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Modelling of the radial forging process of a hollow billet with the mandrel on the lever radial forging machine

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Abstract. The finite-element method (FEM) has been used in scientific research of forming technological process modelling. Among the others, the process of the multistage radial forging of hollow billets has been modelled. The model includes both the thermal problem, concerning preliminary heating of the billet taking into account thermal expansion, and the deformation problem, when the billet is forged in a special machine. The latter part of the model describes such features of the process as die calibration, die movement, initial die temperature, friction conditions, etc. The results obtained can be used to define the necessary process parameters and die calibration.

1. Introduction

To obtain the reliable data about the metal-forming processes studied, particularly about the loads on the equipment, the experimental, theoretical and mixed experimental and theoretical research methods are applied. Although experimental research methods allow obtaining the most accurate results, it is sometimes quite difficult to implement them in real working conditions of the studied equipment operation or on rare occasions they are not implemented at all. In that case theoretical study methods of the processes and machines have become more widespread, especially due to the development of mathematical methods of calculation based on generation of finite-element (FE) models [1-3].

At the Department of Metallurgical and Rotary Machines (UrFU) theoretical research of non-stationary metal-forming processes based on the finite-element modelling of the plastic deformation site are carried out. For example, the department staff have conducted a study of several kinds of reduction of solid and hollow billets on lever radial forging machines (LRFM) [4-6].These machines, depending on the type, are intended for different purposes and, as a result, they have a specified design expressed in the disposition and quantity of forging dies, the trajectory of their movement, various modifications of the feeding device and presence or absence of a mandrel for the formation of the required thickness of a hollow billet wall.

2. The study of the radial forging process

One particular task within the research of the radial forging on LRFM was devoted to generating a mathematical model of the multistage hot forging of the hollow billet on the two-die machine with a vertical disposition of levers and with the application of a mandrel. The purpose of the study is to build the mathematical model which would allow defining the stress-strain state, force and velocity parameters of the process, formation of the billet and temperature conditions of the deformation. The development of this model will make it possible to specify rational parameters of the deformation on a particular machine, to select the necessary heating mode and also to lay the foundations of the design of dies calibration.

On the whole, the algorithm of the mathematical model generation could be divided into two main parts. The first part includes a solution to the problem of the billet heat treatment before forging in order to define the boundary conditions of the modelling and the process data analysis. The second part consists of the study of the forging process, which includes formation of the forging dies model with its assigned movement; modelling of the billet feeding process taking into account different velocity modes during the forging process; assessment of temperature fields defined in the first part of the modelling.

2.1. The heat treatment problem

To complete the heat treatment process the boundary conditions on certain surfaces of the billet with a pre-set thermal mode were set. It is assumed that both heating and heat exchange occur on the outer and inner surfaces of the billet and the heating is carried out at a certain distance from the front end of the billet. The billet has the infinite length. The heat treatment for the given length, which corresponds to a volume required to fill the space between dies taking into account the mandrel, is carried out up to the temperature of 1250 °C during 50 seconds to obtain uniform heating.

The temperature distribution along the cylinder surface of the billet is uniform along the full length required (Figure 1).

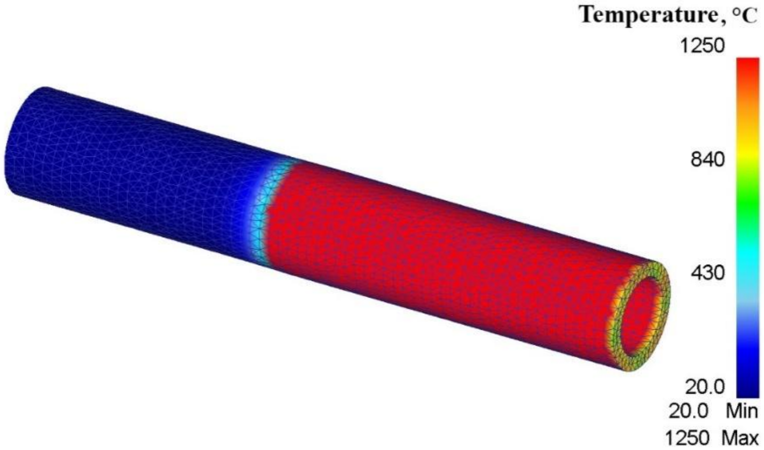

Figure 1. The temperature distribution within the billet

Due to the fact that the billet is considered as anelasto-plastic object it is possible to define temperature-induced deformations of the metal (Figure 2). One of the software features is its capability to interpolate properties from the solution of the previous problem, such as a stress-strain state and temperature distribution, to a new billet.

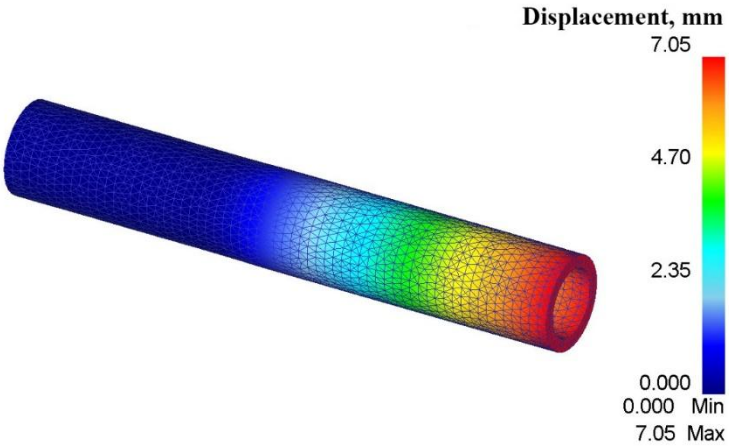

Figure 2. The thermal expansion of the billet

It should also be mentioned that when it exits from the inductor and moves to the axis of the forging machine the cooling process of the billet takes place. Part of the warmth from the heated area of the billet is emitted into the environment. The solution to the problem of the billet cooling starts with the last step of the solution to the heating problem. This step is used to describe the billet stress-strain state, temperature distribution, and volume change after the heating. Boundary conditions are also interpolated with the definition of heat-exchange surfaces.

2.2. The deformation problem

Solutions to the heating and cooling problems used to generate the mathematical model of the forging process which also includes several stages.The forging process is directed to the production of a billet with the required configuration which is achieved by the reduction between two working dies (Figure 3). The striking load of dies is combined with the forward-rotation of the billet produced by the feeding device.

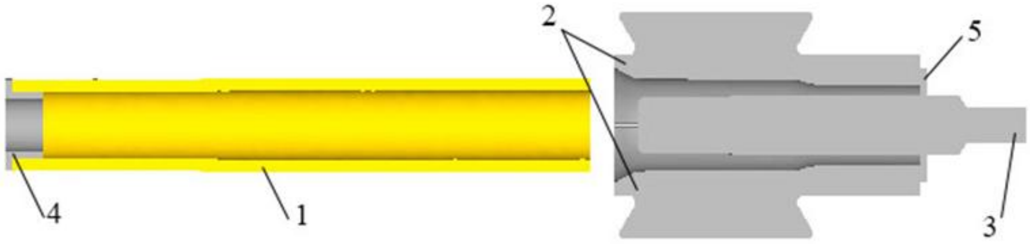

Figure 3. The scheme of the suggested forging process on LRFM: *1* –billet; *2* – forging dies; *3* – mandrel; *4* –object for the feeding device; *5* – thrust collar

Therefore, the scheme of the forging process includes the object from the previous solution step used as a billet, objects for forging dies and the mandrel, heated to working temperature, and an object for the feeding device. The position of the dies and the mandrel in the model and their movement correspond to the real machine kinematics.

To obtain more precise solution results concerning the billet forming during the forging process the local mesh density windows technique is applied in the FE description of the billet object. This allows contracting the areas, most subjected to deformation along with FE, and, at the same time, reducing the whole calculation volume.The choice of the FE quantity is based on the assumption that at least 4 FE should be located in the billet wall thickness at every solution step.Therefore, the part of the billet that does not participate in the forging process has a more rough mesh with a FE size equal to 10 mm, the volume of the billet in the first caliber has a more precise mesh with the size of FE, which is 5 mm, and in the second caliber, where the deformation occurs more actively than in the previous two, it has the size of approximately 3.5 mm.The total number of elements is 195000.

There is also a mechanism of forced re-meshing which depends on the feeding device stroke.After each 5 mm of the feeding device stroke into the deformation site forced re-meshing takes place, which provides the highest accuracy of the results obtained.

The solution to the problem allows getting representation of loads, object velocities, torques and angular velocities correlations depending on the simulation step. The data presented are displayed as discrete points obtained at every step and connected by a smooth curve, which requires further data processing and analysis. The data can also be exported as an array to different software packages. As an example, figure 4 shows the graph of the load placed on the forging die during the forging process.

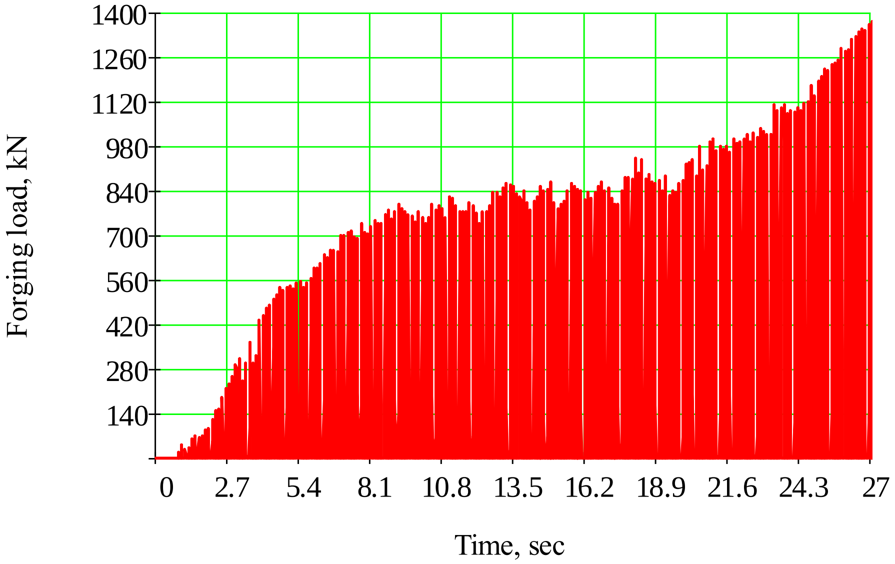

Figure 4. The forging load characteristic graph

The implementation of the mathematical model of the forming process is also carried out as a plain-strain problem which significantly decreases the calculation time. Several examples of forming during the process are shown in Figures 5 and 6.

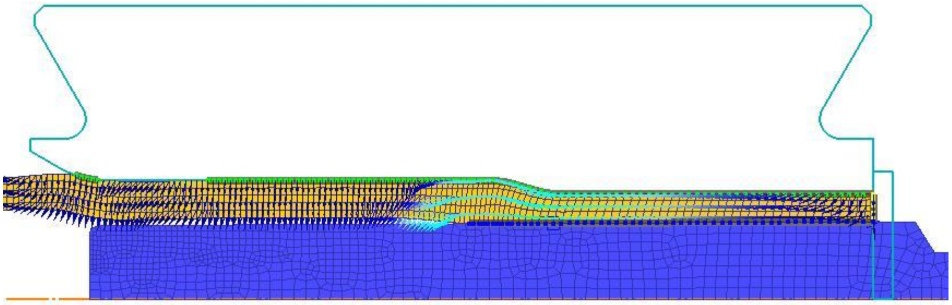

Figure 5. The forming process in the plain-strain problem

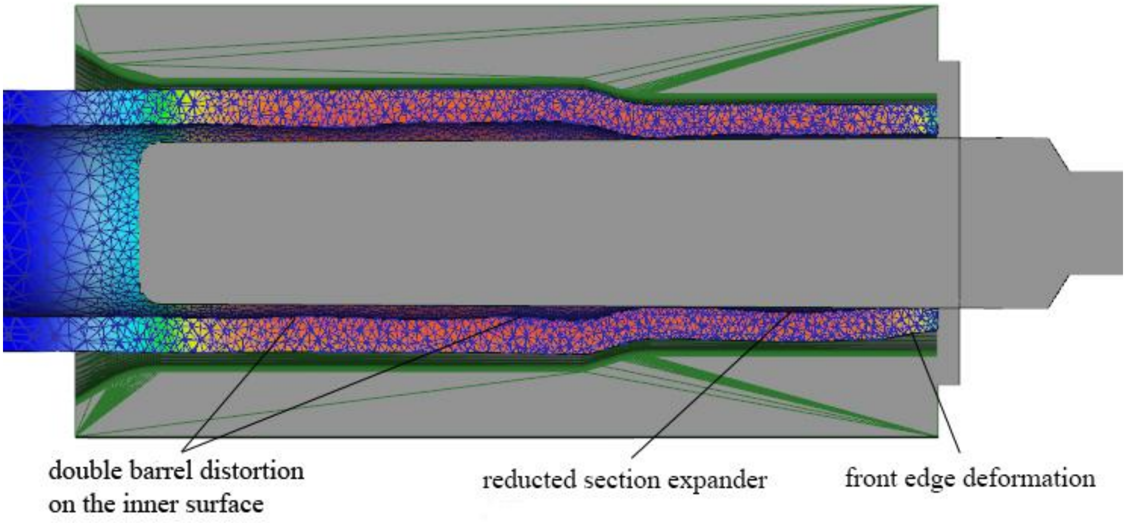

Figure 6. Forming process features

3. Conclusion

3.1. The mathematical model of the definition of the thermal and stress-strain state of the billet has been created. This allows obtaining data about temperature, stress and strain distribution within the billet.

3.2. The mathematical model of the deformation site of the radial forging of the hollow billet located on the mandrel has been created. The model was developed for the lever radial forging machine.

3.3. The created thermal and deformation model of the deformation site on LRFM is used to define the rational process parameters, including reduction and thermal modes, as well as to design dies calibration.

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