J. TOMCZAK, Z. PATER

ISSN 0543-5846
METABK 51(4) 497-500 (2012)
UDC – UDK 621.73, 73, 669.1=111

ANALYSIS OF METAL FORMING PROCESS OF A HOLLOWED GEAR SHAFT

Received – Prispjelo: 2012-02-12
Accepted – Prihvaćeno: 2012-04-30
Preliminary Note – Prethodno priopćenje

This paper presents the results of numerical analysis of forming a hollowed gear shaft forging, used in automotive industry. Numerical simulations of the process were made by means of finite elements method (FEM) in conditions of three dimensional state of strain with consideration of thermal phenomena. During calculations, geometrical parameters of the obtained products were analyzed, distributions of strains and temperatures were determined. The process force parameters were also given. In the result of conducted research works, it was stated that it is possible to form in a rotary way axi-symmetrical hollowed forgings.

Keywords: forming, hollowed shafts, rotary compression, FEM

INTRODUCTION

Hollowed elements are characterized by resistance properties comparable with full products, especially in the case of bending and torsion loads, at simultaneous reduction of their mass. In consequences, machines which are equipped with hollowed parts are lighter than traditional solid elements. Hence, hollowed equivalents of full products are more widely applied. At present, the main recipients of this type of parts are automotive and aviation industries, in which decrease of construction mass can result directly in improvement of machines dynamics, reduction of fuel consumption, increase of load capacity and reduction of pollution emission. Apart from numerous exploitation advantages, the application of hollowed parts allows for reduction of manufacturing costs (reduction of material consumption and work costs). It is possible, however, only in the case of application of hollowed billet (in the form of a pipe or a sleeve) in the manufacturing process. A lot of manufacturing methods of hollowed elements are used, including these of the largest importance - machining and metal forming.

Machining techniques are connected with the necessity of removing of particular material layers. This causes large material and energy consumption and increases machines load. Due to this fact, it can be noticed that metal forming process of hollowed products, in which relatively small allowance for final machining is left, becomes more and more popular [1]. The application of metal forming process not only allows for reduction of manufacturing costs but it also increases products resistance properties due to favorable structure distribution. There exists numerous well known and widely applied metal forming methods of hollowed parts. At present, the largest importance have such processes as: drawing, spinning, traditional forging connected with punching, swaging, rotary forging, high pressure internal pressing and cold squeezing connected with deep drilling. However, these are relatively complex processes, which are most often realized in a few operations [2 - 5]. In the result, manufacturing costs are in many cases higher than in the case of application of traditional methods. Hence, numerous research centers conduct research works on unconventional methods of metal forming of hollowed parts, which will allow for manufacturing of products of high parameters at small financial costs. At Lublin University of Technology, research works on metal forming of hollowed parts, dealing with rotary processes of metal forming, have been conducted for many years. In the result of these research works, a method of forming of axi-symmetrical forgings by means of rotary compression (cross wedge rolling) [6] has been worked out. Parts of commercial thick-walled pipes are used as billet; during the process they are formed by rotating tools in multi-stepped forgings of hollowed shafts.

THE SCOPE OF ANALYSIS

In order to confirm the rightness of the assumption, many numerical simulations of rotary compression of multi-stepped hollowed shafts were made. One of the product, which process was numerically modeled, is a forging of gear shaft used in automotive industry (Figure 1).

It is, at present, manufactured from full semi-finished product by means of machining, which seems to be not economical and increases manufacturing costs. Hence, metal forming of shaft semi-finished part (Figure 2) from hollowed billet (pipe) was proposed. Such a process allows a considerable reduction of energy and

J. Tomczak, Z. Pater, Lublin University of Technology, Lublin, Poland

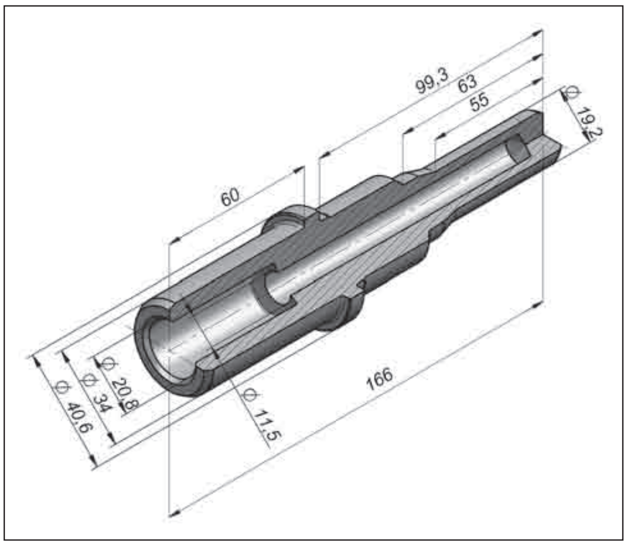

Figure 1 Shape and dimension of hollowed gear shaft

material consumption. It also improves resistance properties of the manufactured elements due to favorable forming of internal structure.

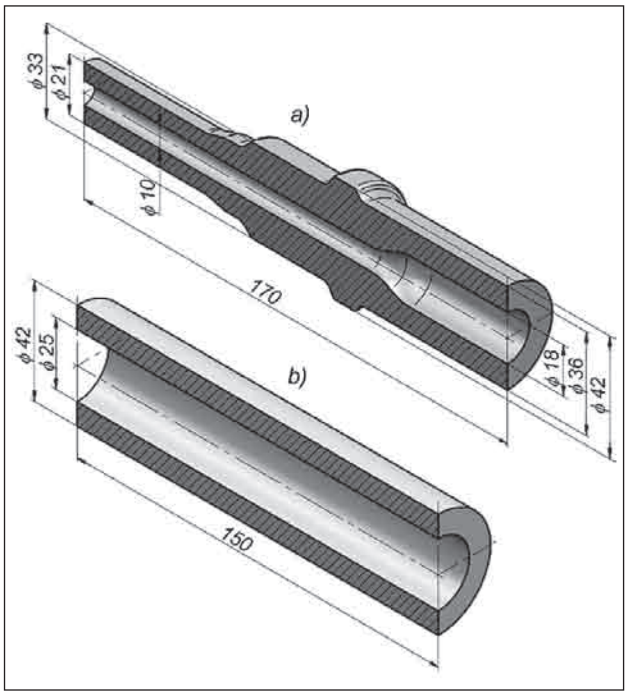

Figure 2 Shape and dimensions of a shaft forging - a and the applied billet - b

Numerical simulations

Numerical simulations of rotary compression of hollowed shaft forging were made by means of finite element method, using commercial software Simufact Forming 10,0. Due to large differences of external pivots, it was assumed that in real process the forging would be formed in double configuration, and later cut into two parts. In calculations the product symmetry was used, which allowed for conducting the analysis for one forging only. This considerably shortened time of simulation. Because of complex character of material flow calculations were made in three-dimensional state of strain. During simulations the following were analyzed: geometrical parameters of obtained forgings, kinematics of metal flow, process force parameters, distributions of strains and temperature of the formed products were also determined.model of the process designed for the analysis needs is shown in Figure 3. This model consists of three equal tools-shaped rolls (1) and billet (2). Tools rotate with constant velocity n_1 = 65 rot/min in the same direction and move radially with constant velocity v = 0,002 m/s in the direction of product axis. At the end of rolling the rolls translational motion is switched off, yet, tools rotary movement is left, which finally size the forging shape. Steel pipe of type 16CrMo4 with external diameter ∅ 42 and internal diameter ∅ 25, and with length l = 150 mm, was used as billet. Semi-finished product was modeled by means of hexahedral with 8-nodes elements. Material model of steel 16CrMo4 was used in data base of software Simufact Forming. It was assumed in calculations that billet was heated to the temperature 1 100 °C, yet tools temperature during the process was constant and equal 150 °C. The rest of the parameters considered in calculations include: friction factor at metal-tool surface of contact m = 1, heat exchange coefficient between tools and material – 15 kW/m^{2}K and between material and environment - 0,2 kW/m^{2}K.

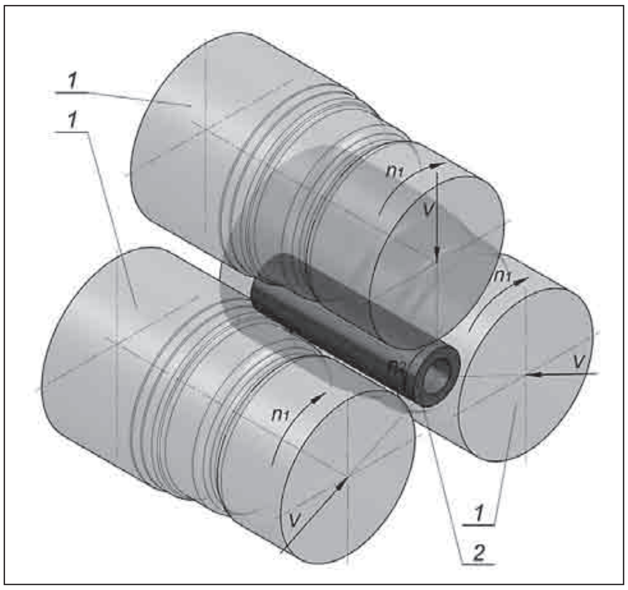

Figure 3 Geometrical model of rotary compression of hollowed shaft forging

Numerically determined shape of hollowed shaft forging is shown in Figure 4. A characteristic feature of the obtained product is the increase of wall thickness in relation to initial thickness of the applied billet, which is the result of reduction of external and internal diameter of the forging. This phenomenon is favorable and it acts on improvement of element resistance properties and allows for application of billet with smaller wall thickness. On the head surface of the formed shaft, a groove in the shape of funnel can be observed. This is the effect of surface metal flow and considerable elongation of the

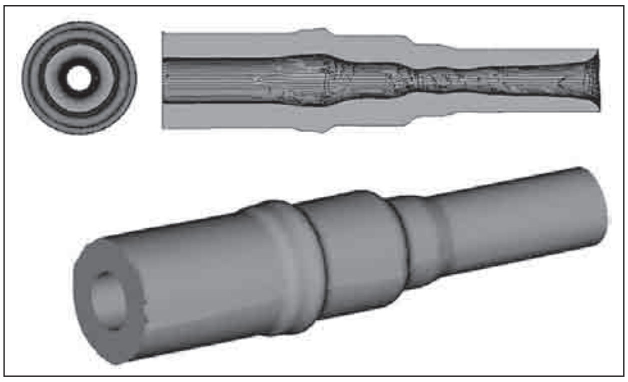

Figure 4 Shape of gear shaft forging

product external step. In consequences, large differences in wall thickness of the shaft external pivot can be observed. This deformation is treated as allowance which will be removed at the next stage of the process.

The application of numerical techniques for metal forming processes analysis allows the investigating of metal flow kinematics. In the result, it is possible to foresee the appearance of various faults which can lower quality of the formed products. Figure 5 presents progression of forging shape depending on the process advancement. At the beginning of the process, moving tools put billet into rotary movement and reduce the diameter of the product external pivot. Metal flows radially in the direction of forging axis, which causes reduction of external and internal diameter of the pipe and small increase of the wall thickness.

Axial metal displacement near the external surface of semi-finished product can be observed, which causes the appearance of concave head surface and pivot elongation. At the second stage of the process, forming of particular forging steps, connected with the further reduction of external pivot diameter and its large elongation, begins. Here, metal in central parts of the forging is limited by tools side surfaces. This makes axial material displacement difficult, due to which it flows radially in the direction to forging axis increasing the wall thickness. The third stage takes place when tools reach their final position. Tools translational movement is then switched off and their rotary motion is left. In the result, rotating rolls remove unevenness which appears at the former stages of the process.

Figure 6 presents determined numerically distributions of strain intensity and temperature for the final stage of the process. The largest values of strains are localized in the area of external step, where the largest reduction of cross section connected with considerable elongation of pivot takes place. However, central steps undergo relatively smaller strains which have surface character in these areas. Temperature distribution is directly connected with strain intensity distribution (Figure 6 b). The largest values of temperature are in these areas where strain assumes maximal values, which is the result of heat generation due to plastic deformation. Considerably high value of temperature is especially important as the process duration time is long (about 8 seconds) and it allows to assume that material will have good plastic properties at the end of forming.

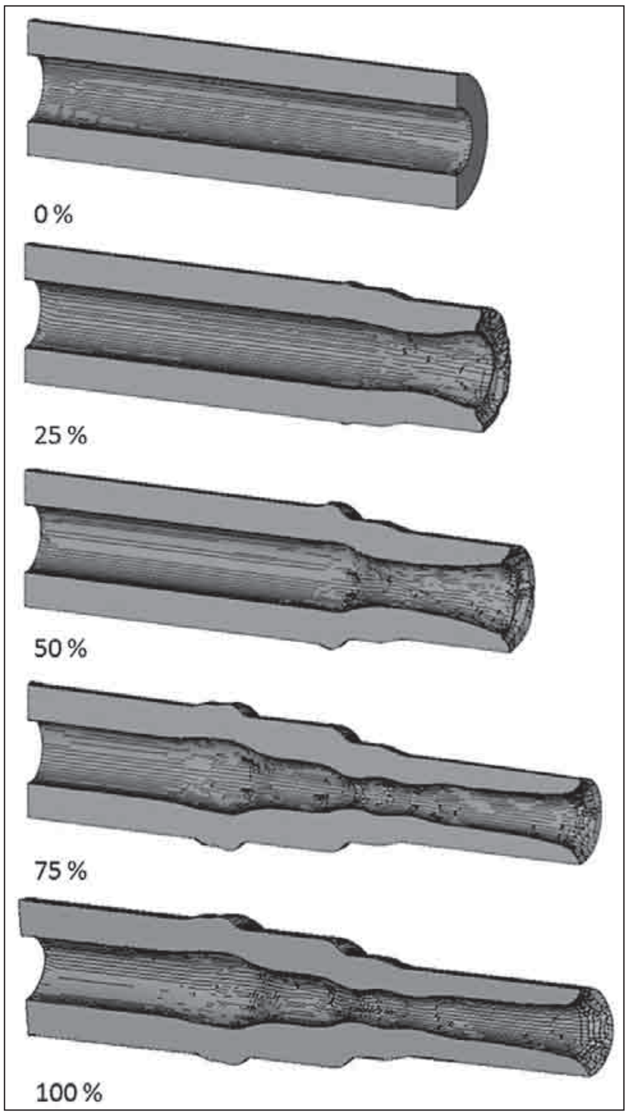

Figure 5 Progression of shape of gear hollowed shaft forging

During numerical simulations also force parameters were analyzed, knowledge of which is important for proper working out of technology. Proper evaluation of forces and rolling moments makes choosing tools and forging aggregate size easier. However, knowledge of these parameters distribution allows for estimating possibilities of phenomena which disturb the process stability.

Determined numerically distributions of forming force and rolling moment on one of the tools are shown in Figure 7. At the first stages of the process, both force and rotary moment slightly increase which is connected with gradual reduction of section of following steps of the forging. When simultaneous forming of all steps of the part takes place, rapid increase of force and moment is observed, which next decrease their values quite fast at the sizing stage.

CONCLUSIONS

Obtained results of the conducted numerical analysis confirm the possibility of forming of hollowed forg-

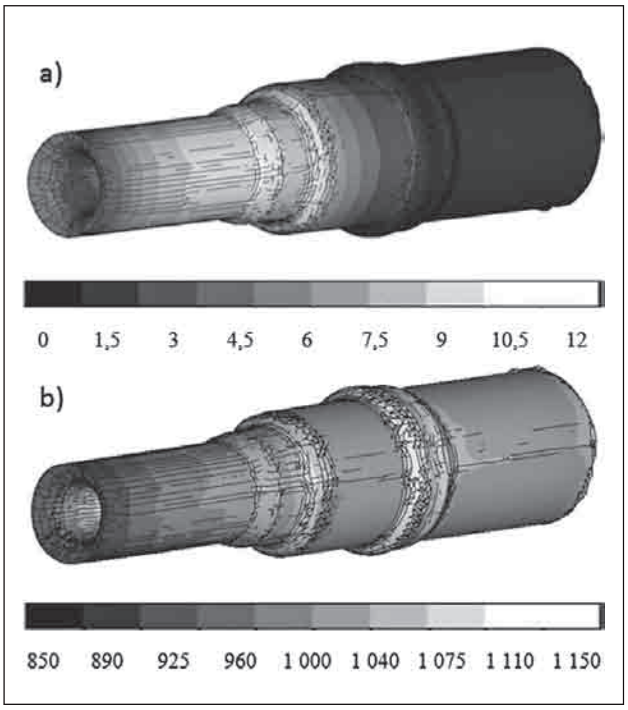

Figure 6 Determined numerically distributions of strain intensity - a and temperature - b

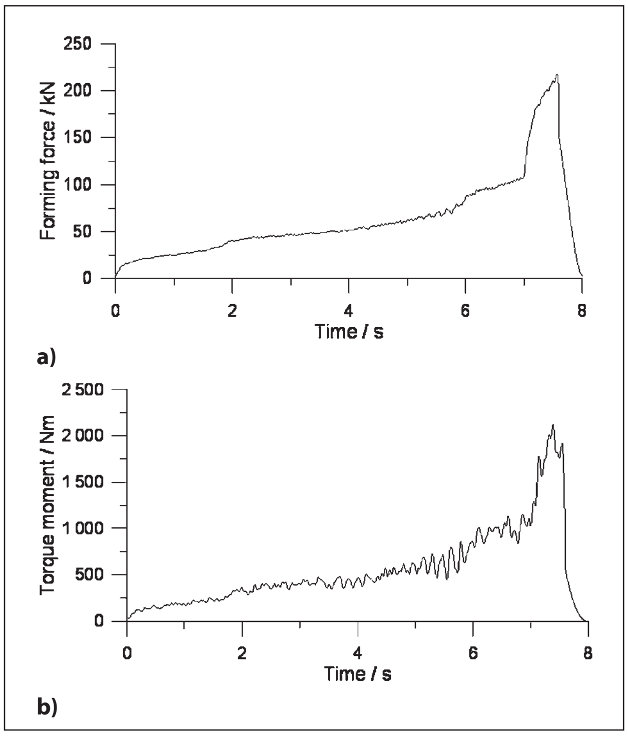

Figure 7 Determined numerically force parameters of the compression process a) forming force b) rotary moment

ings by means of rotary compression. Most of used at present metal forming processes of hollowed elements are characterized by complexity and high financial costs, which make them profitable only in the case of multi-series production. The worked out method of rotary compression, due to application of simple tools and devices, can be successfully used for forming of small series of products and in series production. The application of hollowed billet (sleeve or pipe) allows for a considerable decrease of material consumption, at lowering of labor demand and energy consumption at the same time. Another important issue, in favor of implementation of metal forming processes of elements, is the increase of resistance properties of such manufactured semi-finished products. In the result, machine safety increases, smaller sections can be used, which allows for reducing the construction mass. Results achieved in the effect of conducted analysis seem to be quite promising and constitute the basis for the further research works, which next stage will be experimental verification, planned to be conducted at Lublin University of Technology.

Acknowledgements

The authors would like to acknowledge financial support from The National Research and Development Center, grant No. PB 6234/B/T02/2011/40

REFERENCES

[1] J. Bartnicki, The theoretical and experimental research of Rolling - extrusion process, Ed. Politechnika Lubelska, Lublin 2009.

[2] X. P. Fu, T. A. Dean, Past developments, current applications and trends in the cross wedge rolling process, International Journal of Machinery Tools Manufacture Design, Research and Application, 33, (1993), 367-400.

[3] R. Neugebauer, M. Kolbe, R. Glab, M. Hoffmann, Optimization of processing routes for cross rolling and spin extrusion, Journal of Materials Processing Technology, 125, (2002), 856-862.

[4] C.C. Wong, J. Lin, T.A. Dean. Effects of roller path and geometry on the flow forming of solid cylindrical components, Journal of Materials Processing Technology, 167, (2005), 344-353.

[5] J. Yao, M. Makoto, An experimental study in paraxial spinning of one tube end, Journal of Materials Processing Technology, 128, (2002), 324-329.

[6] Z. Pater, A. Gontarz, W. Weroński, Cross-wedge rolling by means of one flat wedge and two shaped rolls, Journal of Materials Processing Technology, 177 (2006), 550-554.

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