

THEORETICAL ANALYSIS OF THE FORGING PROCESS FOR PRODUCING HOLLOW BALLS

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Received: 2013.04.28
Accepted: 2013.05.24
Published: 2013.06.10

ABSTRACT

Hollow balls are used in the production of various machines and devices. The technology for producing hollow balls by metal forming technologies poses numerous difficulties connected with the forming of a hollow billet. The billet, which is usually in the form of a rod, is subject to such processes as forging, helical rolling or cross-wedge rolling. The paper discusses a new method and conditions for producing a hollow ball. It was assumed that the ball would be produced in two forging operations: an initial forging operation and finish forging operation. The presented results are based on the FEM numerical analysis conducted using DEFORM-3D. It was assumed that the billet material was made from AISI 304 stainless steel used to produce balls for ball valves. Both the shape progression during the forging process and variations in the forming force were analyzed. Based on the conducted analyses, it can be claimed that hollow balls can be produced using the proposed forging method.

Keywords: die forging, hollow ball forging, FEM

INTRODUCTION

Hollow balls are mainly used in the agricultural industry (Fig. 1a) [2] and in the production of various ball valves (Fig. 1b) [1]. In the case of ball valves, one ball is usually used per one valve, while the number of balls used in the production of agricultural machinery, e.g. a three-point suspension system, ranges from 2 to 10 balls. Owing to the number of ball valves or said suspension systems that are manufactured, the demand for hollow balls is very high.

The so-far used metal forming methods for producing balls are mainly applied to the production of full balls. Hollow balls are obtained from full balls, and the holes are made by machining. Such a way of producing holes involves considerable material losses, which can be described by the formula:

$$S = \frac{(D - \sqrt{D^2 - d^2})^2 \cdot (2D + \sqrt{D^2 - d^2}) + 3d^2 \sqrt{D^2 - d^2}}{2D^3} \cdot 100\%, \quad (1)$$

where the denotations used correspond to those in Figure 2.

For example, in order to produce a ball with a diameter of 80 mm and a hole of 50 mm, the percentage of the material loss amounts to 52.4%.

Nowadays there are numerous methods for producing full balls. The main metal forming methods for producing such products include die forging using forging machines, die forging using forging presses, helical rolling and cross-wedge rolling. Die casting and metal machining are also frequently used in the production of such balls.

When balls are produced by means of presses, the billet material is usually in a form of steel rods, whose diameters are smaller than the diameters of parts being formed. Hollow balls can be produced using forging machines, yet the production process of both full and hollow balls is then hindered. Balls

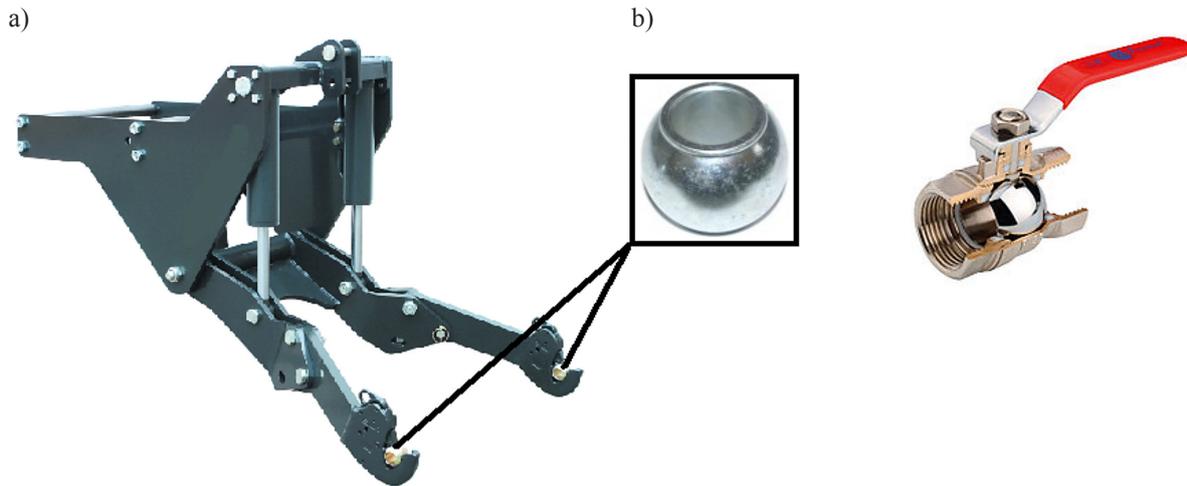


Fig. 1. Examples of applications of hollow balls: a) three-point suspension system in agricultural machinery,] b) ball valve [1, 2]

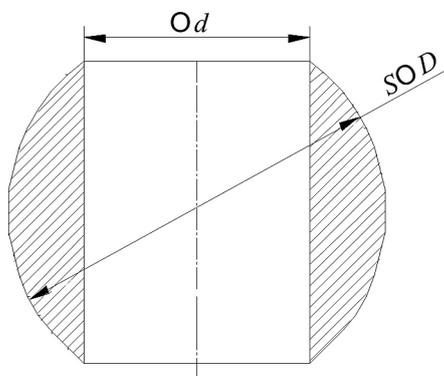


Fig. 2. Hollow ball cross section

with higher diameters are die forged, usually on a screw press equipped with a friction drive, using rods as the billet material.

Another method for producing balls is helical rolling, in which balls are first formed from a full rod by two skewly positioned rolls (equipped with helical impressions) and then separated from one another. Only one ball is formed at one rotation of the rolls [11]. The method is characterized by a very high efficiency, which depends on the speed of rolls.

Cross wedge rolling (CWR) is also used to produce balls, yet only the full ones. The process consists of axial forming symmetric parts with wedge-shaped tools. The tools are mounted either on the rolls or on flat or concave plates of the rolling mill [2].

Also, there are numerous innovative manners for producing balls by helical rolling, developed by the research team of the Department of Computer Modeling and Metal Forming Technologies at Lublin University of Technology. They include:

- rolling in helically-spiral impressions [5];
- rolling with two flat disks in spiral impressions [3, 4, 7];
- rolling with two conical disks in spiral impressions [8];
- rolling in a helical internal impression [9];
- helical rolling with three helical rolls [6].

However, it should be mentioned that the above rolling techniques are intended for the production of full balls with a relatively small diameter. On the whole, it can be stated that the above mentioned ball production methods do not allow effective formation of hollow balls. It is then justified to investigate new methods for producing hollow balls that would ensure lower material consumption and higher efficiency. For this reason, a new method for producing hollow balls is proposed and discussed in the present paper.

METHODOLOGY OF THE FORGING PROCESS FOR PRODUCING BALLS

The analysis of the forging process for producing hollow balls was conducted for a ball with a diameter of 80 mm and a hole of 50 mm. In the analysis, finish machining allowances were taken into account. The dimensions of the analyzed balls correspond to the dimensions of balls used in the production of selected ball valves. Both the shape and dimensions of the analyzed ball are shown in Figure 3. The figure also illustrates axial sections of ball 1 (with the predicted machining allowances) and finished product 2.

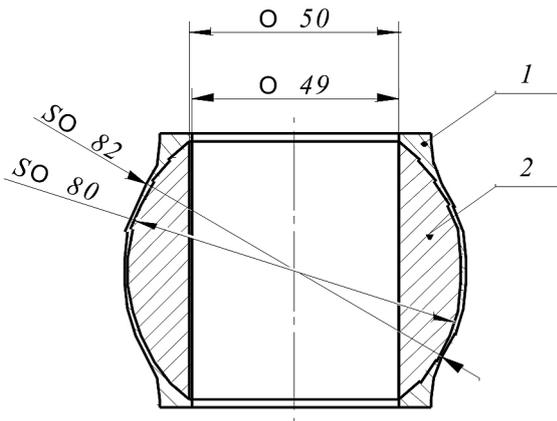


Fig. 3. Shape and dimensions of ball 1 and ball 2

The forging process for producing hollow balls was realized according to the manner that is schematically illustrated in Figure 4 [13].

The proposed forging process consists of placing billet 2 in a form of a rod section in die 4, in which a preliminary impression has been made. In the first operation (Figure 4a) forging preform 5 is made from rod 2, and in the second operation (Figure 4b) the forging preform is used to produce a hollow ball. The ball forming is hence realized during two motions of punch 1. The punch travels with a constant linear speed along its own axis, causing the upsetting of the billet. The dies consist of two twin elements, and the parting plane between the dies goes through both the billet and punch axis. Owing to such

tool design, the dies can be parted to take the formed ball out of the tools once the process is completed. The dimensions of the billet (Figure 4a) were determined based on the constant volume conditions.

The numerical analysis of the forging process for producing balls was made using the FEM-based DEFORM-3D. In the simulations, it was assumed that both the punch and dies would be rigid objects, while the billet would be a discrete object divided into four-node tetragonal elements, described by a rigid-plastic material model. The material model (of the hollow ball to be formed) adopted in the simulations was AISI 304 stainless steel and the material data were taken from the library database of the applied software. This material type is used in the production of balls for ball valves. It was also assumed that the initial temperature of the tools would be 20 °C, while the billet temperature would be 900 °C. The simulations were performed at a constant punch speed of 10 mm/s. The punch translational motion continued until the complete filling of the impression. In the forging process schematically presented in the figure, the distance traveled by the punch was 22.3 mm and 25.1 mm for the initial forging and finish forging, respectively. The tool-billet contact conditions were described by the constant friction model, with the friction factor m set to 0.3 and the tool-billet heat transfer coefficient equal 10 W/m²K.

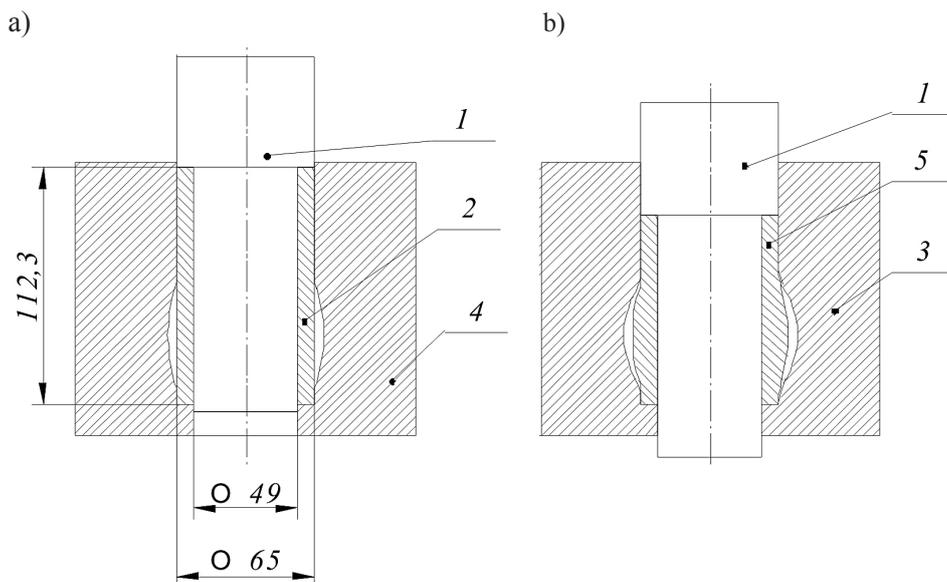


Fig. 4. Model of the forging process for producing hollow balls: a) forming a ball preform, b) finish forming a ball (described in the paper)

RESULTS

The process of forming balls from the billet in the form of a rod is schematically illustrated in Figures 5 and 6. The figures show the shape progression and damage function calculated for the ball preform and finished ball according to the Cockroft-Latham criterion, described by the equation [12]:

$$\int_0^{\varphi^*} \frac{\sigma_1}{\sigma_m} d\varphi = C, \quad (2)$$

where: φ^* – denotes the limit fracture strain,
 σ_1 – denotes the maximum principal stress,
 σ_m – denotes the mean stresses,
 C – denotes the material constant calculated in the simulations.

The forging process is realized in two operations, the first one consisting of forming a ball preform. The preform forming is necessary as the preliminary numerical simulations have proven that it is impossible to produce hollow

balls in one forging operation, as can be seen in Figure 7. In the figure, the lappings that prevent the production of a correctly shaped part occur in the areas marked with letter A. They occur on both the external and internal surface of the ball, over its whole circumference.

If the forging process is realized in two operations, these lappings can be prevented and the formed ball can then undergo finishing. Owing to the use of a mandrel during initial forging (Figure 5), the material axial flow towards the symmetry axis can be prevented. As a result of upsetting, the rod diameter is increasing until the external billet surface contacts the die impression surface.

Due to the application of the preliminary impression, the maximum distance between the external billet surface and die impression surface is short, which means that the process is stable, strains are small and lapping is prevented. The low value of strain also prevents the occurrence of fracture on the external surface of the rod, where the damage function reaches the local maximum, which – according to the

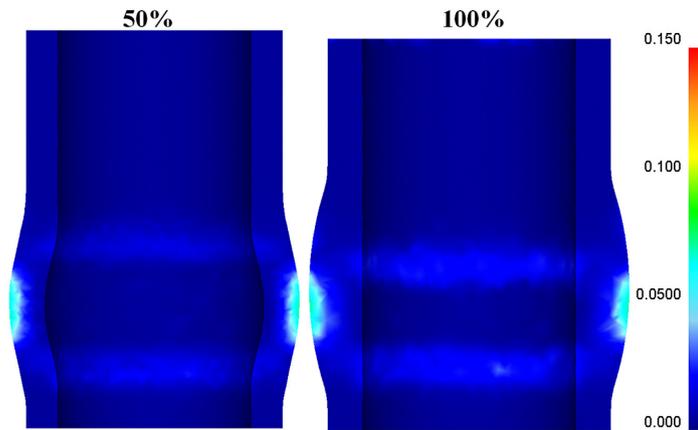


Fig. 5. Shape progression and damage function according to the Cockroft-Latham criterion in the axial section of a ball preform during initial forging

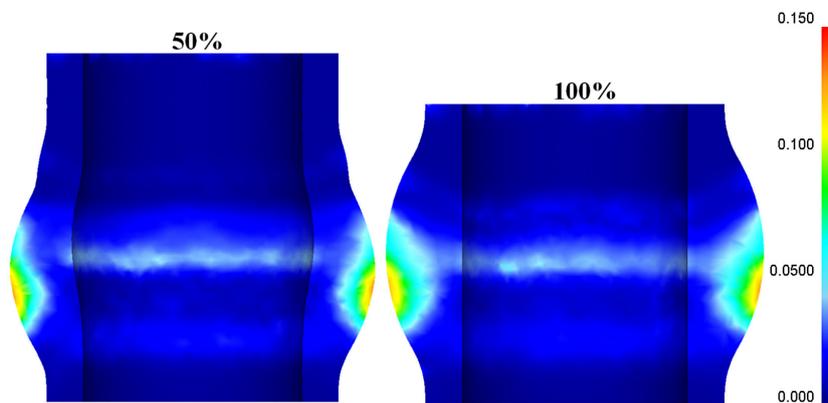


Fig. 6. Shape progression and damage function according to the Cockroft-Latham criterion in the axial section of a ball preform during finish forging

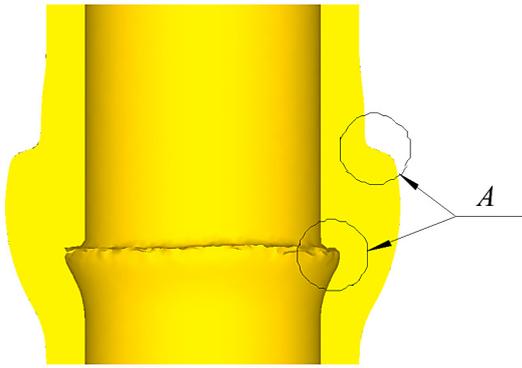


Fig. 7. Hollow ball forging in one operation – the ball axial section profile when the process realization is 80%

Cockcroft-Latham criterion – does not exceed 0.15 (Figures 5 and 6).

The second forging operation to produce a hollow ball is similar to the process of forming the preform. Due to the punch action on the billet, the preform undergoes upsetting. At first, the material flows in a direction that is parallel to the

punch axis; afterwards the external surface of the ball being formed contacts the impression surface. Once the material contacts the whole surface of the impression, it starts flowing towards the punch axis. Given the force parameters of the process, this phenomenon is desirable and advantageous.

Due to the billet-punch contact in the final stage of the forging process, the punch is reduced by the material in a short time. Therefore, the distance traveled by the punch working against the friction resistance is short; in effect, the fraction of the friction force occurring between the punch and material in the total force with which the punch acts on the billet is insignificant. Given the above, the friction forces have an insignificant effect on the maximum force value in the present process for producing balls.

Analyzing the variations of the forming force during initial forging (Figure 8), it can be observed that its increase is nearly linear until the force rapidly increases in the final stage of the process. This rapid increase is caused by the action of the above mentioned friction force on the

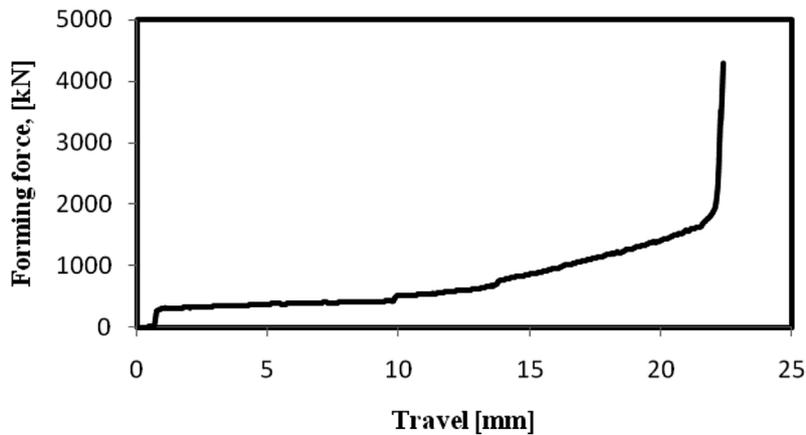


Fig. 8. Dependence of the forging force on punch travel in initial forging

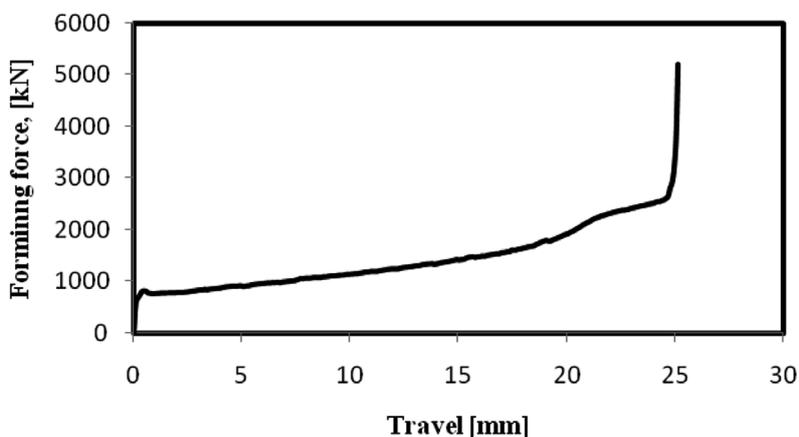


Fig. 9. Dependence of the forging force on punch travel in finish forging

punch and higher material resistances that occur in the final stage of filling the closed impression.

The forming force distribution during finish forging is shown in Figure 9. The maximum value of this force necessary to produce the preform is 4280 kN, while the force value required to form the ball is 5200 kN. Based on the chart shown in Figure 9, it can be observed that the force increases after the punch traveled a distance of approx. 20 mm. This is due to the contact between the billet material and the whole surface of the impression, which leads to an increase in the billet-punch contact area and the occurrence of the friction forces on the said surface.

CONCLUSIONS

The paper presented the numerical analysis results of the forging process for producing hollow balls. Based on the preliminary calculations, it was observed that forging balls in one operation would lead to lapping. For this reason, the process discussed in the paper was realized in two operations to ensure the production of good quality parts.

The results of the performed numerical simulations of the forging process prove that the proposed method is correct. They confirm that it is possible to produce a hollow ball in two forging operations. Such process requires that the tools with die impressions for both initial and finish forging be used. The tool kinematics and geometry are not complicated; therefore, experimental tests can be easily performed in a short time.

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