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STUDY OF TRANSIENTS IN METAL-SHAPING

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This article examines the choice of the computer program DEFORM for finite-element analysis of transients in metal-shaping operations (MSO). The possibilities of the program for solving nonsteady problems that are fairly difficult to model are explored by using two different MSO as an example – forging on an AVS radial-forging machine with complex motion of the tool and the rolling of strip with the formation of fins on one side. The results of the solution are analyzed using the DEFORM post-processor. The availability of experimental data on the rolling of unilaterally finned strip and the forging of bars on AVS machines made it possible to evaluate the accuracy of the theoretical results. It is concluded that use of the DEFORM program is effective for studying transients in MSO. The data obtained in the process make it possible to design new and improve existing technologies and machines for shaping metals.
Key words: *finite-elements method, DEFORM program, MSO transient, radial-forging machine, rolling of strip with finning, equivalent stresses, rolling force.*

Reliable information on the processes that take place in metal-shaping operations (MSO) and on the loads that act on the equipment which is used is obtained by experimental, theoretical, and experimental-theoretical methods. Although experimental methods provide the most accurate results, quite often they are not used due to the cost of the necessary testing equipment or the fact that the conditions which the experiment would simulate are not often encountered in practice. Thus, increasing use is being made of theoretical methods to study the processes and equipment employed in metal-shaping. This trend has arisen in particular because of advances in mathematical methods of calculation based on the creation of finite-element models.

With the advent of powerful computer-based methods of calculation and the associated software, the finite-elements method (MFE) has reached such a level of sophistication and popularity that it now has almost no competition in terms of its simplicity and range of application. There are now many universal and narrowly focused application packages in which the computational module is based on the MFE in one form or another. Among the best-known are ANSYS, DEFORM, LS-DYNA, NASTRAN, and ABAQUS.

The Metallurgical and Rotating Machine Department of Ural State Technical University is conducting theoretical studies of the nonsteady processes that take place in MSO and is using the software DEFORM, which was developed by the Scientific Forming Technologies Corporation (SFTC) in the U.S. This company is one of the leaders in modeling metal-shaping operations. The main advantages of DEFORM are its universality, its compatibility with other software products, its simple and convenient interface, and the broad possibilities it offers for modeling.

Examples of nonsteady processes in MSO are the forging of bars and tubes on AVS radial-forging machines [1] and the cold rolling of sheet and strip with the formation of fins on one side of the product. The semifinished products in these cases are subjected to stresses and strains that vary over time throughout volume of the metal. The variations in the parame-

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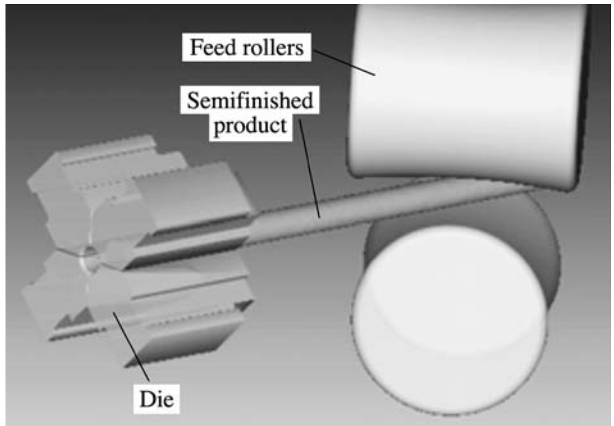


Fig. 1. The deformation process on an AVS radial-forging machine.

ters of the deformation zone are due to the complex motion of the dies in the first case and the presence of a top roll with a specially shaped cogged surface in the second case. Certain difficulties are encountered when attempting to model transients in MSO, especially when allowance is made for the strain-hardening of the material of the semifinished product.

The first step in modeling forging and rolling with the use of DEFORM and the automated design system SolidWorks entailed the construction of virtual prototypes of the tool and the semifinished products in SolidWorks and transfer of the geometry to the DEFORM pre-processor. Figure 1 depicts the deformation process on an AVS radial-forging machine that includes four dies, the semifinished product, and feed rollers. Figure 2 presents a simplified representation of the deformation zone in the rolling of sheet and strip with the formation of fins on one side. The tool and semifinished products that were developed for our investigation reflected the processes that take place during forging and rolling. In the first case, they were for the forging of 30-mm-diam. bars of steel 0Kh18N10T on an AVS-63 radial-forging machine with a reduction to a diameter of 26.5 mm. In the second case, they were for the rolling of 1.5-mm-thick strip made of steel 20. The strip was 70 mm wide and was rolled on a $55 \times 260 \times 220$ four-high laboratory stand to obtain trapezoidal fins 0.1–0.25 mm high across one side of the strip. The backup rolls were excluded from the investigation, since they do not affect the parameters of the process being examined.

We then divided the three-dimensional models that were created into finite elements by using DEFORM, determined the laws that govern the motion of the tool, selected the method to be used to secure the semifinished products, assigned the physicomechanical characteristics of the materials of the semifinished product and the tool, and chose the law governing friction in the contact region between them. The DEFORM pre-processor was used to designate the values of the quantities that control the operation of the processor and allow the solution of the problem to be fully monitored.

The post-processor of the DEFORM software makes it possible to fully analyze the results of the solution. We obtained values for all the components of the stress and strain tensors, the equivalent stresses and strains, and the forces acting on the tool during the shaping operation. As an example, Fig. 3*a* shows the distribution of the equivalent stresses in the metal of one bar for a certain moment in the bar's reduction on the AVS machine. Figure 3*b* shows the same in the material of strip obtained during the cold rolling of sheet and strip with the formation of fins on one side of the product. The sheet and strip underwent incremental deformation in the process.

The reliability of results calculated with DEFORM can be evaluated from experimental data obtained by rolling unilaterally finned strip on a four-high mill and forging bars on an AVS machine.

Experimental values of the stresses created during the forging of bars on an AVS-63 machine were obtained by using the method developed by Dell [2]. This method involved measurement of Vickers hardness in the bar's cross section from the longitudinal axis to the surface. In accordance with the given method, the relationship between the hardness of the metal and stress intensity (the concept of equivalent stresses is used in DEFORM) is unique for different stress states. Thus,

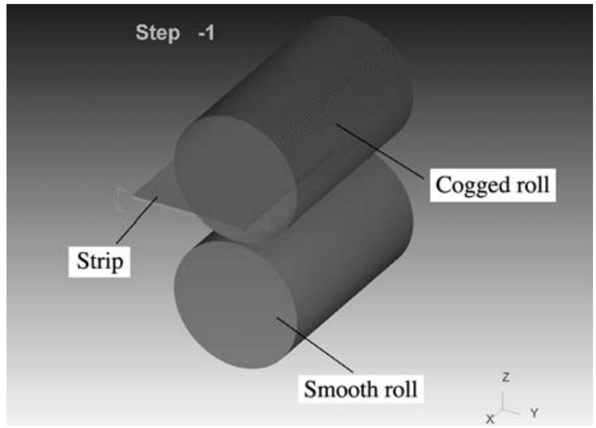
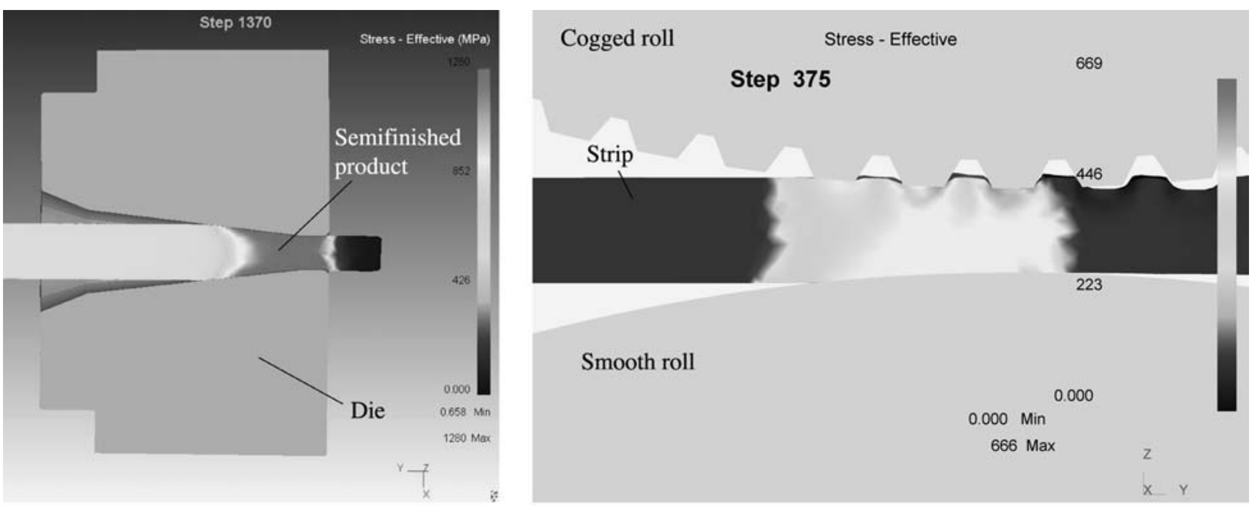


Fig. 2. The deformation zone in the rolling of sheet and strip with fins on one side.



a *b*

Fig. 3. Distribution of the equivalent stresses in a bar for a certain moment during its reduction on an AVS forging machine (*a*) and in a unilaterally finned strip rolled with a certain deformation increment (*b*).

a certain hardness distribution will correspond to a certain distribution of stress intensity. The experimental and theoretical values obtained for the equivalent stresses at different points of the cross section located over the radius of the semifinished product and separated from one another by a distance of 0.83 mm differed from one another by no more than 9.2%. In addition, the fact that semifinished products with good physicomechanical properties have been obtained on AVS radial-forging machines shows that the distribution of the equivalent stresses over the cross section of forged semifinished products is sufficiently uniform.

Experimental values for the rolling forces in the rolling of strip with fins on one side were obtained on a $55 \times 260 \times 220$ four-high laboratory mill equipped with a strain gage. The strip was rolled with drafts in the range 7–20%. The deviation of the theoretical values of rolling force from the experimental values for the given case was no greater than 4.8%.

Conclusions. Theoretical studies made of transients in metal-shaping operations by using the software DEFORM confirm the efficacy of its use to determine the parameters of these operations, including parameters that are quite complex from the modeling viewpoint. The data obtained with the program makes it possible to develop new and improve existing technologies and equipment for shaping metals.

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