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STUDIES OF THE ROLLING OF RIBBED BARS USING THE DEFORM SOFTWARE PACKAGE

I. I. Nekrasov, A. P. Karamyshev, V. S. Parshin, and A. A. Fedulov

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The software package DEFORM-3D is used to construct a mathematical model of the rolling of ribbed bars that makes it possible to determine the change in the shape of the bar, the stress state of the metal in the deformation zone, and the energy-force parameters of the rolling operation. The model accounts for the strain-hardening of the metal during cold deformation and the periodic nature of this process. Experiments confirm that the model adequately describes the actual deformation process. The results obtained from the model can be used to design new production equipment and tools for the given method of metal-shaping and to assess the feasibility of using existing rolling mills to form ribs on different types of flat-rolled semifinished products.

Key words: *formation of ribs, rolling of ribbed bars, mathematical model, shaping of metal, energy-force parameters.*

Technology that uses different methods [1] to form ribs on bars and flat-rolled products is employed in the production of corrugated sheets and bars, ribbed welded tubes, lath, and other goods. The most efficient method of production is the deformation of a flat-rolled semifinished product in rolls with a specially shaped body on hot- and cold-rolling mills. In order to design such technologies and the necessary tools and equipment or to assess the feasibility of using existing rolling mills, it is necessary to know the amount of reduction that will be required, the amount of friction created during rolling, the geometry of the tool, the energy-force parameters of the rolling operation, and the parameters that characterize the deformation of the metal. All these factors affect one another.

The known theoretical studies that have been made of processes used to roll ribbed sheets and bars are based on the use of analytical methods from the mechanics of deformable solids. These methods were developed for specific rib profiles and are thus not universal in scope. The applicability of the methods is also restricted by the large number of assumptions that are made, which diminishes the accuracy of the calculated results. Also, the absence of symmetry in the case in which ribs are formed on just one side of the product means that the methods cannot yield proven analytical expressions for determining the energy-force parameters of the rolling operation and cannot be used to study the distribution of the loads acting on the mill rolls.

The use of modern software products that employ the finite-element method to describe metal-shaping operations is the most effective approach to determining the stress-strain state of the metal and the energy-force parameters during the rolling of sheet and bars with ribs of different shapes. One such product is DEFORM, a software package developed by the U.S. company Scientific Forming Technologies Corporation [2]. The use of this software together with a three-dimensional modeling system such as SolidWorks makes it possible to create prototypes of rolling-mill rolls, guides, and the initial semifinished products. These prototypes are then transferred to the DEFORM pre-processor, which breaks them down into finite elements and assigns the properties of the material, the boundary conditions, and the loading parameters (see Fig. 1).

Yeltsin Ural Federal University (UrFU), Ekaterinburg, Russia; e-mail: nekrasovii@yandex.ru. Translated from Metallurg, No. 3, pp. 40–42, March, 2011. Original article submitted September 23, 2010.

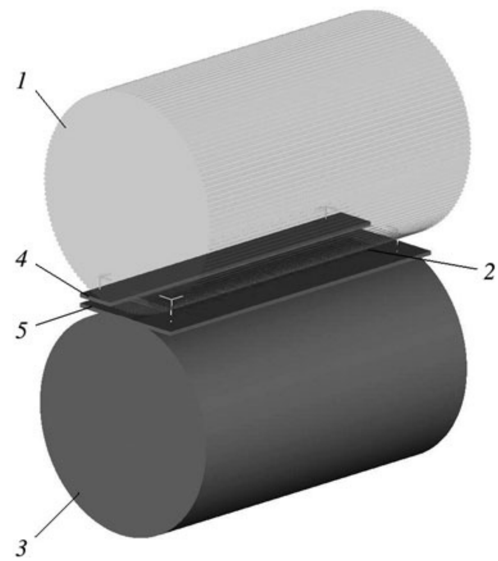

Fig. 1. Diagram of the process of forming ribs: *1*) shaped top roll; *2*) semifinished product; *3*) smooth bottom roll; *4*, *5*) top and bottom guides.

After the problem has been solved, the results are output by the post-processor in the form of graphs, projection diagrams, schematics, or tables.

The Department of Metallurgical and Rotating Machinery at the Ural Federal University conducted theoretical studies of the cold rolling of skelp with the formation of transverse ribs on one side of the rolled product. The researchers examined the use of rolling mills with trapezoidal teeth. The skelp rolled with such rolls serves as the semifinished product for the production of straight-seam electric-welded tubing employed in refrigeration units. The following were the constant parameters in the theoretical studies: material of the skelp (steel 10); skelp width (70 mm); skelp thickness (1.5 mm); distance between the ribs (1.26 mm). The reduction that was made in rolling the skelp varied within the range 6–18%.

It follows from the calculated results that to a large extent the amount of reduction of the strip determines whether or not the depressions formed by the teeth will be filled with metal, i.e., an increase in the reduction of the initial semifinished product is accompanied by an increase in the height of the ribs that are formed (Table 1). In any case, the final thickness of the skelp, measured at the vertices of the projecting ribs, turned out to be less than the thickness of the initial semifinished product.

The rolling force, the rolling moment, and the moments on the spindles of the rolls also increase with an increase in the reduction of the skelp. The rolling forces and moments were compared to the results calculated with the DEFORM program for the case of the rolling of skelp of the above-described type in smooth rolls under the same conditions. The comparison showed that the presence of the toothed ragging on the rolls leads to a change in the energy-force parameters of the rolling operation (Tables 2 and 3). Decreases are seen in both the rolling force (to 24.7% for a reduction of 6%) and rolling moment (to 23.7% for a reduction of 18%).

The calculated results also show that the moments are unevenly distributed between the rolls. For example, the smooth bottom roll was loaded by a greater torque than the ragged top roll. This can be attributed to the fact that the resultants of the normal pressures within the deformation zone are in different locations on the top and bottom rolls. The distribution of the moments between the rolls becomes more uniform with a decrease in size of the reduction that is made. Theoretical studies performed with the program DEFORM also showed that the forces and moments created during the rolling of skelp with transverse ribs on one side were periodic in character.

The results presented here agree satisfactorily with the existing experimental data. For example, Tables 1 and 2 show calculated and experimental data for the rolling of skelp with unilateral transverse ribs of trapezoidal form. These data were

TABLE 1. Height of Ribs for Different Degrees of Reduction of the Strip

Reduction, %	Rib height, mm		Difference, %
	theoretical	experimental	
6	0.055	0.05	10.0
9	0.082	0.08	2.5
12	0.109	0.11	0.9
15	0.136	0.14	2.9
18	0.163	0.17	4.1

TABLE 2. Change in the Rolling Force with a Change in the Reduction

Reduction, %	Rolling force with the formation of ribs, kN		Theoretical force with a smooth roll, kN
	theoretical	experimental	
6	40.5	39.7	50.5
9	53.4	52.7	64.6
12	66.3	65.8	78.6
15	79.3	78.9	92.7
18	92.2	91.9	106.8

TABLE 3. Change in the Rolling Moment in Relation to the Reduction of the Strip

Reduction, %	Theoretical value of rolling moment, kN·m		Difference, %
	rolling with the formation of ribs	smooth rolling	
6	0.067	0.081	20.9
9	0.107	0.131	22.4
12	0.148	0.182	23.0
15	0.188	0.232	23.4
18	0.228	0.282	23.7

obtained from the rolling of skelp that is used as a semifinished product for making straight-seam electric-welded tubes with a diameter of 22×1.5. The rolling operation was performed on a four-high $55 \times 260 \times 220$ laboratory mill equipped with strain gages. The top work roll had a trapezoidal ragged profile 0.4 mm deep. The ribs were spaced 1.26 mm apart and the angle of their profile was 30°. Universal measuring microscope UIM-23 was used to determine the geometric parameters of the ribs obtained from the rolling operation. Statistical analysis of the experimental results made it possible to determine the dependence of the measured quantities on the reduction made in the rolling of the skelp. It can be seen from Table 1 that the largest difference between the height of the ribs obtained in the experiment performed on the $55 \times 260 \times 220$ mill and calculated with the program DEFORM was 10%. Good agreement was also obtained in regard to the dependence of the rolling force on the reduction of the strip (see Table 2). The values of rolling force obtained by experiment and calculation did not differ by more than 2%. All of this points to the adequacy of the given mathematical model with respect to the actual conditions of deformation of the metal.

Conclusions. Studies that were made using the software package DEFORM to examine the rolling of strip with unilateral transverse ribs have made it possible to determine the dependence of the height of the ribs and the energy-force parameters of the process on the degree of reduction of the strip. The data obtained from modeling the process make it possible to design rolling-mill equipment and tools for forming ribs, evaluate the feasibility of using existing rolling mills, and control the rolling operation.

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