ANALYSIS OF THE MICROSTRUCTURE EVOLUTION OF COPPER AT EQUAL CHANNEL ANGULAR PRESSING

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Abstract
The instability of the structure is one of the problems standing in the way of widespread use of submicrocrystalline (SMC) materials. In pure SMC metals there is a relatively low temperature of recrystallization and substantially nonuniform of grain growth at temperatures close to the temperature of recrystallization. Rapid grain growth during heating leads to loss of the unique physical and mechanical properties of the material.
In recent years, a large number of works is devoted to the study of the problems influence of modes of ECAP and heating conditions on the structure and properties of metallic materials, and a number of interesting experimental results are obtained. However, the theoretical models explaining regularities of formation and subsequent evolution of the structure of SMC materials by heating and allowing calculate quantitative calculations of the parameters of these processes are developed is not enough.
The purpose of this work was to investigate the influence of preliminary thermal treatment on the structure that is formed in copper at ECA-pressing and subsequent heat treatment. Microstructure of copper samples subjected ECA-pressing, change under the action simultaneous influence of two factors: the preliminary heat treatment and increasing the pressing temperature. Minimum average grain size obtained during pressing of alloy M1 is 0.6 microns. This grain size is obtained after quenching at 700°C and ECAP at room temperature and 6 cycles of deformation. The use of preliminary quenching provides a more fine-grained structure as well for the alloy M1 also to reduce hardness by 15%, which helps to reduce the pressing force on the first pass, from 620 to 510 MPa.
The use of combined thermomechanical treatment on a "quenching at 700°C - ECAP low-tempered at 200°C" for the alloy M1 allows significantly improving the characteristics of copper and increases the resistance emergence and spread of cracks.

Keywords: microstructure, ECA-pressing, copper, heat treatment.

1. INTRODUCTION
One of the problems standing in the way of widespread use submicrocrystalline (SMC) materials the instability of the structure is. In pure SMC metals there is a relatively low recrystallization temperature [1-2] and a significant heterogeneity of the grain growth at temperatures close to the temperature of crystallization. Rapid grain growth during heating leads to loss of the unique physical and mechanical properties of the material.
In recent years number of works was devoted to the study of the problems influence of modes ECAP and heating conditions on the structure and properties of metallic materials and a number of interesting experimental results was received. However, the theoretical models explaining the regularities of formation and subsequent evolution of the structure of SMC materials by heating and allowing for quantitative calculations of the parameters of these processes are still insufficiently developed.
The purpose of this work was to research the influence of preliminary heat treatment on the structure that is formed in copper at ECA-pressing and subsequent heat treatment. This work was made during research at the scientific theme “Getting high-quality materials combining heat treatment and intensive plastic deformation” of program “Deep processing of raw materials and products - Technology of making new materials”.

2. MAIN TEXT

2.1 Experimental part
The material of the study was a technical copper of grade M1 (99.90% Cu). Before ECA-pressing samples were subjected to preliminary heat treatment: annealing, hardening and normalization by the standard mode. Samples of square section 15×15×70 mm were subjected ECA-pressing in the die with an angle of junction channels 125° on the route Bc with tilting the workpiece by 90° around the longitudinal axis [3].

Three types of experiments were carried out in three different modes:
- Mode 1 - pressing temperature 25 °C, 6 cycles;
- Mode 2 - pressing temperature 90 °C, 6 cycles;
- Mode 3 - pressing temperature 180 °C, 6 cycles.

As the number of passes in ECA-pressing resource of plasticity is lost and further deformation, and the use of the metal in the industry is not possible because its destruction occurs. In order to increase resource of plasticity the metal should be subjected to heat treatment. As is known, the heating above temperature the onset of recrystallization leads to a strong grain growth and to a sharp fall of the strength of copper, so it is necessary to determine the temperature of the onset of recrystallization. Calculated the approximate temperature of the onset of recrystallization on accepted formulas [4] a laboratory experiment was conducted. Samples after ECAP were cut into thin plates with thickness of 5 mm and were heated at temperatures in the range 100 - 270°C with duration of exposure 1 hour. Cooling of the samples is in water.

For studying structural changes the samples were cut along and across the direction of the exhaust. Metallographic study was carried out on an optical microscope LEICA.

2.2 Results and discussion

Consider changing the structure of copper, formed at different modes of preliminary heat treatment and pressing temperatures.

![Fig. 1 Microstructure of copper after preliminary heat treatment, x100](image)

a - the original structure, b - annealing, c – normalization, d - hardening
Fig. 2 The microstructure of copper after 6 cycles of ECA-pressing at a temperature of 25°C, x100

Fig. 3 The microstructure of copper after 6 cycles of ECA-pressing at a temperature of 90°C, x100
Having analyzed the microstructure of the alloy M1 after ECA-pressing at room temperature, it was found that the most intensive grain refinement of copper is observed after hardening because by hardening copper unlike brass becomes softer.

Intensive grain refinement is observed after each cycle of deformation. It was also found that the grain structure in the cross direction worked out a little more intense, but after the 6 cycles of pressing refinement of structure practically uniform in all directions of sample.

Billet heating temperature increase reduces the pressing force and deformation resistance, but the unevenness of the metal flow increases, which increases with the temperature difference between the workpiece and the die. This leads to an uneven distribution of deformation resistance along the cross section of the workpiece. Cooling of the peripheral layers leads to a more rapid flow the internal layers of the workpiece.

Minimum average grain size obtained during pressing of alloy M1 in equal channel step die is 0.6 microns. This grain size is obtained after hardening and ECAP at room temperature and 6 cycles of deformation.

ECAP leads to a significant increase in strength compared to the baseline. Compared with similar indicators large of grain materials in the delivered condition, tensile strength increases almost in 2 times, yield strength in 3 times, but it reduces the flexibility of almost 3-4.

A major shortcoming of most heavily deformed metals and alloys is an almost complete lack of plasticity. Observed in this a significant brittleness prevents further plastic forming of metal. For giving to metal plastic properties is necessary as they say reduce stress, which is achieved by annealing, age hardening, and tempering the metal. In order to pick up the necessary final heat treatment you should know the temperature of the onset of recrystallization.
Analysis of the microstructure of the alloy M1 after heating showed that annealing of copper alloy M1 at temperatures of 100-160°C has a temperature range of recovery characterized by a gradual reduction of the dislocation density, the reduction the concentration of excess defects, redistribution of dislocations leads to a decrease in the level of microdistortions.

At the annealing temperature 220°C the process of primary recrystallization begins, i.e. the formation of new recrystallized grains from the deformed matrix of the boundaries in transitional zone (Picture 5a).

With further increase of the annealing temperature to 270°C in samples after ECAP secondary recrystallization fulminants, which coincides with the observations of S.S. Gorelik [5] for small grains (d ≤ microns) the value of the driving force of secondary recrystallization is of the same order as the magnitude of the driving force of the primary recrystallization. The structure presented at picture 5b has polyhedral structure typical of all pure metals, with the presence of twins.

To confirm the metallographic studies the mechanical testing were conducted to determine Vickers microhardness results, which are presented in table 1.

**Tab. 1** Results of the determination Vickers microhardness of alloy M1, after recrystallization annealing

<table>
<thead>
<tr>
<th>The annealing temperature, °C</th>
<th>Initial</th>
<th>100</th>
<th>160</th>
<th>220</th>
<th>270</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness, HV</td>
<td>246,1</td>
<td>243,4</td>
<td>239,3</td>
<td>196,8</td>
<td>173,5</td>
</tr>
</tbody>
</table>

Based on the data for temperature of the onset recrystallization temperature after which experiencing an absolute decrease of microhardness by 49.3 units (20%) was adopted, which coincides with the appearance of new recrystalline grains (Picture 5a). From the resulting temperature of the onset of recrystallization after hardening and ECAP low tempering on the water conducted at a temperature of 200°C, removing internal stresses.

**CONCLUSION**

Microstructure of copper samples subjected ECA-pressing, change under the simultaneous influence of two factors: the preliminary heat treatment and increasing the pressing temperature. Minimum average grain size obtained during pressing of alloy M1 is 0.6 microns. This grain size is obtained after hardening at 7000°C and ECAP at room temperature and 6 cycles of deformation. The use of preliminary hardening allows getting more fine-grained structure and for the alloy M1 also reducing hardness by 15%, which helps to reduce the pressing force on the first pass, with 620 to 510 MPa.

The use of combined thermomechanical treatment on a "hardening at 7000°C -ECAP low tempering at 2000°C" for the alloy M1 allows to improve the characteristics of copper and increases the resistance emergence and spread of cracks.
LITERATURE


