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SIMULATION MODELING OF THE COMBINED PRESSING TECHNOLOGY OF HIGH-QUALITY RODS

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The structural changes and ultimate plasticity of L63 brass which were studied on STD 812 plastometer is described at this work. It was determined that the deformation of samples by torsion and tensile torsion leads to the formation on a L63 brass of a relatively fine-grained structure with grinding of coarse particles especially coarse particles of the β'-phase. It is shown that L63 brass has the maximum value of plasticity in the temperature range of 650 - 850 °C. The results analysis of computer modeling of the billet stress-strain state (SSS) when pressing the bars on a radial-shift mill (RSM) of a new construction are presented. Rational modes of deformation of billets on a new RSM are determined in the article, which make it possible to obtain rods and wires with a fine-grained structure.

Keywords: brass L63, rods pressing, ultimate plasticity, tensile torsion, simulation modeling

INTRODUCTION

The method of cross-helical rolling (CHR) has found a fairly wide application [1-4] in the metallurgical industry. In combination with traditional methods - pressing, forging and sorted rolling - CHR allows to significantly expand the variety of production means, successfully fitting into the general technological scheme as a blank, intermediate or final operation.

It is known that when designing the technology great importance has the assessment of deformation effect of the stress strain state (SSS) distribution on discontinuity of the billet material, on the structure and properties of the received product [5]. Despite the desire of engineers to develop a technology that allows to evenly distribute the SSS and create a "soft" stress state pattern throughout the volume of the deformable billet, this is not achieved in the real processes of rolling and press production. This leads to a non-uniform study of the metal structure, its uneven grain size, anisotropy of mechanical properties and disruption of the material continuity.

In the opinion of the authors of works [5-7], the most promising direction of research on the processes of MF is the use of mathematical modeling tools. In their opinion, this allows, firstly, to carry out detailed and multivariate analysis of the effect of SSS and temperature-rate modes of deformation on the properties of the product and, secondly, significantly reduces the costs and time for conducting research.

In this work, the goal is to develop a methodology for the design of a technological process for the manufacture of rods and wires without defects on a RSM of a new design

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MATERIALS AND THE METHODS OF RESEARCHES

For the purpose of pressing high-quality rods from non-ferrous metals, we propose RSM of a new design [8]. The proposed mill contains main drive, working stand, roll unit and a press die. Three-roll working stand of RSM consists of a frame, in the bores of which, at 120° intervals, work roll assemblies are mounted. The working corkscrew rolls are mounted on chocks, the torque which is transmitted through the spindles from the electric motors.

The MSC.SuperForge software was used to calculate the SSS when pressing rods on RSM of a new design [9].

When using this software, a three-dimensional geometric model of the workpiece, rolls and matrix was built in the CAD program Inventor and imported into the CAE program of MSC.SuperForge.

To study the pressing process in the RSM, a round billet made of L63 copper alloy with a size of Ø 40 × 150 mm was used. The pressing was carried out at a temperature of 450, 650, and 850 °C on RSM to a diameter of 9 mm. The Johnson-Cook elastoplastic model was chosen to model the plasticity of the workpiece material. The rheological properties were set from the database of the MSC.SuperForge software. Since the rolling process takes place at room temperature, the initial temperature of the rolls was taken to be 20 °C. The contact between the tool and the bar was modeled by Coulomb friction, the friction coefficient was taken as 0,3.

To determine the dependence of the limiting plasticity of L63 brass on the stiffness coefficient of the stress state scheme (k_s) in temperature and speed conditions, typical for rolling-pressing of this alloy on a new RSM, we conducted the plastometric test.

Plastometric studies were carried out using an STD 812 torsion plastometer [10]. Standard samples for torsion, tensile, tensile torsion and compression tests were made from the annealed rods of L63 brass. The tests were carried out in vacuum and constant strain rate. The samples in an induction heater were heated to temperatures of 450, 650, 850 °C at a constant rate of 5 °C/s, held at this temperature for 10 s and deformed by torsion, tension, twisting tension and compression at a strain rate of 1,0 s^{-1}. After deformation, the samples were cooled at a rate of 20 °/s.

To determine the degree of shear deformation to failure (Λ_p) and rigidity coefficient of the stress state scheme (k_s) during torsion tests for tension, tensile torsion, torsion and compression, an equation given at this work was used [11, 12].

Qualitative and quantitative analysis of the microstructure of the alloy was carried out on a NEOPHOT 32 metallographic microscope (Karl Zeiss, Jena) (Germany).

In this work, using a photograph of the fracture of samples from brass L63, the fracture surface was studied. In the study, a JEOL JSM-6490 scanning microscope was used. This microscope provides fine studies of the surface of samples, fractographic analysis of fractures and deformation relief, determination of the size of particles and pores.

At the same time, the criterion $K_{\beta'}$ was determined, which makes it possible to determine the influence of the β′-ordered phase on the fracture process. After the destruction of the samples at temperatures of deformation, the criterion $K_{\beta'}$ was determined by the formula:

$$K_{\beta'} = \frac{V_{\beta(fracture)}}{V_{\beta(section)}} \qquad (7)$$

where $V_{\beta(fracture)}$ – fraction of areas of brittle fracture (estimated by the method of reference meshes);

$V_{\beta(section)}$ – fraction of β′ – phase on the section (evaluated by the Rosival method).

The condition of destruction, that is, the degree of plasticity resource utilization (DPRU) was calculated by the formula [11, 12].

RESULTS AND THEIR DISCUSSION

The conducted research has established that L63 brass is characterized by a sufficiently high level of ultimate plasticity and has a wide range of satisfactory deformability. With an increase in the test temperature, a growth in the value of the ultimate plasticity is observed at the considered deformation rate.

At the temperatures of 450 °C, an increase in true deformation leads to a slight decrease in the value of strain hardening, which slightly increases the plasticity of L63 brass. If at 450 °C the value of the limiting plasticity Λ_p changes in the range of 1,4 – 4,8, then at a temperature of 650 °C this indicator changes in the range of 3,4 – 10,.1 depending on the coefficient of stiffness of the stress state (k_s). It should be noted that the value of the Λ_p index at a temperature of 850 °C reaches values of 4,7 at k_s = 1,0 and 12,7 at k_s = - 1,0. Consequently, plastic deformation of L63 brass in the temperature range from 650 to 850 °C is the most rational. This is due to the fact that at this temperature range in L63 brass dynamic polygonization and recrystallization are intensively undergoing, which stabilize the structural state of this metal.

Based on the obtained results, it can be noted that low-temperature hot deformation of L63 brass can lead to a disruption in the continuity of the workpiece metal. At present, two generally accepted hypotheses are used to explain the decrease in plasticity [13]: a decrease in metal plasticity by hydrogen and the formation of second-phase particles at grain boundaries. However, according to some experimental data, it is difficult to explain the above hypotheses. In the opinion of the authors of [13], the presence of an ordered β′- phase in two-phase brasses can lead to their embrittlement. In copper alloys, low-melting eutectics can be created that have sparingly soluble impurities, which contribute to the maturation of burnout, leading to brittle fracture. To study these hypotheses, we investigated the microstructure and surface destruction of specimens tested under different loading patterns.

Investigation of the initial structure of L63 brass showed that the structure of the sample contains relatively large grains with an average size of ~ 297 μm. The grains are distributed fairly evenly. In the initial sample, at the mesoscale, large particles up to 31 μm in size are observed, the average distance between particles is 28,0 ± 0,3 μm.

Stretching, compression, torsion and tension with torsion of the samples in the temperature range of 450 - 850 °C led to a significant decrease in the grain size compared to the grains of the original structure. In particular, the samples tested by tension, compression and torsion had a fine-grained structure. The average grain size of the samples deformed by tension was 121, 72, and 97 microns, and those deformed by compression were 128, 82, and 112 microns at temperatures of 450, 650, and 850 °C, respectively. It should be noted that the samples tested by torsion had a relatively fine-grained structure with a grain size of 81, 52, 63 μm at temperatures of 450, 650 and 850 °C, respectively. Similar conclusions can be drawn from the structure of samples tested by tensile torsion. The microstructure of the samples deformed by this type of application of loads had small grains with a size of 67, 38, 43 μm at temperatures of 450, 650 and 850 °C, respectively.

The results of studying the sizes and distribution of particles at the mesoscale after testing the samples by tension and compression at a temperature of 450 °C showed that with an increase in the degree of shear deformation, the sizes of large particles decrease. At the same time, the distance between the particles decreases from 34 to 18 microns, which corresponds to an increase in the density of the placement of particles by about 2 times. This can be explained by one of the processes that determine the evolution of particles - mechanical fragmentation of large particles. In our opinion, in brass L63 there is at least one coinciding slip plane between the particles and the copper matrix, along which a mechanical fracture of the particles can pass.

The results of studying the size and distribution of particles of samples tested by torsion at a temperature of 450 °C showed that with an increase in the degree of shear deformation, large particles are more intensively crushed. The average distance between particles has halved, that is, from 37 to 12 microns. This corresponds to an increase in the density of placement of particles with a size of about 10 microns approximately 4 times.

Investigation of the effect of torsional tension at a temperature of 450 °C on the evolution of an ensemble of particles of the formed phases showed that the tested samples have particles with an average size of 4 - 9 microns. The most probable value falls within the range of 4 - 6 microns - particles of this size account for more than 80 % of the total. The average distance between the particles decreased to 5 microns, that is, the packing density of the particles increased by 7 times.

Thus, the results of testing samples with different loading schemes have shown that the distribution density of particles is shifted towards smaller particles. We believe that such a distribution of particles is mainly associated with the fragmentation of particles of different phases by mechanical stress. Because large particles of L63 brass are subject to high mechanical stresses during deformation, their dissolution is less likely than small ones. The research results prove that small particles are fragments of larger particles. However, it is impossible to completely exclude the influence of two other processes influencing the evolution of particles - deformation-induced dissolution of particles and deformation-stimulated decay - at this stage of the study.

By studying the microstructure of the samples, it was found that the average sizes of groups of particles, combined by composition and morphological characteristics, change in different ways. Application of any loading scheme leads to an increase in the average size of rod-shaped particles up to 7 334 ± 7 nm, and round ones up to 5 238 ± 6 nm. Large hexagonal particles appear with a significant average size of 2 371 ± 4 nm. The sizes of the square particles do not change, while the triangular and oval particles decrease in size to values of 1 234 ± 5 and 1 967 ± 7 nm, respectively

The study showed that the structure of L63 brass mainly consists of the α' solid solution and a small volume of the β' phase. It is known [13] that if $K_{\beta}' > 1$, then the β' - phase is the main reason for the decrease in the plasticity of L63 brass, and if $K_{\beta'} \leq 1$, then the β′ - phase does not significantly affect the process of material discontinuity. Due to the fact that at a temperature of 450 °C the value of $K_{\beta'}$ was not more than unity, we believe that the ordered β′ - phase does not significantly affect the embrittlement of two-phase brass. In this case, as it was established above, the application of various loading schemes on the sample at a temperature of 450 °C leads to fragmentation of the β′ - phase particle. The smaller the particle size of the brittle β′ - phase, the lower the probability of destruction of the billet metal.

It should be noted that at a deformation temperature of 450 °C, an intergranular fracture region is formed on the fracture surface of L63 brass. The probable reason for this destruction and a decrease in the value of the plasticity of L63 brass at a test temperature of 450 °C is the difference in sliding in a conglomerate of two phases with very different structure and properties. This is especially true for the α′ solid solution and the relatively large particle of the β′ phase. The reason for the decrease in plasticity can also be the complexity of cross slip in the most plastic α-phase due to a large number of packaging defects.

Based on the results obtained by the numerical modeling, it was established that, when pressing the rods on RSM of a new design, stress and deformation are distributing evenly. At this, powerful macroshear deformations develop along the section of the billet, which leads to the formation of a fine-grained structure.

Based on the DPRU it was established that when pressing the rods on the RSM of a new design, the discontinuity of the workpiece material is not expected.

CONCLUSIONS

- It is proved that during hot deformation of L63 brass samples by torsion and tensile torsion, the volume fraction of particles of excess phases does not change, while the structure and coarse particles are significantly refined, especially coarse particles of the β′-phase.
- It is shown that pressing of workpieces on RSM provides a uniform distribution of the degree of shear deformation, which contributes to the production of rods with a fine-grained homogeneous microstructure without breaking the continuity of the material.
- Based on the calculation of DPRU when rolling billets from L63 brass on a tool with a helical working surface and pressing on a matrix of a standard design, the absence of discontinuity of the billet metal during deformation of it on RSM of a new design was proved.

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