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**NUMERICAL ANALYSIS OF ROLLING EXTRUSION PROCESS OF A HOLLOW HUB****ANALIZA NUMERYCZNA PROCESU PRZEPYCHANIA OBROTOWEGO PIASTY DRAŻONEJ**

This paper presents the results of numerical calculations of rolling extrusion process of a hollow hub. Simulations were made by means of software Deform 3D in three dimensional state of strain. Distributions of effective stress, effective strain and damage criterion in the rolled extruded product were analyzed. Verification of metal flow during process allowed to design tools for experimental verification in PO-2 laboratory rolling – extrusion aggregate. For these needs also process force parameters were calculated.

*Keywords:* rolling extrusion, FEM, hollow products

W pracy przedstawiono rezultaty obliczeń numerycznych procesu przepychania obrotowego piasty drażonej. Symulacje wykonano w przestrzennym stanie odkształcenia korzystając z oprogramowania Deform 3D. Analizie numerycznej poddano, występujące w przepychanym obrotowo wyrobie, rozkłady naprężeń, odkształceń oraz kryterium pęknięcia. Określenie kierunków płynięcia metalu podczas kształtowania umożliwiło zaprojektowanie narzędzi przeznaczonych do weryfikacji eksperymentalnej procesu w agregacie do przepychania obrotowego PO-2. W tym celu oszacowano także parametry siłowe procesu.

**1. Introduction**

Different manufacturing technologies are applied for forming of stepped hollow and full products of axles and shafts type. Among metal forming technologies, rolling, especially cross rolling [1-5], die forging, forging on swaging machines, extrusion and forming at high pressures (for thick-walled products) should be mentioned. In the case of forming of full products, widely applied forging methods fulfil the manufacturers' requirements, however, in the case of hollow products, the application of these methods is considerably limited [6-9].

All mentioned solutions allow for forming of products without disarrangement of material fibres continuity at simultaneous high repeatability of shape (in comparison with machining). This results in possibility of big series or mass production of parts with high mechanical properties and wears resistance. Their main receivers are aviation and automotive markets.

The results of research works on rotary metal forming processes, conducted at Lublin University of Technology [3-12], show that for forming of products with holes, the usage of at least three working tools is espe-

cially favourable. The advantage of such a solution is a unified distribution of stresses and strains in the product, due to which lower shape deviations of manufactured elements are obtained. Apart from material savings, economical profits are also gained mainly by limiting of machining in the whole manufacturing cycle [1-3].

The rolling – extrusion method is 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.

**2. Rolling – extrusion process**

In the rolling-extrusion method material is formed by means of three rotational tools. The workpiece is provided by means of a pusher pushing the billet into a workspace between three profiled rolls. Alternatively, in the opposite side to the pusher, the bumper is placed. The aim of this last tool is to limit material axial free flow and to allow for the correct upsetting of external zones of formed billets.

The rolling extrusion process course depends on different shapes of profiled rolls and their rotary velocities

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correlated with the pusher and bumper displacement. The basic schema of this process is shown in Fig. 1, which presents the predicted movements of particular tools.

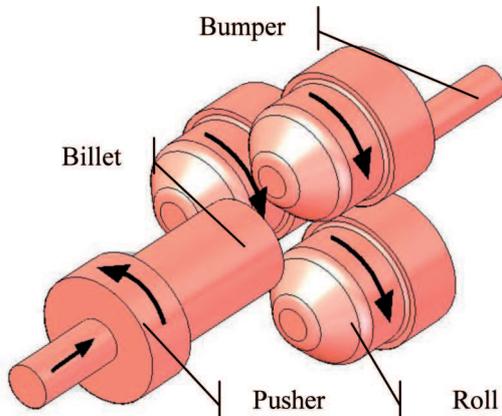


Fig. 1. Schema of rolling – extrusion process

The formed product is placed in the workspace between rolls by the pusher, which plane motion correlated with rolls rotary velocity was described as feed  $p$  [mm/rot.]. This parameter is the most important for all phenomena observed during rolling – extrusion process. Due to the big value of  $p$ , it is very easy to obtain excessive triangulation of formed parts cross sections. This limitation is very characteristic for all rotational metal forming technologies realized by means of three rotating tools – rolls. The presence of this phenomenon is connected with a considerable widening of tolerance range of particular, rolled by extrusion, steps of the product. At large triangulation the forging is completely crushed, which is also connected with rolls immobilizing due to the lack of rotation of the formed product [14,15].

On the contrary, small values of  $p$  decrease the process productivity and lead to significant diminutions of temperature of parts usually formed in hot metal forming conditions. Moreover, due to material cooling, axial and radial forces increase and the risk of cracks appearance in the formed product become bigger. Hence, the values of calculated theoretically tangent forces exceed the design assumptions of the aggregate for rolling extrusion PO-2.

Firstly designed rolling extrusion process does not consider the possibility of changing of rolls spacing during the process realization and the possibility of additional movement of the rear bumper equipped with rotary head. The implementation of changeable rolls spacing allows, on the one hand, for easy removal of the finished product from the working space between them. On the other hand, this solution widens the application scope of this method, where, together with the rear bumper usage,

it is possible to form parts with more complex shapes and with upsetting on two external zones.

### 3. Numerical simulation of rolling – extrusion of hollow hub

The semi finished hollow hub part, shown in Fig. 2, is applied in different type of wheels. This product has a central neck with a smaller diameter and two flanges at external zones. The aim of numerical calculation was to verify possibilities of this kind of parts manufacturing by means of rolling – extrusion.

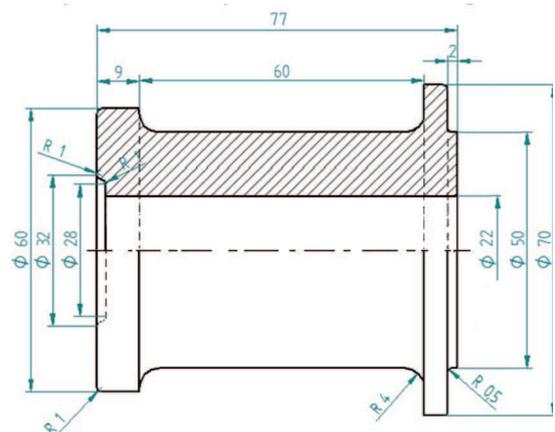


Fig. 2. Shape and dimensions of hollow hub

Numerical calculations of rolling extrusion process of hollow hub were made using the commercial software Deform3D. Numerical model of the process is shown in Fig. 3. In the presented model as billet a bar with diameter  $\varnothing 50$  mm and length  $l = 100$  mm was used, which was modeled by means of four-nodes tetragonal elements of the first type. For the analysis needs, geometrical models of part forming from billets with three different diameters were designed. The designed pusher and rear bumper outline is presented in Fig. 4. The rolls applied in this process have a cylindrical shape with dimensions  $\varnothing 220 \times 60$  mm. The rolls in the analyzed case rotate with constant velocity 6.28 rad/s. The feed rate on rotation  $p$  changes within the scope from  $p = 4$  mm/rot at the process beginning to  $p = 0,5$  mm/rot at the end of forming. This is the result of the mentioned earlier risk of shape fault presence in the form of triangulation leading to disturbance of the process stability [3-5,20].

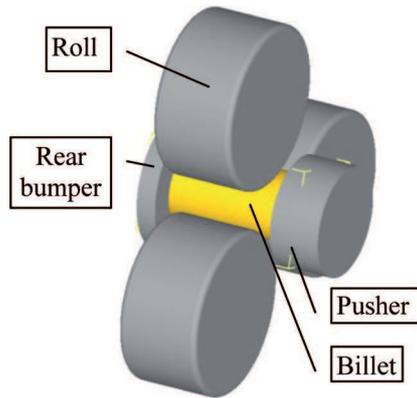


Fig. 3. Numerical model of rolling extrusion process of hollow hub

The implementation of the moveable rear bumper in calculations was imposed by the necessity of material axial flow toward part's central zone, which guarantees the correct material filling in the formed flanges area. This movement was correlated with small decreasing of rolls spacing about 1 mm in diameter. Due to large changes of shape of the product during the forming, remeshing was often used in calculations. In numerical calculations material model of steel C35 was used, being in the data base of the software Deform3D. It was assumed in calculations that the billet was heated to the temperature 1150°C, yet, the temperature of all tools during the process was constant and equal 150°C. The model of constant friction dependant on slide velocity was used in calculations, with the limiting value of friction factor  $m = 1.0$  [9-11].

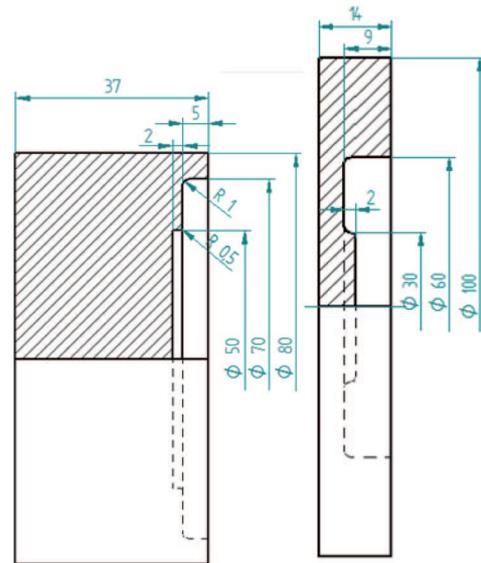


Fig. 4. Shape and dimensions of the pusher (left) and the rear bumper (right)

In numerical simulations it was possible to analyze kinematics of metal flow in the process, depending on the applied values of feed rate  $p$  parameter. The force parameters such as course of the forming force acting on one roll and axial force with which the pusher and rear bumper implemented material between rotating rolls were also analyzed. The progression of shape of the rolled – extruded hollow hub at a different state of advancement is presented in Fig. 5.

In Fig. 6 are presented distributions of effective strains, effective stresses and damage criterion according to Cockroft – Latham integral.

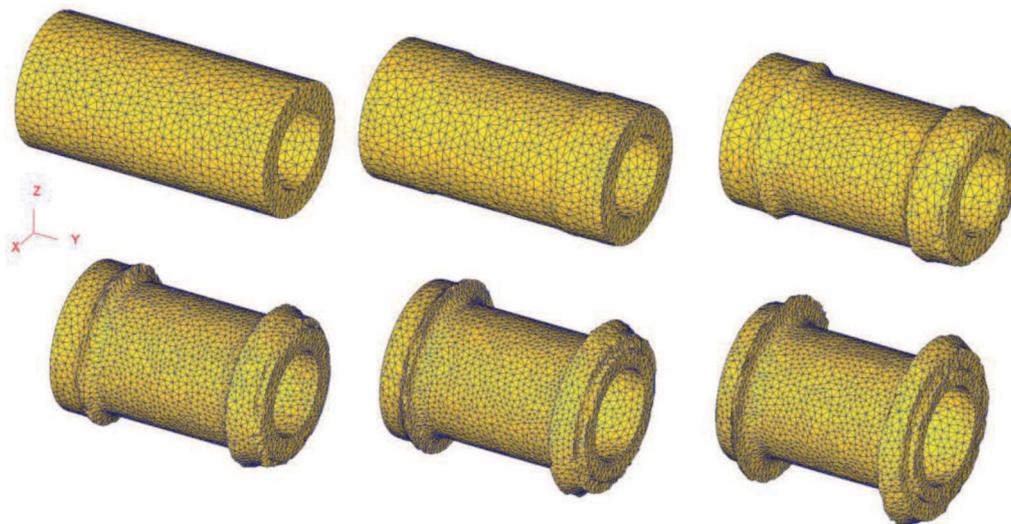


Fig. 5. Progression of shape of rolled – extruded hollow hub in different state of advancement

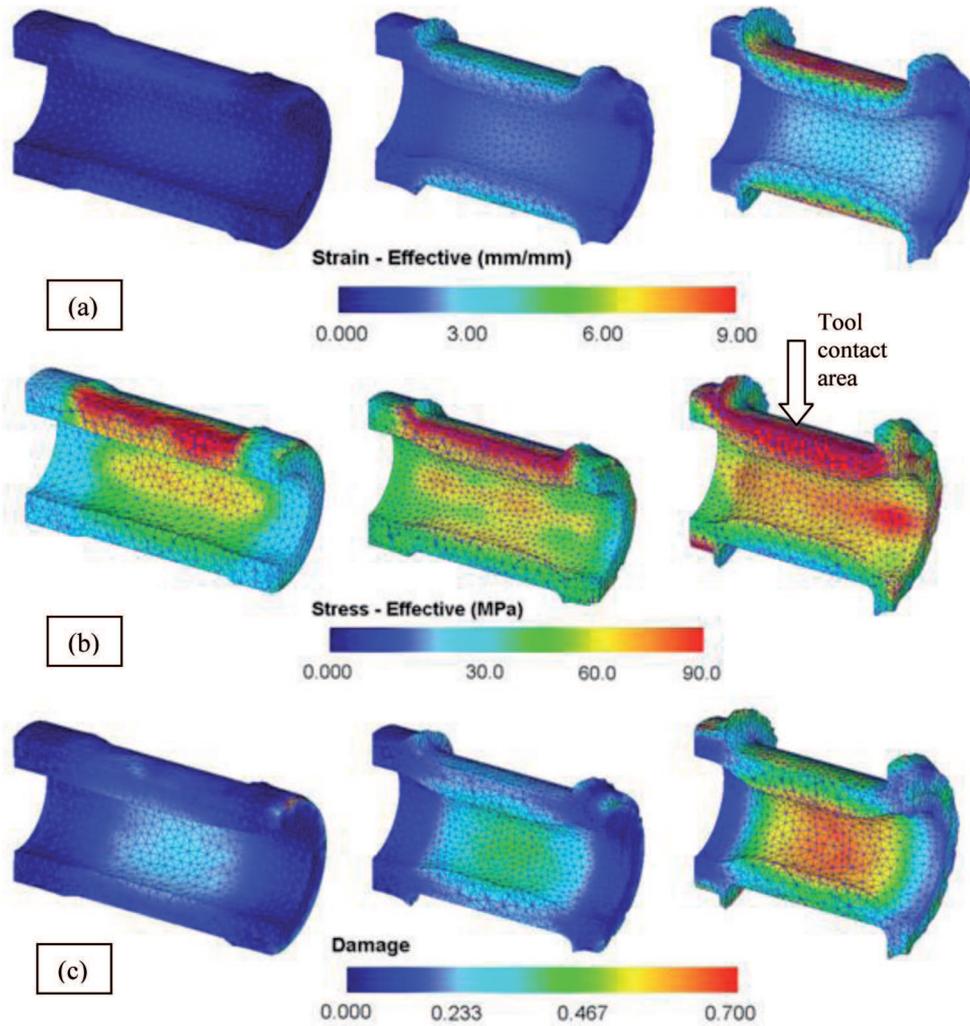


Fig. 6. Distributions of effective strains (a), effective stresses (b) and damage criterion (c) according to Cockroft – Latham integral during hollow hub rolling extrusion process

Distributions of effective strains 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. Distributions of effective strains are also connected with effective stresses presented in the second rank of Fig. 6. The biggest values of effective stresses (up to 90 MPa) are observed in the area of contact between formed material and rolls. The last presented in this figure distribution of damage criterion according to Cockroft – Latham shows significant values of the mentioned earlier integral inside the surface of the formed hollow hub. Usually, for steel materials formed in hot conditions, it is assumed that the value of C-L

integral must not exceed 0.7. Above this value there is a real risk of cracks initiations in the formed material.

The obtained in numerical simulations hollow hub was formed in the result of axial and radial flow causing upsetting of metal which gradually filled impression in tools. The distributions of forces acting on different tools during the hollow hub forming are shown in Fig. 7.

The observed in the diagram (Fig. 7) fast increase of all forces in the fourth second of the process is caused by initiation of flanges upsetting. After stabilization of material flow in the direction outside from part's axis, the forces on rolls slightly decrease. The final increase of all forces is connected with fulfilling of foreseen impressions area by material forming hollow hub. At this moment, the registered values of C-L integral reach the value below 0.7 (Fig. 6).

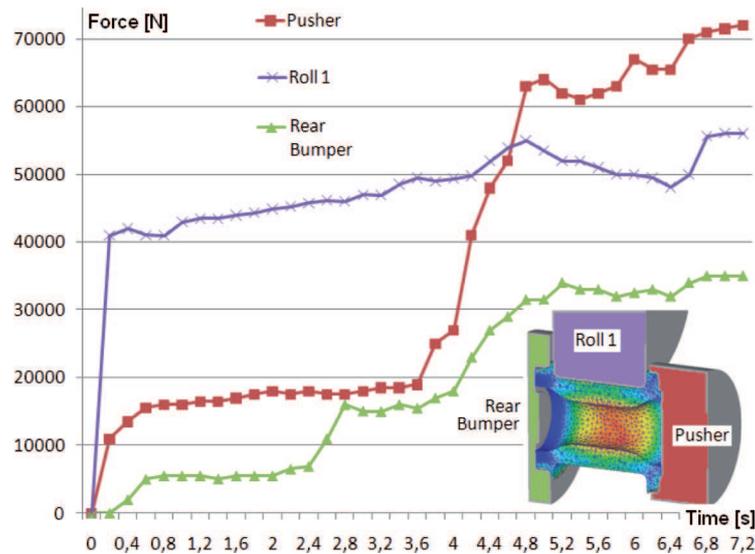


Fig. 7. Distributions of forces acting on different tools during hollow hub forming

Rotating rolls constantly reduced the triangulation phenomenon presence, which was also connected with the increase of effective strains. The problem of parts' cross – sections triangulation is one of the most important phenomena which limits the fields of application of rotational forming methods with the usage of three tools [15-19]. In the presented case, due to the application of sequence of feed rate  $p$ , it was possible to decrease this shape fault under value of 1 mm. In the case of free formed hollow parts with diameter of central part  $\varnothing$  50 mm this allowance can be accepted.

#### 4. Conclusions

The worked out numerical analysis of the rolling – extrusion process of hollow hub part confirms the possibility of forming of this type of products. Presented in the paper application of additional (in rolling – extrusion) movable tool as rear bumper permits to widen the scope of technology application on forming of parts with two upset ends. In practice, the realization of parts of hub types with two flanges will be confirmed in laboratory rolling – extrusion aggregate PO-2, placed in laboratories of Lublin University of Technology. The last modernization of this machine permits to do research with tools and billets presented in this paper. Designed and numerically calculated process will be developed to obtain this kind of parts with smaller technological allowances. It is foreseen that rolling – extrusion technology allows for a considerable lowering of manufacturing costs, especially of short stepped products series as hubs, axles and shafts.

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