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Research Article

FEM SIMULATION OF THE TUBE ROLLING PROCESS IN DIESCHER'S MILL

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ABSTRACT
This paper deals with the issue of numerical modelling of the piercing process of a thick–walled bush in a two-rolled skew rolling mill, equipped with guiding devices of Diescher's type. After a short characteristic of the subject matter, the developed geometric model of the process was discussed, with taking kinematics of tools movement and thermal phenomena present in metal during forming into consideration. Next, the results of calculations were presented in a form of fields of strain, damage criterion and temperature. Distributions of force parameters acting on particular tools during the process of bush rolling were also given.

Keywords: tube rolling, FEM, state of stress and strain.

INTRODUCTION

Thick-walled bushes, from which later seamless pipes are manufactured, are made in skew piercing rolling mills. Depending on the number of rolls, the skew rolling mills are divided into [1]:

- Two-roll rolling mills with two working rolls and two guiding devices, which aim at holding of the rolled bush along the rolling axis. These guiding devices are manufactured as rolls of Mannesmann's type, flat of Stiefel's type and disk of Diescher's type.
- Three-roll mills with three working rolls, which work without additional guiding devices.

Although the piercing process in skew rolling mills has been used for more than a hundred years, this technology has not been so far analyzed theoretically in a satisfactory way, which is the result of a complex kinematics of metal flow. The improvement of this situation can be seen in possibilities provided by the numerical modelling application, based on FEM.

The first works concerning numerical modelling in skew piercing rolling mills made in the 90's of the XXth century based on two-dimensional FEM models. Due to the complex character of material flow, piercing processes should be modeled in three-dimensional state of strain. Pietsh and Thievien [2], Cereti et al. [3] and Komori [4] were the first researchers who tried modelling the piercing process. However, numerical models developed by these researchers, based on considerable simplifications, e.g.: omitting of thermal phenomena present in the formed material, considering only the initial stage or given stage of the piercing process during calculations or assuming that the formed material is perfectly plastic. More complex models of the piercing process, taking into thermal phenomena account, were presented by Pater and et al. [5–7] and Lu and et al. [8].

The results of calculations obtained by means of these models remained in good convergence with the results of experiments. A disadvantage of the above mentioned works was, however, omitting rotational movement of the piercing plug and friction forces present at the workpiece – plug interface.

This paper presents a new numerical model of the piercing process of a bush in the skew rolling mill with Deischer's guiding devices, in which all tools' kinematics of movement was considered.

NUMERICAL MODEL OF THE PIERCING PROCESS

The numerical analysis of the piercing process in the skew rolling mill was made by applying the commercial software Simufact.Forming 10.0, which uses FEM displacement representation. The schema of the analyzed case is shown in Figure 1, in which basic parameters describing the used tools and their reciprocal position are also marked.

It was assumed in simulation that cylindrical billet (of dimensions Ø60×150 mm) from 100Cr6 steel would be used. The material model was taken from the applied software library. It was also assumed that rolls moved in the same direction with a constant rotational velocity n = 60 rpm, disks rotated (in the opposite direction) with velocity 6.8 rpm, and the plug rotational movement was caused by the formed semi-finished part.

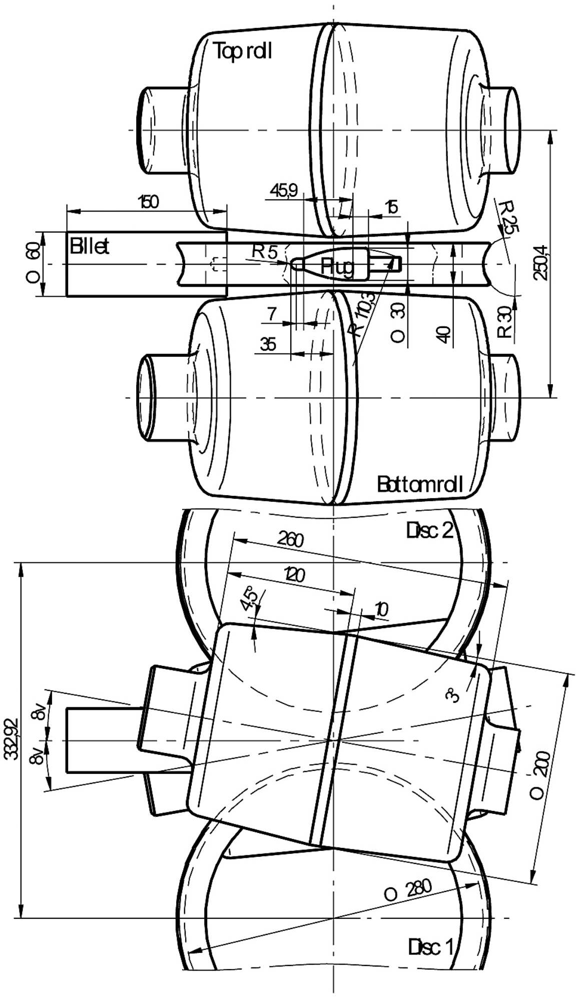

Fig. 1. Schematic view a of the analyzed numerically piercing process of a thick-walled bush

Thermo-mechanical schema of the calculations was considered. It was assumed, that the billet was heated in its whole volume to the temperature 1180 °C, tools temperature was constant during the whole forming process and equal 900 °C for the piercing plug and 50 °C for rolls and disk guiding devices. On a basis of the reference [9], it was presumed that the coefficient of heat exchange between tools and the workpiece was 4000 W/m^{2}K. Yet, the coefficient determining heat exchange between workpiece and the environment was equal 200 W/m^{2}K.

Due to the change of direction of friction forces acting on the tool-workpiece interface, a model of constant friction dependent on metal slide velocity in relation to tool was assumed in calculations, and described by the equation:

$$\tau = -m\,k\,\arctan\left(\frac{v_p}{a_p}\right)\frac{v_p}{|v_p|} \tag{1}$$

where: m – friction factor,
k – shear yield stress,
v_p – slide velocity vector,
a_p – coefficient a few grades lower than slide velocity (it was assumed in calculations that a_p = 0,1% of roll velocity).

Due to the lack of lubrication and purposeful rolls coarseness (for an easier billet implementation into the space between rolls), it was assumed that friction factor for rolls reached limiting value m = 1.0. In the case of other tools (discs and piercing plug), a lower value of the friction factor m = 0.7 was considered.

Figure 2 shows FEM model of the piercing process. This model consists of: two barrel rolls,

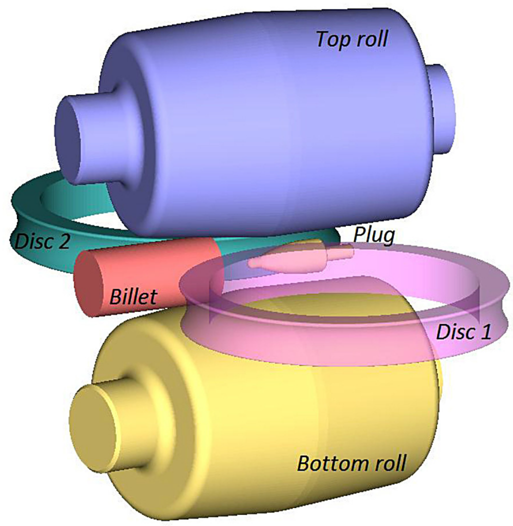

Fig. 2. FEM model of the piercing process of a thick-walled bush

two disc guiding devices, a piercing plug and a workpiece. All tools were modelled as rigid bodies. Hexahedral elements were used for billet modelling.

RESULTS OF NUMERICAL ANALYSIS

The application of FEM for the analysis of the piercing process in the skew rolling mill allows for precise observations of the workpiece shape changes during rolling. These changes are shown in Figure 3, in which, in order to improve visibility, one of the disc guiding devices was made transparent. At the beginning of the process, the billet is grabbed by rolls which rotate and displace the workpiece in the axial direction. At this stage of forming, rotary compression process is realized, which lasts until the plug nose contacts the workpiece surface. Then the hollow forming begins. The hole diameter depends mainly on the applied piercing plug. During the hollow forming, the disc guiding devices also contact the metal and their rotation increases the axial forces drawing the workpiece on the piercing plug. After the whole head goes into the metal the forming process becomes stable and is characterized by relatively stable forming forces. At the end of the process, the plug pierces (in the axial direction) through the material and a thick-walled bush is formed.

During rolling the formed element is put into rotation, which dominates. Tool forces acting on the formed element cause also its displacement in the axial direction. In consequence, the material in the piercing process displaces in screw motion. The most intensive axial flow of the material is localized at the surface area adhering the rolls, the smallest flow is before the piercing plug nose.

The analysis of strain distributions presented in Figure 3 shows that they reach relatively large values. This is the result of the presence (during forming) of internal shearing of the metal structure, which does not influence the desired change of shape and causes unnecessary metal deformation. It is the most intensive at the bush external surface, which is influenced by friction forces causing material flow mainly in the circumferential (tangent) direction. The appearance of large deformations is a characteristic feature of skew and cross rolling processes [10–13].

Figure 4 presents the distribution of damage function according to Cockroft-Latham [14] criterion in the semi- finished product axial section at the determined stage of the piercing process. This function assumes the largest values in the area of the piercing plug nose, where the hole forming begins. However, these values are smaller than critical (being about 0.8), at which the material cracks. This means that the piercing process has been properly designed as the bush internal surface is formed in the result of plastic flow of material and is free from surface faults caused by cracking.

Figure 5 presents distributions of temperature at the surface and in cross section of the formed element in the piercing process. Although the

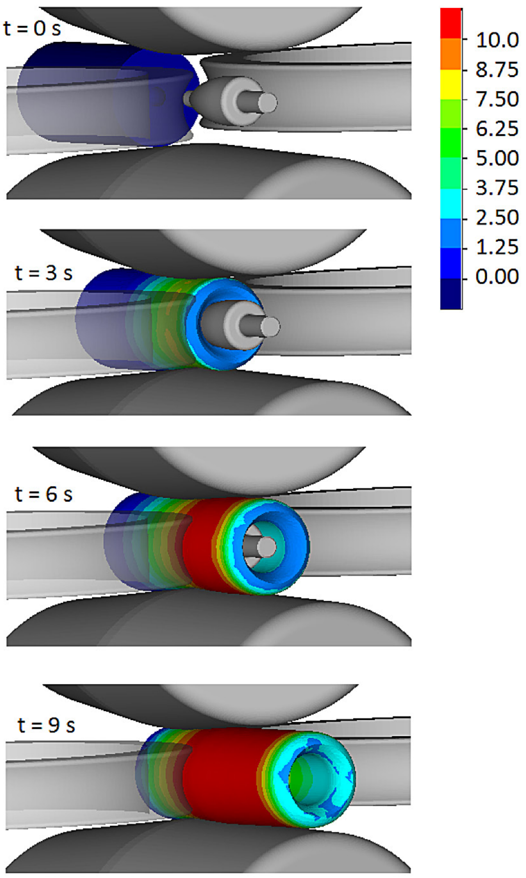

Fig. 3. Progression of the workpiece shape in the piercing process with marked distribution of effective strain

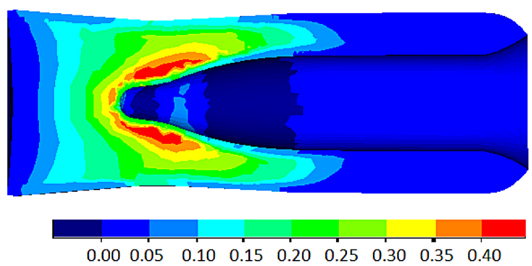

Fig. 4. Distribution of damage function according to Cockroft-Latham criterion for time t = 7 s

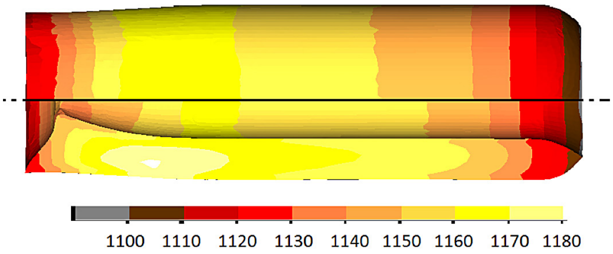

Fig. 5. Distribution of temperature in the bush at the end of piercing process (for t=10 s)

forming time is relatively long, the metal temperature in the wall of the rolled bush remains at the level close to the billet temperature (1180 °C). This is the result of compensation of loss of heat abstraction into tools by heat produced by plastic strain work and friction work. The smallest temperatures are observed at the formed product edges, where the best conditions of heat abstraction into the environment take place.

During the piercing process the forming tools rotate. The rolls and guiding devices are driven and they move with constant rotary velocity. Hence, the piercing plug rotates due to the influence of the workpiece which displaces in screw motion. Yet, at the determined forming stage, rotary velocity of this tool is the largest and it remains at relatively constant level – Figure 6.

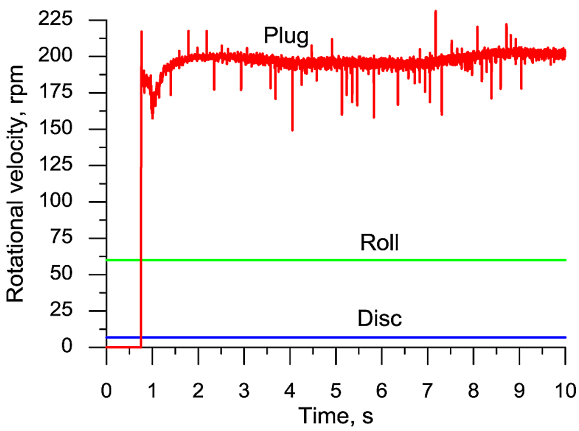

Fig. 6. Rotational velocities of tools in the analyzed piercing process

The application of FEM allows for precise determining of loads of particular tools during piercing. Distributions of forces obtained for the analyzed piercing process are shown in Figure 7. It can be seen that at the beginning all forces increase gradually until the bush contacts the piercing plug. After that, the process reaches the determined stage, at which forces are kept at constant level. It should be considered that loads of both rolls are almost identical. Certain differences can be observed in loads distributions of particular disc guiding devices, which is the result of irregular pressure of the semi-finished product to these tools. The forces acting on rolls are the largest; yet, the disc guiding devices have the smallest loads during piercing. At the end of the process all forces undergo a gradual decrease.

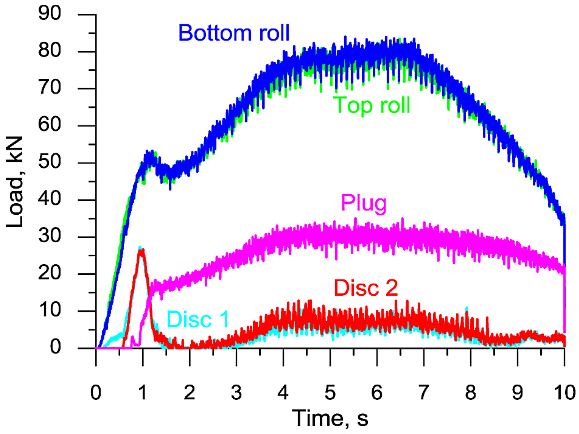

Fig. 7. Forces acting on tools In the piercing process, marked according to Figure 1

Distribution of rolls and discs rotary moments, shown in Figure 8, can be used for determining the rolling mill energy requirements. It is visible that a decisive role within this scope plays the rolls drive. The discs rotary moment is much lower, which is mainly the result of the resultant force placement acting on the disc placed angularly to the disc rotation axis. Considering the character of moments distribution it can be stated that it is similar to the course of forces shown in Figure 7.

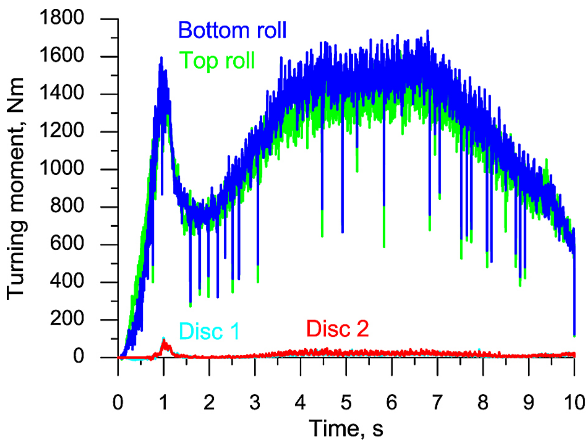

Fig. 8. Turning moments acting on tools in the piercing process, marked according to Figure 1

SUMMARY

This paper presents the thermo-mechanical analysis of the piercing process in the skew rolling mill made by means of finite element method and based on commercial software Simufact. Forming 10.0. The development model of the piercing process deals with real kinematics of all tools movement (piercing plug for the first time) and allows for the analysis of the stress, strain and temperature distributions in the workpiece as well as force-energetic parameters. Basing on this model, it is planned to make numerical simulations of a number of piercing processes in order to determine the process basic parameters influence on the diametric dimensions of the manufactured bush and particular tools loads. It is also possible to develop the worked out model FEM of the piercing process in the direction of stresses calculations in forming tools, assumed as elastic bodies.

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