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NEW-DESIGN RADIAL-SHEAR ROLLING MILL (RSRM) AUTOMATION

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The article deals with a new-design radial-shear rolling mill combined with pressing function. Finite element methods and MSC.SuperForge SW were used to generate quantitative data and establish basic patterns of strain-stress state (SSS) and temperature distribution during workpieces rolling-pressing in helical rollers. Formulas were derived by theoretical data approximation to allow a highly accurate determination of the SSS and temperature distribution pattern in the deformed workpiece. An equation-based mathematical model for the RSRM operation is proposed. The RSRM operation mathematical model is implemented in WinCC 7.0 and Step 7 SW using FBD and SCL PL. Sensor-derived data allow to automatically adjust the process modes of manufacture of bars and wires while avoiding any production defects.

Keywords: rolling mill, pressing, strain-stress, temperature, mathematical model.

INTRODUCTION

Multiple researches [1] focus on casting and rolling facilities as the object of study, which are used for combined casting and rolling processes to produce long components from metals and alloys.

Authors of a number of works [1,2] point out that the development of a mathematical model allowing to comprehensively describe the effect of inter-related process parameters on components of combined units, makes it possible to calculate, visualize the process, and fine-tune operation algorithms in a virtual model.

The publication [2] provides evidence that simulation calculations of combined processes can be carried out using a mathematical model of the process integrated in the program. In this setting, steady-state automatic control of combined processes ensures constant feeding of metal, predetermined temperatures at the inlet of the rolling mill and the matrix outlet, as well as a predetermined temperature in the pressing assembly.

The analysis of publications [2] suggests that modern rolling mills operation lacks efficiency without computer-assisted control of their mechanical assemblies, temperature and deformation modes, etc.

The purpose of this work is to establish a new-design radial-shear rolling mill (RSRM) automated control system.

MATERIALS AND EXPERIMENT METHODS

In this paper a new-design RSRM is proposed. [3] The radial-shear rolling mill for bar or wire pressing is comprised of the main drive, work stand, roller assembly and press matrix. The RSRM three-roll work stand consists of a frame, in the bores of which working roll units are mounted with a 120° spacing around rolling axis. The working rolls are mounted on the pads, with torque transmitted to them via the spindles of motors. The new mill stands design provides for the opportunity to arrange the rollers at various angles to the rolling axis and an 18 mm tangential displacement relative to it. The mill rolls feature smooth and wavy-conical grip and compression sections, respectively, as well as calibrating cylindrical portions. It should be noted that the protrusions and hollows of wavy-conical conical sections are located along a helical line. In this case, the geometrical dimensions of the protrusions and hollows are gradually reduced in the direction of rolling.

The workpiece is rolled by the rolls in the course of bars or wires pressing. The rotational movement of the rolls ensures translational and rotational forward motion of the metal workpiece being deformed in the direction of rolling and extrusion of it through the matrix hole.

MSC.SuperForge software package was used to determine rational temperature-deformation modes of rolling and pressing. The three-dimensional geometric model of the workpiece, the rolls and the matrix was designed in Inventor CAD program and imported into MSC.SuperForge CAE program. Technical specifications of the proposed RSRM were used to calculate stress-strain state (SSS).

Modeling of the process tested using MSC.SuperForge software package was performed as follows [4]:

1 CTETRA dimensional element was chosen (quadrinodal tetrahedron used for modeling of three-dimensional bodies) with the finite element grid applied to the workpiece.

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2 Using either MSC.SuperForge database or thermo-mechanical properties of the workpiece material, the rheological properties of the workpiece were set (to simulate the plasticity of the workpiece material Johnson-Cook elastoplastic model was chosen).
3 The initial pressing temperature of the workpiece was set.
4 The conditions at the interface of the workpiece, roller, and matrix were set, i.e. friction coefficient (the contact between the tool and the bar was simulated based on Coulomb's friction law, with the friction coefficient set to 0,3).
5 Depending on the type of equipment used, the law of motion of the movable tool was established.
6 Highly accurate calculations of the workpiece SSS were performed, as well as calculations of normal pressure force, temperature distribution across the workpiece body.

It should be noted that in implementing the above-described operations using MSC.SuperForge program complex the calculation results were generated in the form of the fields of distribution of the respective parameters across the body being deformed or in the form of numerical values of the tested parameters at the crosspoints of the deformed grid.

A circular cross-section workpiece of aluminum alloy D16 sized Ø 40 × 150 mm was used to study the bars pressing process on the RSRM. Pressing operations on the RSRM were carried out at temperatures of 200, 250, 300, 350 and 400 °C to a diameter of 6 mm and 9 mm. The elongation ratio, feed and rolling angles were varied in the course of pressing. 9X1 grade steel was chosen as tool material from the materials database. Since the rolling process is run at room temperature, the initial temperature of the rolls was set to 20 °C.

Data obtained using computer simulation, such as stress and strain intensity, temperature field, pressure and strain at the rolls and the matrix, were grouped in a data set and approximated using an exponential equation. The accuracy of approximation was evaluated using R^2 determination coefficient.

RESULTS AND DISCUSSION

Using state transition and structural state diagrams, we found that the temperature range of aluminum alloys rolling should vary within the range of 200 - 400 °C, and maintain at 400 °C in the course of pressing. Metal deformation heating was taken into account during the procedure.

Based on the numerical simulation results obtained it was determined that:

– at the initial phase of pressing, contact pressure is localized in the sections where the workpiece is gripped by the working surfaces of the rolls;
– further rolling in helical rolls results in an increased contact pressure and contact area across the deformation zone;
– subsequent pressing of the workpiece leads to an increase in contact pressure in the matrix, which is typical of the extrusion process, together with an increase in contact pressure at the rolls. These effects are caused by the growth of backup pressure in the deformation zone due to extrusion force;
– in the course of bars pressing on the RSRM, the contact pressure at the rollers is greater than that at the matrix. This is caused by an increase in the workpiece contact surface during rolling with three rolls and a dynamic backup pressure increase in the deformation zone due to extrusion forces;
– pressing on the RSRM leads to an intense increase in the temperature at bars area within zones of metal contact with the roll and the matrix, i.e., as elongation increases, there is an increase in the temperature of up to 500 °C on the workpiece surface.

Based on the obtained results it can be concluded that pressing of workpieces on the new-design RSRM leads to an intense increase of pressure and temperature at the bar sections located within areas of contact of metal with the roll. In this setting, an increase in elongation ratio, feed and rolling angles lead to further increase of pressure and temperature on the workpiece surface.

When rolling on helical rollers and pressing in the matrix of the new-design RSRM, the metal piece advances along a helical path at different velocities of outer and inner layers. Metal feed movement at various velocities causes intense shear displacement in the workpiece body, which leads to a significant increase in stress intensity s contributes to a significant refinement of grains and obtaining a fine-grained structure. It should be noted that, as elongation ratio, feed and rolling angles increase, a gradual increase in strain rate intensity and strain is observed over the cross section of the workpiece.

The dataset obtained using computer simulation was approximated by exponential equations $x = a \cdot y^b$, where x is temperature; pressure; strain rate intensity; stress intensity; strain intensity; y is elongatioand strain rate, as well as strain intensity. All thin ratio, feed and rolling angles; a and b are unknown coefficients of the equation. This being said, approximation equations were selected so that $R^2 = 0,70 – 0,99$ (approximation equations are not provided due to their large extent). The equations obtained were used for automatic assignment of rational temperature-deformation modes of rolling and pressing.

To visualize the simulation model calculations and develop computer program «Automatic control of process modes of bars and wires pressing on the RSRM», it created projects Simatic Step 7 and Simatic WinCC 7.0 software products. Simatic Step 7 is standard SIMATIC software used to create programs for SIMATIC S7-

300/400 programmable logic controllers [5]. This software is extensively used in controllers programming as well as configuration (setting) of rolling mills and networks. Configuration utilities allow to carry out diagnostics and correct installation of equipment, detect hardware errors, etc. Controllers are programmed using the program editor allowing to write programs in three main languages: LAD - ladder logic language; FBD - functional block diagram language; STL - instruction list language. Extra four languages can be used: SCL - structured control language; GRAPH 7 - sequential process control language; HiGraph 7 - system states graph-based control language; SFC - state diagrams language.

The draft program developed by us consists of blocks of data, functions, and an organizational block. The organizational block is composed of FBDs. FBD is a graphical programming language used to represent the logical operations as logical blocks known in Boolean algebra [6].

The initial data are entered into BD100 basic data block, i.e. all the program data required to initiate calculation are obtained from BD100 data block. From the data obtained using computer simulation, the program will select the optimal process parameters, and these data will be transmitted to BD100 block. For example, the program selects the optimal temperature values of workpieces from BD1 block data obtained using computer simulation and sends it to BD100 block. Similarly, BD2, BD3, BD4, BD5, BD6, BD7 blocks contain simulation modeling data on the distribution of rolling force in the rollers, pressing force in the matrix, stress intensity, strain rate, rolling speed and single pressings, which will also be transmitted to BD100 block in the course of pressing. Functions F1, F2, ..., F7 correspond to BD1, BD2, BD3, BD4, BD5, BD6, BD7 data blocks. For example, in BD1 initial and calculated data on the distribution of temperatures of metal workpieces will be stored, while F1 will contain the algorithm of data conversion in BD1 block, i.e., F1 function processes data obtained by computer simulation and determines the optimum parameters of the pressing process. At the end of the calculation data will be sent to BD100 block to generate a summary table of process parameters.

F1, F2, ..., F7 functions are created by applying SCL (Structured Control Language) [7]. This is a high-level programming language for PLC SIMATIC S7. SCL language is very well suited for programming difficult algorithms or tasks related to data management, supports the block structure characteristic for Step 7, and also allows to create S7 programs, including fragments on basic programming languages, namely, STL, LAD and FBD. SCL is applied in the program due to its simplicity in optimization problems solving.

OB1 organizational block will be included in the program structure. In this block, a between-blocks data transfer will be carried out.

To visualize data calculated using the model, a mnemonic diagram was designed in Simatic WinCC 7.0 software product for the process of pressing bars and wire on the RSRM. Simatic WinCC (Windows Control Center) is a powerful HMI system. This system runs on Microsoft Windows XP, Windows Vista and Microsoft Windows Server 2003 [8]. HMI stands for Human Machine Interface (HMI), i.e., the interface for communication between human and machine. WinCC system allows to control and monitor the process running on the RSRM. The automation system ensures a connection between WinCC and the radial-shear rolling mill.

Some of WinCC options are as follows [8]: technical process visualization (Graphic Designer); configuration and setup of communication with the controllers of various manufacturers (Tag Management); displaying, archiving and logging of process-generated messages (Alarm Logging); displaying, archiving and logging of variables (Tag Logging); open OPC-interface (OLE for Process Control); interaction with Simatic Step 7 package.

It should be noted, that the choice of this software was based on WinCC options.

Based on the above results it can be noted that at the initial stage simulation modeling of bars and wires pressing from non-ferrous metals was carried out. Next, based on these data, a mathematical model was developed for the RSRM components operation control. This model is implemented in Step 7 and WinCC 7.0 software packages.

The modeling results were used in designing and introduction of the RSRM and the technology for production of bars and wire on this mill for the needs of various industries.

CONCLUSIONS

1 In the course of processing on the RSRM, rotational-translational movement and deformation of the workpiece ensures shear straining across the entire section of the workpiece that results in an effective crushing of the structure and formation of fine-grain structure of bars and wires, thus, obtaining high quality products.

2 In the proposed mill a modern automated control system is used which allows to deform the workpiece under rational temperature-deformation processing modes.

3 The rational rolling-pressing modes introduced in the program allow to automatically maintain rational technological parameters.

4 The implementation of the RSRM Automatic Process Control System described in the article ensures a reduction in the number of defective bars and wires, reduction in the RSRM power consumption, as well as time required for maintenance of the rolling mill.

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