DEVELOPMENT AND COMPUTER SIMULATION OF A NEW TECHNOLOGY FOR FORMING AND STRENGTHENING SCREW FITTINGS

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ABSTRACT

The paper presents the results of computer simulation of a new technology for forming and strengthening screw fittings, carried out using the planned experiment. The purpose of the simulation was to determine the parameters at which the deformation process is stable. The friction coefficient in the rolls, the distance of the matrix from the forming rolls and the initial diameter of the workpiece were selected as variable factors. The workpiece speed was considered as the main parameter and the model was considered unsuccessful if the front end of the workpiece had a zero value of speed (the workpiece was stuck). It was found that all three parameters have a significant impact on the process stability. The best parameters are an increase in the friction coefficient in the rolls and the initial diameter of the workpiece (or absolute compression in the rolls) and a decrease in the distance of the matrix from the forming rolls. Also, a rational factor that has a beneficial effect on the process is the reduction of backpressure from the matrix, which can be realized by reducing its length.

Keywords: severe plastic deformation, radial-shear rolling, twisting, combined process, simulation, planned experiment.

INTRODUCTION

Screw reinforcement rolling differs from the usual one in that the ribs of its periodic profile serve not only to strengthen adhesion to concrete, but also, due to their special arrangement, form a modified large screw thread along the entire length of the rods, making it possible to screw various kinds of threaded fasteners - nuts, connecting couplings, anchor nuts with a similar internal thread. Thus, the reinforcing bar essentially turns into a threaded stud of large length (up to 12 m from transportation conditions), which opens up a variety of possibilities for the use of such fittings in construction. At the moment, there is no screw reinforcement profile in Kazakhstan. Therefore, the development of the production of screw reinforcement bars in Kazakhstan will help to get rid of dependence on its supply from abroad, which can provide a serious economic effect, especially in the construction of transport and underground structures.

Traditionally, steel reinforcement is obtained from a round lining by hot rolling to form a reinforcing profile and subsequent hardening of low-alloy steel to ensure the required mechanical and plastic properties [1]. The disadvantage of such methods is the use of energy-intensive processes of hot deformation and heat treatment.

A method of thermomechanical processing of rolled products is known, related to ferrous metallurgy, in particular to the manufacture of heat-strengthened core reinforcing steel in large profiles using heat of rolling heating from continuously cast low-alloy steel during thermal hardening of rolled products in the flow of medium-grade mills [2]. However, the method requires the creation of a specialized production line with a high-tech system for matching processing speeds and provides for an energy-intensive operation of plastic reinforcement profile formation.

A method is known for rolling reinforcement of a periodic screw profile made of alloy steel 25G2S, 30HG2S, 35GS for reinforced concrete structures, including hot rolling of reinforcement from a tubular billet and rolling ridges on its surface in the form of reefs, while the ridges are rolled in a hot state by transverse rolling along the right or left single-pass or multi-pass helical spiral [3]. The method includes hot rolling and rolling of a helical spiral, which are very energy-intensive operations and significantly increase the cost of production.

There is also a known method for strengthening a reinforcing bar made of a material with a yield point, including twisting the reinforcing bar around its longitudinal axis with an excess of the yield strength of the material of the outer fibers of the reinforcing bar to reach the strength limit level, while twisting one end of the reinforcing bar is fixed, and twisting the reinforcing bar is performed from the other end to the formation of a non-twisting helical shape along the entire length of the rod [4].

An alternative solution to the problem of reinforcement profile hardening is the use of severe plastic deformation (SPD) in its production [5]. Currently, a number of combined processes have already been developed, which make it possible to process long blanks with a sufficient degree of elaboration of the cast metal structure to obtain an ultrafine-grained structure in it [6 - 14]. One of the latest such developments is the process, which combines the reduction rolling of a rod of round or square cross-section in a square caliber with twisting in a molding matrix (twisting mechanism) [15]. This combined method makes it possible to obtain a reinforced reinforcement profile with a gradient ultrafine-grained structure [16]. Despite the rather simple design and effective processing of the initial workpiece, this method has a significant drawback associated with its manufacturability. When transferring production to a different size assortment, you will need not only a new matrix, but also a new pair of rolls with a caliber of the specified sizes.

In order to increase the manufacturability of the process of obtaining a reinforced reinforcing profile, a new scheme for its formation, including deformation of a round cross-section workpiece on a radial-shear rolling mill (RSR) and subsequent twisting of the workpiece in a special design molding matrix was proposed (Fig. 1) (similar to the one presented in [15]). The use of radial-shear rolling instead of longitudinal rolling will provide a more intensive processing of the initial structure of the metal and ensure the formation of a gradient ultrafine-grained structure, due to the fact that, in the deformation zone during radial-shear rolling, a stress state scheme close to comprehensive compression with large shear deformations is implemented [17 - 19]. It is this deformation scheme that is optimal for the formation of a gradient ultrafine-grained structure in various materials with a minimum number of passes.

The development of new methods or technological processes for processing and obtaining metal products is quite a complex task and requires an integrated approach. At the initial stage of development, the main goal is to determine the possibility of implementing these methods or processes, which is carried out by conducting numerous complex calculations. One of the tools that make it easier to carry out calculations is the use of programs that carry out computer modeling by the finite element method (FEM). In addition, modern software complexes of FEM modeling provide the user with a wide range of opportunities to study the processes of metal forming, allowing for a complete analysis of the parameters of the stress-strain state of the workpiece, energy-strength parameters, etc., which in turn allows, after their analysis, to optimize the process of obtaining metal products.

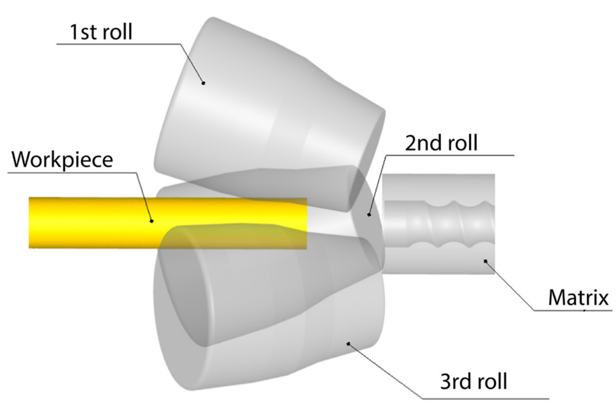

Fig. 1. Scheme of new combined process.

The purpose of this work is computer modeling of the combined process of radial-shear rolling and twisting in a screw matrix to determine rational geometric and technological parameters that allow implementing a new technology for forming and strengthening screw fittings in practice.

EXPERIMENTAL

The main deforming tool is a three-roll radial shear rolling mill, rolling the workpiece to a smaller diameter and pushing it through a screw matrix. The construction of solid-state models of the tool and the workpiece was carried out in the KOMPAS software package [20]. Modeling of the process was carried out in the DEFORM software package [21].

When creating a computer model of a new combined process, the parameters of the radial shear rolling mill 10-30 were used as the main equipment. In particular, the dimensions of the rolls and their structural arrangement correspond to the design of this particular rolling mill. When designing the matrix structure, it was decided to make it out of two zones - a deforming screw and a smooth one, acting as a stabilizer and wiring into the screw part (Fig. 1).

When creating a model in the Deform program, the following assumptions were made at the first stage:

- the material of the workpiece is isotropic, there are no initial strain, discontinuities, inclusions, etc.;
- the type of workpiece is plastic, the type of tools is rigid;
- a grid of 85,000 finite elements with an average element edge length of 1.3 mm is applied to the workpiece;
- the material of the workpiece is AISI1015 steel;
- the initial heating temperature of the workpiece was 1100°C;
- temperature of rolls, matrix and environment was 20°C;
- the heat transfer coefficient between the workpiece and the tool was assumed to be equal to 5 kW/(m^2 °C), as the recommended value by the Deform program for deformation processes. The heat transfer between the workpiece and the environment has been activated;
- the matrix length was adopted 50 mm;
- the rolls rotation speed was assumed to be 100 rpm;
- at the contact of the workpiece and the tool (in the matrix), the type of friction according to Siebel was established with a friction coefficient of 0.1 (in accordance with the results obtained in [22]);
- 1000 calculation steps were set with a time increment of 0.01 sec/step.

The following parameters were selected as variable factors:

- friction coefficient in the rolls - X_1;
- the distance of the matrix from the forming rolls - X_2;
- the initial diameter of the workpiece - X_3.

In computer modeling, in all cases, the final diameter of the workpiece after deformation on the radial shear rolling mill was 19 mm, namely, the initial diameter varied, due to this, the relative compression of the workpiece in the rolls varied.

The deformation process according to the new combined scheme was regulated by changing variable factors X_i (Table 1).

RESULTS AND DISCUSSION

The optimization parameter of this experiment was the successful (or unsuccessful) implementation of a new energy-efficient technology for obtaining hardened screw fittings. The experiment planning matrix and the obtained results are shown in Table 2. Here the symbol (+) means that factor is at the top level; the symbol (-) means that factor is at the lower level; the symbol zero (0) means that the factor is at the basic level.

During the simulation, all possible models were built, taking into account the combination and variation of all the above factors. After the simulation, a number

Table 1. Conditions of the experiment.

Factors	Basic level	Variation interval	Upper level	Lower level	Measurement unit
X_1	0.5	0.2	0.7	0.3	-
X_2	10	9	19	1	mm
X_3	22	2	24	20	mm

Table 2. Planning matrix and the result of computer modeling.

№	Factors			Optimization parameter У
	X_1	X_2	X_3	
1	-	+	+	failed model
2	+	+	+	failed model (Fig. 2)
3	-	-	+	failed model
4	+	-	+	successful model (Fig. 4)
5	-	+	-	failed model
6	+	+	-	failed model
7	-	-	-	failed model
8	+	-	-	failed model
Experiments with the values of some factors at the basic level				
9	0	0	0	failed model
10	0	-	+	failed model
11	0	-	0	failed model
12	+	-	0	failed model (Fig. 3)

of unsuccessful models were obtained (Fig. 2 and Fig. 3), and one successful model of a new combined process of radial-shear rolling and twisting in a screw matrix (Fig. 4).

Analysis the influence of the distance between the screw matrix and the forming rolls showed that an increase in this distance negatively affects the process of forming the reinforcement profile. So at a certain moment of the passage of the workpiece through the matrix channel due to the increasing forces of contact friction between the workpiece and the matrix channel, it begins to additionally twist arbitrarily in the free space between the screw matrix and the forming rolls, which leads to the accumulation of metal before entering the matrix channel and subsequent jamming of the workpiece in the matrix (Fig. 2). Analysis the effect of the friction coefficient in the rolls showed that when it decreases, the workpiece slips in the rolls, since the pushing force is not enough even to push the workpiece into the screw matrix.

The implementation of the combined process at rational values of factor X_1 and X_2, i.e. with a friction coefficient in the rolls of 0.7 and the distance of the matrix from the forming rolls of 1 mm, but with less compression of the workpiece in the rolls (experiment No. 12), also did not allow to achieve a positive result. In this case the blank filled almost the entire channel of the screw matrix, but still stopped almost at the exit from it (Fig. 3). This can be explained by the fact that the contact area of the workpiece with the screw matrix

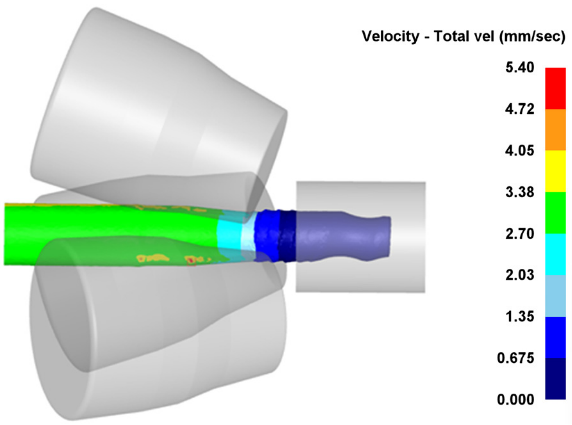

Fig. 2. The model with the matrix arrangement from the forming rolls at a distance of 19 mm.

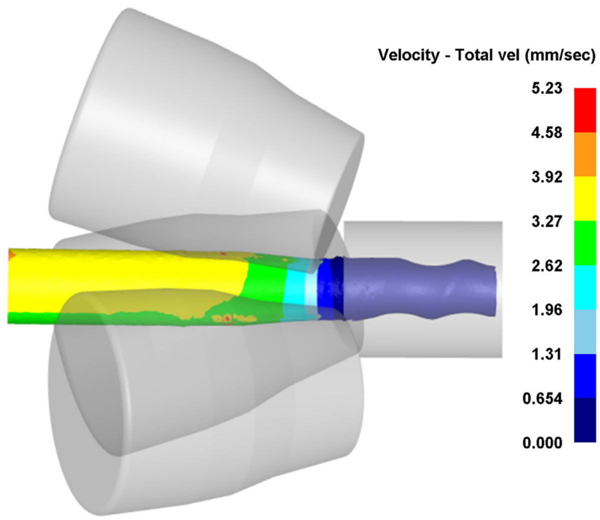

Fig. 3. The model with the values of variable factors in experiment No. 12 of the planning matrix.

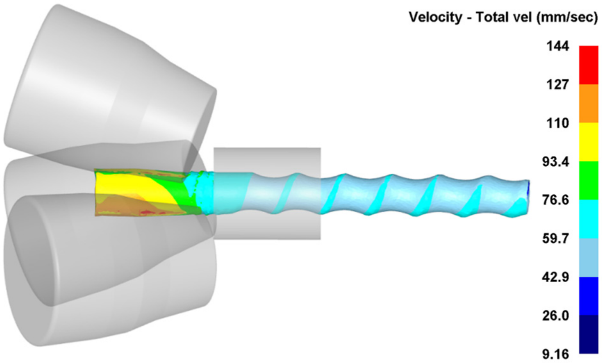

Fig. 4. Successful model.

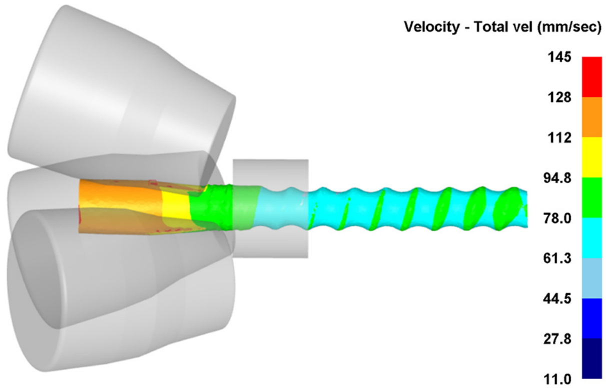

Fig. 5. Successful model with a shortened matrix.

at this moment has reached almost the maximum value and the rolling force begins to be insufficient for further pushing the workpiece through the channel of the screw matrix.

A successful model was obtained only with the following geometric and technological factors: the friction coefficient in the rolls is 0.7; the distance of the matrix from the forming rolls is 1 mm; the initial diameter of the workpiece is (at least) 24 mm (Fig. 4).

This model can be considered successful, because in this case the reinforcement profile was formed, and the workpiece completely passed through the screw matrix. But for its implementation, a large compression of the initial workpiece in the rolls of the radial-shear rolling mill is required. It is possible to reduce the amount of necessary compression of the initial workpiece in the rolls, including in the following two ways:

- by increasing the friction coefficient in the rolls, which is unreasonable due to the use of its maximum possible real value [20];
- by reducing the friction coefficient in the matrix, but this will be difficult to implement in practice even when setting up a laboratory experiment.

Therefore, in order to reduce the necessary compression of the initial workpiece in the rolls for its successful pushing through the matrix and the formation of the correct reinforcement profile, based on the results already obtained, the matrix design was adjusted by reducing its length to 33 mm. This will allow to reduce the friction forces in the matrix by reducing the contact area of the workpiece with the matrix. When modeling the process of implementing a new combined process with a shortened matrix, the following parameters were taken: the distance of the matrix from the forming rolls is 1 mm; the coefficient of friction on the rolls is 0.7, in the matrix 0.1; the diameter of the initial workpiece is 22 mm.

The constructed model was successful. As can be seen from the simulation results (Fig. 5), this model implements a sufficiently complete filling of the screw channel of the matrix, which allows you to obtain a given profile without the occurrence of jamming of the workpiece or its decompression at the entrance to the matrix.

CONCLUSIONS

The computer simulation of the new process of obtaining a reinforcement profile by the combined process of radial-shear rolling and twisting in order to determine the feasibility of this process in reality showed that this process can be implemented in practice, but it is necessary to correctly select the main technological and geometric parameters of the implementation of this process.

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