A. NAIZABEKOV, S. LEZHNEV, I. VOLOKITINA, E. PANIN, A. TOLKUSHKIN, S. BELSKY, M. PISHCHOV

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INVESTIGATION OF THE EFFECT OF COMBINED THERMOMECHANICAL PROCESSING ON THE BRASS MICROSTRUCTURE EVOLUTION AND THE MICROHARDNESS CHANGE

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The article investigates the effect of combined thermomechanical processing, including pre-heat treatment and radial-shear rolling on the brass microstructure evolution and the microhardness change. The microstructure analysis of heat-treated samples according to various modes showed that the most optimal heat treatment before radial-shear rolling for L63 brass is annealing at a temperature of 500 °C. As a result of combined thermomechanical processing, a gradient structure was obtained, so in the resulting rods with a diameter of 16 mm in the surface layer, a structure with an average grain size of 9 µm was obtained. In rods with a diameter of 12 mm, a fine–grained, equal-grained structure of 3 µm was obtained in the surface layer.

Keywords: brass, radial-shear rolling, heat treatment, microstructure, microhardness

INTRODUCTION

For more than a decade, scientists around the world have been working to reduce the metal consumption of machines and structures and increase their reliability by improving the quality of metal products. In order to improve the quality of metal products and the formation of increased mechanical properties in it, many technologists traditionally use heat treatment, which generates structural and phase transformations in materials. At the same time, one of the most important tasks of heat treatment is to obtain an optimal grain structure of the material, which determines its high structural strength. It is the production of such a structure and fine grain that avoids many disadvantages of alloys associated with its grain-boundary structure. However, it is impossible to achieve an improvement in the quality of metal products by increasing the mechanical and operational properties to the currently required level only by heat treatment.

Therefore, much attention is currently being paid to the development of various combined thermomechanical treatments of metals and alloys, including various types of heat treatment and various methods of processing these metals and alloys by pressure in a hot or cold state. And special attention is paid to the methods of metal forming, which make it possible to implement severe plastic deformation (SPD) in metals and alloys [1-2].

S. Lezhnev, A. Naizabekov, A. Tolkushkin, Rudny Industrial Institute, Rudny, Kazakhstan; I. Volokitina, E. Panin (e-mail: ye.panin@tttu.edu.kz), Karaganda Industrial University, Temirtau, Kazakhstan; S. Belsky, M. Pishchov, Belarusian State Technological University, Minsk, Belarus

Among the many methods of SPD implementing developed to date, the most well-known are high-pressure torsion (HPT) [3] and equal-channel angular pressing (ECAP) [4]. The HPT method makes it possible to obtain nanostructures with a grain size of 100 - 200 nm or less [5-7] in small samples suitable for most basic research. The ECAP method makes it possible to grind grains in bulk samples of a number of metals and alloys up to 200 nm, and at the same time obtain significantly improved mechanical properties [8-11]. The main disadvantages of these methods of implementing intensive plastic deformation, which prevent their widespread industrial introduction into production, are also well known, these are limitations in the size of the initial samples and extremely low manufacturability of the production itself.

These disadvantages can be eliminated by using a method of radial-shear rolling [12], which also allows obtaining an ultrafine-grained (UFG) state in metals and alloys with some structural distribution features, but already due to the implementation of severe plastic deformation in long round bars. The main feature of radial-shear rolling is the non-monotonicity and turbulence of deformation, as well as differences in the plastic flow and the study of the structure of different zones of the workpiece due to the trajectory-velocity features of the process [12-13]. A significant advantage of this method of deformation is that in the deformation zone during radial-shear rolling, a stress-strain state scheme is implemented that is close to comprehensive compression with large shear deformations, which is favorable for the formation of the UFG structure. But at the same time, pre-heat treatment is one of the promising ways to obtain a pre-regulated microcrystalline structure in various metals and alloys, including copper and its alloys [14].

The purpose of this work is to study the effect of combined thermomechanical processing, including preheat treatment (PHT) and radial-shear rolling (RSR), on the evolution of the microstructure and the change in the microhardness of brass.

MATERIALS AND METHODS

To achieve this goal, a laboratory experiment using a Nabertherm tubular resistance furnace and a radial-shear rolling mill RSR 10-30 was conducted.

The material of the study was L63 brass. The choice of L63 brass is justified by the fact that it is one of the most popular brasses, due to the high Zn content, good mechanical performance and low cost, compared with alloys containing more Cu. Two-component alloys, including L63, mainly belong to single-phase structures. When the second phase appears, the mechanical characteristics of the products fall: the brittleness, hardness increases, the plasticity of the products decreases. For this reason, two-phase brass is difficult to process by pressure. Single-phase alloys are well processed by pressure, as well as cast into ingots. L63 contains a small amount of substance in the β-phase, therefore, it lends itself well to pressure treatment: rolling, deep drawing, chasing, drawing, bending without serious consequences, while observing the processing mode even in a cold state.

Bars with a diameter of 30 mm and a length of 200 mm were prepared as initial blanks for conducting studies on the effect of combined thermomechanical processing, including preliminary heat treatment and radial-shear rolling, on the brass microstructure evolution.

At the first stage of the research, the task was to determine the optimal mode of preliminary heat treatment of L63 brass, which ensures both obtaining 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 PHT were selected and implemented in practice:

1) annealing at a temperature of 500 °C;
2) annealing at a temperature of 800 °C;
3) quenching at a temperature of 400 °C;
4) quenching at a temperature of 500 °C;
5) quenching at a temperature of 800 °C.

Samples were cut from all the blanks for metallographic studies and microhardness studies.

RESULTS AND DISCUSSION

The analysis of the microstructure of L63 brass obtained after annealing and quenching from various temperatures is shown in Figure 1.

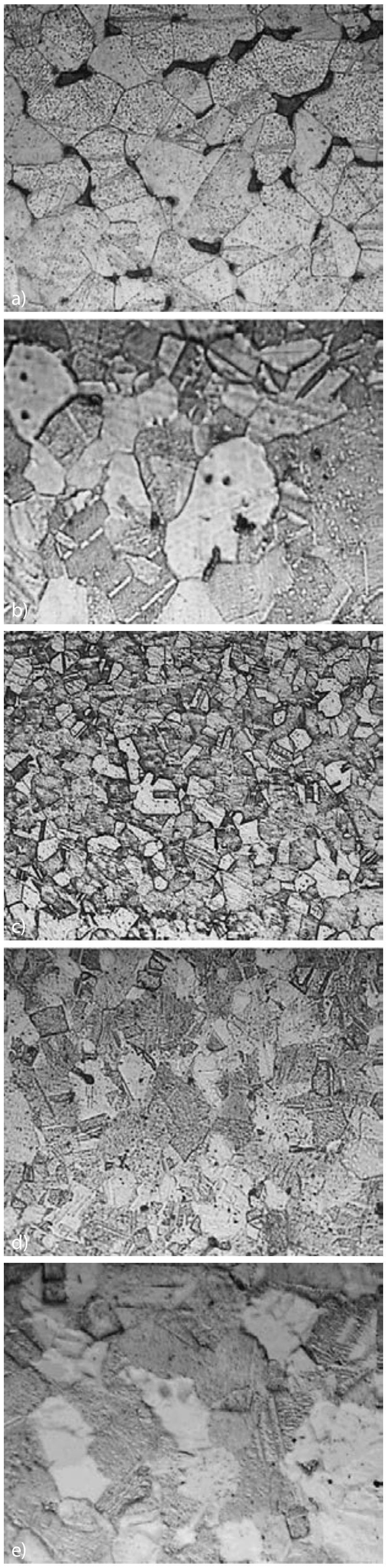

Figure 1 Microstructure of brass after preliminary heat treatment: a – annealing 500 °C; b – annealing 800 °C; c – quenching 400 °C; d – quenching 500 °C; e – quenching 800 °C

As is known from the Cu-Zn state diagram, the structure of brass consists of α or α + β’ phases, where α-phase is a solid solution of zinc substitution in copper having a HCC lattice, high plasticity, low strength and hardness values; β'–phase is an ordered solid solution based on an intermetallic compound with a crystal lattice BCC. This phase is characterized by higher hardness than the α-phase and brittleness.

Analysis of Figures 2a and 2b showed that slow cooling during annealing forms an equilateral structure and ensures maximum transition of the β-phase to the α-phase. An increase in the annealing temperature to 800°C leads to grain growth.

Thus, at a temperature of 500 °C, a grain with a size of 40 μm was obtained (Figure 1a), and at a temperature of 800 °C, a grain with a size of 60 μm was obtained (Figure 1b).

After quenching from 400 °C, a predominantly single-phase structure with a certain amount of β-phase was obtained, which is characterized by heterogeneity due to the formation of a zone of very small grains of this phase and inclusions of the β-phase along the boundaries of the α-phase grains (Figure 1c). Quenching from 500 °C due to rapid cooling ensured the production of a homogeneous martensitic-type structure from α-phase crystals and β-phase residues. The crystals of the α-phase have the shape of plates, at the boundaries of these crystals, the remnants of the β-phase (dark areas) are observed (Figure 1d). When quenching from 800 °C, a structure consisting of the remains 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. Since the etcher tints the β-phase in a dark color, it can be seen how much the amount of the β-phase increases (Figure 1e).

After the heat treatment, measurements of the microhardness of the obtained samples were also performed. The microhardness of the brass samples after annealing was 560 MPa at a temperature of 500 °C and 485 MPa at a temperature of 800 °C. After quenching from 400 °C, the hardness of the alloy was 960 MPa. Quenching from 500 °C provided a hardness of 1 100 MPa. Quenching from 800 °C with the rapid cooling provided an increase in hardness up to 1 120 MPa due to increased β-phase separation.

Since the β-phase embrittles the brass alloy, it is undesirable for further deformation of the samples. Therefore, annealing is the most suitable PHT for L63 brass. In order to save energy and obtain a fine-grained structure after deformation by radial-shear rolling, annealing at a temperature of 500 °C was chosen as a PHT for brass.

At the second stage of the research, the task was to identify the effect of radial shear rolling on the evolution of the microstructure of L63 brass, previously subjected to the most optimal (of the above) heat treatment, namely annealing at a temperature of 500 °C.

To solve this problem, a physical experiment was carried out on the deformation of brass samples subjected to annealing at a temperature of 500 °C on a radial-shear rolling mill. This experiment was as follows.

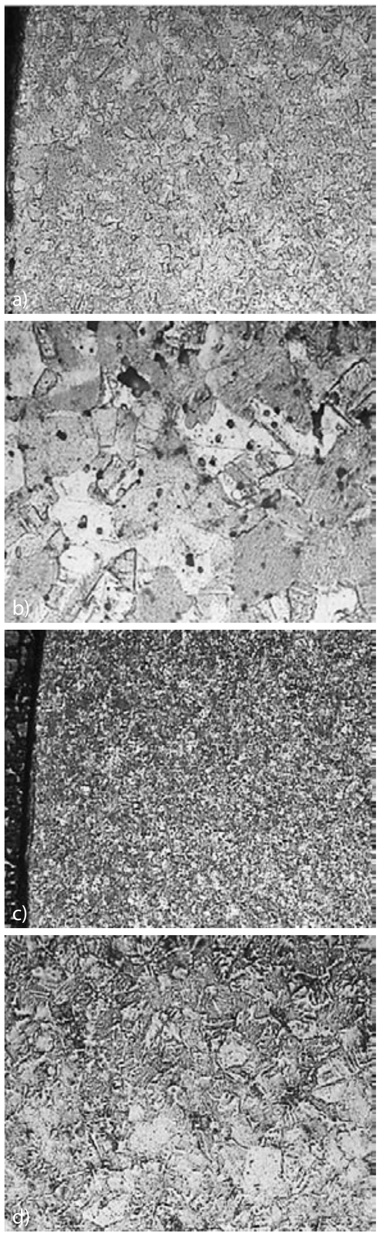

Figure 2 Microstructure of L63 brass formed on a radial-shear rolling mill (cross section): a – 16 mm diameter (surface); b – 16 mm diameter (center); c – 12 mm diameter (surface); d – 12 mm diameter (center)

Rods with a diameter of 30 mm and a length of 200 mm were preheated to a temperature of 500 °C with exposure in a Nabertherm tubular furnace to equalize the temperature along the cross-section of the samples before deformation. After that, the deformation of these samples was carried out on the radial-shear rolling mill RSR 10-30 up to a diameter of 16 mm and 12 mm with an absolute compression step of 2,0 mm in diameter.

Samples from all deformed workpieces for metallographic studies and microhardness measurements were cut. The microstructure analysis after deformation at the radial-shear rolling mill (Figure 2) showed that the microstructure in the surface layers of the bars, both with a diameter of 16 mm and a diameter of 12 mm, differs significantly from the microstructure in the central part of the bar.

Thus, in rods with a diameter of 16 mm in the surface layer, a structure with an average grain size of 9 μm was obtained, and in the center of the rod a multigrained structure with an average grain size of 35 μm was obtained. After RSR up to a diameter of 12 mm, a fine–grained, equal-grained structure of 3 μm was obtained in the surface layer, and 20 μm in the center. in both cases, the gradient nature of the microstructure distribution over the cross section of the workpieces is observed.

After deformation of the brass on the radial-shear rolling mill, as well as after the PHT, measurements of the microhardness were performed. These measurements also confirmed the gradient nature of the microstructure distribution over the cross section after radial-shear rolling. Thus, the microhardness of brass rods after RSR up to a diameter of 16 mm in the surface layer was 980 MPa, and in the center of the rod – 650 MPa. The microhardness of the brass rods after their RSP to a diameter of 12 mm was 1225 and 730 MPa, respectively.

CONCLUSIONS

Based on the results obtained, it can be concluded that combined thermomechanical processing, including preliminary heat treatment and radial-shear rolling, allows to obtain a gradient fine-grained structure in brass. At the same time, it was proved that the most suitable pre-heat treatment for brass of the L63 brand is annealing at a temperature of 500 °C, since in this case both the maximum complete transition of the β-phase to the α-phase and the production of a uniform fine-grained structure is ensured.

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Note: Translated by D. Rahimbekova, Temirtau, Kazakhstan