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THE ANALYSIS OF THE INFLUENCE OF PLUG SHAPE AND ITS POSITION ON PIERCING PROCESS IN SKEW ROLLING MILL

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Abstract

In this paper the results of FEM simulations of piercing process in skew rolling mill with disc guiding devices of Diescher type are presented. During this process material is formed by means of two skew rolls, two guiding devices and piercing plug mounted on mandrel. The analysis of this process aimed at determining the influence of plug shape and its placing comparing with rolls position on the piercing process. Six cases of piercing were analysed in which four different plugs were used. The changes of basic parameters were analyzed: strain, strain rate and temperature distributions in characteristic longitudinal sections of formed part in the function of shape and position of plug. The numerical results obtained by means of software MSC.SuperForm 2005 were verified in experimental conditions, in which tube shell from bearing steel of 100Cr6 type was pierced. The comparison of FEM calculations and experimental results showed good consistence.

Key words: skew rolling, tube piercing, plug, FEM, experiment

1. INTRODUCTION

In skew rolling mill for piercing thick walled tube shells are made, from which seamless pipes are later manufactured. Depending on the number of rolls skew rolling mill can be divided into three – rolls and two – rolls rolling mills equipped with two guiding devices. It is estimated that the best manufacturing possibilities and the best accuracy are obtained when using two – rolls rolling mills with disc guiding devices of Diescher's type. In this process the piercing plug is very important in view point of the tube shell inner hole forming. During rolling the plug is heated to high temperatures. Because of large pressure on the metal – plug contact surface, the plug often needs to be changed for a new one (Kazanecki, 2003).

Experimental research of plug loads during rolling are very difficult due to the character of this tool work and complex kinematics of metal flow. The alternative to experimental research is numerical modeling of the skew rolling process in such a way that it is possible to determine necessary forming parameters. The first work (Urbański, Kazanecki, 1994) dealing with numerical simulation of rolling in skew piercing mills were based on two dimensional FEM models. However, due to the character of material flow, these processes should be simulated in conditions of 3D state of strain. In recent years numerous tests of modeling of the piercing process with considering 3D state of strain have been made (Pietish & Thievien, 2003; Ceretti et al., 2004; Komori, 2005). Yet, the worked out numerical models were based on many simplifications concerning e.g.: omitting of thermal phenomena present in the formed metal, limiting in calculations only to the stable phase or beginning of forming. In order to present real conditions the authors (Pater et. al., 2006) proposed a new model of piercing process in

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the skew piercing mill in which thermal phenomena during forming were taken into consideration.

In this paper are presented the results of numerical calculations basing on FEM and aiming at determining the role of plug in the piercing process in skew piercing mill. The calculations were completed by experiments which justified the worked out model of piercing process.

2. DESCRIPTION OF FEM MODEL APPLICATION

The numerical analysis of the piercing process in skew rolling mill was made using commercial software MSC.SuperForm 2005 which uses the displacement representation FEM. Six cases of piercing of tube shell in two – rolls piercing mill with guiding disc devices of Diescher's type were analyzed. The schema of one of the analyzed case is shown in figure 1 in which the basic geometrical parameters are also presented. In the calculations the plug size and its axial position were changed. The detailed comparison of changed parameters assumed for the particular case is shown in table 1. It was assumed that as charge a cylindrical billet was used (dimensions Ø60x150 mm). 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 direction opposite with the velocity 6.8 rpm. In the analyzed piercing process it was assumed that reduction ratio in the area between rolls was 11.3% and coefficient of ovalization was 1.05.

In figure 2 one of worked out FEM models of piercing process was shown. This model consists of: 2 barrel rolls, 2 disc guiding devices, piercing plug and billet. Additionally, for putting the billet into space between rolls a pusher was used. All tools were modeled as rigid bodies. For billet modeling hexahedral elements were applied.

In simulations thermo-mechanical schema of calculations was used. It was assumed that the billet was heated up to 1150ºC and that tools temperature did not change during forming and was 50ºC for rolls and guiding devices and 900ºC for plug. It was also assumed that the coefficient of heat transfer between tools and material was 4000 W/m^{2}K (Prince et. al., 2003) and between material and environment its value was 200 W/m^{2}K.

In order to determine the model of the formed metal (steel of 100Cr6 type) plastometric research was done with the application of torsion test. On the basis of calculations the flow curves of the analyzed steel within the range of temperatures 750÷1150°C were determined. The value of flow stress σ_p, at forming temperatures T=950÷1150°C, was described by means of equation:

$$\sigma_p = 1932{,}9\varepsilon^{0{,}158}\exp(-0{,}0759\varepsilon)\,\dot{\varepsilon}^{0{,}189}\exp(-0{,}00328T), \quad (1)$$

where ε – strain intensity, $\dot{\varepsilon}$ - strain rate.

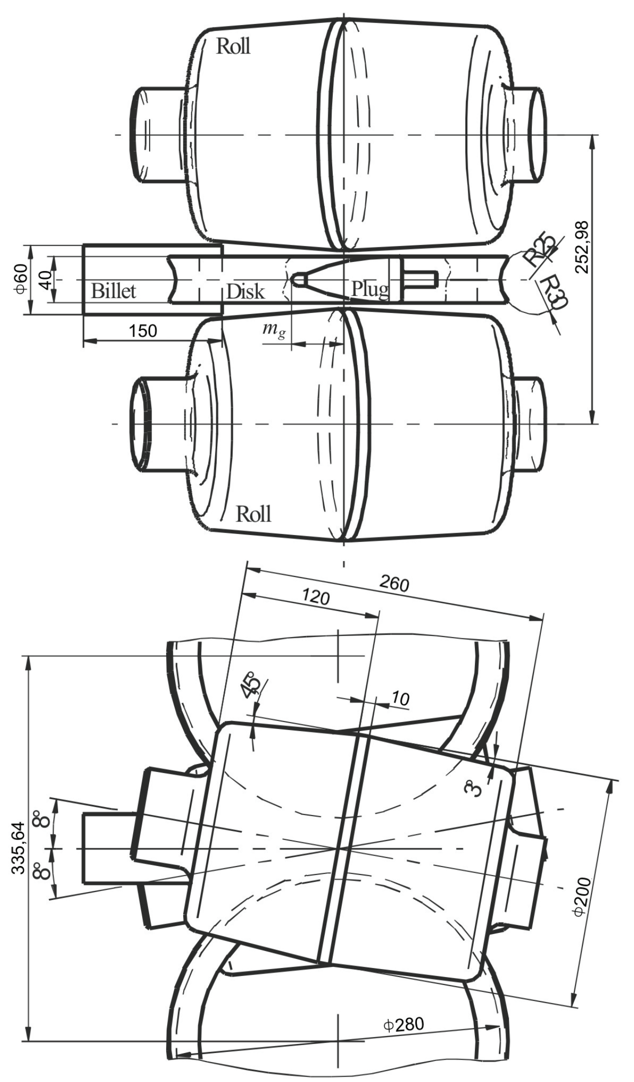
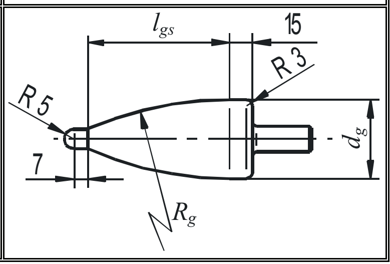


Fig. 1. *Schema of the analyzed piercing process in the skew rolling mill together wit most important parameters.*

Table. 1. *Compositions of piercing process parameters changed during calculations.*

Case no	Parameter, mm				Sketch of piercing plug
	d_g	l_{gs}	R_g	m_g (Fig. 1)	
1.	30	45,9	110,3	35	
2.	32	48,9	114,2	32	
3.	32	48,9	114,2	35	
4.	32	48,9	114,2	38	
5.	34	52,0	118,7	35	
6.	36	55,0	123,0	35	

Because of the changes of direction of friction forces present at the tool – metal contact surface, the model of constant friction was assumed which depends on metal slipping velocity in regard to tool, described by equation:

$$\tau = -m \ k \ arctg\left(\frac{v_p}{a_p}\right)\frac{v_p}{|v_p|}, \qquad (2)$$

where: m – friction factor, k – shear yield stress, v_p – vector of slipping velocity, a_p – coefficient few grades lower than slipping velocity (in calculations it was assumed that a_p = 0,1% of roll velocity). Due to the lack of lubrication and purposeful roughening of rolls (for easier putting of billet between rolls) it was assumed that friction factor had a limiting value m = 1,0. In case of other tools (discs and piercing plug) the value of friction factor was assumed lower m = 0.7.

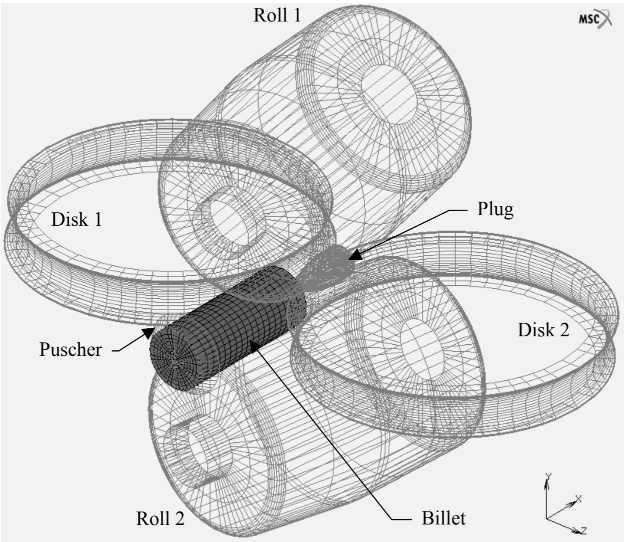
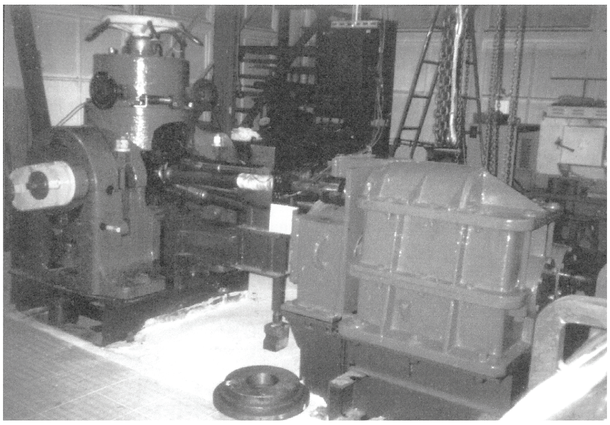


Fig. 2. FEM model of piercing process in skew rolling mill.

3. EXPERIMENTAL RESEARCH

Experimental research of the piercing process were made in laboratory rolling stand (figure 3) at AGH in Cracow. In this rolling stand it is possible to apply various types of calibration of working rolls, rolls compositions (two or three rolls) and guiding tools (include guiding disc devices of Diescher's type). Skew rolling mill was equipped with special measuring system using strain gauges (for measuring torque and loads) and mechanical indicators. The stand is also additionally equipped with heating furnace used for heating of billets. The heating chamber has dimensions 0,25 x 0,3 x 0,6 m.

In scope of experiments tests of rolling were made with the use of different piercing plugs and with constant value of plug advance m_g = 35 mm. The applied forming parameters (geometrical parameters of tools and billet, type of the formed material, tools velocity, temperature of heating etc.) were identical as those assumed in numerical simulation (table 1 – case 1,3,5 and 6).



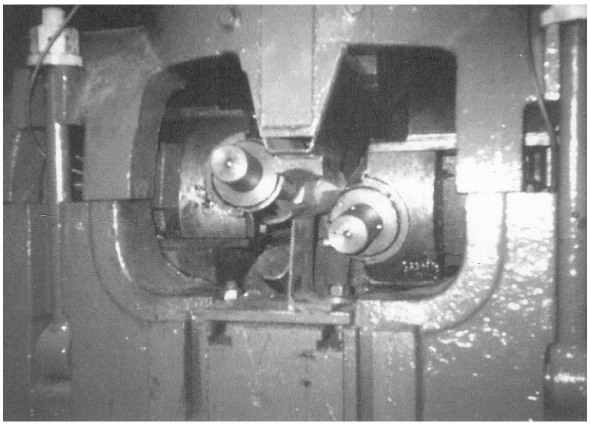


Fig. 3. Laboratory stand for skew rolling.

4. OBTAINED RESULTS

The application of FEM for analysis of the piercing process in the skew rolling mill made possible following the changes of workpiece shape during rolling. These changes are shown in figure 4 in which in order to make it more readable, one disc guiding device is omitted. At the beginning of the process the billet is clamped by rolls which turn it and move in the axial direction. At this stage of forming the process of rotational compression is realized till the plug nose contacts with the head surface of the billet. Then, the forming of the tube shell inner hole begins. The size of this hole is determined by diameter of the used piercing plug. During hole forming the disc guiding devices also contacts with metal and they increase axial forces which draw the billet on the piercing plug. After the whole plug comes fully into metal the forming process reaches the stable phase.

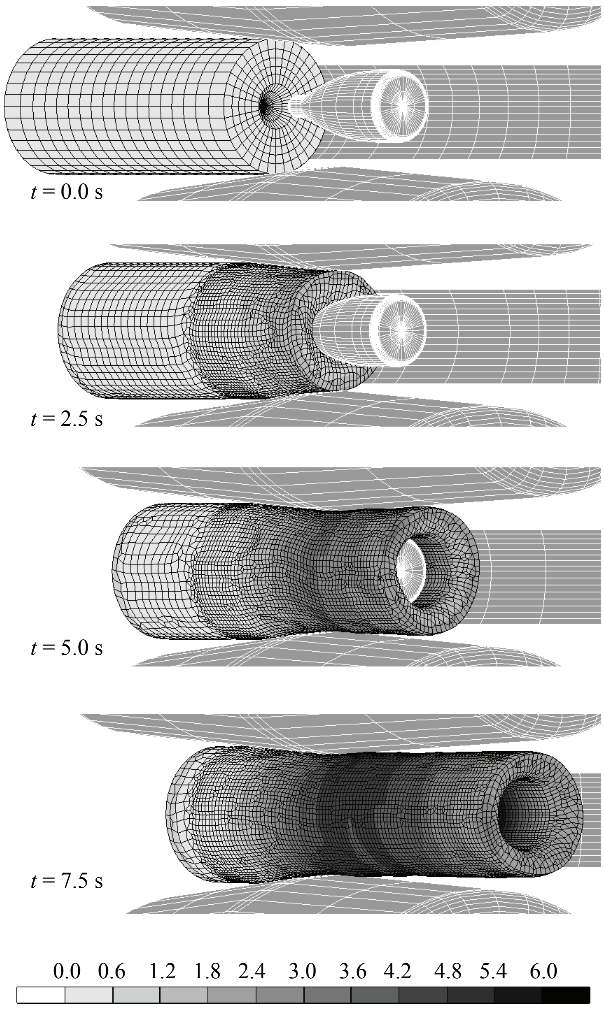


Fig. 4. *The workpiece progression of shape during piercing process with marked distributions of effective strain (case 2 – table 1).*

In figure 5 are presented the calculated FEM distributions of effective strain in workpiece obtained in the analyzed piercing cases. From the data shown in this figure it results that the largest strains are in the tube shell wall and they are localized near the tube shell inner surface. It should be notices that the increase of plug diameter results in the increase of effective strain. However, the influence of plug advance (within the analyzed scope) on the obtained distributions of strains is omitted.

The analysis of strain distributions present in figure 5 shows that they reach large values. This is because of the presence (during forming) inner shearing of metal structure which does not result in the desirable change of shape but leads to redundant strain of metal. The presence of large redundant strains is a characteristic feature of skew rolling and cross rolling processes. The values of redundant strains, in the analyzed piercing processes in the skew rolling mill, can be evaluated by comparing together distributions of effective strain ε and homogeneous strain ε_H (where:

$$\varepsilon_H = \sqrt{3}/2\sqrt{\left(\varepsilon_x - \varepsilon_y\right)^2 + \left(\varepsilon_x - \varepsilon_z\right)^2\left(\varepsilon_y - \varepsilon_z\right)^2}$$

shown in figure 5.) From the obtained maps result that ε_H is distributed in the formed tube shell more uniformly than ε which is distributed in the form of various ring layers.

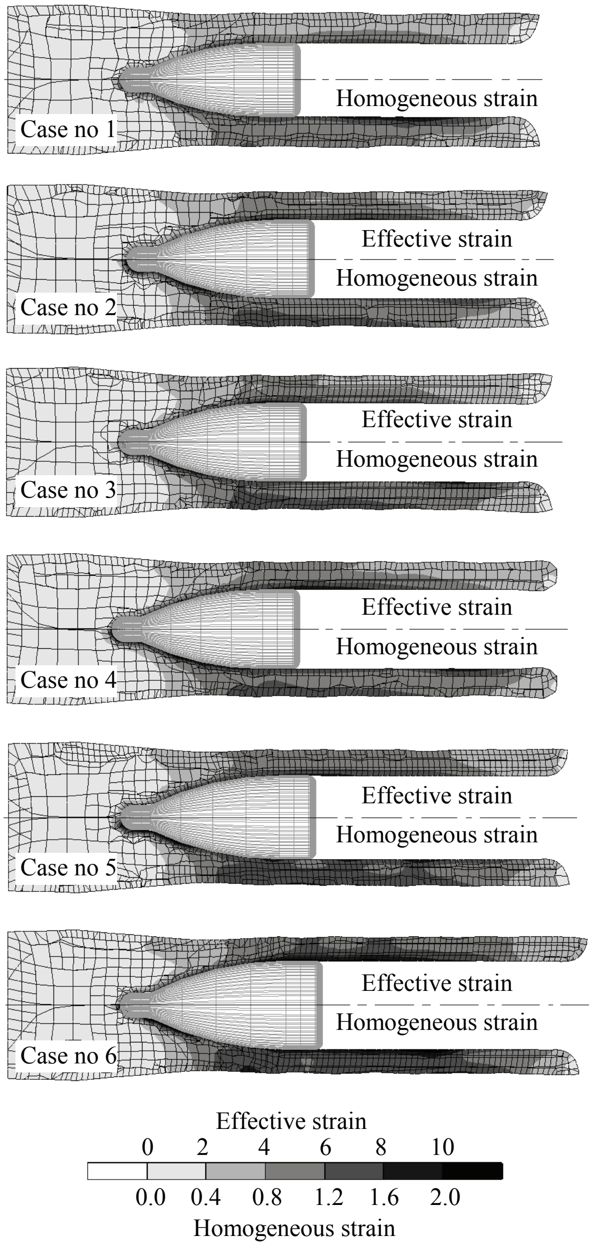


Fig. 5. *Distributions of effective and homogeneous strain in longitudinal sections of workpieces for time t=7 s at the parameters shown in table 1.*

According to figure 6, the change of piercing plug size does not influence the character of material flow. The largest increase of strain is present in the rolling zone (before the piercing plug) and in the piercing zone (on the length of plug conical part). However, in the sizing zone (on the length of the plug cylindrical part and outside it) where the incorrectness of the tube shell cross shape are removed, this increase is very small. The localization of maximal values of strain rate is very interesting. They appear in these parts of material which adhere rolls surface. There, the material undergoes intensive flow in the circumferential direction which is the direct cause of the appearance of large redundant strains.

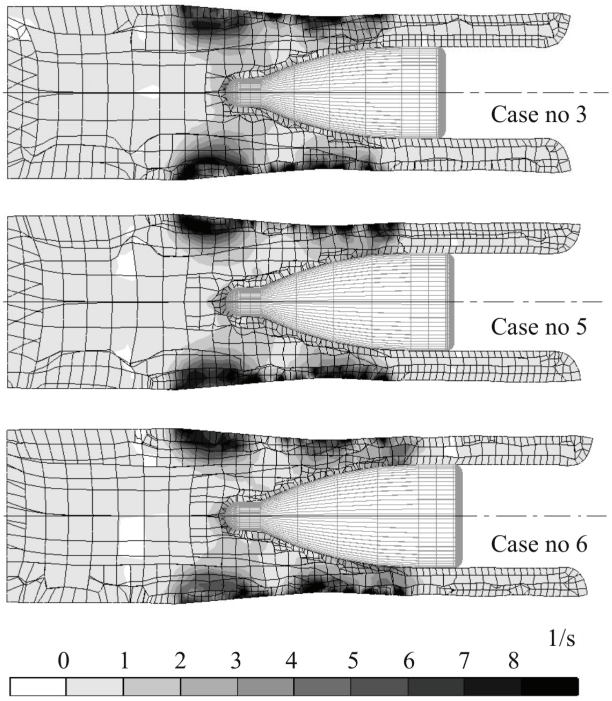


Fig. 6. *Chosen distributions of strain rate in longitudinal sections of workpieces for time t=5.5 s at the parameters shown in table 1.*

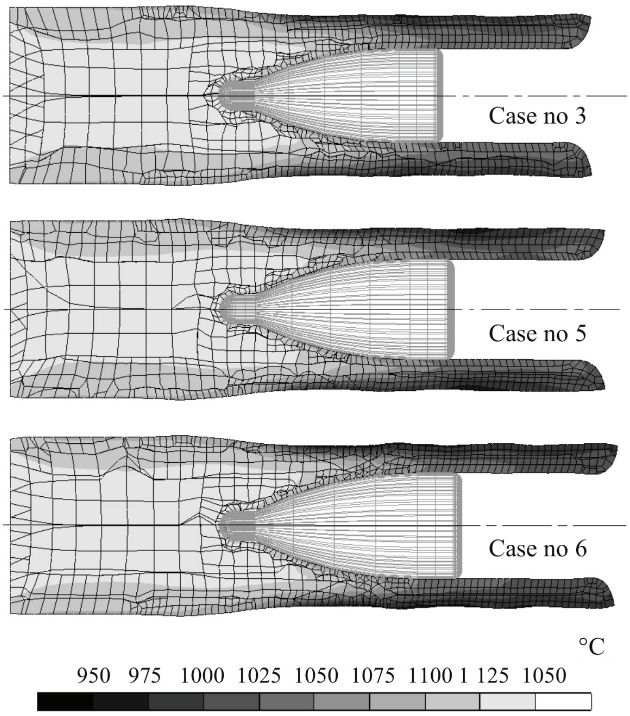


Fig. 7. *Chosen distributions of temperature in longitudinal sections of workpieces for time t=5.83 s at the parameters shown in table 1.*

In figure 7 are shown the distributions of temperatures in longitudinal sections of workpiece formed with the use of plugs of different sizes. Although, the forming time is long, the temperature of the metal in the rolled wall remains within the scope of forming in hot conditions. This is the effect of compensation of heat loss which is transmitted into tools by heat generated by deformation work and by friction work. The lowest temperatures were noticed in the external layers of the formed tube shell, where the best conditions for heat transmitting into rolls were present. Considering the influence of the plug size on temperatures distribution it was stated that the increase of this tool diameter led to the light decrease of metal temperature in the tube shell wall. This is the result of the decrease of thickness of pipe wall from which the heat was taken by rolls.

Basing on FEM the diameter of the tube shell formed in the piercing process in skew roiling mill can be calculated. In figure 8 are presented the calculated mean thickness of tube shells walls formed in the analyzed rolling cases (table 1). However, in this figure the walls thicknesses of the tube shell formed in the real conditions are given. Those thicknesses were measured at both ends of the tube shells on the depth of the slide caliper jaws. Because at the ends of tube shell has the thickness larger than in the middle part, additionally, in figure 8 the maximal walls thicknesses of the tube shells obtained in the numerical simulations of the piercing process are presented. The analysis of the data from figure 8 shows good agreement between the tube shell thickness calculated and measured which confirms the rightness of the worked out FEM model of the piercing process in the skew rolling mill. Taking into consideration the influence of the plug on the wall thickness it was stated that, as it was expected, the increase of this tool diameter led to the decrease of wall thickness.

The size of the piercing plug has a large influence on the force parameters in the piercing process in the skew rolling mill. In figure 9 are compared the forces values (calculated and measured) influencing the plug in the analyzed forming processes. The research results show that the smallest forming forces were for the plug with diameter d_g=34 mm. As for the plug advance m_g before rolls necking it was noticed that the decrease of plug advance led to the decrease of forces on the plug. However, the changes of forces accompanying the changes of m_g were considerably small. Hence, the precise determination of this parameter influence on the piercing process requires the further research in which the plug advance m_g will be changed in a wider range. Considering the comparison of forces in figure 9 the agreement between calculations and real process (real conditions) can be analyzed. The obtained agreement is assumed as the correct.

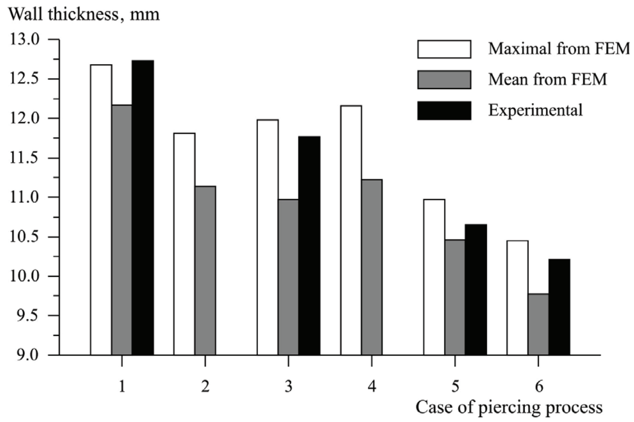


Fig. 8. *Comparison of measured and calculated wall thicknesses for the analyzed cases of piercing in skew rolling mill.*

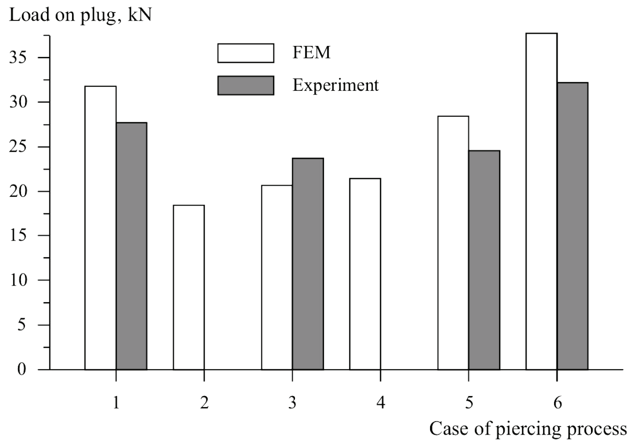


Fig. 9. *The comparison of loads calculated and measured for the analyzed cases of piercing in skew rolling mill.*

5. SUMMARY

In this paper is described the theoretical and experimental analysis aimed at determining the piercing plug influence on the piercing process in the skew rolling mill. Using the commercial software MSC.SuperForm 2005 numerical simulations of the piercing process were made. Additionally, four from the analyzed forming cases were verified in laboratory conditions at AGH in Cracow. The Comparison of wall thickness of the tube shell and loads influencing the plug (calculated and measured) showed good agreement confirming the usefulness of FEM in the analysis of such a complex forming process as the tube shell piercing in the skew rolling mill. In the result of the made calculations the influence of the plug parameters on the strain distributions, strain rates and temperatures in the rolled parts were presented. The worked out FEM model of the piercing process can be further developed e.g. in the direction of calculating the stresses in the forming tools.

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ANALIZA WPŁYWU KSZTAŁTU GŁÓWKI ORAZ JEJ POŁOŻENIA W PROCESIE DZIUROWANIA W WALCARCE SKOŚNEJ

Streszczenie

W artykule przedstawiono rezultaty termo-mechanicznej symulacji MES procesu dziurowania w walcarce skośnej z prowadnicami tarczowymi (typu Diescher'a). W procesie tym materiał jest kształtowany za pomocą dwóch walców skośnych, dwóch tarcz prowadzących i główki dziurującej umieszczonej na trzpieniu. Wykonana analiza miała na celu ustalenie kształtu główki oraz jej położenia względem walców na przebieg procesu dziurowania. Przeliczono sześć przypadków dziurowania, w których stosowano cztery rodzaje główek dziurujących. Badano przebieg zmian podstawowych parametrów procesu tj. rozkładów naprężeń, odkształceń i temperatur w charakterystycznych przekrojach poprzecznych i wzdłużnych kształtowanego wyrobu w funkcji kształtu i położenia główki. Rezultaty numeryczne uzyskane za pomocą pakietu MSC.SuperForm 2005 zweryfikowano w warunkach doświadczalnych, w których dziurowano tuleje ze stali łożyskowej w gatunku 100Cr6. Uzyskane porównanie między wynikami obliczeń MES i rezultatami prób doświadczalnych wykazało bardzo dobrą zgodność ilościową i jakościową.

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