ROLE OF PRE-HEAT TREATMENT IN THE FORMATION OF A FAVORABLE FINE-GRAINED STRUCTURE IN COPPER AND BRASS FOR FURTHER DEFORMATION

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Received 07 March 2023
Accepted 15 April 2023

ABSTRACT

In this paper the influence of various modes of preliminary heat treatment of workpieces made of M1 copper alloy and L63 brass on the possibility of forming a favorable fine-grained structure for further processing using severe plastic deformation during radial-shear rolling was investigated. The results of the microstructure study obtained during the physical experiment had proved once again that for copper the most rational pre-heat treatment is quenching at a temperature of 500°C, since it allowed the initial structure to be refined from 80 microns to 50 microns, while the structure of copper after quenching consists of polyhedral grains elongated in the direction of the cooling gradient. For brass L63, annealing is the most suitable pre-heat treatment, since with slow cooling in this alloy, the most complete transition of the β-phase to the α-phase is ensured, which favorably affects the further processing of this alloy using radial-shear rolling.

Keywords: *pre-heat treatment, quenching, annealing, microstructure, copper and brass alloy.*

INTRODUCTION

In order to reduce the metal consumption of machines and structures, increase their service life and reliability, it is necessary to improve the quality of metal products. To form the mechanical properties of metal, heat treatment and plastic deformation are used in practice, generating structural and phase transformations in the system [1 - 4].

One of the main tasks of heat treatment is to obtain an optimal grain structure of alloys, ensuring their high structural strength. Obtaining such structure and ultrafine grain makes it possible to avoid many defects of alloys due to its grain-boundary structure. In this regard, the development of modes of heat treatment of alloys that provide significant grain refinement and the associated significant increase in plasticity and viscosity, as well as a decrease in sensitivity to reversible brittleness, is very relevant and of great practical importance. But to date, the improvement of the mechanical characteristics of metal alloys through the use of traditional types of heat treatment has been studied in detail and practically exhausted. Further progress in solving this problem can be achieved by applying promising deformation methods. Therefore, recently more and more attention of researchers has been directed to the development and study of ultrafine-grained and nanostructured states obtained by the methods of severe plastic deformation (SPD) in inexpensive alloys [5 - 9].

SPD methods have been widely used and researched in recent years. Such methods can be used for almost any metals or alloys, including hard-to-form. The most studied SPD methods are high-pressure torsion (HPT), equal-channel angular pressing (ECAP) and comprehensive isothermal forging [10 - 14]. Radial-shear rolling (RSR) is one of the not fully studied SPD methods that allow to effectively form a gradient microstructure [15, 16]. A feature of this process is the stress-strain state scheme, which allows the formation of a gradient microstructure, fine-grained in the surface layer and larger in the center of the deformable workpiece. Also, unlike well-known processes such as ECAP, HPT, radial-shear rolling has a number of advantages, in particular, lower values of the deformation force, no restrictions on the length of the final billet, as well as the possibility of rolling with significant extraction coefficients without destruction.

There are known research results showing that both technological and operational properties of copper alloys can be significantly improved by the use of heat treatment processes leading to refinement and transformation of the structure [17, 18]. One of the promising processes that allow obtaining a regulated microcrystalline structure is pre-heat treatment. When developing the technology of preliminary heat treatment of copper and its alloys, two of their features have to be taken into account: high thermal conductivity and active interaction with gases during heating. Due to the high thermal conductivity during the hardening heat treatment of copper alloys, there is no problem of hardenability. There are no polymorphic and martensitic transformations in copper, so heat treatments associated with these transformations can be excluded. But in the work [19] it is shown that with the help of heat treatment, copper alloys can be made either softer or harder. And also, unlike brass, copper acquires the highest hardness with slow cooling in air, and it acquires softness with rapid cooling in water.

The aim of this work is to study the microstructure evolution of the M1 copper alloy and L63 brass under various modes of pre-heat treatment.

EXPERIMENTAL

The materials of the study are L63 brass, as one of the most popular brasses due to the high zinc content, good mechanical properties and low cost, and M1 copper, which is a good model material, since there are no polymorphic and martensitic transformations in it. The delivery condition is a cold-rolled rod. Based on the results obtained by the microstructure evolution modeling of M1 copper and L63 brass [20], optimal parameters for conducting a laboratory experiment on preliminary heat treatment before radial-shear rolling were determined.

In order to maximize the refinement of the initial grain size, the bars of a circular cross-section with a diameter of 30 mm and a length of 150 mm were subjected to preliminary heat treatment (PHT). According to the simulation results given in [20], quenching at a temperature of 500°C was chosen as a PHT for M1 copper. Since there is no information about the processes of phase transformations and phase separation, which may be brittle, when modeling brass in the Deform materials database, it was decided to conduct a laboratory experiment to determine the PHT of L63 brass. Based on the Cu-Zn state diagram, the following PHT were selected:

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.

The choice of heating temperatures for quenching was due to the desire to obtain a different phase composition of the alloy. The first temperature is 400°C, which is slightly higher than the ordering temperature of the β-phase, but with rapid heating, one can expect the dissolution of particles of the brittle and solid ordered β’-phase and the formation of a small amount of plastic β-phase in the heated state. Heating up to 500°C will make it possible to obtain a two-phase structure (α + β) with a sufficiently large amount of β-phase in the heated state. At a heating temperature of 800°C, one should expect to obtain a single-phase structure in the heated state, which consists of β-phase crystals. The exposure time was selected taking into account that for uniform heating of the sample over the entire cross-section, it takes 1 minute per 1 mm of cross-section.

All samples were examined in the middle plane of the sample to avoid the influence of peripheral areas. The obtained samples were considered in two sections: transverse and longitudinal. The structure and phase composition of the alloy were analyzed by optical and transmission electron microscopy. Qualitative and quantitative analysis of the microstructure of the groundmass and primary phases was carried out using an optical microscope LEICA, equipped with an attachment for determining the microhardness of individual phases, as well as software for determining the grain score and the number of phases on mechanically polished and etched by Keller’s reagent thin sections.

The microhardness was determined on an AntonPaar hardness tester in accordance with State standard GOST 9450-76 by the method of indenting a diamond pyramid with an angle between opposite faces of

136° with a load of 1 N and a loading time of 2 s. To calculate the microhardness value, an average value of 5 measurements was used in each considered area.

RESULTS AND DISCUSSION

In initial state without heat treatment, M1 alloy has a polyhedral structure with the presence of deformation twins (Fig. 1(a)), the grain size is 80 microns. The structure of copper after quenching consists of polyhedral grains elongated in the direction of the cooling gradient with a grain size of 50 microns (Fig. 1(b)).

The analysis of the microstructure of L63 brass obtained after annealing and quenching from various temperatures is shown in Fig. 2. As it is known from

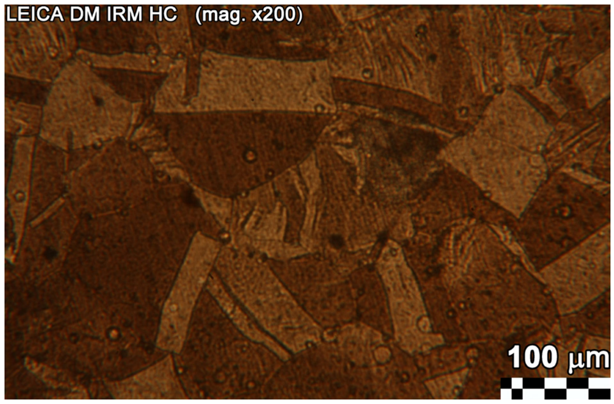

Fig. 1. Optical photographs of M1 copper microstructure: a - initial structure, average grain diameter of 80 microns; b - quenching at 500°C, average grain diameter of 50 microns.

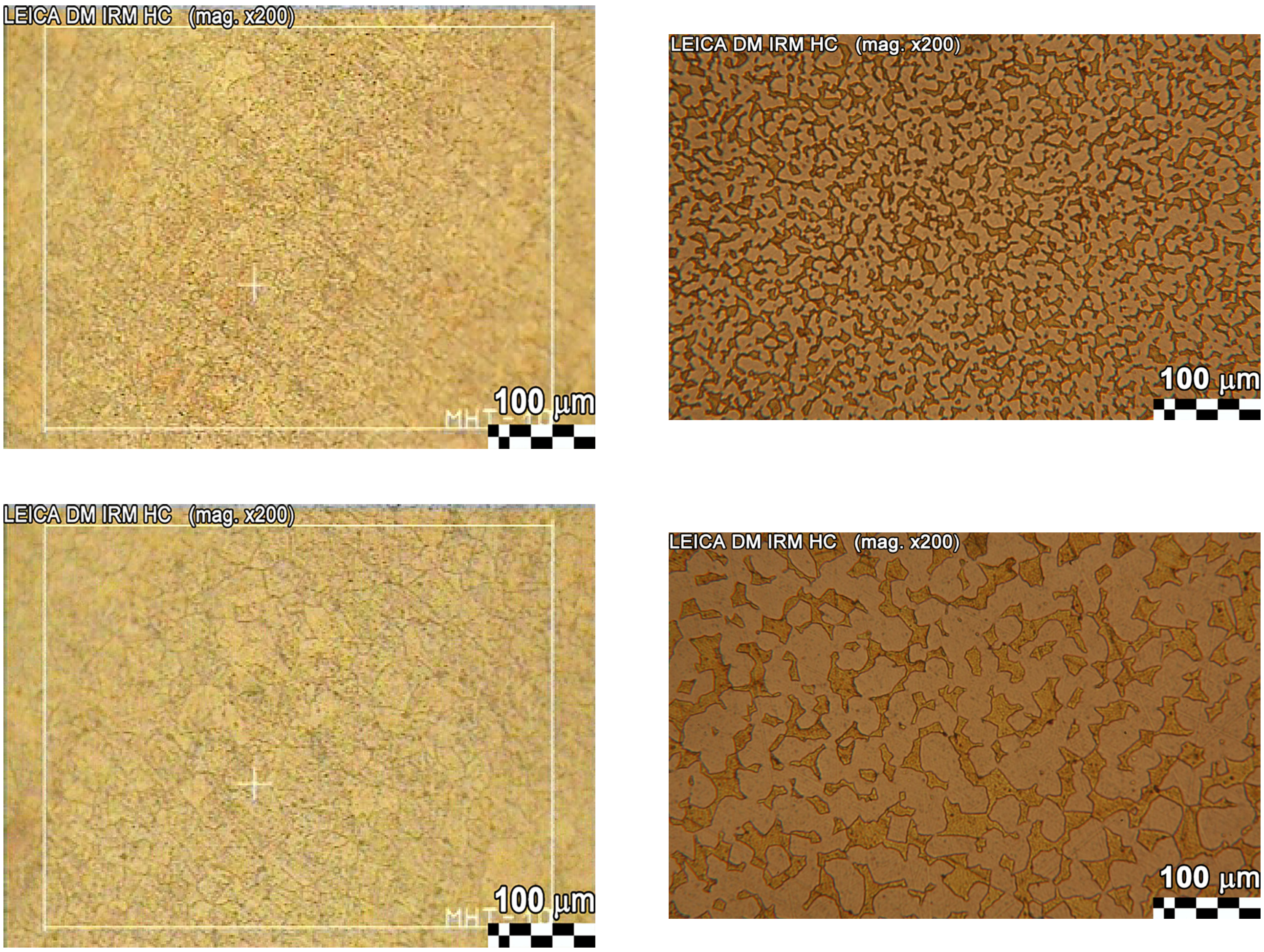

Fig. 2. Optical photographs of brass L63 microstructure after preliminary heat treatment: a - annealing at 500°C, average grain diameter of 40 microns; b - annealing at 800°C, average grain diameter of 60 microns; c - quenching at 400°C, average grain diameter of 20 microns; d - quenching at 500°C, average grain diameter of 30 microns.

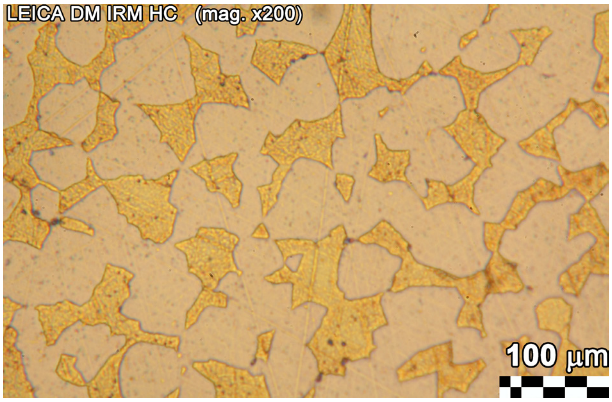

Fig. 2. Optical photographs of brass L63 microstructure after preliminary heat treatment: e - quenching at 800°C, average grain diameter of 50 microns.

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.

Figs. 2(a,b) show that the slow cooling during annealing ensures the maximum transition of the β-phase to the α-phase. But 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 microns was obtained (Fig. 2(a), and at a temperature of 800°C a grain with a size of 60 microns was revealed (Fig. 2(b)). 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 (Fig. 2(c)). 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 (Fig. 2(d)). 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 etchant stains the β-phase in a dark color, it can be seen how much the amount of the β-phase increases (Fig. 2(e)).

After the heat treatment, measurements of the microhardness were performed. Their results show that the microhardness of M1 copper decreases from 545 MPa in the initial state to 275 MPa after quenching.

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 1100 MPa. Quenching from 800°C with the help of rapid cooling provided an increase in hardness up to 1120 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, the most suitable PHT for L63 brass is annealing. In order to save energy and obtain a finer-grained structure after deformation by radial-shear rolling, annealing at a temperature of 500°C was chosen as a PHT for L63 brass.

CONCLUSIONS

Based on the results obtained, it can be concluded that if brass is intended for further pressure treatment by radial shear rolling, then annealing is the most suitable PHT, since with slow cooling, the most complete transition of the β-phase to the α-phase is ensured.

The results of a physical experiment to study the microstructure of M1 copper subjected to preliminary heat treatment confirmed the data obtained during computer modeling, i.e., indeed, quenching copper at a temperature of 500°C allows achieving a favorable fine-grained structure for its further evolution in the process of radial-shear rolling.

Acknowledgements

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

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