Z. PATER, J. BARTNICKI, J. KAZANECKI

ISSN 0543-5846
METABK 51(4) 501-504 (2012)
UDC – UDK 621.73, 77, 669.1

3D FINITE ELEMENTS METHOD (FEM) ANALYSIS OF BASIC PROCESS PARAMETERS IN ROTARY PIERCING MILL

Received – Prispjelo: 2012-02-12
Accepted – Prihvaćeno: 2012-05-10
Preliminary Note – Prethodno priopćenje

In this paper 3D FEM analysis of process parameters and its influence in rotary piercing mill is presented. The FEM analyze of the rotary piercing process was made under the conditions of 3D state of strain with taking into consideration the thermal phenomena. The calculations were made with application of different rolls' skew angles and different plug designs. In the result, progression of shapes, temperature and distributions of stress and strain were characterized. The numerical results of calculations were compared with results of stand test with use of 100Cr6 steel. The comparisons of numerical and experimental tests confirm good agreement between obtained results.

Keywords: Forming, Tube piercing process; FEM analysis

INTRODUCTION

Skew rolling is one of the basis technologies of manufacturing of thick – walled tubes. In this process two or three working rolls are used. In the case of forming with two rolls in order to support the formed tube in the rolling axis, two guiding devices are applied (rolled guiding devices of Mannesmann's type, flat guiding devices of Stiefel's type or disc guiding devices of Diescher's type). Among the mentioned rolling methods, rolling by means of two rolls with two guiding devices of Diescher's type is regarded to be the best due to the stability of forming and the precision of the obtained product. Since the beginning of 1970's several production lines basing on rolling mills with guiding devices of Diescher's type have been started in the world. In majority of these rolling mills barrel shaped rolls are used [1]. With the computer and software development, new numerical models of piercing processes in skew rolling mills appeared. These new models are based on finite element method (FEM) and at the beginning they were 2D models [2].

In the recent years, Pietish and Thieren [3] Ceretti at al. [4] and Komori [5] tried to simulate the discussed process in the conditions of 3D state of strain.

However, the models worked out by these authors had many simplifications concerning mainly: omitting of thermal phenomena during the forming process [3-5], analyzing of only the stable phase of piercing [5] or at its beginning (before the metal contacts with the plug) [3, 4]. Because of that, the authors decided to model the whole piercing process in skew rolling mill, taking into consideration thermal phenomena at the same time.

The knowledge of process parameters is very helpful for designing of complex forming processes basing on piercing technology i.e. forming of bearing rings, hollow shafts and axles.

Z. Pater, J. Bartnicki, Lublin University of Technology, Lublin, Poland
J. Kazanecki, AGH University of Science and Technology, Krakow, Poland

THE WORKED OUT FEM MODEL OF PIERCING PROCESS IN THE SKEW ROLLING MILL

The piercing process in two rolls rolling mill with disc guiding devices of Diescher's type was considered. The scheme of this process is shown in Figure 1 in which the basic dimensional parameters are also presented. It was assumed that as charge for rolling a cylindrical billet with dimensions Ø 60 x 120 mm was used. This billet was made from steel 100Cr6 type. It was also assumed that rolls were moving in the same direction with the same rotary velocity n = 60 rpm and the disc guiding devices were rotating in the opposite direction with the velocity 6,8 rpm.

In the analyzed piercing processes following parameters were changed: α – skew angle, a and b distances between rolls and discs, c – plug working position and δ_c area reduction ratio. Additionally, the changes of plug geometrical shape described by 4 parameters were assumed – Figure 2.

Compositions of mentioned above technological parameters presented in Table 1 were taken into calculations. Moreover, in the worked out numerical model pusher and positioning ring which were responsible for putting the charge between rolls in order to begin the piercing process. The pusher moved in the direction equal to the charge longitudinal axis with the velocity of 15 mm/s.

The worked out FEM model of the piercing process in skew rolling mill is shown in Figure 3.

In simulations thermo-mechanical scheme of calculations was used. It was assumed that the charge was heated up to 1 180 ºC and that tools temperature did not change during forming and was 50 ºC for rolls and guiding devices and 500 ºC for plug. It was also assumed

Table 1 **Statement of technological parameters applied in numerical calculations of piercing process (descriptions according with Figures 1, 2)**

Case no	Angle α	Distance a / mm	Distance b / mm	Area reduction ratio δ_c	Plug position c / mm	Plug dimensions / mm			
						d_g	l_{gs}	l_c	R_{gs}
1	10 °	250,4	332,92	16 %	40	40	72,0	11,5	180,3
2	10 °	250,4	332,92	16 %	42	40	72,0	11,5	180,3
3	10 °	250,4	332,92	16 %	38	40	72,0	11,5	180,3
4	10 °	250,4	332,92	16 %	40	38	67,8	11,0	171,2
5	10 °	250,4	332,92	16 %	40	42	76,2	12,0	189,4
6	12 °	250,4	332,92	16 %	40	40	72,0	11,5	180,3
7	8 °	250,4	332,92	16 %	40	40	72,0	11,5	180,3
8	10 °	251,6	334,18	14 %	40	40	72,0	11,5	180,3
9	10 °	249,2	331,66	18 %	40	40	72,0	11,5	180,3
10	10 °	250,4	332,92	16 %	40	36	63,6	10,5	162,1
11	10 °	250,4	332,92	16 %	40	34	59,4	10,0	153,0

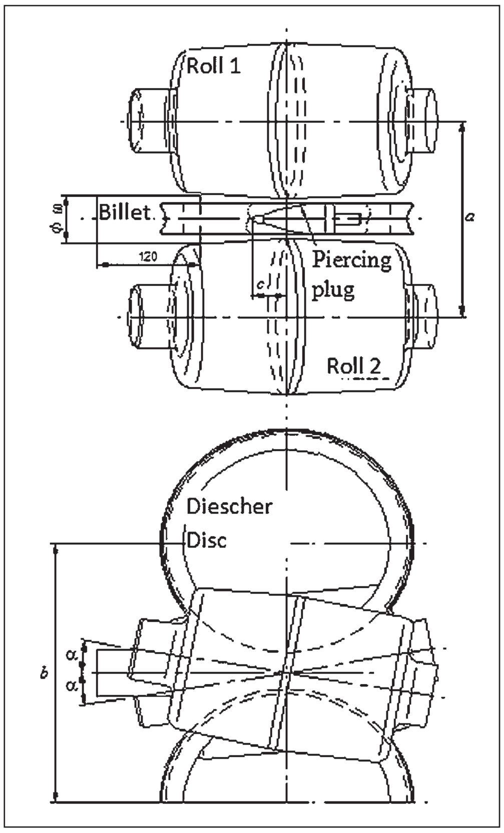

Figure 1 Scheme of the analysed piercing process in the skew rolling mill together with most important parameters

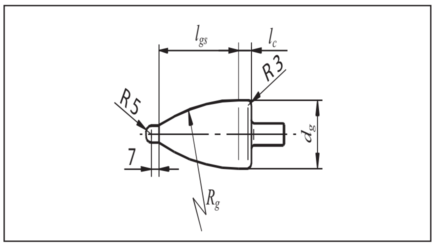

Figure 2 Scheme of the piercing plug with marked technological parameters described in Table 1

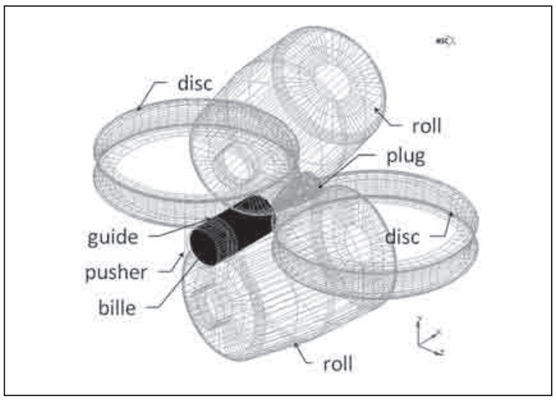

Figure 3 The worked out for the calculations needs model of piercing process of the tube shell in the skew rolling mill with the Diecher's guiding devices

that the coefficient of heat transfer between tools and material was 5 000 W/m^{2}K and between material and environment its value was 200 W/m^{2}K.

In the analysis constant friction model was considered. This friction depended on the slipping velocity of metal relatively to tools position. Due to the lack of lubrication and aimed rolls roughening, for easier putting out of the charge it was stated that friction factor for rolls had limiting value m = 1,0. For other tools the friction factor was m = 0,7.

In order to work out the material model of steel of 100Cr6 type, the results of research made by Kazanecki were used. On the basis of these results the author determined the flow curves of the analyzed steel within the range of temperatures 900 ºC ÷ 1 200 ºC. The practical usage of these research results, in the applied software MSC.SuperForm 2005, required describing the flow curve by equation. Using the optimization methods it was stated that in description of the flow curves of steel 100Cr6 the following equation could be used:

$$\sigma_p = 40 + 103366\varepsilon^{0,5403} \cdot \exp(-0,6644\varepsilon) \cdot \dot{\varepsilon}^{0,3550} \cdot \exp(-0,00623T)$$

where: σ_p – flow stress, ε – strain, $\dot{\varepsilon}$ – strain rate, T – temperature.

The good precision of the determined function is confirmed by the comparison of yield stress values, calculated from equation (1) and obtained in experiments by Kazanecki [1] and shown in Figure 4.

RESULTS OF NUMERICAL CALCULATIONS

In the result of the made numerical simulation the possibility of analysis of the workpiece shape during the piercing process was obtained. According to the Figure 5, at the beginning of the process the wedges clamp the charge, put it into rotary motion and draw in the area between the rolls. The workpiece movement in the axial direction is accompanied by its external diameter reduction.

At the main stage of the process, when the internal cavity is formed all tools are applied together with disc guiding devices. These discs move consistently with the preform movement, they not only size the workpiece external surface but they also draw it on the plug. At the final stage of the process the formed tube shell is rolled out which leads to the removal of the cross section ovalization.

Only in one of analyzed cases the obtaining of proper tube shells were impossible. In case no 5 with application the biggest plug diameter after the forming process, the strong ovalization appeared. The presence of this phenomenon stopped rotating movement of workpiece and it provokes uncontrolled deformation of workpiece. This situation is shown in Figure 6.

In Figure 7 (case 1 acc. to Table 1) the distributions of effective strain in the workpiece are shown, calculated for the determined stage of the piercing process.

From this Figure 7 results that strains are distributed in a characteristic for cross – wedge rolling processes laminar way (ring – shaped). However, the largest strain are present in the external layers which is due to the intensive material flow caused by friction forces present on the contact surfaces: roll – workpiece and disc – workpiece.

VERIFICATION OF THE WORKED OUT FEM MODEL OF PIERCING IN A SKEW ROLLING MILL

The experimental research of the piercing process was focused on obtaining of final part with very close dimensional tolerances with good inner and outer surface quality. Numerically calculated cases were analyzed with measuring of obtained tube shells' diameters in distance of 70 mm from axis of rolls. The results of these analysis are shown in table 2.

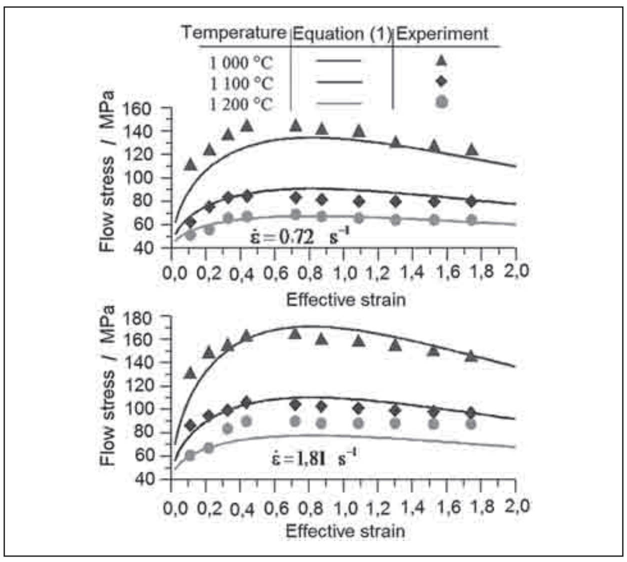

Figure 4 Curves of steel flow of 100Cr6 type

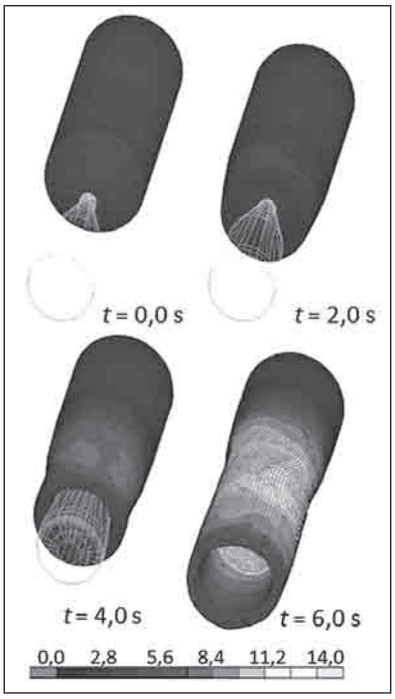

Figure 5 The workpiece progression of shape during piercing process with the marked distributions of effective strain (case 1 acc. to Table 1)

The experimental verification of the analyzed cases was made in a laboratory rolling mill at AGH in Krakow – Figure 9.

In this rolling mill, it is possible to apply various types of: sizing of working rolls, rolls composition and guiding devices. The rolling mill is equipped with measuring system allowing for noticing rotation moments and forces influencing the particular tools. For verification of the worked out piercing model in the skew rolling mill, the tests of forming were made in the described rolling mill. The parameters of the realized rolling case no 1 were identical as it was in the numerical analysis. During piercing the process basic force parameters were observed. These parameters dealing with the stable stage of rolling after averaging were presented in Figure 10.

Additionally, in Figure 10 were shown forces and moments values calculated by means of FEM. The comparison of the measured and calculated values show good

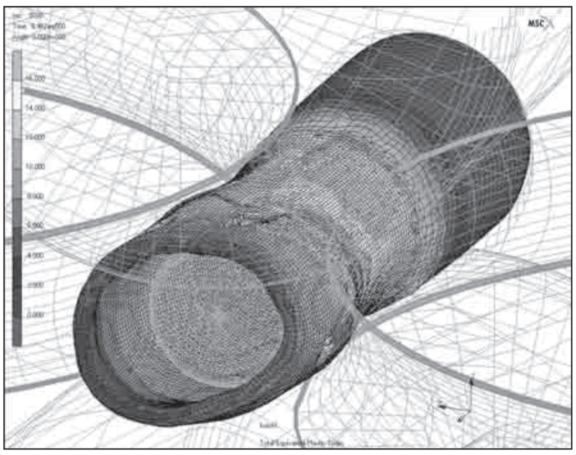

Figure 6 The deformed tube shell with excessive ovalization(case 5 acc. to Table 1)

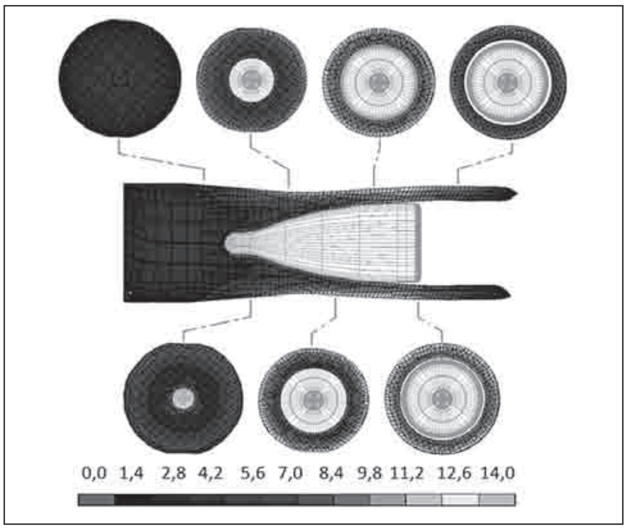

Figure 7 Distribution of effective strains in the rolled workpiece (case 1 acc. to Table 1)

Table 2 **Distributions of external and internal deviations in inner and outer diameter of formed tube shells**

Case no	External diameter d_t / mm	Internal diameter d_w / mm	Cross section area F / mm^2
1	57,42 ± 0,09	43,22 ± 0,34	1 122,4
2	56,53 ± 0,18	42,68 ± 0,07	1 079,2
3	58,12 ± 0,24	43,93 ± 0,29	1 137,3
4	55,73 ± 0,21	40,14 ± 0,21	1 173,9
5	Excessive ovalization		
6	57,54 ± 0,10	43,34 ± 0,11	1 125,1
7	56,12 ± 0,36	42,45 ± 0,45	1 058,3
8	57,85 ± 0,33	42,89 ± 0,30	1 183,6
9	55,59 ± 0,15	42,38 ± 0,07	1 016,4
10	54,31 ± 0,30	37,65 ± 0,20	1 203,3
11	54,11 ± 0,18	35,82 ± 0,18	1 291,8

consistence, confirming the rightness of the worked out model of piercing process in the skew rolling mill.

SUMMARY

New model of piercing process in the skew rolling mill equipped with discs guiding devices of Diescher's typeis described in this paper. In presented model, thermo-mechanical phenomena during the forming process were considered. The calculations dealt with the rolling course until reaching the stable stage. The discs rotary movement and effects connected with the presence of friction force on the contact surface between metal and tools (rolls, discs and mandrel) were taken into considerations. Using the worked out FEM model were determined the distributions of: stresses, strains, strain rates, temperature of workpiece.

It was stated that piercing plug position and its shape has an influence on the external and internal diameter' deviations. Forward plug positioning helps to decrease internal deviations but, contrary to this tendency, the external ones become bigger because of more intensive material flow before workspace between rolls and discs. In the analyzed process the application of the bigger angle α values is favorable for obtaining parts with close tolerances, but this parameter must be also correlated with

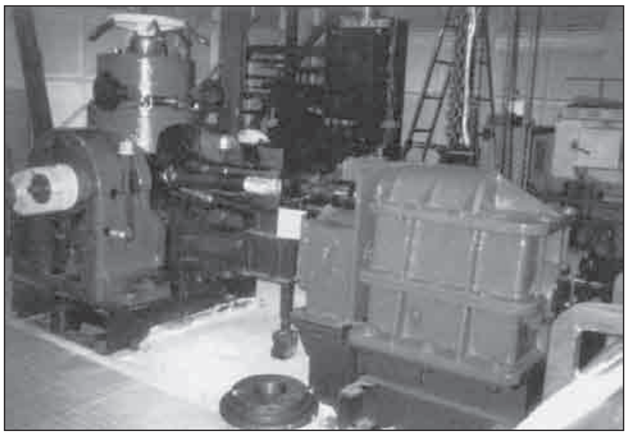

Figure 9 The rolling mill for analyzing of skew rolling processes

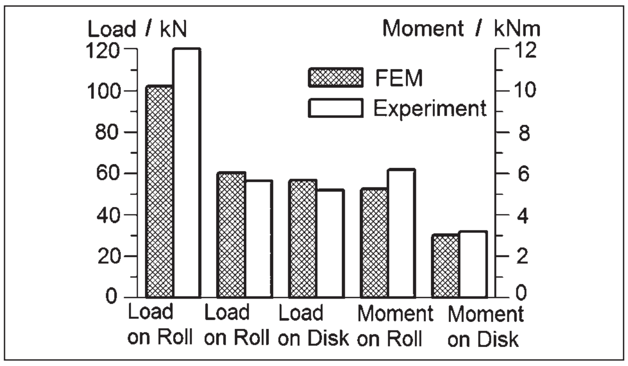

Figure 10 The comparison of forces and moments calculated and measured for the analyzed case of piercing in skew rolling mill (case 1 acc. to Table 1)

proper choice of plug position and area reduction ratio. The smallest obtained deviations values about 0,10 – 0,11 mm (case no 6) permit to foresee that obtained by this method ring shaped parts will be finished by grinding only, which significantly lowers manufacturing costs.

The worked out model of piercing process was verified during stand tests at AGH in Krakow. The comparison of forces and moments measured in experiments with those calculated showed the usefulness of this model for analysis of such a complex forming process.

REFERENCES

[1] J. Kazanecki, Rolling of seamless pipes. Ed. AGH, Kraków, 2003 (in Polish).

[2] J. Yang, G. Li, W. Wu, K. Sawamiphakdi, D. Jin, Process modelling for rotary tube piercing application, Materials Science & Technology , 2, (2004), 137-148.

[3] J. Pietsh, P. Thievien, FEM simulation of the rotary tube piercing process. MPT International, 2, (2003), 52-60.

[4] E. Ceretti, C. Giardini, A. Attanasio, F. Brisotto, Capoferri G. Rotary tube piercing study by FEM Analysis: 3D simulations and Experimental Results. Tube & Pipe Technology, March/April, (2004), 155-159.

[5] K. Komori, Simulation of Mannesmann piercing process by the three-dimensional rigid-plastic finite-element method. International Journal of Mechanical Sciences, 47, (2005), 1838-1853.

Note: The professional translator for English language is Aleksandra Bartnicka, SIMPTEST Lublin, Poland