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DEVELOPMENT OF RATIONAL TECHNOLOGY OF RODS PRODUCTION ON A RADIAL-SHIFT MILL (RSM)

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The radial- shift mill (RSM) of a new design, which makes it possible to obtain high quality rods by the combined rolling-pressing process is proposed in this article. By using the MSC.SuperForge program the quantitative data has been obtained and main regularities of the stress-strain state distribution during rolling in smooth, helical rolls and rolling-pressing of billets on a RSM of a new design were established. Special attention is paid to the influence analysis of rolling in smooth and helical rolls and to the rolling-pressing on the formation of structures in rods from M1copper alloy. It has been established that processing by the combined process makes it possible to form a fine-grained structure along the cross-section of the bars without disrupting the continuity of the billet material. By using physical modeling the effect of temperature-deformation processing modes on the kinetics of dynamic recrystallization of copper alloy M1has been studied. The dependence of the size of the recrystallized grain from temperature and degree of deformation has been established.

Key words: copper alloy M1, rolling, pressing, rod-wire, simulation model

INTRODUCTION

Radial shift rolling (RSR) is a widespread process of metal processing by pressing (MPP) and differentiate by a wide variety of technologies, equipment and the manufactured products [1,2]. It is known that RSR by the developing of macroshear deformation allow obtaining a fine-grained structure [3]. However, the RSR has problems with the uniformity of the stress-strain state (SSS) distribution and by this with the structure and properties over the section of the billet. Therefore, the development of technology or equipment of a new design, which allows uniformly distribute SSS and by this the structure over the section of the billet, becomes a relevant task.

Computer modeling is widely used to study the stress-strain state of MPP dynamic processes [4].

The rapid growth of the calculating power of modern computers and the rapid development of software for calculating the shape change of metals facilitate to this. At the present, the standard programs as Simufact. forming, Qform-3D, LS-DYNA, DEFORM-3D, MSC. SuperForge, etc. are widely used to construct a finite element model of MPP processes.

It have chosen one of the best programs in the world - MSC.SuperForge [5] as a tool for modeling and calculating the stress-strain state of a deformed billet.

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The purpose of this work is to develop a rational technology for rolling-pressing of rods made of copper alloy M1 on a radial- shift mill (RSM) of a new design.

MATERIALS AND THE EXPERIMENTAL TECHNIQUE

The RSM of a new design is proposed in this work [6]. Given rod rolling- pressing mill contains a main drive, a working stand, helical rolls and a press- matrix. The stands of a new mill are designed with the possibility of positioning of the helical rolls with different angles to the rolling axis and tangential displacement concerning to it by 18 mm.

The calculation of the stress-strain state when rolling billets made from copper alloy M1 on the existing RSM with smooth and helical rolls and rolling-pressing on a new RSM was carried out using the standard MSC.Super Forge program [7]. Three dimensional geometric models of the billet and the tool were built in CAD Inventor program and imported into CAE MSC.SuperForge program.

When studying the rolling process in smooth and helical rolls and rods rolling-pressing on a RSM, a round billet made of M1 copper alloy with a size of Ø 40 × 150 mm was used. Rolling and rolling-pressing on a RSM was carried out at temperatures of 300, 400 and 500 ° C up to a diameter of 9 mm. At the same time, the reduction ratio, feed and roll angles were varied. The Johnson-Cook elasto-plastic model was chosen for modeling the plasticity of the billet material. The rheological properties were set from the database of the

MSC.SuperForge software package. The contact between the tool and the rod is modeled by Coulomb friction; the friction coefficient was taken as 0,3.

Plasticity resource utilization level according to below formula was calculated in this work (PRUL) [8]:

$$\psi = \int_0^t \frac{H(\tau)dt}{\Lambda_p[k_s(\tau)]} = \frac{\overline{\Gamma}}{\Lambda_p\left[k_s(\varepsilon)\right]} \prec 1 \qquad (1)$$

where Λ_p –is an ultimate metal ductility, which depends from the stress state coefficient $k_s = \sigma_o / Ò$; T, $\overline{\Gamma}$, H - intensity of stresses, deformations and shearing strain rates; σ_o – medium voltage.

To determine Λ_p of copper alloy M1, we performed a plastometric experiment of cylindrical samples for tension, torsion, tensile torsion and compression on a STD 812 torsion plastometer. The chosen method allows to determine current values of the ultimate plasticity Λ_p according to the known formulas under the conditions of constant k_s, strain rate and test temperature [8].

Strain resistance of copper alloy M1 was determined and the evolution of the microstructure was also studied on this plastometer.

Cylindrical samples with dimensions of Ø 8 × 20 mm for tension, torsion and tensile torsion, and also Ø 10,0 × 15 mm for compression were made from annealed rods of copper alloy M1. Given samples were heated in an induction heater to temperatures of 300, 400, 500 ° C at a constant rate of 5 ° C / s, held at this temperature for 10 s, and deformed under vacuum by torsion, tension, torsional tension and compression at a strain rate of 1,0 c^1. After deformation, the samples were cooled at a rate of 20 ° / s.

Metallographic analysis was performed by using the universal microscope NEOPHOT 32 (Karl Zeiss, Jena) (Germany).

RESULTS AND DISCUSSION

On the basis of the obtained results of numerical simulation of rolling and rolling-pressing of billets from copper alloy M1 on the RSM, it was established that

- when rolling in smooth and helical rolls T, $\overline{\Gamma}$ and H acquire high value on the surface zones of billet, while they have the smallest value in the central zone;
- during rolling-pressing, T, $\overline{\Gamma}$ and H also acquire the highest value on the surface zones of the billet, while in the central zones they have a moderate value. At the same time, during the pressing of the billet in the matrix, these indicators are leveled over the entire section of the manufactured products;
- when rolling the billets in smooth and helical rolls, as well as in rolling-pressing the deformed metal flows along a helical trajectory at different speeds of the outer and inner layers, which leads to the occurrence of macro-shear deformations in the surface zones of the billet;
- in the protrusions and hollows of the rolls, powerful macro-shear deformations occur on the surface and neighboring zones of the billet due to the flow of metal at a different speeds during rolling of billets in helical rolls and rolling-pressing;
- during rolling-pressing, the occurrence of powerful macro-shear deformations lead to a significant increase of $\overline{\Gamma}$ on the surface zones of the billet, while this value is aligned when the metal passes through the matrix;
- an increase of the feeding and rolling angles reduction ratio, leads to a much higher increase of $\overline{\Gamma}$ and H on the surface zone of the billet;
- in the process of billet rolling in smooth and helical rolls, as well as in rolling-pressing, the temperature of the deformed billet arises in the contact zones of the billet with the tool, while the temperature of the billet increases especially sharply in the areas located in front of the matrix during deformation by the combined rolling-pressing process.

At this work, stress-strain curves (σ-ε) during torsion of samples at a rate of 1,0 s^{-1} at temperatures of 300, 400, 500 ° C were obtained. Analysis of the curves (σ-ε) indicates that, with decrease of deformation temperature, the flow stress increases at the investigated deformation rate. In this case, in the interval of real degrees of deformation which used in hot deformation (up to ε = 0,9), the continuous increase in the flow stress is observed in the range up to ε = 0,6. A further increase of the deformation degree leads to a moderate (300 ° C) and relatively intensive (400 and 500 ° C) stress reduction.

To estimate the evolution of the grain structure according to the results of metallographic analysis, histograms of the grain size distribution were constructed. Analysis of the grain distribution histograms shows that with an increase of the deformation degree, the sizes of grain decrease.

To use the results of physical modeling to determine the grain size during rolling in smooth and helical rolls, as well as during rolling-pressing on the RSM of a new design, the sizes of dynamically recrystallized grains were calculated. For such a calculation, the Zener-Holomon parameter and the activation energy were estimated [9].

To calculate the Zener - Holomon parameter (Z) applied the formula:

$$Z = \dot{\varepsilon} \cdot \exp\left(\frac{Q}{RT}\right) = f\left(\sigma\right), \qquad (2)$$

where, $\dot{\varepsilon}$ – deformation rate; Q – hot deformation activation energy; R – universal gas constant (8,31 $J \cdot mole^{-1} \cdot K^{-1}$); T – absolute temperature / K.

The calculation of the given parameter was performed in accordance with the method described in this work [9].

According to the authors of work [9], the use of a hyperbolic sinus gives a more adequate approximation of Z dependence from stress at any stress values and types of hot deformation:

$$Z = f\left(\sigma\right) = C\left[\sinh\left(\gamma\sigma_p\right)\right]^n, \qquad (3)$$

where, σ_p – peak voltage; C, γ, and n –approximation parameters.

In the result of σ-ε curves processing and calculating by the method of least squares of all the necessary values of the unknown parameters, the activation energy value was found according to the following formula [9].

$$Q = Rn\left[\frac{\partial \ln\left[\sinh\left(\gamma\sigma_p\right)\right]}{\partial\left(\frac{1}{T}\right)}\right]_{\dot{\varepsilon}=const} \quad (4)$$

The activation energy value reach: Q = 221 kJ / mol. Using the obtained Q value, the Zener-Holomon parameter Z was calculated for the selected deformation modes (300 °C – Z = $1{,}44\cdot10^{20}$; 400 °C – Z = $1{,}45\cdot10^{17}$; 500 °C – Z = $8{,}74\cdot10^{14}$).

To calculate the size of recrystallized grains d_{din}, the following formula was used [9]

$$d_{din}=A_{din}\cdot Z^{n_{din}} \quad (5)$$

where A_{din}, n_{din} – material constants.

In the result of dependence approximation of d_{din} from Z the following values of formula coefficients were obtained (5): A_{din} = 63,42; n_{din} = - 0,437.

Like so, the size of dynamically recrystallized grains of copper alloy M1 can be estimated by the formula:

$$d_{din}=43{,}42\cdot Z^{-0{,}053} \quad (6)$$

Using formula (6), the size of dynamically recrystallized grains specific for each temperature-deformation regime was calculated: 300 °C – d_{din} = 3,71; 400 °C – d_{din} = 5,35; 500 °C – d_{din} = 6,21.

PRUL calculation showed that due to the cyclical change of k_s on the surface zones of the billet during rolling in smooth and helical rolls, the value of PRUL on these zones also changes abruptly. With that, the value of PRUL does not exceed one, which means that it is impossible to break the continuity of the billet material. Such a cyclical change of PRUL value and $k_ж$ is connected with the occurrence of large compressive stresses σ_1, σ_2, and σ_3 in the areas of rolls contact with the billet and small compressive stresses σ_1, σ_2 and σ_3 on the billet zones free from the impact of rolls.

Analysis of the stress distribution over the billet cross-section in a steady state process showed that at the beginning of rolling in the axial and surface zone of the billet, compressive stresses prevail. During the further rolling on the surface zone, the arising stresses σ_1, σ_2 and σ_3 remain compressive, and tensile stresses appear on the axial zone. Tensile stresses can lead to discontinuity of the metal in the axial zone of the billet

However, large negative in magnitude k_s matched to the contact zone of the tool and the billet, and small negative in magnitude k_s matched to the deformation-free surface zone of the billet. Such a distribution character of k_s determines a high deformability of the material in the process of radial- shift rolling (RSR). This is due to the fact that the main deformation of the billet metal takes place under conditions of high hydrostatic pressure.

In our opinion, the abrupt nature of deformation will influence on the kinetics of a fine-grained structure formation in copper alloy M1. Cyclic deformation, in contrast to monotonic deformation, will lead to an increase in the value of cumulative deformation, which contributes to the formation of a fine-grained structure. This is due to, both, the possible realization of structure return mechanism due to the action of Bauschinger effect and the unavoidable annealing of the alloy in the intervals between deformation cycles and rolling stages. So, due to the action of the processes mentioned above, one should expect the formation of a fine-grained structure at RSR in comparison with monotonic deformation. In the vicinity of the point located on the axis of the rod, the PRUL and k_s also change. The average value sign of the stress state stiffness coefficient will be positive, which matches to the value typical for processes of rolling on the RSM. The PRUL value approximates to one. It follows that the kinetics of structure formation in the central area of the rod will be similar to that observed one at a monotonic deformation, i.e., comparatively coarse-grained structure is formed. Accordingly, when rolling on smooth and helical rolls, an uneven structure is formed.

The analysis of the PRUL and k_s distribution showed that during rolling-pressing, there is also a cyclical change of analyzed parameters take place on the surface zone and the zones of the billet neighboring to the surface. The reason for the cyclic change in the value of PRUL and k_s is also related with the occurrence of large compressive stresses σ_1, σ_2 and σ_3 in the contact zones of the rolls with the billet and small compressive stresses σ_1, σ_2 and σ_3 on the billet zones free from the impact of rolls. All this and the development of macro-shear deformations on the surface zone of the billet during rolling and concentration of $\overline{\Gamma}$ in the central zone during pressing leads to the formation of a uniform structure when manufacturing the products on the RSM of a new design.

It should be noted that, due to the supporting action of the matrix during rolling-pressing, comparatively large compressive main stresses σ_1, σ_2 and σ_3 appear on the central and axial zones of the pressed billet. This and the small value of PRUL, in contrast to rolling in smooth and helical rolls, makes it possible to produce rods or wires of the required quality without interruption the continuity of the billet material.

On the base of data, obtained by physical modeling, it can be noted that for the passage of dynamic recrystallization, it is necessary to achieve a degree of deformation of 0,9 or more. It should be noted that the results of computer simulation of rolling in smooth and corrugated rolls show that the values of $\overline{\Gamma}$ more than 2,5 has been reached on the surface and neighboring areas. At the same time, in the central zone of the billet, the PRUL value does not exceed 1. All this proves that during rolling a different-grain structure will be formed on these rolls.

The results of physical and computer simulation show that when rolling-pressing on a new RSM, the value of $\overline{\Gamma}$ reaches 15 or more over the entire cross section of the billet. This proves the possibility of fine-grained structure obtaining over the entire section of the billet made of copper alloy M1.

CONCLUSION

Results in the work are: installed the temperature-deformational modes of processing of copper alloy M1 on a new RSM, which lead to the formation of a fine-grained structure without interruption the continuity of the billet material.

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