

FEM ANALYSIS OF HOLLOW HUB FORMING IN ROLLING EXTRUSION PROCESS

Received – Prispjelo: 2014-01-31
Accepted – Prihvaćeno: 2014-05-30
Preliminary Note – Prethodno priopćenje

In this paper are presented the results of numerical calculations of rolling extrusion process of a hollow hub. As the flanges manufacturing at both sides of the product is required, in the analyzed process of rolling extrusion, a rear bumper was implemented as additional tool limiting axial metal flow. Numerical calculations of the hub forming process were conducted basing on finite element method, applying software Deform3D and Simufact in conditions of three dimensional state of strain. The obtained satisfactory results show that it is possible to conduct the further research works of experimental character, with the application of a modernized aggregate for the rolling extrusion process PO-2.

Key words: rolling extrusion, hollow hub, finite element method (FEM)

INTRODUCTION

A rolling extrusion method has been proposed as a new method of metal forming processes. The schema of this method is shown in Figure 1. The rolling extrusion process is based on forming of billet material of circular section (full or hollow) by means of rotating tools, and on its moving by the pusher's plane motion. During the contact of the material and tools, material rotates around its own axis and its external surface undergoes rotary compression. It is possible to adjust the product's diameter by means of the forming rolls spacing. The implementation of the rolling extrusion technology is not connected, in the assumption, with limiting of the product length and allows for any setting of the forming cycle, within the scope of matching of rolls rotational movement and the linear movement of a pusher displacing the formed material. Research works on rotary metal forming processes were conducted in laboratory conditions [1]. They show that for forming of products with holes, the usage of at least three working tools is especially favourable. The advantage of such a solution is a unified distribution of stresses and strains in the product, due to which lower measurement deviations of manufactured elements are obtained.

Economical profits, apart from material savings, are also gained mainly by limiting of machining in the whole working cycle.

An alternative possibility of widening of the scope of metal forming technology application on shorter series of stepped axi-symmetrical products of joints, shafts and axles type can be the rolling - extrusion method. Additional possibilities are provided by a rear bumper or a mandrel, positioning the billet into the workspace

and limiting axial material flow or forming circular or shaped holes inside formed materials.

Applying two different software it was possible to analyze and compare obtained results concerning kinematics of metal flow in the process, which depended on values of feed rate parameter described as pusher motion (in mm) divided by rolls rotations ($p = \text{mm} / \text{rot}$). In that way, the length of the product obtained in this method is limited by a stroke of the pusher and rigidity of the rotating billet, which can undergo buckling [2-8].

FEM MODELLING OF THE HOLLOW HUB ROLLING EXTRUSION

In the paper are discussed the results of numerical calculations of the rolling – extrusion process of hollow

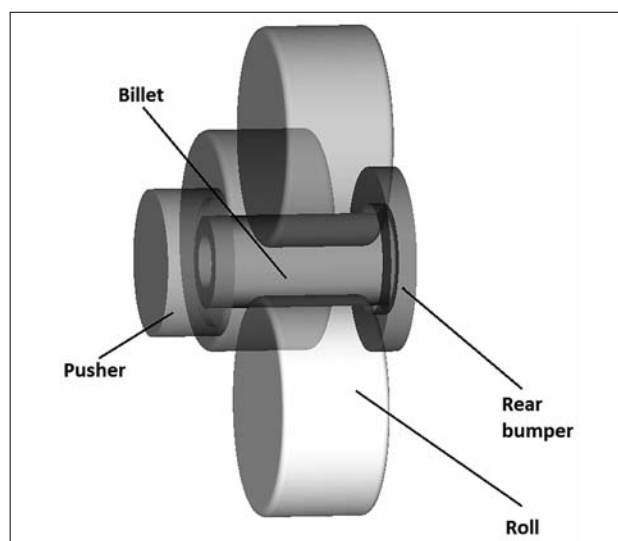


Figure 1 Schema of rolling-extrusion method with rear bumper

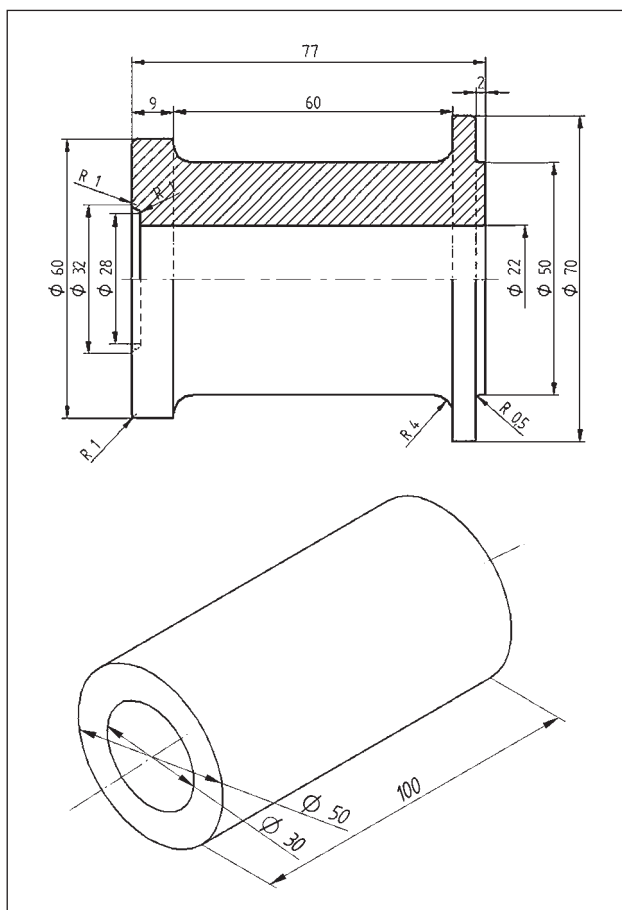


Figure 2 Design of final part shape (upper) and billet (lower)

hub, according to the Figure 2, realized with the application of software Deform3D and Simufact [9, 10].

In order to achieve the conditions the most similar to the real ones, it was decided that the process would take place with full heat exchange with the environment. Material model of titanium Ti6Al4V was taken from the software library. The temperature of the billet was 920 °C and of the forming rolls (modeled as rigid bodies) was assumed 250 °C. The coefficient of heat exchange between tools and the billet was assumed equal 10 000 W/m²K and between the billet and the environment it was 200 W/m²K. Constant friction model with friction factor $m = 1$ was taken into account into calculations.

NUMERICAL CALCULATION RESULTS

Feed rate p , the mentioned earlier main technological parameter of the rolling extrusion process, was changed during calculations. Simulations were made with $p = 2,5$; 5,0 and 7,5 mm/rot. This modification allowed for noticing different results. The process with the biggest feed rate $p = 7,5$ was calculated up to 4,5 s till external flanges were finally upset. In the case of $p = 7,5$ s forming was realized respectively by 13,5 s. Due to this time extension, material was cooled (especially in zones of contact with pusher and rear bumper) and the forces on these tools were much bigger than in other analyzed cases. Temperatures in these zones de-

crease up to 790 °C. Distribution of effective stress during this process was presented in Figure 3 (Simufact) and effective strain in Figure 4 (Deform3D). The biggest values of effective stress (up to 260 MPa) are observed in the area of contact between formed material and the roll near zones of flanges upsetting. Distributions of effective strain at the end of the rolling extrusion process show that the biggest values of this parameter (about 9,0) are reached near the surface of central part's necking. According to the earlier experiences with other rotational forming processes, significant values of strain intensity can result from very large redundant strains. The real strain level in the whole formed product is not bigger than 3,0.

According to the earlier research works [1,3,5], the shape fault Δ (triangulation deviation) was determined, described by the dependency: $\Delta = d_{\max} - d_{\text{nom}}$; where: d_{\max} – maximal obtained part diameter; d_{nom} – nominal part diameter. For feed rate $p = 2,5$ mm/rot triangulation deviation Δ was 3,1 mm. After, additionally added, special sizing at feed rate $p = 0$ mm/rot (one full rotation without moving of pusher) triangulation deviation lowers to $\Delta = 0,2$ mm, guaranteeing obtaining the product of the assumed initially round shape.

Realized at the same time research works on the thickness change of the formed hub walls showed inconsiderable influence of feed rate p on this parameter changes within the scope of calculations conducted with the application of one software. The results of the analysis conducted with the application of Deform 3D and Simufact differ from each other, pointing at the assumption of different schema of metal flow in the process. Apart from the differences in the flange making of the hub, changes of wall thickness measured in the hub's length central part are especially visible. In Table 1 are compared results obtained within this scope for both software.

Table 1 Comparison of parts wall thickness for analyzed hollow hub (according to Figures 3, 4) obtained with different feed rates and software

Analyzed case at feed rate	th_1 / mm ($th_{\text{nom}}=16,5\text{mm}$) Deform3D	th_2 / mm ($th_{\text{nom}}=16,5\text{mm}$) Simufact
$p = 7,5$ mm/rot	18,7	26,7
$p = 5,0$ mm/rot	17,9	24,8
$p = 2,5$ mm/rot	17,4	23,2

All calculated in Simufact software walls thickness were bigger than the same obtained in Deform3D. Material flow in the area of diameters changes was disturbed by the upsetting phenomena. In longitudinal section of the obtained hollow hub (Figures 3, 4), it is shown that part wall thickness at these zones is smaller. The obtained results were also compared concerning force values distributions calculated by different software. In Figure 5, the forces changes on pusher, rear bumper and roll during forming at feed rate $p = 2,5$ mm/rot are presented. Especially big difference was observed comparing force dis-

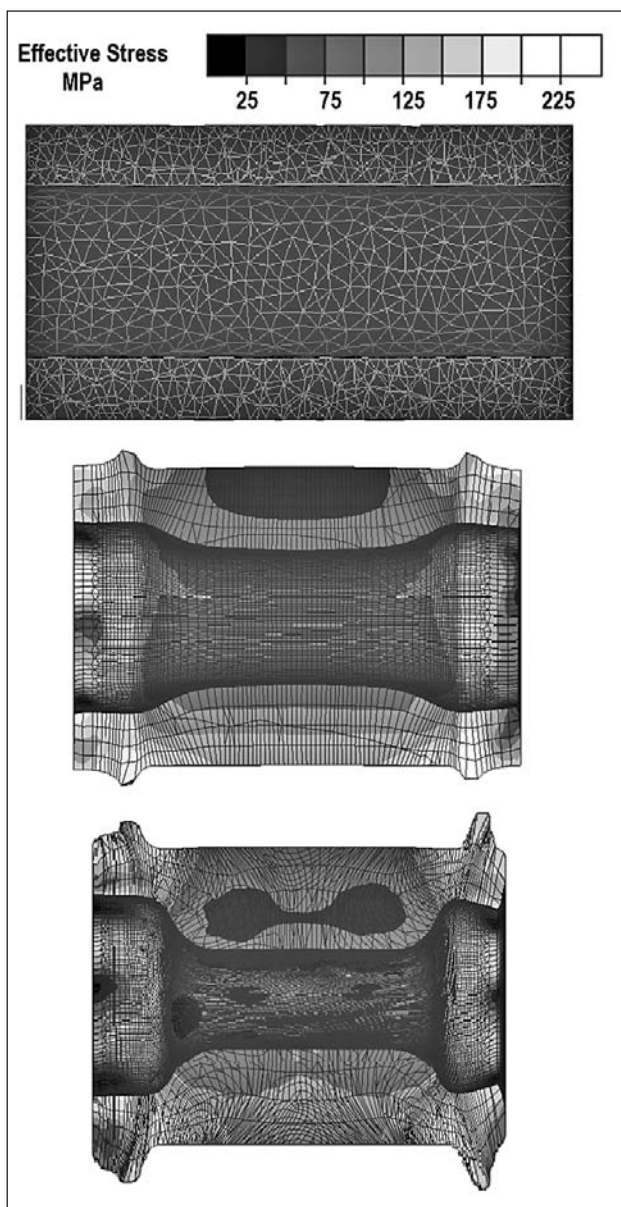


Figure 3 Distributions of effective stress during hollow hub rolling extrusion process (Simufact)

tribution on rolls. During simulation realized in Simufact the mentioned values were almost two times bigger than the same ones calculated in Deform3D. This difference was clearly visible in changes of the wall thickness of the formed hubs.

Considerable differences in results obtained for the same numerical models and technological parameters of the process calculated by different software show the necessity of experimental verification, which will confirm the rightness of the assumptions and obtained shapes of the hollowed hub.

Future research on this kind of hollow parts will be continued also with the application of internal mandrels, in which a pusher and a rear bumper will be equipped. This modification will decrease material flow towards part axis and permit to obtain parts with controlled internal diameters. In this case very important will be the proper choice of billet shape and its volume because it is strictly connected with triangulation phenomena pres-

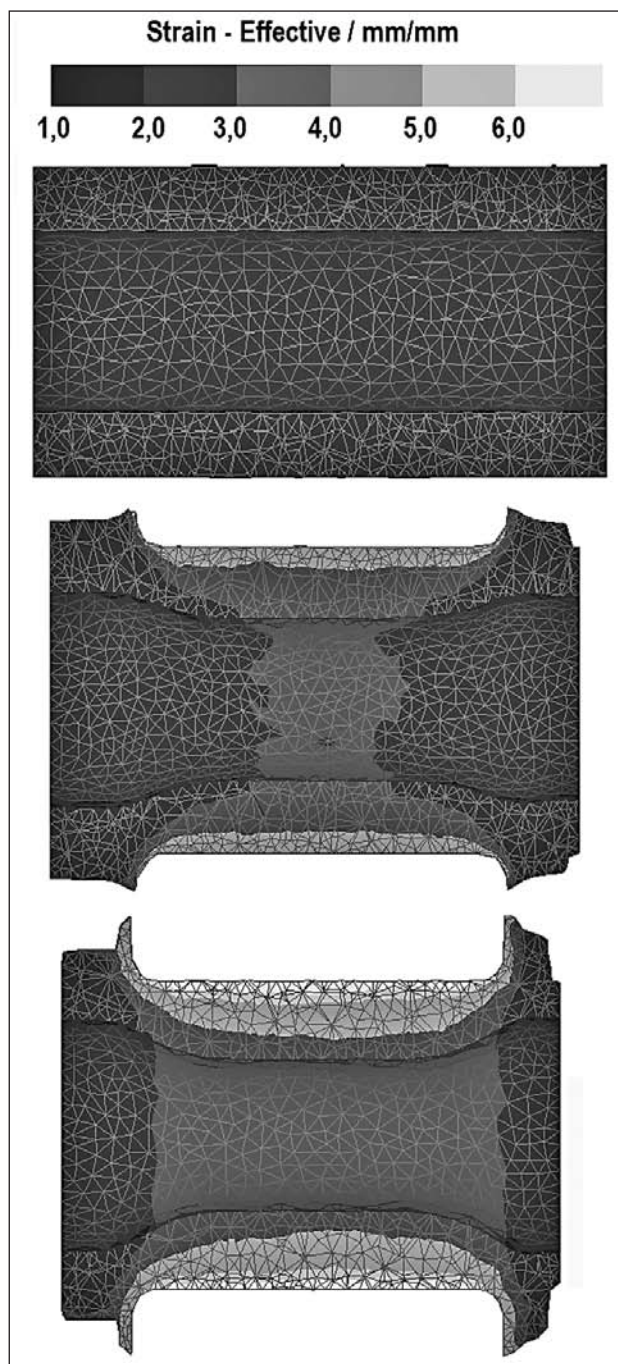


Figure 4 Distributions of effective strain during hollow hub rolling extrusion process (Deform3D)

ence, which limits application of this method. This problem is also significant in the case of application of full billets. In rolling extrusion realized for full parts the material does not have the possibility to flow inside (toward billet axis) and the triangulation phenomena can be observed earlier than in the same process with hollow parts.

SUMMARY

Discussed in this paper theoretical analysis of the rolling-extrusion process with rear bumper successfully verifies the possibility of the presented hub type products forming. Due to this process, considerable lower-

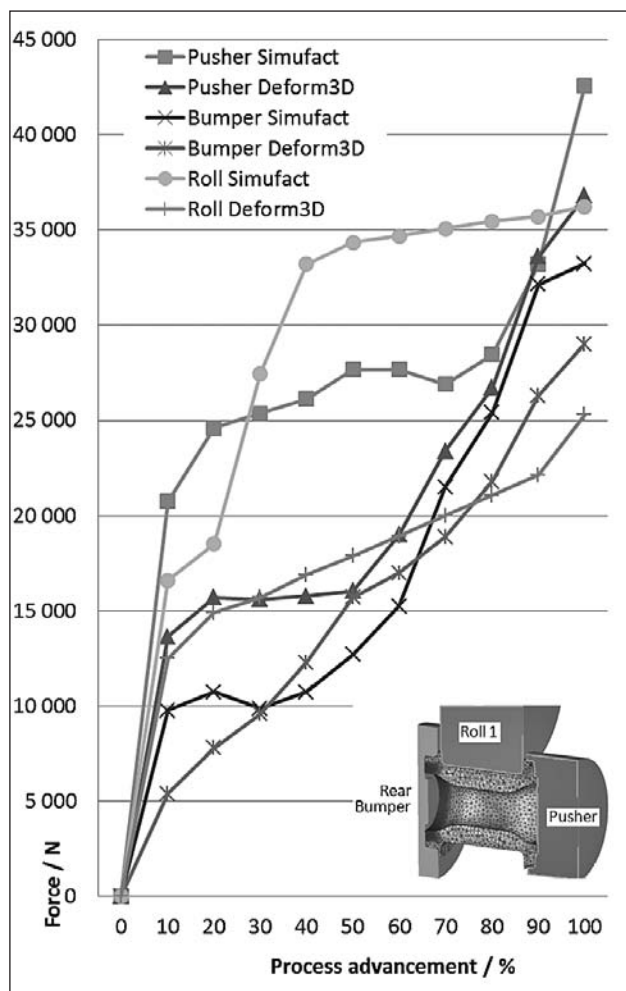


Figure 5 Distributions of forces during rolling extrusion calculations by Simufact and Deform3D software at $p = 2,5 \text{ mm/rot}$

ing of manufacturing costs is probable, especially of short series of stepped products. The application of virtual forming techniques at the designing stage makes easier the choice of the process optimal parameters. In order to foresee impressions filling in such a complex kinematic process, it is also possible to analyze the metal flow kinematics. The obtained loads results constitute the basis for the further research works, which aim at working out of metal forming process of full and hollow hub and stepped shafts products. The work realized within the scope of single theoretical tests was initially experimentally verified in the aggregate for the rolling-extrusion process PO-2 (Figure 6).

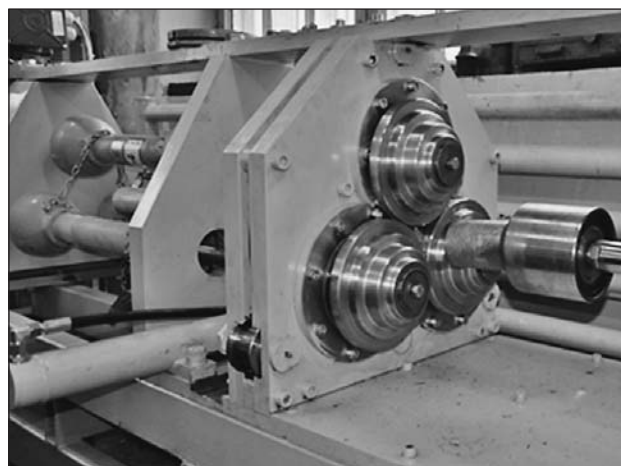


Figure 6 The aggregate for the rolling-extrusion process PO-2

Acknowledgements

Financial support of Structural Funds in the Operational Programme - Innovative Economy (IE OP) financed from the European Regional Development Fund - Project "Modern material technologies in aerospace industry", No POIG.01.01.02-00-015/08-00 is gratefully acknowledged.

REFERENCES

- [1] J. Bartnicki, *Key Engineering Materials*, 572 (2014), 323-326.
- [2] J. Tomczak, Z. Pater, *Metalurgija* 51 (2012) 4, 497-500.
- [3] Z. Pater, J. Tomczak, J. Bartnicki, M.R. Lovell and P.L. Menezes: *Journal of Machine Tools & Manufacture* 67 (2013), 1-7
- [4] A. Tofil, *Archives of Metallurgy and Materials* 58 (2013) 3, 725-729.
- [5] J. Bartnicki, *Archives of Metallurgy and Materials* 2012 (57), 1137-1142
- [6] G. Samołyk, *Journal of Materials Processing Technology* 213 (2013), 1692-1702.
- [7] A. Gontarz, A. Dziubińska, *Steel Research International, Spec. Ed.* (2012), 843-846.
- [8] J. Tomczak, Z. Pater, T. Bulzak, *Eksploatacja i Niezawodność – Maintenance and Reliability* 2013; vol. 15, no 3, p. 279–283.
- [9] DEFORM material library, DEFORM 2D/3D v.10.2, Scientific Forming Technologies Corporation, 2011.
- [10] SIMUFACT manual library, SIMUFACT engineering gmbh

Note: The professional translator for English language is A. Bartnicka, SIMPTTEST Lublin, Poland