DEVELOPMENT OF THEORY AND TECHNOLOGIES FOR HYBRID METAL FORMING OF STEEL COMPLEX PARTS

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Abstract

Manufacturing steel complex figurine parts remains a fundamental scientific challenge. This article suggests the solution of using hybrid methods that unite processes like combined rolling/stamping, rolling/plastic bending, and asymmetric rolling to produce steel complex figurine parts with wall thickness of 40-100 mm and diameter (width) up to 4000 mm. Traditionally, machine-building factories produce large-size bodies of rotations, with the help of an inefficient and rather costly process, using stamping or sheet-bending machines. These details are designed for usage as casings for various technological aggregates (converters, mixers, scrubbers, steel teeming ladles, etc.). The aim of the work is to develop a technology for obtaining large-sized parts with a curved surface in conditions of a plate rolling mill. The man objectives of the study:1) The choice and adaptation of the visco-plastic mathematical model for describing the new combined rolling and stamping and asymmetric rolling and plastic bending processes of production large-sized parts with a curved surface; 2) Numerical and experimental studies of the new combined processes with the study of the influence of various parameters on the geometry and mechanical properties of large-sized parts with a given curvature; 3) Determination rational process schemes and operating modes of the combined processes of production. large-sized parts with a curved surface. The chief features of new hybrid processes are identified. Results of theoretic and experimental investigations are provided. A technology of manufacture of converter housing parts at the 4500 PJSC "MMK" has been developed. Two cases were manufactured and installed in PJSC MMK. The economic effect was more than 1 million dollars.

Keywords: Hybrid metal forming, steel complex parts, plate rolling mill, plastic bending, stamping

1. INTRODUCTION

The basic principles of asymmetric rolling are studied and presented extensively in academic literature [1-2]. Many works have studied asymmetric rolling technology by using finite element method (FEM). Ji et al. [3] and Sverdlik et al. [4] investigated deformation mechanics of differential-speed rolling with a high-speed ratio between the top and the bottom rolls by rigid-plastic FEM. Ji and Park [5] have analyzed various asymmetric rolling processes by the rigid-viscoplastic FEM. The findings of the numerical simulation have revealed that differences in size, rotational speed or friction condition between the top and the bottom rolls can cause asymmetric deformation in the sheet. Angella et al. [6] has researched the strain distribution developed during asymmetric and symmetric rolling with a large number of passes. FEM results have demonstrated that surface strain effects related to local friction between working rolls and sample surface regions promote an additional deformation leading to a significant contribution at large plastic strain and generate discrepancies between equivalent strain values assessed by continuum theories and those evaluated by FEM models. This study presents a new technology of the combined process of asymmetric rolling and plastic bending to produce large-sized parts with a curved surface. Traditionally, machine-building factories produce large-size bodies of rotations, with the help of an inefficient and rather costly process, using stamping or sheet-bending machines. These details are designed for usage as casings for various technological aggregates (converters, mixers, scrubbers, steel teeming ladles, etc.). The man objectives of the study:1) The choice and adaptation of the visco-plastic mathematical model for describing the new combined rolling and stamping and asymmetric rolling and plastic bending processes of production large-sized parts with a curved surface; 2) Numerical and experimental studies of the new combined processes with the study of the influence of various parameters on the geometry and mechanical properties of large-sized parts with a given curvature; 3) Determination rational process schemes and operating modes of the combined processes of production. large-sized parts with a curved surface.

2. INTRODUCTION OF PRODUCTION TECHNOLOGY FOR LARGE-SIZED BODIES OF THE CURVED SURFACE IN THE LINE OF THE THICK PLATE MILL 4500 PJSC "MMK"

Results of numerical investigation showed the difficulty and sometimes outright impossibility of producing the required product curvature using only thick plate vertical asymmetric rolling processes. The new operation, which ensures a plate of the required curvature, is needed. Plastic bending, performed with a special unbending roller, located behind the stand, serves as such an operation (**Figure 1**) [7-8]. In such conditions, a sheet with far less than required curvature (larger radius) was formed. Then, with this roller, the curvature was increased (by decreasing the radius) to the required value. Such one is the combined asymmetric rolling and plastic bending process.

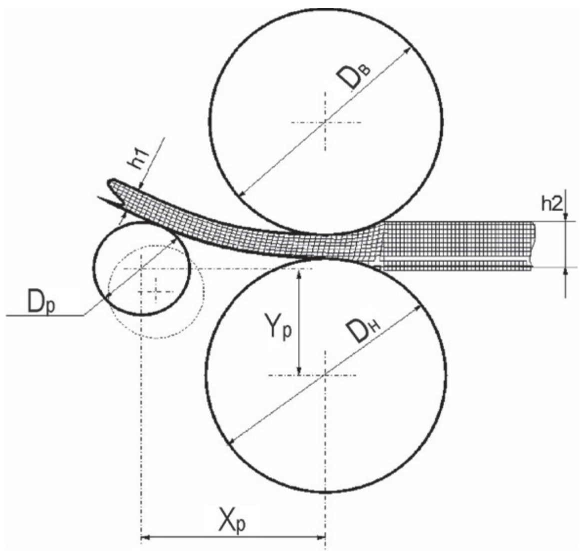

Figure 1 Combined process of asymmetric rolling and plastic bending

Combined process of vertical asymmetric rolling and plastic bending can be divided into three characteristic stages: actual asymmetric rolling (when the front end of the metal doesn't yet touch the unbending roller), asymmetric rolling in combination with initial unsettled plastic bending (when the front end touches the unbending roller), and asymmetric rolling combined with settled plastic bending (after the metal's front end moves beyond the unbending roller).

In the first stage, the front end of the metal follows a path, close to a circle. When touching the roller, the metal starts to bend more. In the third stage, processes of asymmetric rolling and plastic bending occur simultaneously. The third-stage and the process as a whole ends after the metal rear end leave the working rolls of the rolling stand. It is clear that the rear end, in the stretch between the exit from the rolls and the area of contact with the unbending roller, will have less than required curvature. It has taken place since this stretch is not subject to the plastic bending. Then the dynamics of changing process parameters depending on the following factors: stages of the process; ratio between the rolls' diameters; absolute reduction was investigated.

Covers for two converters have been manufactured and installed in the Oxygen-converter shop of PJSC "MMK". They served more than 10 years and the economic effect from the introduction of the developed technology amounted to more than 1 million dollars.

3. A NEW HYBRID TECHNOLOGY FOR THE PRODUCTION OF LARGE-SIZED BODIES WITH A CURVED SURFACE IN THE LINE OF A THICK PLATE MILL ON THE BASIS OF A COMBINED ROLLING-STAMPING PROCESS

The new process is based on the principle of rolling a package consisting of a punch, a die and a thick plate between them (**Figure 2**). Two conceptual schemes of the combined process of thick-plate rolling and stamping for the production of large-sized products with a curved surface are developed: direct and reversible [8].

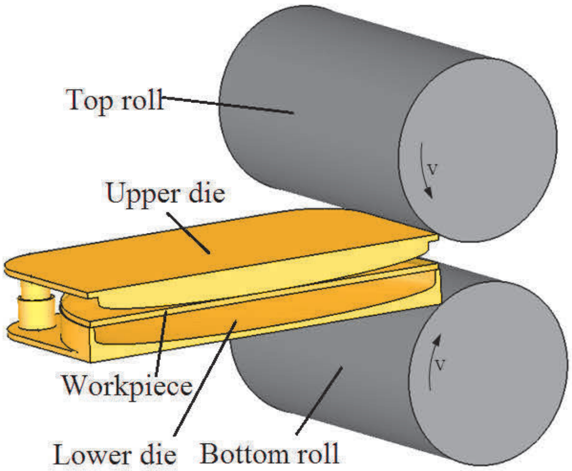

Figure 2 Scheme of the combined process of thick plate rolling and stamping

Geometrical dimensions of products: wall thickness (of a sheet) - 40 ... 120 mm; diameter (width) to 4350 mm made of metallic materials. New combined processes make it possible to produce machine-building products on a thick plate rolling mill.

To implement the new combined rolling-stamping process, an experimental study was carried out on a laboratory rolling mill duo 150. A package was made from the upper punch and the lower die and the blank. The punch was provided with a ring-shaped projection extending radially inwards and having a convex surface. A sheet blank made of 6 mm thick lead was placed between the punch and the matrix. The sheet blank had a circle shape with a diameter of 183 mm in the horizontal plane. The use of lead as a workpiece material makes it possible to simulate hot deformation at room temperature. The rolling of the bag was carried out at a speed of 25 to 100 mm/s.

The combined process of rolling and stamping was performed in one or several passes (from 2 to 4) in a straightforward manner. Based on the results of the experiment, the obtained accuracy of the product geometry was estimated. 10 items were received as total amount. Curvature of finished products was checked by special templates. The deviation was from 10 to 2 %, depending on the number of passes: the more the number of passes, the less the deviation. The form of the final product of the given shape is shown in **Figure 3**.

4. COMPARISON OF TRADITIONAL STAMPING AND COMBINED ROLLING-STAMPING PROCESS

A comparison between the forces of deformation in traditional stamping and the combined rolling-stamping process was made on the basis of a numerical study. In this case, the general types of steel model parts such as "bottom" and the intensity field of deformations are shown in **Figures 4** and **5**.

Figure 3 The obtained experimental sample: a) the detail and the bottom base (matrix) of the package in the assembly; b) general view of the part; c) the shape of the lower surface of the part

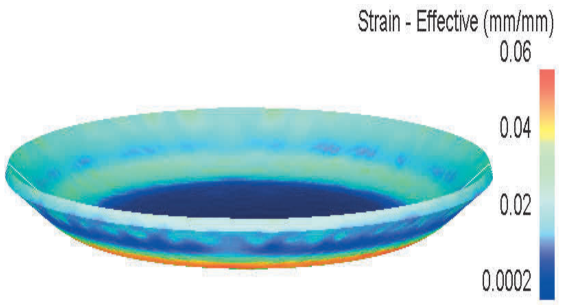

Figure 4 - General view of the modeled part of the "bottom" type and the intensity field of deformation (after industrial stamping)

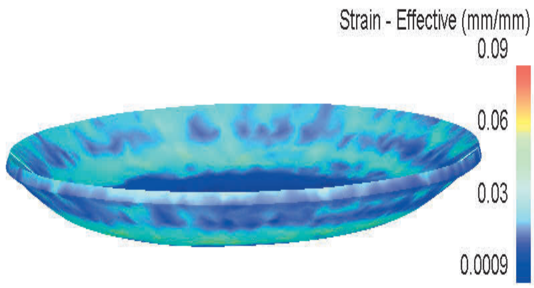

Figure 5 - General view of the modeled bottom part and strain intensity field (after industrial rolling- stamping)

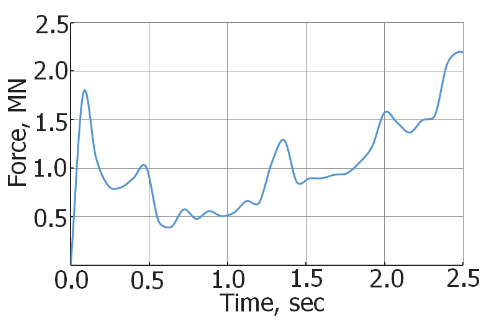

Figure 6 - Graph of the change in the force of deformation in the production of a "bottom" type part by the traditional stamping method

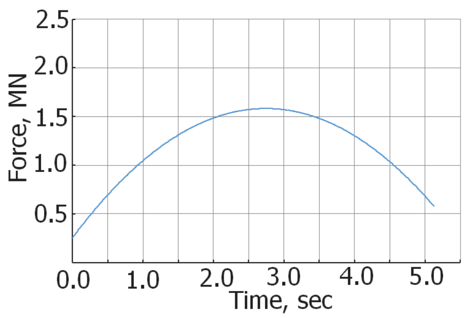

Figure 7 - Graph of the change in the force of deformation in the production of a "bottom" type part by the "rolling-stamping" method

Deformation in a combined process was carried out in 2 passes. In the first pass the full required reduction has been set, and in the second pass, ironing has been performed. The graphs of the change in the force of deformation in both cases are shown in **Figures 6** and **7**. The maximum force during stamping reaches 2.2 MN, and with the combined "rolling-stamping" process only - 1.6 MN.

The developed technology for the production of large bodies parts with a curved surface on a thick plate mill makes it possible, on the one hand, to significantly reduce the energy-force parameters of the process, and on the other hand, to ensure the production of long-length, large-sized parts without welding.

5. CONCLUSION

The mathematical modeling and analysis of metal shaping and force parameters of the "rolling-stamping" process has been performed on a laboratory mill. A technique for the experimental study of the combined "rolling- stamping" process has been developed. The verification of the adequacy of the mathematical model and the experimental testing of the new combined "rolling-stamping" process in the conditions of a laboratory rolling mill have been carried out. A comparative analysis of the advantages and disadvantages of the direct and reversible schemes for implementing the combined "rolling-stamping" process for obtaining parts with a curved surface have been done. Rational geometric forms of matrices and punches for obtaining spherical and elliptical bottoms of various thickness and diameters have been developed. New technical solutions have been proposed aiming at ensuring the stability of the package in the process of deformation and preventing the displacement of its elements relative to each other.

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