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研究轧制对有色合金纳米结构形成的影响
STUDYING THE EFFECT OF ROLLING ON THE FORMATION OF NANOSTRUCTURES IN COLORED ALLOYS

Mashekov Serik Akimovich
Doctor of Technical Sciences, Professor. Head of Department
Maulenova Mariya Rysbaevna,
Erubaev Erlan Audanbekovich
Candidate of Technical Sciences
Tussupkaliyeva Elmira Adietovna
Satbayev University

注解。 本报告介绍了一种具有纳米结构的金属板材的新技术。 通过施加由螺旋辊产生的严重塑性变形获得纳米结构。 在这项工作中，研究了在螺旋辊和纵向楔形轧机（LWM）中轧制过程中工件的应力 - 应变状态（SSS）。 有限元方法和MSC.SuperForge程序获得了定量数据，建立了SSS分布的基本规律，螺旋轧制条带和PKS轧制过程中的温度，具有不同数量的过道和单一还原。 已经在实验室条件下测试和测试了具有纳米结构的钛（VT1-0）和铝（AD31）合金的合理轧制技术。

关键词：铝合金，纳米结构，轧制，数值模拟，应力和应变强度，单一还原。

Annotation. *This report presents a new technology for sheet metal with nanostructure. The nanostructure is obtained by applying severe plastic deformation developed by a helical roller. In this work, the stress-strain state (SSS) of the workpiece during rolling in a spiral roller and a longitudinal wedge mill (LWM) was investigated. The finite element method and the MSC.SuperForge program obtained quantitative data and established the basic laws of the distribution of SSS, the temperature during the rolling of strips in helical rolls and PKS, with a different number of aisle and single reduction. A rational rolling technology for titanium (VT1-0) and aluminum (AD31) alloy with nanostructure has been tested and tested under laboratory conditions.*

Keywords: *aluminum alloys, nanostructure, rolling, numerical modeling, intensity of stresses and strains, single reduction.*

Currently, new methods of intense plastic deformation (IPD) have been developed, which allow, through deep fragmentation of grains, to obtain a new nanocrystalline structure with high strength properties. [1]. It has been established that using known IPD methods it is difficult to manufacture rolled sheets with a nanograin structure. Therefore, in this work, to obtain high-quality sheet blanks with a nanocrystalline structure without significant changes in their sizes, we propose a tool with rolls with screw-like working surfaces [2], and for rolling strips from these blanks a longitudinal wedge mill (LWM) [3].

The tool for rolling metals contains upper and lower rolls with helical working surfaces. In this case, the opposing protrusions and depressions of the upper and lower rolls are made along the left and right helix, respectively.

Longitudinal wedge mill for rolling sheets of steel and alloys contains, electric motors, gearboxes, gear stands, universal spindles, couplings, stands with work and back-up rolls. At the same time, in the first three stands there are two, and in the last two stands, four support rolls. Rotation of the work rolls decreasing in the direction of rolling is carried out through bearing stands by five gear motors with angular speed $\omega = \upsilon \cdot R$ (where υ is the rolling speed in each mill stand; R is the radius of the work rolls in each mill stand). While adjusting the distance between the work rolls produce a single worm pressure mechanisms located above and below the camp frame and bearing stands.

It should be noted that the work rolls in each stand have a constant diameter, and in consecutive stands the diameter of the rolls decreases in the direction of rolling. At the exit, a thin strip is cut or rolled into rolls.

For the development of the technological process allowing to evenly distribute the accumulated strain, i.e. To obtain strips of titanium alloy VT1-0 and aluminum alloy AD31 of high quality, as well as to determine the optimal value of a single reduction, the stress-deformable state (SSS) of the workpiece was studied during rolling in a spiral roller, as well as on LWM.

To calculate the SSS, a specialized standard program MSC.Super Forge was used. A three-dimensional geometric model of the workpiece and rolls was built in the Inventor CAD program and imported into the CAE program MSC.SuperForge. When creating a finite element model of the workpiece and the rolls, a three-dimensional CTETRA (four-node tetrahedron) volume element was used. The process calculation time was 30-40 minutes on a Pentium Duo computer with a clock frequency of 3.4 GHz and 2 GB RAM.

For the calculation, we used rectangular in cross section samples of size 6 × 100 × 200 mm. From the material database, the material of the rolled stock VT1-0 or AD31 was assigned with a temperature range of deformation of, respectively, 500-1200 °C or 20 - 450 °C. To simulate the plasticity of the material, the Johnson-Cook elastoplastic model was chosen. Tool material, density and thermal properties, which the program assigned by default, was selected as the material for the rolls. The rolling process takes place at room temperature, therefore the initial temperature of the rolls is assumed to be 20 °C. The contact between the roller and the workpiece is modeled by Coulomb friction, the friction coefficient was adopted 0.3.

Rolling titanium alloy VT1-0 carried out according to the following mode: heating to a temperature of 850 °C, rolling four passes in a spiral roller to a thickness of 5.9 mm, heated at a temperature of 950 °C, rolling on LWM to a thickness of 1.5 mm.

The rolling of the aluminum alloy AD31 was carried out according to the following mode: heating to a temperature of 380 °C, rolling four passes in a spiral roller to a thickness of 5.9 mm and rolling at a temperature of 100 °C on LWM to a thickness of 1.5 mm.

Launched the program "MSC.SuperForge". The step method was calculated components of the strain tensor and stress, the temperature distribution over the volume of the workpiece.

Under laboratory conditions, we rolled the strips of titanium (VT1-0) and aluminum (AD31) alloy in a spiral roller and LWM.

Titanium (VT1-0) and aluminum (AD31) alloy was tested after processing in a spiral roller and LWM on an Instron 5882 machine at a deformation rate of 10^{-3} s^{-1}.

Before mechanical testing, aluminum samples were subjected to heat treatment consisting of quenching and subsequent aging. The heating temperature for quenching was 450 °C, holding at this temperature for 2 hours, cooling in oil. Aging was carried out at a temperature of 120 °C for 5 h.

The metallographic analysis was performed using an energy-dispersed JNCA-ENERGY spectrometer (England) installed on a JEOL electron probe microanalyzer with an accelerating voltage of 25 kV. The range of magnifications of the device JEOL from 40 to 40000 times. The structural features of the deformed samples were also examined using a JEM-2100CX electron transmission microscope (TEM) at 200 kV accelerating voltages.

Quantitative analysis of the mechanical properties and parameters of the defective substructure was carried out by standard methods. The sections for metallographic examination were prepared according to the traditional method on grinding and polishing wheels. The grain size (D_3, μm) was determined by the secant method (by measuring ~ 300 grains) under the assumption that the grains have a spherical shape, based on the average chord (X) according to the formula: $D_3 = 4 / \pi \cdot X$.

The process of deformation in a spiral roller, can be divided into two stages. In the first stage, the protrusion of the upper roll bends the strip towards the depression of the lower roll. In the second stage, due to the development of a torsional stress, macro-shear deformation occurs under the inclined surfaces of the protrusions or depressions of the rolls.

Based on the results of numerical simulation, it was established that:

- the seizure of the workpiece with helical rollers leads to the formation of a minimum-size tensile σ11 and σ22 in the deformation zone, as well as compressive σ33 stresses;
- the further rolling of the helical rolls lead to the formation of deformation in the focus area, which are mainly compressive in magnitude of normal stresses;
- at the initial moment of rolling, the intensity of stresses and strains are localized in the contact zones of the workpiece with the working surfaces of the protrusions of the rolls, with an increase in a single reduction leads to the transfer of stress and strain intensities from the contact zones to the zones of the strip and the roll bottoms;
- in the process of rolling the helical rollers, the zones of contact of the tool with the strip are cooled, while in the zones of action of the bending deformation the temperature rises slightly;
- in the second, third and fourth rolling passes in helical rolls, the magnitudes of the intensity of stresses and strains increase under the inclined sections of the protrusions and hollows of the rolls;
- the developed method of rolling the strip in a spiral roller, provides intense alternating deformation of the strip with a slight reduction;
- the maximum possible shift is realized when the ratio of the width of the protrusion to the width of the depression is 0.8 ... 0.9.

The calculation and analysis of the SSS billet during rolling of titanium (VT1-0) and aluminum (AD31) alloys on LWM shows that:

- during the seizure of the workpiece by the first, second, third, fourth, and fifth LWM stand, small in magnitude tensile σ11, compressive σ33 and σ22 stresses occur in the deformation zone;
- further rolling of the billet in LWM leads to the formation of deformation in the focus mainly of compressive normal stresses;
- when rolling in the first stand of LWM, the intensity of stresses and strains are localized in the zones of metal capture by rolls, and with an increase in compression, the values of the intensity of stresses and strains increase in the center and along the edges of the deformable workpiece;
- continuous rolling of the billet in subsequent LWM stands allows you to gradually transfer the areas of concentrated deformation from the center to the zone of contact of the rolls with the rolled billet;
- gradual transfer of areas with localization of deformation from the center to the surface leads to a more uniform distribution of accumulated deformation;
- rolling in LWM leads to intensive cooling of the sections of the bands in the zone of contact of the metal with the roller;
- the most uniform distribution of the total intensity of stresses and strains over

the height and length of the rolled strip was obtained by rolling with a single compression in the first stand of 20%, in the second stand of 18%, in the third stand of 13%, in the fourth stand of 15%; in the fifth stand 12%. .

It should be noted that under any conditions of rolling titanium (VT1-0) and aluminum (AD31) alloys in a spiral roller and LWM most of the plastic zone is under a comprehensive non-uniform compression. At the same time, in some conditions, tensile stresses of small size appear on a small portion of the strips, which are located under the inclined working surfaces of the protrusions and depressions of the helical rolls, as well as on the edges of the strips rolled in the LWM.

Using the obtained results on the SSS distribution over the cross section of the workpiece during rolling in a spiral roller and on LWM, we developed a technology for manufacturing bands with nanostructures. This technology was tested in the laboratory.

Rolling bands on the mill with a spiral roller and LWM carried out in the following modes. A billet with a thickness of 8 mm of titanium alloy VT1-0 or aluminum alloy AD31 was sequentially heated and heated, respectively, to a temperature of 850 or 380 ° C. After that, the heated billet rolled with four, eight and twelve passes in a spiral roller to a thickness of 7.4 - 7.8 mm. Next, the deformed billet of titanium alloy VT1-0 or aluminum alloy AD31 was heated, respectively, to a temperature of 950 or 100 ° C and rolled with optimal squeezing modes on LWM to a thickness of 1.5 mm.

In the initial state, the billet of titanium (VT1-0) and aluminum (AD31) alloy had a non-uniform microstructure. This structure consisted of large non-recrystallized grains with an average size of, respectively, ~ 56 and ~ 87 microns in the longitudinal and ~ 56 and ~ 98 microns in the transverse directions. Fine grains ~ 14–18 μm in size were located along the boundaries of these grains.

The study of the microstructure of the aluminum alloy AD31 showed that rolling in a spiral roller at a temperature of 380 °C in four passes leads to a strong fragmentation of grains into thin shear bands with a width of about 645-850 nm. Transverse boundaries form inside the bands and multiple microtwinning develops. As a result, the structure is heavily crushed. During the study, it was found that after four passes in the studied alloy an anisotropic submicrocrystalline state is formed - the sizes of grains in different directions differ by 3-4 times: 5.8 - 6.3 μm in the parallel plane and 0.94 ÷ 1.15 μm in the plane perpendicular to the directions of rolling. In our opinion, this is a consequence of the characteristic for deformation by bending and torsion under pressure of high anisotropy of the fields of displacements and rotations.

A different picture is observed in the alloy AD31 during the rolling of helical rolls with eight passes. It was found that rolling in eight passes at a temperature of 380 ° C leads to the division of the strip structure into deformation, intermediate and microbands consisting of subgrains separated by small and large angle boundaries. Consequently, with an increase in the number of passes, the microbands are fragmented into pieces due to the formation of shear bands, an increase in the proportion of high-angle boundaries is observed, and a mixed structure is formed. At the same time, the deformation of the workpieces at a temperature of 380 °C in spiral-shaped rollers with eight passes leads to the formation of a uniform and equiaxial structure in the longitudinal and transverse sections of the billet. From the microstructure it can be seen that further grinding of the grain-subgrain structure occurs. At the same time, in the longitudinal section of the grain billet, the substructures are definitely stretched along the bending direction, and in the transverse section - have an equiaxial shape with an average size of about 0.68 - 0.74 μm. The dislocation density is very high and it was not possible to calculate its value from the structure images.

Thus, when rolling with eight passes, a further evolution of the structure occurs, namely, the number of lattice and grain-boundary dislocations is reduced, clear extinction contours appear at the grain boundaries, i.e. all signs of dynamic recovery and dynamic recrystallization by a continuous mechanism are manifested. As a result of these processes, an ultra fine-grained (UFG) structure consisting of crystallites, 0.68 - 0.74 nm in size, is formed in the material.

Consequently, the relaxation of the elastic energy during rolling in spiral-shaped rolls with eight passes in the alloy AD31 is carried out by two mechanisms — fragmentation and dynamic recrystallization.

It should be noted that with an increase in the number of rolling passes in wavy rolls, the grinding of the structure occurs not only by twinning, but also by the formation of cellular substructures as a result of the development of dislocation slip processes. At large degrees of accumulated deformation, the boundaries of the former twins and subgrains are transformed into high-angle ones.

After rolling by twelve passes in spiral-shaped rolls in an aluminum alloy AD31, an inhomogeneous grain-subgrain structure is formed. Grains and subgrains are unequal in shape and elongated along the direction of bending and torsion. The average size of the elements of the grain-subgrain structure in the transverse and longitudinal section of the workpiece is 0.125 ± 0.04 μm. The diffraction pattern shows that the nanocrystalline structure contains predominantly high-angle grain boundaries with a nonequilibrium structure, leading to an increase in the energy of grain boundaries.

The microstructural heterogeneity in the bulk of the blanks of the aluminum alloy AD31 is significantly reduced in the subsequent plastic deformation by rolling in LWM. Rolling with a total reduction to 90% leads to the formation of a microstructure with an average characteristic size of almost equiaxial elements = 95 ± 20 nm, which corresponds to the nanostructured state.

Naturally, rolling on LWM at a temperature of 100 ° C provides additional strain hardening. Annealing at 200 °C for one hour practically does not change the nature of the microstructure. The nanostructured state of the aluminum alloy AD31 is preserved. Only the average size of the elements of the grain-subgrain structure increases slightly, reaching 0.125 ± 0.03 μm. Increasing the temperature to 300 °C for the same duration initiates recrystallization processes. The growth of the average size of the grain-subgrain structure becomes more noticeable and is 0.145 ± 0.01 μm. The size of the subgrain after annealing at 400 °C is 0.180 ± 0.045 nm. After annealing at 450 °C, an increase in the grain size to 0.262 ± 0.048 μm was observed, and after annealing at 500 °C, the structure of the aluminum alloy AD31 became fine-crystalline with an average grain size of 5.3 ± 0.3 μm.

Thus, after rolling in helical rolls with twelve passes and LWM in the aluminum alloy AD31, a relatively homogeneous, equilibrium nanostructure was formed with an average characteristic grain size of a subgrain structure less than 100 nm. This structure provides high static strength (σт - 275 MPa, σB - up to 295 MPa) and good ductility of aluminum strips made of AD31 alloy.

The study of the structure of the billet titanium alloy VT1-0 rolled helical rollers at a temperature of 850 ° C showed that rolling with four and eight passes lead to uneven deformation of the metal grains. As a result, an uneven elongated structure with a grain size of 3.9 - 15.9 μm is formed in the longitudinal and transverse sections of the workpiece.

Rolling in a spiral roller at a temperature of 850 ° C with twelve passes causes inactive passage of dynamic recrystallization over the cross section of the workpiece, which leads to the formation of a plate structure with a cross-sectional size of the plates from 1.8 to 2.7 microns.

Further deformation in LWM at a temperature of 950 ° C with optimal single reductions facilitates active dynamic recrystallization throughout the cross-section of the rolled strip, which leads to the formation of a globular fine-grained structure with a grain size of 0.2 - 0.6 μm.

Thus, the broach in spiral rollers and LWM at temperatures below and above T_{PP} allows you to get a globular fine-grained structure throughout the cross section of the workpiece.

On the basis of the conducted research, it can be concluded that the grinding of the microstructure of the titanium alloy VT1-0 is associated with the occurrence of dynamic recrystallization in the α and β phases. The driving force of spheroidization is to achieve an angle of 120 in the triple junction between the interfacial and intergranular boundary. During the deformation in the α-phase plates, the formation of transverse sub-boundaries occurs, at the same time the interphase boundaries are transformed from semi-coherent to non-coherent. At the points where the sub-boundaries reach the surface of the plates, grooves are formed, which is facilitated by the incoherence of the interfacial boundaries, since this results in the activation of diffusion processes. With an increase in the degree of deformation, the misorientation of grain boundaries increases, and parts of the plates are able to shift relative to each other as a result of grain-boundary slippage. The process of spheroidization leads eventually to the formation of a globular structure.

Visual inspection of the surface of rolled sheets showed that the surface quality is good, there are no cracks. Deviations of the sheet thickness from the given 1.5 mm did not exceed 0.01 mm.

It is established that the mechanical properties of titanium (VT1-0) and aluminum (AD31) alloy subjected to rolling in a spiral roller and on LWM are significantly higher than the initial values. In particular, the temporary tensile strength σB increases by 15–20%, and the plasticity is one and a half times higher than the corresponding parameter of the initial samples. This combination of sufficient strength and good ductility opens up wide possibilities for the use of this material in practice.

Thus, our proposed method of processing titanium and aluminum alloys in a spiral roller and LWM improves the quality of the bands, reduces the labor intensity by 18–25%, increases the yield by 7–9%.

References.

1. Valiev R.Z. Nanostructured materials obtained by severe plastic deformation / R.Z. Valiev, I.V. Alexandrov. - Moscow: Logos, 2000.– 272 p.

2. Patent of the Republic of Kazakhstan No. 16804. Tool for hot rolling of metals and alloys / S.A. Mashekov, B.N. Absadykov, L.A. Kurmangalieva and others. Publ. 16.01.2006, Byul. № 1. - 2 p .

3. Patent of the Republic of Kazakhstan No. 31750. Multifunctional longitudinal wedge mill for rolling sheets of steel and alloys / S.A. Mashekov, A.S. Mashekova, E.Z. Nugman et al. // Publ. 30.12. 2016 in the BI number 18.