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THE DISTRIBUTIONS OF WALL-THICKNESS OF HOLLOWED PARTS IN ROLLING EXTRUSION PROCESS

ROZKŁADY GRUBOŚCI ŚCIANEK WYROBÓW DRĄŻONYCH PRZEPYCHANYCH OBROTOWO

The new worked out technology of forming of stepped axi-symmetrical parts is rolling – extrusion. In this process, full or hollowed billets are placed in workspace between three rotating rolls by means of a pusher. During numerical research, variants of forming of hollowed parts with using of tools with different shapes and changing velocity of working rolls and the pusher were analyzed. The research was focused on determining the process parameters which guarantee, during forming, equal metal flow and obtaining final parts with assumed shape and wall-thickness along their whole length. In order to verify results of calculations in practice, tests of forming of steel parts in a prototype machine for rolling-extrusion PO-1 were made. The results of these tests confirmed the rightness of numerical calculations.

Keywords: rolling – extrusion, FEM

Nowo opracowaną technologią kształtowania stopniowanych wyrobów osiowosymetrycznych jest przepychanie obrotowe. W procesie tym wsady pełne lub drążone podawane są do przestrzeni roboczej, pomiędzy trzy obracające się rolki, za pomocą popychacza. W badaniach numerycznych przeanalizowano warianty kształtowania wyrobów drążonych o pojedynczym stopniu z wykorzystaniem narzędzi o różnym kształcie oraz przy zmieniającej się prędkości rolek roboczych oraz popychacza. Badaniami objęto rozkłady grubości ścianek wyrobów drążonych kształtowanych przy różnych prędkościach określonych wielkością posuwu na obrót. W pracy skupiono się na określeniu parametrów kształtowania zapewniających równomierne płynięcie metalu, warunkujące uzyskanie wyrobów o zakładanych wstępnie własnościach. W celu praktycznej weryfikacji wyników obliczeń, przeprowadzono próby kształtowania wyrobów stalowych w prototypowym agregacie do przepychania obrotowego PO-1. Wyniki tych badań potwierdziły rezultaty obliczeń numerycznych.

1. The rolling – extrusion technology

Rolling extrusion process is one of the newest technologies of metal forming of axi-symmetrical parts of stepped axes and shafts type [1-3]. The schema of this method is presented in Fig.1. The technology is based on forming of a billet with circular section (full or hollowed) by means of three rotating working tools in the form of rolls and a pusher moving in axial motion. During the process, the formed product rotates round its axis and, at the same time, its external diameter undergoes reduction determined by adjustable forming rolls spacing. In the method's assumption, the hydraulic pusher, moving the workpiece in plane motion correlated with rolls rotary velocity, makes possible forming of multi-stepped shafts.

This solution connects in itself advantages of cross-wedge rolling by means of three working tools with additional possibilities provided by the pusher placing the billet in the work space. In that way, the length of the product obtained in this method is theoretically limited by the pusher working stroke and stiffness of the rotating billet which can undergo buckling.

2. Numerical calculations FEM

Simulations of the rolling extrusion process were made within the scope of conducted numerical research works. The case of forming of side necking of the billet cross section within the range of geometrical and technological parameters presented in Fig. 1 was analyzed during simulations. In order to guarantee the proper billet movement in the workspace between forming rolls, the pusher moving in linear motion was redesigned. This tool had the possibility of free rotation imposed by the movement of the formed part. Due to a complex character of material flow, during numerical modelling of the rolling – extrusion process, calculations were made

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only in conditions of 3D state of strain. The relatively long time of simulation was the result of difficulties in remeshing and problems of numerical character connected with constantly changing contact surfaces.

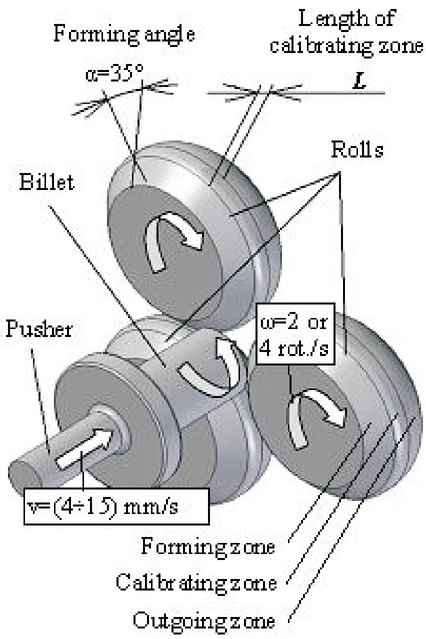

Fig. 1. Schema of rolling – extrusion process with description of tools/billet movements and basic process parameters

Numerical research of the rolling – extrusion process were done by means of specialized commercial software MSC.SuperForm 2005. Realized calculations considered thermal phenomena present during forming - in all simulations the workpiece temperature 1150°C and tools temperature 50°C were assumed for profiled rolls and the pusher. Moreover, the values of coefficient of heat exchange between tools and the workpiece 5000 W/m^{2}K and the workpiece and the environment 200 W/m^{2}K were assumed.

In the further simulations, the forming angle α=35° was applied, guaranteeing certain state of equilibrium between axial and radial flow of the material during the process [3]. Profiled rolls rotary velocity ω was ω=(2.0÷4.0) rot./s. These values were compared with the pusher linear velocity v fitted within the scope v=(4.0÷15.0) mm/s, changeable values of feed rate p=(1.0÷7.5)mm/rot. were obtained. It was assumed that the tool forming zone (conical shape) changed into output zone in a smooth way, with consideration of relatively large radius of transition. However, in the result of the further research it was stated that at the feed rate p=6 mm/rot. the lack of the calibrating zone causes to disturbances of the forming profile of the hollowed products. After introducing in tools separated calibrating zone of length L=12 mm, it was noticed that a considerable improvement of measurement stability of the parts took place, which was presented in works [2, 3]. The example of calculations results at p=5 mm/rot. with application of rolls with cylindrical calibrating zone L=12 mm is shown in Fig. 2.

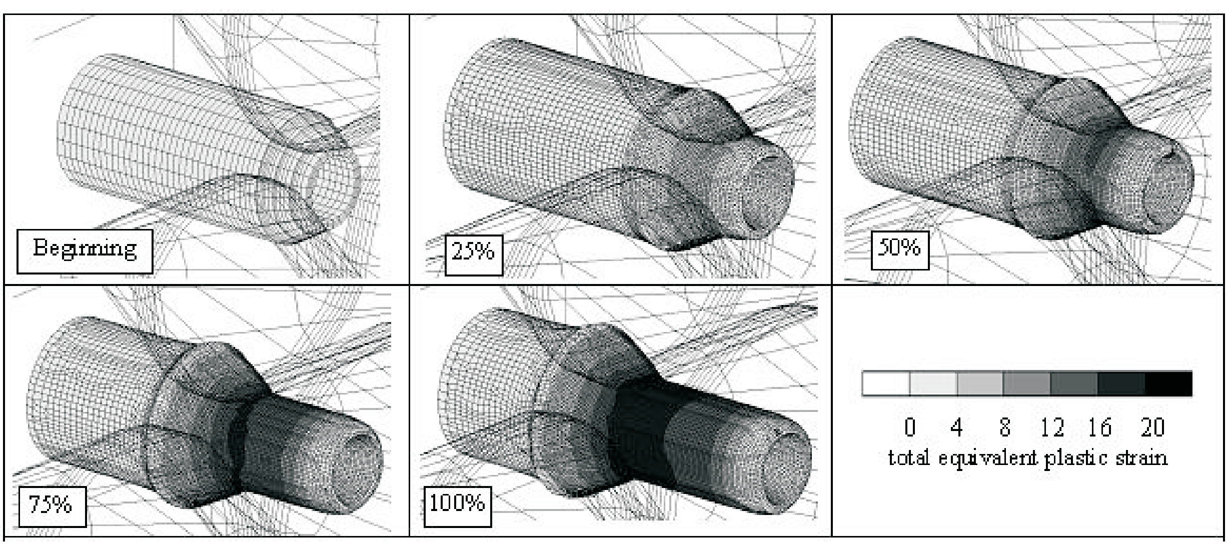

Fig. 2. Distribution of strains and progression of shape of hollowed part during rolling -extrusion process at: *alpha*=35°, L=12 mm and p=5 mm/rot.

The billet for the process in the form of thick-walled pipes, made from steel C45, had the external diameter D_W = Ø60 mm and the internal diameter D_F = Ø40 mm. The billet external diameter was reduced to the value D_F = Ø40 mm during simulation of the rolling –

extrusion, which allowed for obtaining the coefficient of diameter reduction δ=1.5 ($\delta = D_W/D_F$).

The research was focused on the analysis of wall thickness distributions in longitudinal sections of the formed parts. During the calculations, it was observed that the character of material flow changed together with the changes of the value of feed rate *p*. This influenced directly the final external shape of the obtained parts (parts upsetting before the rolls forming zone). The application of small values of feed rate favored the part upsetting before the forming zone. This phenomenon can be explained by a considerable increase of the process length (particularly at the smallest tools velocities), which resulted in workpiece cooling before entering the rolls workspace. This phenomenon was also favorable for cross section triangularization tendency and it provokes increase of cross section dimensions allowances. For obtaining the final parts with relatively close tolerances (about 0.3 mm at circular sections at whole length of parts) it was necessary to realize numerical calculations at feed rates bigger than *p*= 5mm/rot. The best results were obtained with application of feed rate *p*= 6mm/rot. at working time about 5.5 s. Detailed results of wall thickness distributions in longitudinal section of formed part at two different feed rates are shown in Fig. 3. This comparison of wall thickness distributions shows that forming at *p*=6mm/rot. assures obtaining relatively uniform distribution. It is the result of proper choice of such a parameter which guarantees stable metal flow in axial and radial (toward to part axis) directions. The increase of pusher axial speed (*p*=7,5mm/rot.) provokes disturbances in material axial flow, which results in creation of two zones (sections 5-6 and 15-17) with increased wall thickness. Unfortunately, the second area of local increase of wall thickness, just after rolls outgoing zone, obtained inner shape different from circular. In case of future application of parts manufactured by means of this technology it may create problems with mass balancing.

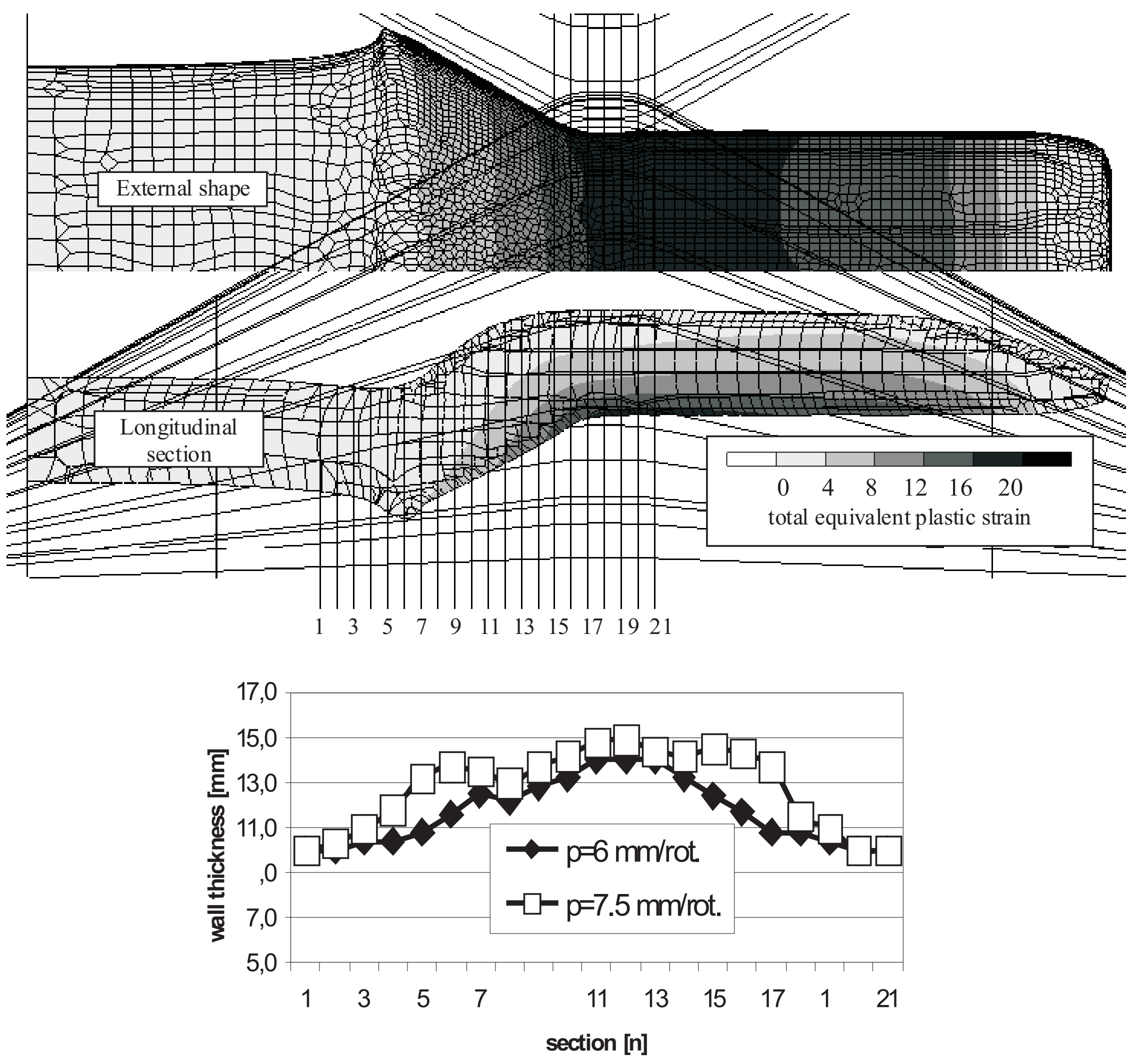

Fig. 3. The external shape and longitudinal section of hollowed parts with distribution of wall thickness at different feed rates

3. Experimental verification

The presented in this paper results of numerical research were verified in a prototype machine for rolling extrusion PO-1. The workspace of this machine with rolls, guiding device and formed part is shown in Fig. 4. The analysis of the case of forming a single shaft step by means of a chosen (on the basis of earlier works) set of rolls shows the dependences between the basic parameters of this process. An example of parts and their longitudinal section formed in rolling – extrusion process at feed rate p=5 mm/rot is shown in Fig. 5. Comparing results obtained in numerical and experimental research, it was noticed that in laboratory conditions it is necessary to take into consideration also the vibrations generated mainly in pusher mechanism. This phenomenon influences the appearance of parts external surface waving. In case of numerical calculation this problem was not observed due to the assumed condition of pusher axial displacement. The stiffness of the pusher mechanism was increased by application of specially designed rotating head which provides workpieces during forming process.

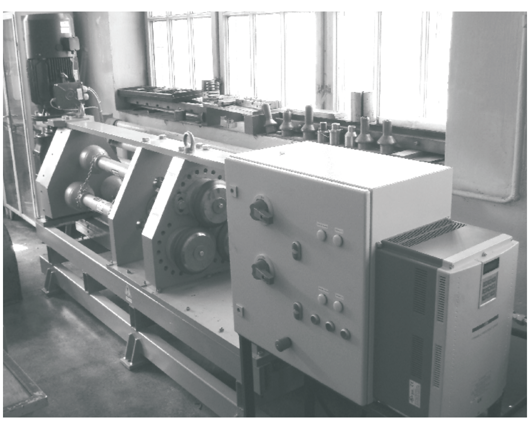

Fig. 4. The formed part in the workspace of prototype machine for rolling – extrusion process

Fig. 5. An example of hollowed part obtained in rolling – extrusion process at p=5 mm/rot. with characteristic external surface waving depending on application of guiding device

4. Summary

Obtained results show that the effects of changes of feed rate values in the rolling extrusion process were local increases of walls thickness of parts before the rolls calibrating zone and just after outgoing zone. It was also observed in that case that the proportionality of these increases connected with the increase of compared together tools velocities appears. The External increase of wall thickness (before rolls forming zones) may be needed in some processes which require upsetting of parts and it would be potentially used for the further machining of i.e. conical teeth. The second area of this phenomenon appearance is difficult to analyze because of placing inside formed parts and it should cause some problems with possible mass balancing of future rotating parts. In the worked out technological processes, this phenomenon imposes limiting the values of the applied feed rate or is the basis for the application of optional mandrels sizing the internal surface shape of the parts rolled in the rolling extrusion process.

The conducted research allows for choosing tools shapes, which will be destined for making in metal. These tools, after mounting in the unit for rolling extrusion PO-1, will be used for conducting research works within the widen scope of process parameters and obtained shapes of parts. The results of these works will be useful for determining guidelines for designing of technological process of rolling extrusion of hollowed parts.

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