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INFLUENCE OF TECHNOLOGICAL PARAMETERS OF ROLLING IN SCREW-SHAPED ROLLS AND LONGITUDINAL WEDGE MILL ON FORMATION OF NANO-STRUCTURE IN THIN SHEETS FROM ALUMINUM AD31ALLOY

Abstract. New technology for the production of sheet metal with a nanostructure is presented in the article. Screw-shaped roll was used to develop severe plastic deformation and therefore to obtain nanostructure. The stress-strain state (SSS) of the workpiece during rolling in screw-rolled rolls and longitudinal-wedge mill (LWM) was investigated. Finite element method and the MSC.SuperForge software were exploited to obtain quantitative data and establishthe main distribution regularities of SSS and temperature during modelling of rolling process in the screw-shaped roll and LWM with different number of passes and single reduction. A rational technology of rolling of aluminum AD31 alloy has been developed andtested under the laboratory conditions. Analysis of the influence of the rolling modes in screw-shaped rolls and LWM on the formation of nanostructures in an aluminum AD31 alloy was in particular interest.

Keywords: aluminum alloys, nanostructure, rolling, stress-strain state, numerical simulation, intensity of stresses and deformations, single reduction.

Introduction. The progress in the development of aviation, machinery construction and other industries is largely ensured by the development of new materials and the technology of manufacturing various products made from them, including rolled sheet products [1]. Nowadays rate of specific weight of aircraft equipment is achieved due to use of aluminum and titanium alloys of high strength, low density and high corrosion resistance.

It should be noted that one of the main factors influencing into the level and anisotropy of the properties of sheet material from aluminum alloys, obtained by the existing technology, is the nonuniformity of deformation in different parts of the workpiece [2]. Therefore, to create scientifically grounded modes of deformation of aluminum alloys, it is necessary to develop new methods or tools to reduce the nonuniformitydistribution of deformation.

To obtain high-quality strips with a nanostructure, without significant changes in their dimensions, severe plastic deformation methods (SPD) can be used, such as: torsion under high quasi-hydrostatic pressure, equal-channel angular pressing, overall isothermal forging and radial shear rolling, etc. [3-9]. SPD methods are mainly realizedby macro-sheardeformations, with a total degree of more than 2-3. Macro-shear deformations cause changes in the structure of the metal due to transgrained sliding, which does not depend on the crystalline orientation of the grains. The result of these changes is an increase of the level and uniformity of metal mechanical properties, as well as a decrease of their anisotropy.

In the above given works and other researches of the last decade [10-13], it has been shown that nanostructured by SPD method materials have very high physical and mechanical properties. In this case, metals and alloys with submicro- and nanocrystalline structure exhibit unusually high and useful strengths and plasticity.

Intensive macro-shears in the process of sheet rolling can be provided by different technological and constructive methods [14]: the use of workpieces and rolls with a wavy or corrugated surface, asymmetric rolling, uneven cooling of rolling in its thickness and width, by using of crossed rolls, and the rolls with a ledge on surface, etc. The authors of work [14] note that in all these cases, intensive macro shears are achieved as a result of local deformation effects on the rolling metal.

The Japanese company "JFE Steel" offered a method of multiple consecutive alternating bending of the steel strip after hot rolling [15]. It can be seen from the materials of the work that, in contrast to usual rolling, the use of alternating bending makes it possible to roll a sheet workpiece without changing its thickness. Therefore, this method allows deforming the sheet workpiece by cyclic bending unlimited number of times. This makes it possible to obtain hot-rolled strips with an ultrafine-grained structure. According to the authors of work [15], this method of rolling can be used in industry to raise the quality of rolled metal.

Thus, in order to increase the quality of sheet roll products, many new constructions of rolls and tool shapes have been offered. However, many rolls and tools have not found wide application in production due to the following reasons: the complexity of their manufacture; the difficulty of installing them on rolling mills, etc.

The purpose of the work is to calculate the stress-strain state (SSS) of deformation during rolling of sheet metal and its uniform distribution over the volume of the workpiece, as well as development of a rational technology for rolling of aluminum AD31 alloy.

Materials and the method of experiment. To obtain workpieces with a nanostructure, an instrument with screw-shaped rolls and a continuous five-cage longitudinal-wedge mill (LWM) for strip rolling were developed [16, 17].

Instrument for metals rolling contains upper and lower rolls with screw-shaped working surfaces. At the same time, oppositely placed projections and hollows of the upper and lower roll are made along the left and right screw-shaped lines, accordingly.

Continuous LWM for rolling sheets made of steels and alloys contains electric motors, reduction gears, pinion stands, universal spindles, couplings, stands with working and supporting rolls (figure 1). At the same time, in the first three stands there are two, and in the last two stands, four support rolls. Rotation of working rolls decreasing in the rolling direction is carried out through bearing stands by five motor-reducers with an angular velocity $\omega = \upsilon \cdot R$ (where υ is the rolling speed in each mill stand, R is the radius of working rolls in each mill stand). Herewith, the distance between the stands is increased on the rate of outrunning, and the adjustment of the distance between working rolls is made by single wormscrewdown mechanisms located at the top and bottom of the mill stands and bearing stands.

It should be noted that the working rolls in each stand have a constant diameter, and in consecutively placed stands the diameter of rolls decreases in the direction of the rolling. At the output, a thin strip is cut or winded into rolls.

For the development of the technological process allowing uniformly distribute the cumulative deformation, another word to obtain high-quality strips of aluminum AD31alloy, and also to determine the optimum single squeezing value, the SSS of the workpiece was investigated during rolling in screw-shaped rolls and LWM.

MSC.SuperForge was used to calculate the SSS of the strip. The three-dimensional geometric model of the workpiece and rolls was built in the CAD Inventor program and imported into the CAE program MSC.SuperForge.Three-dimensional (3D) element CTETRA (a four-nodal tetrahedron) was used to create the finite-element model of the workpiece and rolls. The calculation time of the process was 30-40 minutes on a computer with a clock frequency of 3.4 GHz and 2 GB RAM.

Rectangularsamples with dimension of 6×100×200 mm were used for the calculation. From the materials database AD31 alloy with a deformationtemperature range of 20-450 °C was assigned. Johnson-Cook's elastic plastic model was chosen to model plasticity of the workpiece material. In MSC. Super Forge for modelinginstruments are taken absolutely rigid and only properties of heat conductivity and heat transfer are taken into account, whereas mechanical properties are ignored. As the material of the rolls, on default, tool steel is selected, density and thermal properties of which are also assigned on default.The rolling process takes place at a room temperature, so the initial temperature of the rolls is assumed equal to 20 °C. The contact between the roll and the workpiece is modeled by the Coulomb friction, the friction coefficient was 0.3.

The rolling was carried out according to the following mode: heating up to a temperature of 380 °C, rolling by four passes in screw-shaped rolls to a thickness of 5.9 mm and rolling at a temperature of 100 °C on a LWMup to a thickness of 1.5 mm.

MSC.SuperForge software has been launching. By stepwise method thedeformation and stress tensor components and the temperature distribution along the volume of workpiece were calculated. At the same time, the calculation results are shown by dividing the total deformation time to the four stages (in percent). The following intervals were selected: the first stage 25, the second stage 50, the third stage 75 and the fourth stage 100 percent from the total deformation time.

In the laboratory conditions a strip rolling was made from aluminum AD31alloy in screw-shaped rolls and LWM. The chemical composition of this alloy is shown in table 1.

Table1 – Chemical composition of aluminum AD31alloy

The content of alloying elements, mass. %					
Mg	Si	Cu	Mn	Cr	Fe
0.45 – 0.50	0.41 – 0.48	0.001 – 0.015	0.001 – 0.01	0.001 – 0.003	0.18 – 0.21

Aluminum AD31alloy was tested after treatment in screw-shaped rolls and LWM. Mechanical tests of experimental materials included: static tensile tests to determine the standard characteristics of material, such as $\sigma_в$, $\sigma_т$ ($\sigma_{0.2}$), δ, impact viscosity, hardness.

Before the mechanical test, the samples were heat treated, consisting of tempering and subsequent senescence. The heating temperature for tempering was 450 °C, extracting at this temperature was 2 hours, cooling was in oil. Senescence was carried out at a temperature 120 °C during 5 hours.

The metallographic analysis was carried out by using an energy-dispersive spectrometer JNCA ENERGY (England) mounted on a JEOL electron-probe microanalyzer at an accelerating voltage 25 kV. The range of the JEOL device increases from 40 to 40,000 times. Structural features of the deformed samples were also researched with the help of transmission electron microscope (TEM) JEM-2100CX at accelerating voltages 200 kV.

A quantitative analysis of the mechanical properties and parameters of the defective substructure was carried out by standard methods [18]. The thin sections for metallographic analysis were prepared according to the traditional method of grinding and polishing circles. For etching the samples, a concentrated solution of nitric acid in ethyl alcohol was used. The grain size (D3, micron) was determined by the secant method (according to measuring ~ 300 grains) under the assumption that the grains have a spherical form, based upon the average chord value (X) according to formula: $D_g = 4/\pi \cdot X_{med}$.

Results and discussion. The process of deformation in screw-shaped rolls can be divided into two stages. In the first stage, the projection of the upper roll bends the strip towards the hollow of the lower roll. In the second stage, due to the development of torsional stress a macroshift deformation occurs under the inclined surfaces of the projection or hollows of the rolls.

On figures 1 and 2 the distribution picture of the main stresses is shown, as well as the intensity of stresses and deformations and the temperature field in the workpiece when rolling in screw-shaped rolls by the four passes. The temperature of the workpiece heating is 380 °C.

Based on the numerical modelling results, it is established that:

- capture of workpiece by screw-shaped rolls leads to the appearance in the deformation zone minimalby value stretching σ_{11} and σ_{22}, also squeezing σ_{33} stresses;

- further rolling in the screw-shaped rolls leads to the appearance of normal stresses in the deformation zone σ_{11}, σ_{33} and σ_{22}, changing in range: σ_{11} - from 22.211 to 28.264 MPa (Figure 1, *a*); σ_{33} - from – 30.569 to 21.018 MPa (Figure 1, *b*); σ_{22} - from – 30.243 to 12.726 MPa (figure 1, *c*);

- at the initial rolling moment stresses and deformations intensity are localized in the zones where the workpiece and working surfaces of the rolls projections are contacted;

- an increase in a single reductionleads to a shift of stress and deformation intensity accent from the contact zones to the zones where the strips located under the inclined working surfaces of the rolls projections and hollows (Figure 2, *a, b*);