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A THERMOMECHANICAL ANALYSIS OF THE MULTI-WEDGE HELICAL ROLLING (MWHR) PROCESS FOR PRODUCING BALLS

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Preliminary Note – Prethodno priopćenje

This paper presents the results of a numerical analysis of the helical rolling process for producing 30 mm diameter balls using multi-wedge helical tools. The numerical modelling was performed by finite element method (FEM) using the commercial Simufact Forming v. 12 simulation software. The modelling was performed in a three-dimensional state of strain and included a full thermal analysis. As a result, the changes in workpiece shape as well as the distributions of strains, temperature, damage, loads and torque were determined. The numerical results confirm that balls can be produced by multi-wedge helical rolling.

Key words: helical rolling, multi-wedge tool, ball, finite element method (FEM)

INTRODUCTION

Due to a huge demand for balls used in rolling bearings and ball mills for raw material grinding, extensive research has been undertaken to develop new efficient production methods. The research works focus on ways of reducing manufacturing costs and improving product quality. At present, balls are produced by such techniques as machining, casting, die forging, cross rolling and helical rolling [1-4]. Out of the above mentioned methods, helical rolling is one of the most efficient forming methods and thus deserves special attention. Helical rolling is a continuous process, which means that the tools do not have to be stopped in order to place billet in the machine or to remove products. In addition, this technique is free from machine idle run which occurs in other forming methods. Helical rolling is a very efficient method and offers a number of other advantages, including small material losses, high accuracy of produced parts, favourable fibre orientation as well as relative ease of automation. Consequently, from an industrial perspective, helical rolling is a very attractive method for producing balls.

The research on helical rolling conducted at the Lublin University of Technology led to the development of an innovative process for producing balls using tools in the form of wedges helically wound on the roll faces [5, 6]. Compared to the standard helical rolling technique, where the roll passes are separated by flanges of gradually increasing width and height, this innovative solution enables significant reduction in loads and torque in the rolling process, while being very efficient at the same time. It seems that this efficiency can be even several times higher if multi-wedge tools are used. The above observation has been confirmed by the results of a thermo-mechanical analysis of the multi-wedge helical rolling (MWHR) process presented in this paper.

NUMERICAL MODEL OF MWHR

The numerical modelling of the MWHR process was performed using the Simufact.Forming v.12 simulation software which is based on finite element method (FEM). This software was previously employed by a number of authors in analyses of cross and helical rolling processes, and their numerical results showed good agreement with the experimental results [7-10].

Figure 1 shows the geometrical model of the investigated rolling process for producing 30 mm diameter balls. The model consists of two identical multi-wedge

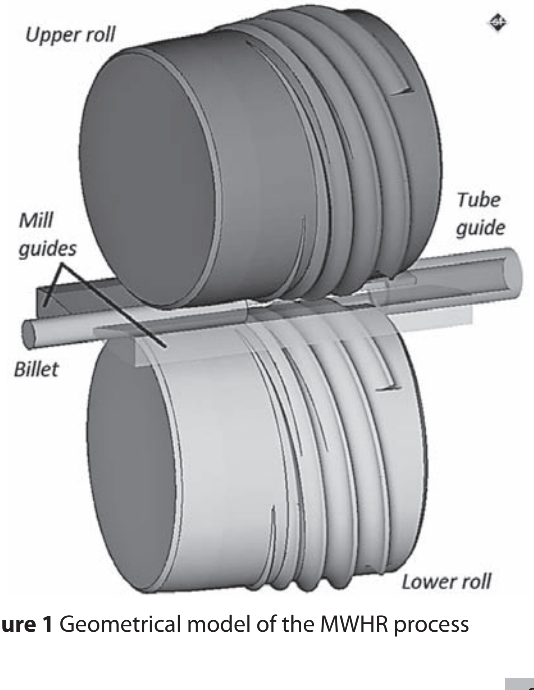

Figure 1 Geometrical model of the MWHR process

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

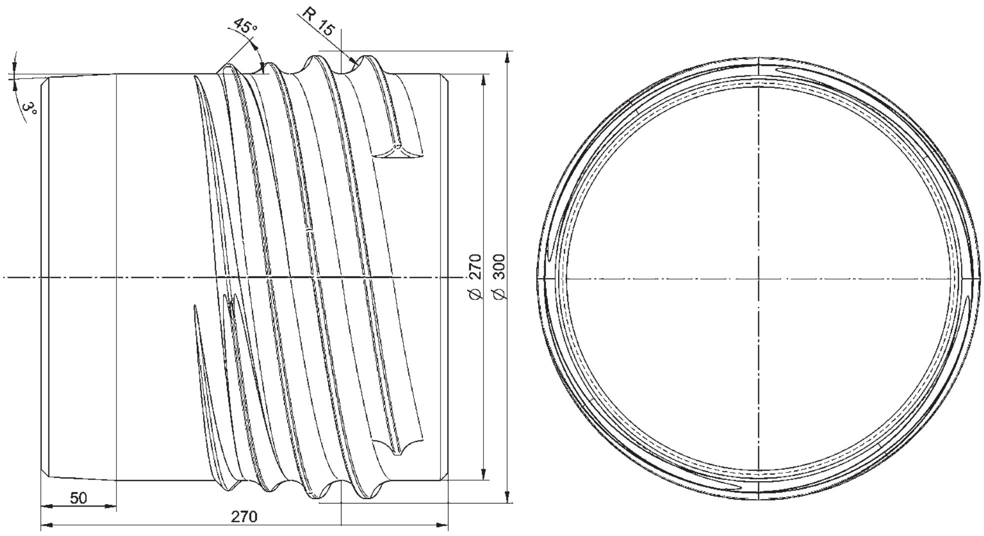

Figure 2 Multi-wedge rolls used in helical rolling for producing 30 mm diameter balls

rolls, two mill guides, one tube guide which collects produced parts and a bar stock (its diameter is equal to that of a ball) modelled by 8-node hexahedral elements. The rolls (Figure 2) have four identical wedges which are helically wound on their circumference (every 90°). However, the wedges have a varying pitch of the helical line to ensure constant contact between the material constrained in the pass and the flanges of the rolls.

A thermo-mechanical analysis of the process was based on the following assumptions. The billet was heated in its entire volume to a temperature of 1 150 °C, while the temperature of the rolls and the guides was maintained constant at 150 °C during the forming process. The heat transfer coefficient was set to 10 kW/m²K. The material model of steel grade AISI 52100 was obtained from the material database library of the applied software. Given that the rolls were not lubricated and made rough intentionally (to facilitate the pulling of the material into the forming zone), their maximum friction factor was set to 1. The friction factor of the mill guides was set to 0,7. In addition, it was assumed that the rolls would be rotated in the same directions with a rotational speed of 60 revolutions per minute and inclined to the axis of the workpiece at an angle of 6°.

NUMERICAL RESULTS

The application of FEM to analyze the MWHR process enabled a thorough examination of changes in the workpiece shape in rolling. Figure 3 shows the semi-finished product after two revolutions of the rolls. For clarity reasons, one of the guides is not shown in the figure. As can be seen in the figure, the semi-finished balls produced by this method have the required shape. They are connected end-to-end by cylindrical connecting links and will be separated in the last stage of the rolling process (this stage is omitted in the numerical modelling). It is worth noting that the forming time for individual balls is significantly reduced (the barstock is shaped into balls during one revolution of the rolls). Moreover, the efficiency of the rolling process is higher (4 balls are produced per one revolution of the rolls).

Figure 4 shows the FEM-simulated distributions of effective strain, temperature and damage in a semi-finished product shaped during two revolutions of the rolls. The distribution of the effective strain reveals that the material flow is most intensive in the region of necking where the cross-sectional area of metal is reduced. In the central region, however, the strains are the smallest. A similar trend can be observed for workpiece temperature, i.e. the temperature of the connecting links between the balls is even by approx. 100 °C higher that of the billet (plastic deformation is converted into heat). In addition, the damage function (determined based on the Cockroft-Latham criterion) has the highest value in the region of ball-connecting links. Hence, it is in this region that material cracking will occur, thus leading to separation of individual balls.The rolling processes for balls run in cycles, which is reflected in the loads and torque distributions shown in Figures 5 and 6, respec-

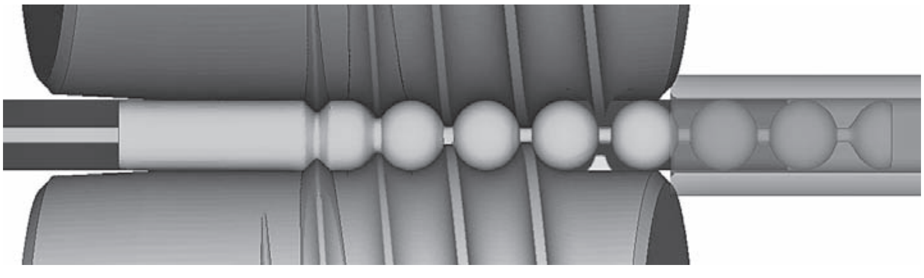

Figure 3 FEM-simulated view of the workpiece after two revolutions of the rolls

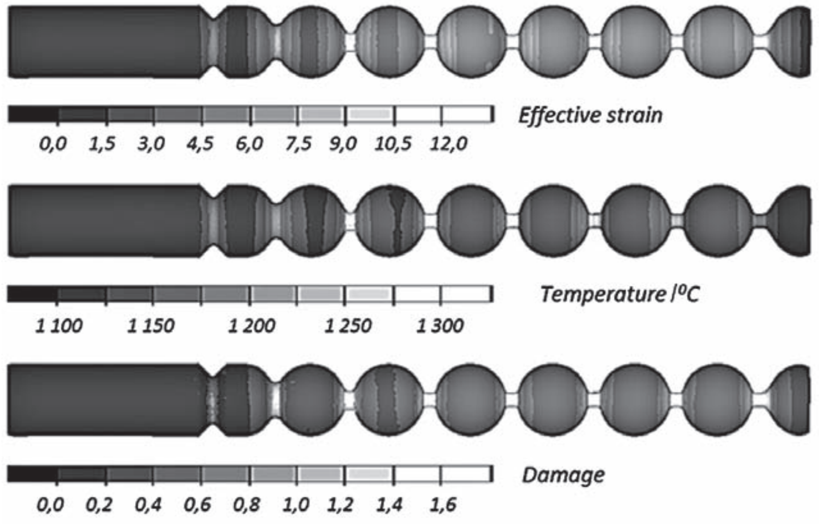

Figure 4 FEM-simulated view of the workpiece after two revolutions of the rolls

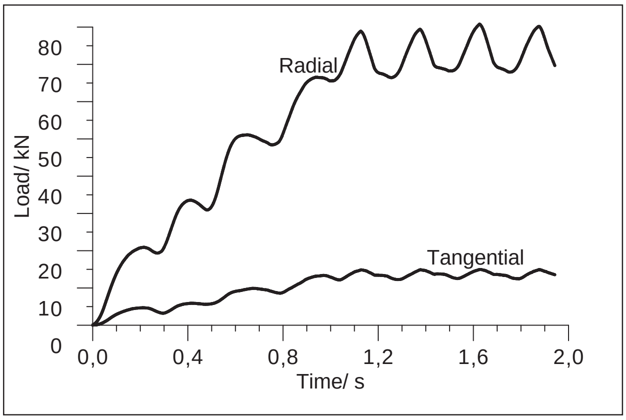

Figure 5 Loads in the multi-wedge rolling process for balls

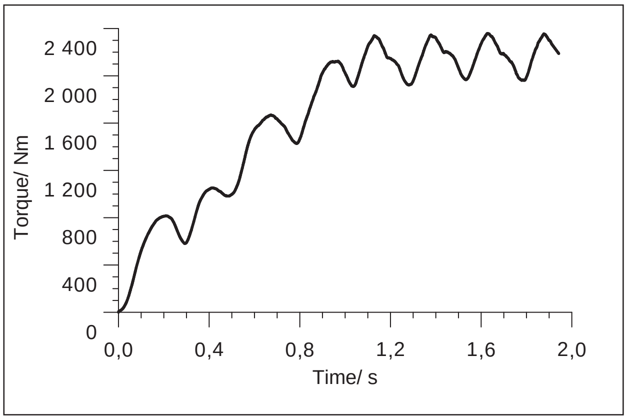

Figure 6 Torque in the multi-wedge helical rolling process for balls

tively. It can be observed that once the forming process becomes stable (i.e. the material is inside the forming zone), the loads and torque become stable, too, their values being: radial load – 72,85 ± 4,51 kN, tangential load – 13,69 ± 0,78 kN (18,8 % of radial load), torque – 2 165 ± 128 Nm. It must however be noted that there are four times when the above values slightly swing with every revolution of the rolls, when the wedges contact the material.

CONCLUSIONS

The following conclusions have been drawn from the numerical results:

- the MWHR method produces balls with the required shape;
- the MWHR process is more efficient than the standard helical rolling for producing balls; its efficiency increases proportionately to the number of applied wedges;
- the conditions in the region of ball-connecting necking are favourable for material separation;
- during rolling, the loads and torque vary cyclically within a range of approx. ± 6 % of their mean value determined at a stable stage of the process;
- research on MWHR should be continued and extended to other products.

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