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ISSN 0543-5846
METABK 53(4) 653-656 (2014)
UDC – UDK 621.73:621.91.07:621.771:536.45=111

ANALYSIS OF THE HELICAL-WEDGE ROLLING PROCESS FOR PRODUCING A WORKHOLDING BOLT

Received – Prispjelo: 2013-11-04
Accepted – Prihvaćeno: 2014-04-30
Preliminary Note – Prethodno priopćenje

The paper describes an example of application of the helical-wedge rolling process for producing a workholding bolt. The design of this new metal forming technique is discussed and the tools used therein are described. This rolling process was numerically simulated and found to be correct. The strain and temperature distributions in the workholding bolt as well as the variation of forces and rolling moments are presented.

Keywords: helical-wedge rolling, workholding bolt, strain, temperature, Finite Element Method

INTRODUCTION

One of the main objectives of modernizing production processes is reduced material consumption; hence the focus on developing high-efficient production processes that can be realized with less billet material. Cross-wedge rolling (CWR) is a modern forming technology that enables the production of parts such as stepped axes and shafts as well as axially-symmetric forging preforms [1, 2]; also, it allows for non-scrap cropping of metal bars [3, 4].

The CWR process offers numerous advantages, in particular [1, 2]: high efficiency, eco-friendliness, enhanced strength properties of products, low energy consumption of the process, process automation possibility and low production costs. The above mentioned advantages of the CWR process, however, depend to a great extent on the shape of the shaft being rolled. Their importance is diminished particularly in the production of stepped shafts because the diameter of end steps is much smaller than that of the central step. In such processes, large technological allowances should be applied (for the so-called end discards), their size being dependent on the kinematics of material flow in the CWR process. Also, these allowances must be cut off in the final stage of the process. The elimination of frontal discards can lead to substantial savings depending on batch quantity.

The present paper discusses a solution for eliminating end discards. It consists in forming stepped shafts by a new helical-wedge rolling (HWR) method. To illustrate the benefits of the proposed production method, the rolling process for a workholding bolt shown in Figure 1 is investigated.

DESIGN OF THE HELICAL-WEDGE ROLLING (HWR) PROCESS

In the HWR process, the wedges are helically wound on the roll face. To form a product, two identical rolls have to be used, both skewly positioned relative to the axis of the billet (cylindrical bar). To maintain the material between the rolls, guides are additionally applied. In the course of rolling, the wedges, which are placed on the rolls rotating in the same direction, cut into the material, making it rotate and translate (towards the billet axis) at the same time. In the final stage of the process, the product formed is cut off from the barstock by the cutters located right behind the wedges (Figure 2).

The above-described HWR process developed at Lublin University of Technology, Poland, has been successfully applied to produce semi-finished balls for grinding media. This process, including its variant with the use of multi-coil tools, is discussed in the study [5].

To apply the HWR method to produce workholding bolts, tools with a quite complex shape (Figure 3) must be used. Namely, the wedges, characterized by two basic angles: forming angle α and spreading angle β (Figure 3), are wound on the roll face with a variable pitch.

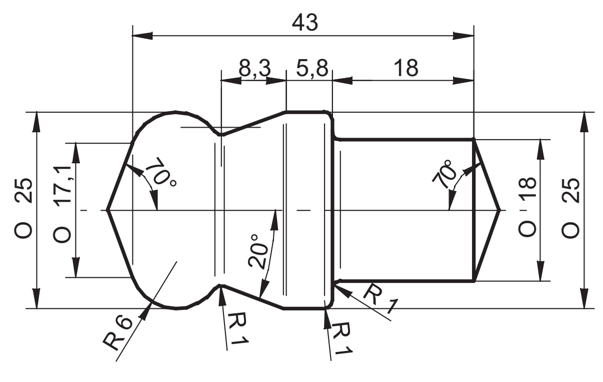

Figure 1 Workholding bolt being rolled

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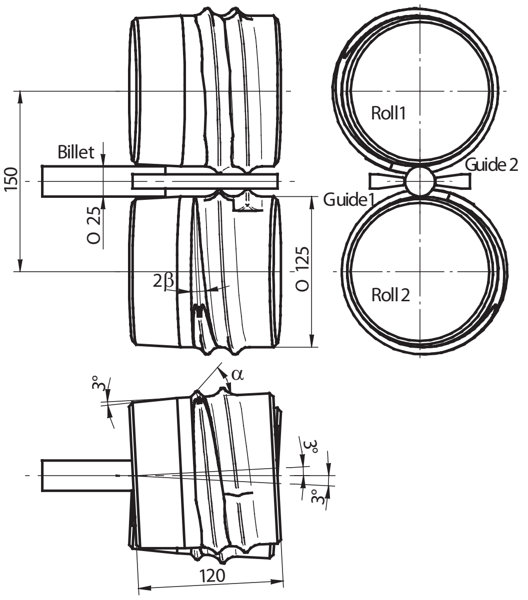

Figure 2 Design of HWR process for balls

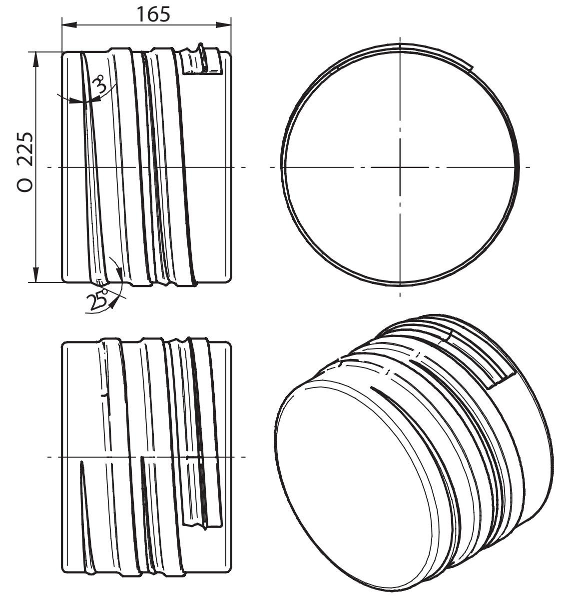

Figure 3 Helical roll for forming workholding bolts

The pitch value should be selected in such way that the roll pass volume is equal to the workpiece volume at any moment of the rolling process. The design of tools for HWR should therefore take into account workpiece elongation that occurs in every stage of the rolling process. On setting values of the angles α and β, the principle developed for the CWR process can be employed [1], according to which:

$$0{,}04 \leq \tan\alpha \cdot \tan\beta \leq 0{,}08 \qquad (1)$$

As for the case being analyzed, the angles were set to the following values: α = 25° and β = 3°.

NUMERICAL ANALYSIS

A numerical simulation was performed to verify the developed method for producing workholding bolts. The simulation was performed using the Simufact. Forming software, which had previously been employed to simulate metal forming processes [6-10]. The results obtained from the simulation showed good agreement with the experimental results.

Figure 4 shows the geometrical model of the HWR process for producing a workholding bolt. The model consists of two identical helical rolls, two mill guides, a tube guide and a cylindrical billet with a diameter of 25 mm and length of 185 mm. All the tools were treated as perfectly rigid bodies, and the billet material (X12CrNi17 stainless steel) was described by an elasto-plastic model, whose parameters were obtained from the database library of the software used. The parameters of the HWR process for producing workholding bolts were as follows: the feed angle was 3,5 °, the roll velocity was 15 rotations per minute, the friction factor for the rolls was set to 1,0, while for the guides it was set to 0,4, the rolls had a temperature of 50 °C, while the temperature of the guides was set to 250 °C, the billet temperature was 1 100 °C, and the material-tool heat exchange coefficient was set to 10 kW/m^{2}K.

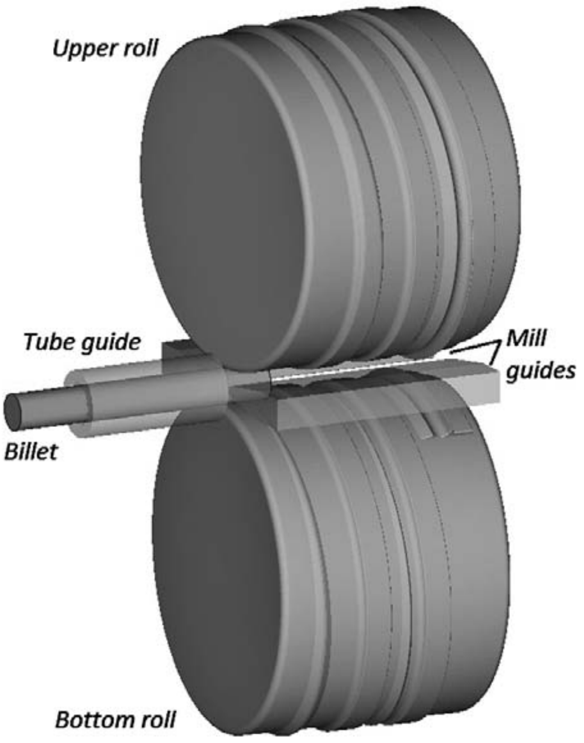

Figure 4 Geometrical model of the HWR process for workholding bolts

The material was formed using eight-node brick elements; the elements were concentrated in the roll impact zone. Due to the fact that the workpiece shape was changing in the course of rolling, it was necessary to use more and more elements to describe it (in the final stage of the process, the number of elements used amounted to about 72 000) – Figure 5. Combined with low time step, this resulted in longer computation time - for the analyzed case the computation time was 10 days (the simulation was performed using a 24-core computer, equipped with 32 GB RAM).

As a result of the computations performed, the HWR method was found to be a viable technique for produc-

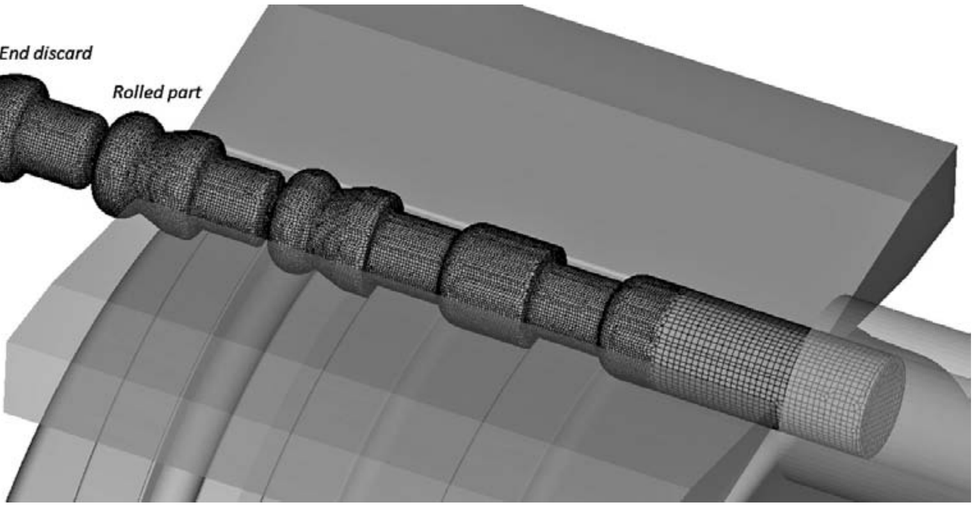

Figure 5 Workpiece shape after five rotations of the helical rolls; division into elements is shown

ing workholding bolts. This process is illustrated in Figure 5. A workholding bolt is formed within three rotations of the rolls. During the first rotation of the rolls, necking is formed (between two adjacent bolt heads); the necking has a diameter of 18 mm, which is equal to the diameter of the step in the workholding part. During the second rotation of the rolls, the necking is sized and its shape does not change. During the third rotation of the rolls, the spherical and conical parts of the bolt head are formed simultaneously; next, the bolt formed during the second roll rotation is cut off by the cutter.

The metal flow characteristics in the HWR process are similar to those in the CWR process. This similarity is reflected in the distribution of strains (Figure 6) whose arrangement is typical of cross rolling processes. The highest strains occur over the surface area of the material (which is caused by the action of friction forces), while the lowest strains occur in the axis of the product. The high strain values result from intensive material flow in the tangential direction.

The forming time for a workholding bolt is 12 seconds, which is necessary for the rolls to perform three full rotations. This, however, does not lead to excessive decrease in material temperature. As can be seen from Figure 7, the temperature of the part produced by the HWR process is within the hot working range. It should yet be observed that the lowest temperature occurs in the cylindrical part which is formed during the first rotation of the rolls and then plays a piloting role. In contrast, the temperature in the spherical part of the bolt head is approximately 1 000 °C, which can be attributed to the fact that this part is formed during the final (third) rotation of the rolls and the heat then generated (when friction work changes into deformation work) was not distributed over the material volume yet.

The application of FEM also allowed for investigating the variations in forces that occur during the HWR process for workholding bolts. As can be seen from Figure 8, the forces change in a cyclic way in the analyzed process. In the steady state of the rolling process (after

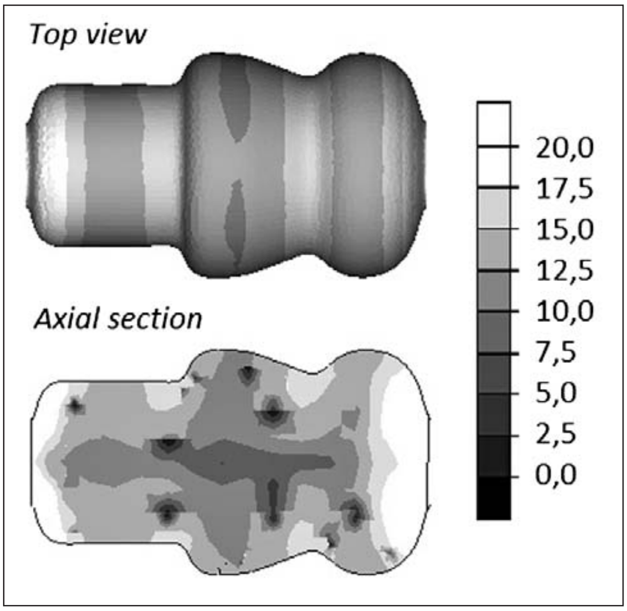

Figure 6 Effective strain distribution in the product being rolled

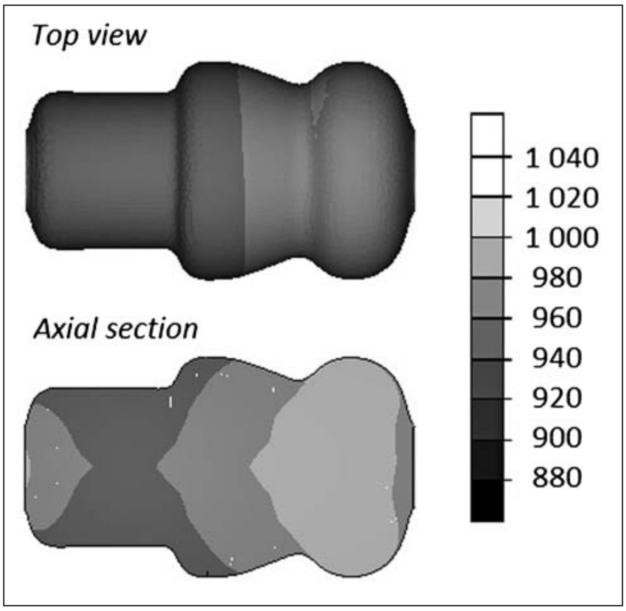

Figure 7 Temperature distribution (°C) in the product being rolled

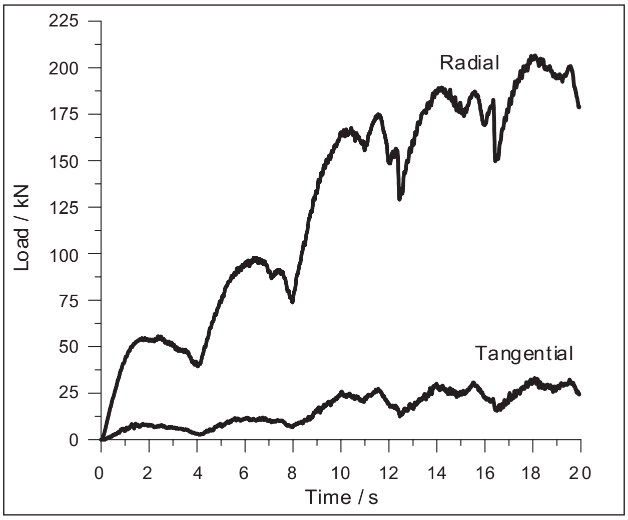

Figure 8 Distribution of forces in the analyzed HWR process

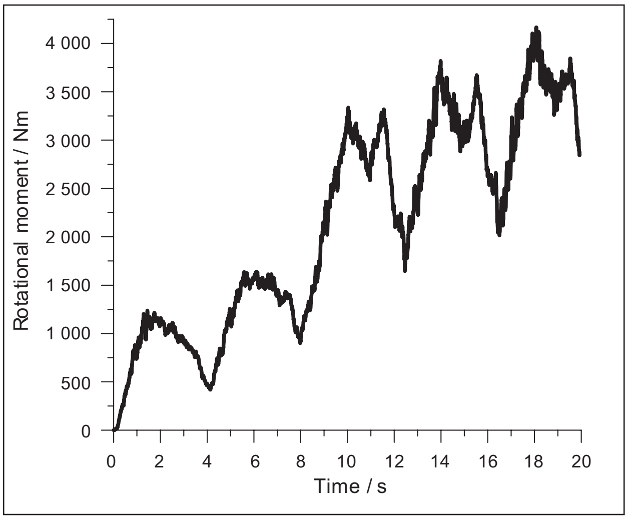

Figure 9 Rolling moment distribution in the analyzed HWR process

12 s of the process), the average value of the tangential force is 24,6 kN, which amounts to 13,6 % of the average value of the radial force equal to 180,6 kN. This relationship between the forces differs from the one occurring in the CWR process which ranges between 20 – 40 %.

The force distribution is identical with that of the rolling moment (Figure 9), which in the steady state of the process exhibits an average value of 3,25 kNm (the maximum value being 4,17 kNm). The obtained rolling moment distribution proves that the HWR process should be conducted using a rolling mill equipped with a flywheel.

CONCLUSIONS

Based on the analysis conducted, the following conclusions were formed:

- the helical-wedge rolling (HWR) method can be applied to produce workholding bolts;
- the distribution of strains in workholding bolts produced by the HWR method is similar to that obtained in the classical CWR process;
- despite the long forming time, the material does not undergo excessive cooling that could hinder the HWR process for producing the part;
- both the forces and rolling moments in this process have an oscillatory character, which justifies that the HWR process for producing workholding bolts be conducted using a rolling mill equipped with a flywheel;
- the research on the HWR method should be extended to cover other axially-symmetric products.

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Note: The professional translator for the English language is M. Jung, Lublin, Poland