μm when rolling it to a diameter of 12 mm. In the central layer of the bars, a structure with a grain size of 31 μm and 17 μm was obtained when rolling the bar to a diameter of 18 mm and 12 mm, respectively.

Keywords: Pre-heat treatment, Annealing, Quenching, Radial-shear rolling, Brass, Microstructure

Introduction

For more than a decade, scientists around the world have been paying great attention to the development of various combined thermomechanical treatments, both ferrous and non-ferrous metals and alloys, including various types of heat treatment and various methods of processing these materials by pressure in a hot or cold state. Special attention is paid to pressure treatment methods that allow the implementation of severe plastic deformation (SPD) in ferrous and non-ferrous metals and alloys, as described by Bogatov and Leshchev (2012), Valiev et al. (2022), Galkin et al. (2009) revealed that one of the promising such methods is radial shear rolling (RSR). Due to the design features implemented in the working cage of mini radial-shear rolling mills (feed angle 18-20 °, rolling angle 0-12 °) and unique trajectory and deformation conditions, as described by Galkin et al. (2014), Iskhakov et al. (2020), Galkin et al. (2021), when deforming bars from various ferrous and non-

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ferrous metals on these mills, the possibility of obtaining a gradient ultrafine structure is realized, that was proved by Galkin et al. (2022), Akopyan et al. (2020), Mishin et al. (2020), Gamin et al. (2022). It has also long been proven that one of the promising ways to obtain a pre-regulated microcrystalline structure in various metals and alloys is pre-heat treatment. For example, Naizabekov et al. (2022), Naizabekov et al. (2023), Naizabekov et al. (2024) described the effects of combined thermomechanical processing, including pre-heat treatment and radial-shear rolling, on the microstructure evolution of M1 copper and CuZn36 brass. This work is devoted to the study of the effect of combined thermomechanical processing, including pre-heat treatment and radial-shear rolling, on the microstructure evolution of CuZn23Mn7Fe4 brass.

Method

The choice of CuZn23Mn7Fe4 brass as the starting material is justified by its wide application in various industries, including medicine, mechanical engineering, instrumentation, cable industry, etc. Due to the fine-grained structure caused by the presence of iron in the alloy, this brand of brass has high strength and increased viscosity. To achieve this goal, a physical experiment was conducted using a chamber furnace of resistance RCF 12/1400 and a radial-shear rolling mill RSR 10-30 (Figure 1). And as the initial blanks for the laboratory experiment, blanks with dimensions D × L = 30 × 200 mm were prepared.

Figure 1. Radial-shear rolling mill RSR 10-30

The laboratory experiment consisted of two stages. At the first stage of the research, the task was to determine the optimal mode of pre-heat treatment of CuZn23Mn7Fe4 brass, which ensures both the production of a fine-grained structure and the possibility of further workability on a radial-shear rolling mill without destruction. To solve this problem, based on the Cu-Zn state diagram, the following types of pre-heat treatment were selected and implemented:

- quenching at a temperature of 400 °C;
- quenching at a temperature of 500 °C;
- quenching at a temperature of 800 °C;
- annealing at a temperature of 500 °C;
- annealing at a temperature of 800 °C.

After all types of pre-heat treatment were carried out, templets were cut from the obtained blanks to prepare micro-grinders. The operation of cutting templets from the workpiece is performed using the Labotom-3 cutting machine, which is a high-precision cutting machine. The preparation of micro-grinders was carried out on the Tegra Pol – Tegra Force grinding and polishing machine by Struers. For etching the CuZn23Mn7Fe4 brass, a solution of ferric chloride with hydrochloric acid $FeCl_3$, HCl, H_2O mixed from a ratio of 1:20:100 was selected. The microslips were etched in the resulting solution at the beginning by wiping, and then by immersion from 30 seconds to 1-2 minutes, depending on the degree of deformation. Metallographic studies were carried out using a Leica optical microscope.

Results and Discussion

The analysis of the microstructure of CuZn23Mn7Fe4 brass obtained after quenching and annealing from various temperatures is shown in Figure 2. The analysis of the obtained data showed that annealing of

CuZn23Mn7Fe4 brass forms an almost equal-grained structure in it. The microstructure has two phases α and β. At the same time, an increase in the annealing temperature to 800 °C leads to grain growth. For example, at a temperature of 500 °C, a grain of 60 μm was obtained (Figure 2a), and at a temperature of 800 °C, a grain of 80 μm was obtained (Figure 2b). After quenching at temperatures of 400 °C, 500 °C and 800 °C, we also obtained a two-phase structure (Figures 2 c, d, e), only the grain size is different. Thus, quenching from 400 °C due to rapid cooling ensured the production of a homogeneous martensitic-type structure from α-phase crystals and β-phase residues (Figure 2c). When quenching from 800 °C, a structure consisting of residues of the initial α-phase and sections of a two-phase structure is observed, which includes crystals of a metastable β-phase with dispersed alpha-phase secretions in the middle of these sections (Figure 2e).

Since the β-phase embrittles the brass alloy, it is undesirable for further deformation of the samples. But in this alloy, a two-phase structure was obtained after all the pre-heat treatments. Therefore, based on the results [11], annealing at a temperature of 500 °C is applicable for further deformation of workpieces on a radial-shear rolling mill, as for CuZn36 brass.

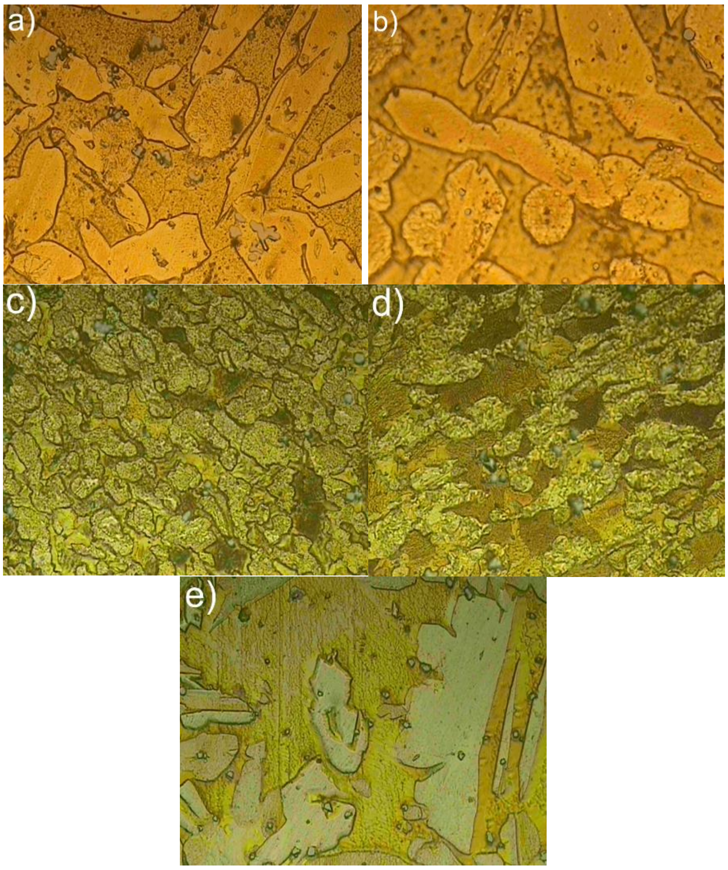

Figure 2. Microstructure of CuZn23Mn7Fe4 brass after preliminary heat treatment: a – annealing 500 °C; b – annealing 800 °C; c – quenching 400 °C; d – quenching 500 °C; d – quenching 800 °C

At the next stage of the research, the task was to identify the effect of radial-shear rolling on the microstructure evolution of CuZn23Mn7Fe4 brass subjected to the annealing at a temperature of 500 °C as the most optimal heat treatment. To solve this problem, a laboratory experiment was conducted on the deformation of brass samples subjected to annealing at a temperature of 500 °C at a radial-shear rolling mill RSR 10-30. This experiment was as follows. The initial workpieces with dimensions D × L = 30 × 200 mm were preheated to a temperature of 500 °C with exposure in a resistance furnace before deformation. After that, these samples were deformed at the RSR 10-30 mill with an absolute compression step of 3.0 mm in diameter until bars with diameters of 18 and 12 mm were obtained.

Metallographic analysis of RSR 10-30 CuZn23Mn7Fe4 brass rods obtained after deformation at the RSR mill showed that the microstructure of the surface layer of the rod differs significantly from the microstructure of the central zone of the rod (Figure 3), as well as in the cases of M1 copper [13] and CuZn36 brass [11]. Thus, in bars with a diameter of 18 mm in the surface layer, a structure with an average grain size of 7 μm was obtained, and in the center of the bar a multi-grained structure with an average grain size of 31 μm. After the RSR to a diameter of 12 mm, a fine–grained, equal-grained structure of 3 μm was obtained in the surface layer, and 17 μm in the center. The presence of such an alloying component as iron in CuZn23Mn7Fe4 brass, which inhibits grain growth during recrystallization, made it possible to achieve more intensive refinement of the initial grain size than during a similar combined thermomechanical processing of CuZn36 brass. As can be seen from Figure 3, dynamic softening processes do not lead to complete softening of the deformed metal, since they retain excessive dislocation density. Due to the short time of hot deformation, the hardening and softening processes lead to an unstable and heterogeneous structural state of the material. The heterogeneity of the grain structure in terms of volume and cross-section of the rod is manifested in the form of general zonal grain diversity, zones with abnormally large grains, line or island grain diversity.

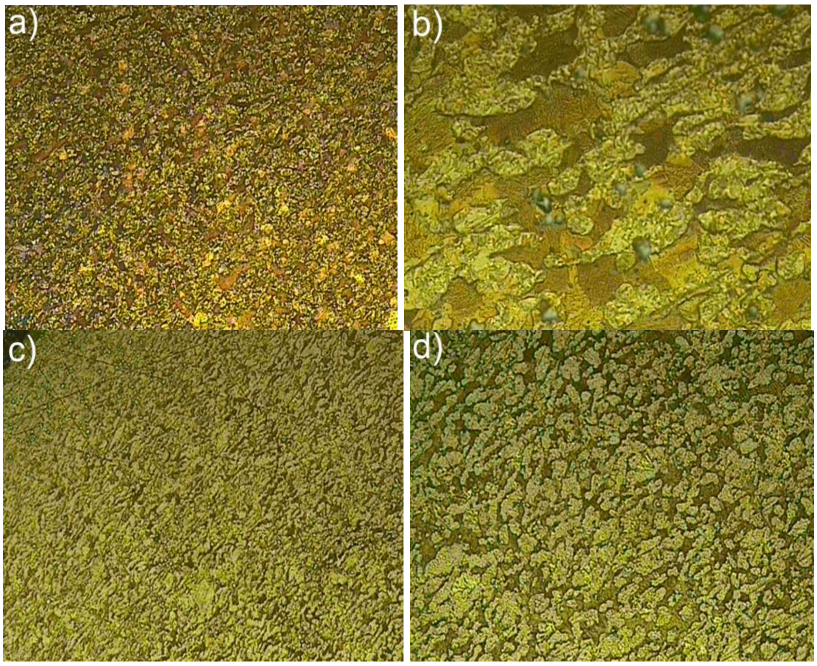

Figure 3 Microstructure of CuZn23Mn7Fe4 brass deformed at 500 °C (cross section): a – diameter of 18 mm (edge); b – diameter of 18 mm (center); c – diameter of 12 mm (edge); d – diameter of 12 mm (center)

Conclusion

Based on the results obtained, it can be concluded that combined thermomechanical processing, including pre-heat treatment and radial-shear rolling, makes it possible to obtain a gradient fine-grained structure in CuZn23Mn7Fe4 brass. At the same time, it was proved that the most suitable pre-heat treatment for CuZn23Mn7Fe4 brass is annealing at a temperature of 500 °C, since in this case both the most complete transition of the β-phase to the α-phase and the production of a uniform fine-grained structure is ensured.

Scientific Ethics Declaration

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

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