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EXTRUDING ALUMINUM BARS ON A NEW STRUCTURE RADIAL SHEAR MILL

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In this work the stress-strain state (SSS) billet made by an aluminum 7075 alloy were investigated during combined rolling-extrusion on a radial shear mill (RSM) of a new design. The billet was first rolled in smooth or helical rolls and then extruded through the matrix channel. The main regularities of the SSS distribution and the combined process of the blank temperature have been established by using the finite element method and MSC.SuperForge program. The influence of rolling modes in smooth or helical rolls and further extrusion in a matrix on the formation of rods structures were analyzed. It was found that, a fine-grained structure was formed along the section of the manufactured bars, which increases the quality of metal products.

Keywords: aluminum alloys, rolling extrusion, recrystallization, numerical simulation, stress/strain

INTRODUCTION

In the XXI century, technologies and equipment for continuous extrusion were developed [1]. Continuous extrusion can eliminate certain disadvantages of discrete and semi-continuous extrusion by implementing the required degree of deformation in one unit – the unit of continuous deformation. At the same time, depending on the type of continuous processing may be combined with the extrusion operations in the deformation zone, such as rolling, a precipitate distribution and others. The authors of [2-4] analyzed the main methods of continuous extrusion, such as Conform, Linex and Extrolling, technologies and equipment for continuous extrusion, as well as the results of research in this area.

It should be noted that the types of combination of technological processing processes are very diverse [4-6]. A particularly important achievement in this direction is the combination of casting and rolling, as well as casting and extrusion. Based on the rational choice and compact arrangement of the main and auxiliary equipment, it was possible to create a mini-production – a small casting and rolling or casting and press complex with unsurpassed technical and economic indicators.

The widespread use of extruded profiles in various industries and the identification of their defects is always accompanied by the improvement of processing methods and designs of existing equipment. However, most of the studies were conducted in isolation, relate to particular problems and mainly has an empirical character. Thus, the modern metal processing has weak point as the lack of a unified approach to assessing the dynamics of changes in SSS in many of the proposed options for manufacturing profiles. It should be noted that at present, specialized simulation programs are widely used to study various metal forming processes [7-9]. Nevertheless, many studies are aimed at studying the stationary processes of manufacturing round solid and hollow profiles. At the same time, non-stationary dynamic processes of variable diameter blank extrusion into a round bar or constant diameter wire have been little studied in the known literature.

The purpose of the work is to simulate the combined process of processing rods on a new design of RSM to determine the SSS of a variable diameter and assess the structural state of finished products from 7075 aluminum alloy.

MATERIALS AND METHODOLOGY OF THE EXPERIMENT

In this paper, a new design RSM is proposed [10]. In this mill, metal rods of small diameters are obtained by combining hot screw rolling and extrusion.

To obtain rods of high quality, and also to determine the optimal value of a single reduction, the stress-strain state (SSS) of the workpiece was investigated during their deformation in the RSM of a new design.

To calculate the SSS, force and temperature modes of deformation of bars and wires, the MSC.SuperForge software was used [10]. It can be noted that the proposed bar manufacturing process is an extremely complex process. This is due to the fact that during processing the workpiece is continuously deformed on RSM with smooth or helical rolls, and then extruded through a die.

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In the work, a three-dimensional (3D) geometric model of the billet, rolls and matrix was built in CAD program Inventor and imported into CAE program MSC.SuperForge.

To study the rolling-extrusion process on a new RSM, a round billet made of 7075 aluminum alloy with a size of Ø 40 × 150 mm was used. The billet was rolled and extruded on this mill at a temperature of 300 °C to a diameter of 9 mm. The Johnson-Cook elastoplastic model was chosen to model the plasticity of the workpiece material. Rheological properties were set from the program database.

To calculate the SSS, temperature field and force parameters, we used the technical characteristics of the proposed RSM. From the material database, steel 9X1 was assigned as the tool material. For this material, the program assigned the default density and thermal properties. Since the extrusion and rolling processes take place at room temperature, the initial temperature of the tools was taken to be 20 °C. The contact between the tool and the bar is modeled by Coulomb friction, the friction coefficient was taken as 0,3.

The "MSC.SuperForge" software was launched and the contact pressure, SSS, force parameters and temperature distribution over the volume of the rolled and then extruded billet were calculated by the stepwise method.

In this work, the Johnson-Meil-Avrami-Kolmogorov model of grinding grains of metals and alloys was used to determine the grain sizes of the rods rolled and then extruded on a new RSM [10]. To determine the coefficients of the Avrami equation for the 7075-aluminum alloy, a series of experiments were carried out on a torsional plastometer STD 812. During the experiments, the rate and degree of deformation, temperature were varied and their effect on the structure was evaluated. The coefficients of the Avrami equation were calculated by the least squares method. Taking into account the found coefficients, the average grain size was determined by the following formula:

– average dynamic recrystallized grain size d_{DRX}:

$$d_{DRX} = 76,962 \cdot d_0^{0,22} \cdot \varepsilon^{-0,61} \dot{\varepsilon}^{-0,0412} \cdot exp\left(-1902,72 / RT\right) \quad (1)$$

– average medynamic size of recrystallized grains d_{MRX}:

$$d_{MRX} = 23,34 \cdot d_0^{0,28} \cdot \varepsilon^{-0,39} \dot{\varepsilon}^{-0,0346} \cdot exp\left(-1902,72 / RT\right) \quad (2)$$

– average static recrystallized grain size d_{SRX}:

$$d_{SRX} = 31,08 \cdot d_0^{0,21} \cdot \varepsilon^{-0,39} \dot{\varepsilon}^{-0,0297} \cdot exp\left(-1902,72 / RT\right) \quad (3)$$

where d_0 an initial average grain size;
ε and $\dot{\varepsilon}$ – a true degree and rate (s^{-1}) of deformation;
R – an universal gas constant ($J \cdot K^{-1} \cdot mol^{-1}$);
T – an absolute temperature (K).

The average grain size d_{avq} for the entire deformation process was calculated using the equation:

$$d_{avq} = X_{SRX} d_{SRX} + X_{MRX} d_{MRX} + X_{DRX} d_{DRX} + \left(1 - \left(X_{SRX} + X_{MRX} + X_{DRX}\right)\right) d_o. \quad (4)$$

where X_{SRX}, X_{MRX}, X_{DRX} – volume fraction of statically, medynamically and dynamically recrystallized grains.

RESULTS AND DISCUSSION

On the basis of the obtained results of numerical simulation of rolling billets of 7075 aluminum alloy in smooth rolls and extrusion in a matrix, it was found that

– the highest values of the intensity of stresses, deformations and strain rates acquire in the surface zones of the workpiece, while in the central zone they have the lowest value;
– 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 workpiece;
– the arising macro-shear deformations lead to an increase in the deformation intensity in the surface zone of the rolled bars;
– during the extrusion of the billet, the intensity of deformation is equalized over the entire section of the bars being produced. However, in the central zone of the workpiece, this indicator has a relatively lower value;
– an increase in the elongation ratio, feed angles and rolling leads to an even greater increase in the deformation intensity and deformation rate in the surface zone of the workpiece;
– the temperature of the workpiece being deformed rises in the contact zones of the workpiece with the tool;
– in the deformation zone, compressive principal stresses σ_1, σ_2 and σ_3 appear, while in the central layers of the workpiece, an opposite stress state pattern arises, which can lead to the destruction of the workpiece material.

On the basis of the obtained results of numerical simulation of the processing of a billet made of 7075 aluminum alloy in helical rolls and a new RSM matrix, it was found that

– at the initial stage of deformation, the contact pressure is localized in the gripping zones of the workpiece with the working surfaces of the rolls, and then increases throughout the deformation zone;
– the value of the contact pressure in the process of extrusion increases both in the die, which is characteristic of the extrusion process, and on the rolls. All this is associated with an increase in the back-up pressure in the deformation zone as a result of

the action of the force of extrusion of the metal through the matrix;

- small tensile principal stresses σ_1 appear on the surface of the workpiece, while in the outer layer each element is subjected to compressive principal stresses σ_2 and σ_3;
- in the central layers of the extruded billet, comparatively large compressive principal stresses σ_1, σ_2 and σ_3 appear, which makes it possible to manufacture products without disrupting the continuity of the billet material;
- intensities of stress, deformation and strain rates take on the greatest importance in the surface zones of the workpiece, deformed in helical rolls, while in the central zones they have an average value. At the same time, during the extrusion of the blank in the matrix, these indicators are aligned over the entire section of the manufactured products;
- the deformed metal flows along a helical trajectory with different speeds of the outer and inner layers, which leads to the occurrence of powerful macro-shear deformations in the volume of the workpiece;
- the emergence of powerful macro-shear deformations leads to a significant increase in the intensity of deformation in the surface zones of the workpiece, while these values are equalized when the metal passes through the matrix;
- an increase in the elongation ratio, angles of feed and rolling leads to an even greater increase in the intensity of deformation and the rate of deformation along the entire cross section of the workpiece;
- the temperature of the workpiece being deformed rises in the zones of contact between the workpiece and the tool, while the temperature of the workpiece increases especially high in the areas located in front of the RSM matrix.

It should be noted that when the billet is deformed in helical rolls installed on the RSM of a new design, the billet metal flows along a helical trajectory with different deformation rates, both in the outer and inner layers of the billet, and in the projections and valleys of these rolls. The movement of metal flows in protrusions and valleys along a helical line with different strain rates causes an increase in shear deformations over the volume of the workpiece. This leads to a significant increase in the intensity of deformation when extruding the workpiece on a new RSM. An increase in the intensity of deformation should lead to a significant refinement of the structure of the original workpiece.

Calculation of the average grain size according to the above formulas showed that rolling of 7075 aluminum alloy rods on smooth rolls, and then extruded in a matrix at a temperature of 300 °C leads to the formation of a different-grain structure. In this case, a fine-grained structure with an average grain size of 19 μm is formed in the peripheral zones of the workpiece, and a coarse-grained structure with an average grain size of 93 μm is formed in the central layers. This means that rolling the billets in smooth rolls and then extrusion in the matrix leads to the passage of primary recrystallization in the peripheral zone of the rods. It is known that this process is accompanied by the formation of a fine-grained structure. In our opinion, the formation of a relatively coarse-grained structure in the central layers of the workpiece is associated with the passage of hardening processes such as return and polygonization.

Evaluation of the microstructure of billets from aluminum alloy 7075, rolled at the beginning in helical rolls and subsequently extruded in a die, showed that at a processing temperature of 300 °C, a fine-grained structure is formed in the billet metal. In this case, the average grain size in the peripheral part of the workpiece is 11 μm, and in the central layers - 16 μm. The formation of a fine-grained structure can be associated with the passage of stable primary recrystallization throughout the entire volume of the billet when the billets are extruded on the RSM of a new design with helical rolls.

Based on the data obtained, it can be concluded that during rolling-extrusion of billets on a RSM with smooth rolls, recrystallization processes take place in the peripheral zones of the billet, while in the central zones of the billet, processes of return and polygonization take place. The passage of these processes contributes to the preservation of the original structure in this zone.

When rolling billets in the helical rolls of a new mill, recrystallization processes in the peripheral regions of the billet are much easier than in the central regions. We believe that the reason for the good passage of such a softening process is the increased values of the deformation intensity and temperature in the peripheral zones of the rolled billet.

Further extrusion of the billet in the matrix of this mill leads to a less intensive passage of medynamic and dynamic recrystallization in the peripheral zones and their intensive passage through the central regions of the billet. The reason for such a relatively slow passage of recrystallization in the peripheral zones of the workpiece is an increase in the friction force in the contact zone of the workpiece metal with the tool.

Thus, after rolling and extruding the billet on a RSM with helical rolls, the grain sizes along the bar cross section are leveled and a fine-grained structure is formed.

CONCLUSION

The simulation results showed that the use of RSM with helical rolls allows efficient deformation of the 7075-aluminum alloy structure over the entire section of the workpiece and thereby obtains a bar with a fine-grained structure.

It is shown that the rotational-translational deformation of the workpiece arising during processing on the RSM of a new design ensures the development of shear deformations along the entire section of the workpiece, which leads to the formation of a fine-grained structure in the rods of aluminum alloys 7075.

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Note: the responsible for English language is D. Rahimbekova Kazakhstan