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TESTING A NEW TECHNIQUE FOR PRODUCING ARTILLERY CARTRIDGE CASES FROM PIPE WORKPIECE BY ROUGHING WITH A FRICTION TOOL

Oleg Markov
Corresponding author
Doctor of Technical Sciences, Professor, Head of Department
Department of Automation of Production Processes*
E-mail: oleg.markov.omd@gmail.com
Serhii Shevtsov
PhD
Department of Higher Mathematics*
Natalia Hrudkina
Doctor of Technical Sciences, Associate Professor
Department of Natural Sciences
Technical University «Metinvest Polytechnic»
Pivdenne highway, 80, Zaporizhzhya, Ukraine, 69008
Vitalii Molodetskyi
Postgraduate Student
Department of Metal Forming*
Anton Musorin
Engeneer
Gear Bureau
Private Joint Stock Company
«Novokramatorsky Mashinostroitelny Zavod»
O. Tykhoho str., 1, Kramatorsk, Ukraine, 84313
Volodymyr Zinskyi
Postgraduate Student
Department of Metal Forming*
*Donbass State Engineering Academy
Akademichna str., 72, Kramatorsk, Ukraine, 84313

The object of this study is the technological process of manufacturing parts such as artillery shells using pressure treatment methods. The work is aimed at solving the current scientific and technical task to improve the technological processes for manufacturing parts such as cartridge cases based on the use of a tangential rolling operation with a friction tool, which ensures the production of hollow products with a bottom. Using the finite element method, modeling of the bottom rolling processes was carried out, which made it possible to establish the effective geometry of the processed workpieces and their heating temperature. Recommendations have been devised for the design of new technological processes for roughing bottoms, which consist of determining the wall thickness of the workpiece before deformation, the heating temperature of the workpieces, and the amount of supply of the workpiece to the friction tool. The resulting recommendations were verified by experimental studies. Roughing of spherical bottoms should be carried out for pipes with a relative wall thickness (D/s) in the range of 15…20, the homologous heating temperature should be 0.8, and the relative feed of the workpiece into the friction tool should be 0.9. Testing the established relationships under laboratory conditions confirmed the recommendations for changing the shape of spherical bottoms during the roughing process. The results of metallographic studies on full-scale products confirm the results of the theoretical study. It is recommended to use this technique for products that have an axial hole (artillery shells, hydraulic cylinders, etc.), which will allow removing axial defects in the bottom after drilling the axial hole. The results could be used at machine-building enterprises in the manufacture of dual-use parts

Keywords: workpiece deformation, cartridge case, hollow workpiece, pipe roughing, internal defects, FEM

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1. Introduction

Under modern conditions, an important issue for Ukraine is the development of mechanical engineering for the manufacture of dual-use products while simultaneously improving the quality and reducing the cost of manufactured metal products [1–3]. All such parts belong to critical-use products and a significant part of them are produced by hot plastic deformation [4]. A special place among these products is occupied by thin-walled parts with a bottom (gas cylinders, fire extinguisher housings, hydraulic cylinder housings, artillery shells, etc.). These products have a specific shape and consist of several parts (hollow body, bottom, and neck), which are welded. The cost of these products is high. Parts manufactured in this way do not guarantee high reliability of the connection between the metal of the bottom and the cylinder body [5]. As a result, the impact strength and strength of the cylinder metal in the weld zone remain low. Under these conditions, the bottom of the product may break under the influence of high pressure. Therefore, research into the manufacturing processes of parts such as cartridge cases, which improve quality and reduce the costs of their production, is relevant for mechanical engineering.

2. Literature review and problem statement

Using the energy method, the authors of [6] established a model for determining the longitudinal deformation of metal during radial roughing. The proposed model makes it possible to set the deformation force depending on the degree of compression. However, the proposed model does not allow establishing the radial flow of the material during deformation, which requires solving the problem in a three-dimensional statement.

The author of [7] devised a technology for manufacturing complex-profile hollow products, in which part of the workpiece is heated and deformed in a stamp. The combination of axial and radial deformation ensures the flow of metal in the central parts of the workpiece. After upsetting the stepped profile, the axis of the product is formed using a mandrel, and this significantly increases the cost of the production process.

The process of radial deformation of pipes was simulated using the finite element method (FEM) [8]. Analysis of the results allowed the authors to establish that this process is effective at low axial feeds. Axial stresses on the inner surface of a hollow workpiece lead to crack formation due to the appearance of tensile stresses [9]. Based on the results of FEM modeling, in [10], a 3D model of the process of radial deformation of pipe blanks was built and an analysis of the stress-strain state (SSS) of the blank was carried out. The effectiveness of the process of comprehensive deformation of a pipe blank has been proven. However, deforming hollow workpieces using this technique complicates the design of the equipment [11].

In [12], the authors studied the radial deformation of pipe blanks using experimental methods. This technique is a new approach to improving equipment to ensure optimal design and avoid deformation on hammers. In [13], the influence of the geometry of the deforming tool on the stress-strain state of the workpiece during the deformation process was established. Based on the results of the work, it was found that to ensure minimal heterogeneity in the mechanical properties of the wall thickness, it is advisable to use a tool with convex geometry.

The authors of [14] simulated the process of pipe crimping. Pipes of different diameters with different wall thicknesses were deformed. The pipes were crimped using four tools, which made it possible to direct the flow of metal in the axial direction. The work established the influence of the deformation technique on the efficiency of processing when crimping long workpieces using tools of different geometries [15]. It was found that in this case it is possible to obtain uniform mechanical properties in the longitudinal and transverse directions.

The issue of pipe surface quality during deformation is considered in [16]. The work proposes two types of tools that ensure uniform distribution of deformations. It was concluded that with an increase in the angle of inclination of the working edge of the tool, the uniformity of the distribution of deformations increases. However, an increase in crimping helps reduce the surface roughness of the workpiece but this may result in destruction of the product [17].

A comparison of the processes of radial deformation of copper pipes between two and three tools was made in [18, 19]. It was found that the deformation force with two tools is greater than with three. The SSS of the metal in manufactured hollow products is distributed more evenly when using three tools. However, these methods of radial crimping of thin-walled pipes cannot be used in the manufacture of products from steel tubes [20].

Radial crimping of hollow workpieces was carried out by [21]. Based on the research results, the geometry of the products, the deformation forces and the distribution of the workpiece stress-strain state were compared. It has been established that when deformed without a mandrel and the outer diameter of the pipe is reduced by 15 %, the wall thickens by 10 %. Work [22] experimentally established the stress-strain state during roughing of hollow workpieces. For research the grid method was used. The roughing processes of tools with flat and concave geometry were compared. It has been established that the use of a flat deforming tool leads to an increase in the uniformity of strain distribution.

In [23], it was found that pipe deformation promotes intensive closure of the hole and minimal elongation of the hollow workpiece. However, the study did not establish the shape of the deforming tool that would enhance the elongation of the workpiece.

Based on studies of pipe crimping processes on radial forging machines, it was found that the process helps improve the mechanical properties of the metal [24]. The influence of the degree of deformation on the force parameters of crimping has been established. It is noted that further research should be aimed at establishing the influence of the stress-strain state scheme on the formation of the internal structure of the metal, which affects the heterogeneity of mechanical properties. Assessments of failure criteria during pipe crimping are presented in [25]. The authors investigated the crimping process with different deforming tools. As a result, patterns of changes in deformation pressure depending on the friction factor were established.

The authors of [26] studied the process of radial crimping of pipes. The authors established the following results: the deformations in a hollow workpiece are more uniform than in a solid one. The mechanical properties of the material along the pipe axis were the same. The greatest stresses and deformations appear along the axis of the workpiece, which leads to an increase in the mechanical properties of the workpiece. Similar results were established in the manufacture of bottoms and necks from sheet blanks by roughing with a roller [27]. The work investigated the influence of the workpiece rotation speed on the roughing performance. Based on the study, operating algorithms, and the trajectory of the manipulator for roughing were established. This technique is suitable for making necks with a hole.

Paper [28] established a parameterized roughing tool path based on a quadratic Bezier curve. As a result of the research, it was possible to determine the roughing force. However, researchers have not taken into account the heating of the workpiece during roughing, which significantly affects the deformation forces. The authors of [29] took into account the deformation temperature when studying the process of roughing pipe blanks and analyzed the appearance of the main types of defects. But the results of the work are aimed only at the production of flat bottoms.

It is rational to produce a significant number of products with bottoms by the tangential roughing of IT [30]. Analysis of the state of the problem made it possible to identify a group of issues that our work is considering. Resolving them in the course of our work will help determine the technical capabilities of the process of hot tangential roughing of pipes and improve the technical and economic indicators of the products [31]. The use of a processing technique requires an analysis of the processes of forming and interaction of the workpiece with the working surface of the tool, and, accordingly, the determination of the boundaries of its use. Moreover, this issue concerns individual cases of manufacturing products with a bottom that require increased performance characteristics, requiring special thermomechanical deformation modes. To devise rational technological processes for tangential roughing, IT requires establishing quantitative estimates of shaping, obtaining reliable data on the influence of tangential roughing conditions, tool parameters, as well as process conditions on the geometry of the resulting products. Solving this problem requires the construction of finite element models for designing technology and determining the main characteristics of equipment from the point of view of increasing the accuracy and stability of the resulting geometric characteristics of products.

3. The aim and objectives of the study

The purpose of this work is to devise a new technique for producing artillery cartridge cases from tubular blanks based on determining quantitative estimates of shape formation during rotational roughing with a friction tool (FT), which will make it possible to use them for mass production.

To achieve the goal, the following tasks are set:

– to establish the effective heating temperature, relative feed, and relative wall thickness of the workpiece pipe before roughing with FT, which will facilitate welding of the bottom hole and will not lead to overheating and burnout of the workpiece metal;

– to conduct an experimental test of welding of the axial hole during tangential roughing with FT of a spherical bottom.

4. The study materials and methods

The object of our study is the technological process of roughing pipe blanks with FT.

The research hypothesis assumes that roughing pipe blanks with FT will make it possible to obtain a bottom in the product for the manufacture of artillery cartridge cases, which would reduce costs and increase productivity for their production.

The main assumptions of the study are the uniformity of heating throughout the wall thickness and the absence of oxidation on the surface of the deformed workpiece.

At the first stage, the influence of the relative thickness of the hollow wall of the workpiece and the initial heating temperature on the heating of the bottom was established at a constant value of the workpiece supply to FT. Based on the results of this study, the maximum bottom temperature at the end of the FT roughing process was determined. This temperature was rational for the implementation of this process. The study of the process was carried out at various initial homologous temperatures (t_{hom}) in the range of 0.6, 0.7 and 0.8. The relative pipe wall thickness (D/s) varied in the range of 10, 15, 20. The relative supply of the workpiece in FT (l/D) was 0.8 and was constant. The thermal and deformed (Fig. 1) states of the workpiece during the roughing process were established using FEM. For this modeling, a special research methodology was devised. Structural steel 34XH was chosen for the material under study.

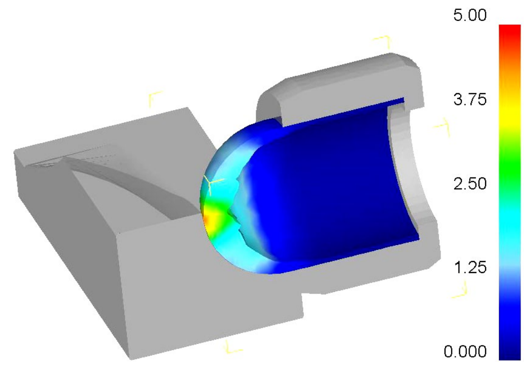


Fig. 1. Finite element model of the process of tangential roughing with a friction tool at the final stage

The initial data and boundary conditions for modeling the FT roughing process were as follows: Young's modulus for this steel was $2\cdot10^5$ MPa; Poisson's ratio was 0.32; tool temperature was 30 °C; and the Siebel friction coefficient was 0.35. The number of finite elements was set to 80000. The preheating temperature of the workpiece was 900 °C; 1050 °C; and 1200 °C; the workpiece rotation speed – 1150 rpm; the tool feed speed – 0.5 mm/s; the pipe diameter – 90 mm; the wall thickness varied in the range of 9 mm; 6 mm; and 4.5 mm.

5. Results of research into the process of roughing a pipe blank with a friction tool

5. 1. Theoretical study of the thermogeometric parameters of the workpiece for the formation of the bottom

Analysis of the temperature distribution results in the longitudinal section made it possible to establish that the temperature is distributed unevenly over the cross section of the workpiece (Table 1). The maximum heating of the workpiece is localized in the axial zone of the bottom, which is explained by the long-term contact of the workpiece with FT and the maximum accumulation of deformation in this zone. The workpiece has a minimum temperature at the point where it is gripped by the machine chuck. This temperature distribution can be explained by the maximum heating of the bottom of the pipe and intensive cooling of the workpiece from the gripping side of the machine, as well as uneven initial heating.

Along the cross-section of a hollow workpiece during tangential roughing with FT, the temperature gradient does not go beyond the temperature range of hot pressure treatment for the ratios of the simulated sizes of the workpiece. Determining rational modes requires establishing the deformed state of the workpiece during tangential roughing. After establishing the temperature distribution, the distribution of the intensity of logarithmic deformations over the volume of the workpiece after roughing was determined (Table 2).

Roughing leads to an increase in the thickness of the bottom wall. The thickness of the bottom increases gradually from the pipe section to the axial zone. This pattern is typical for hollow workpieces with different relative wall thicknesses and initial heating temperatures.

Table 1

Temperature distribution in workpieces with different initial temperatures and relative wall thicknesses with constant feed of the workpiece to the friction tool

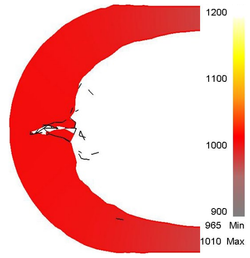
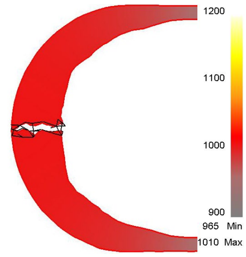
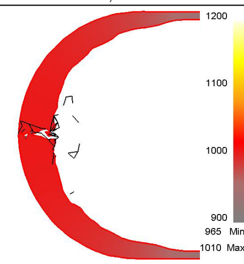
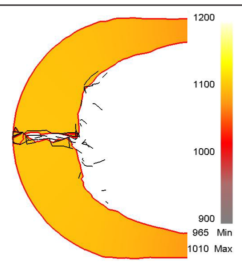
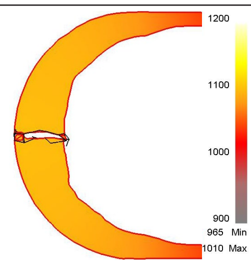
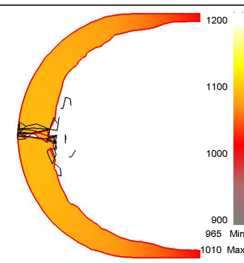
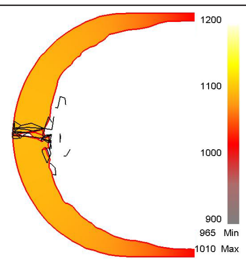
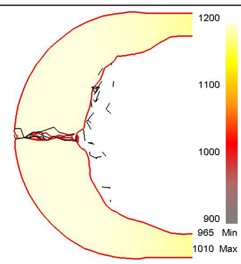
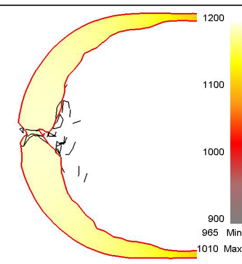
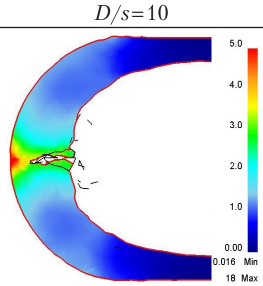
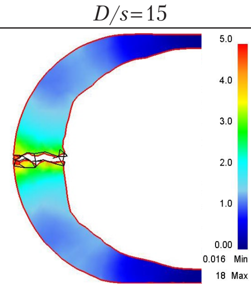
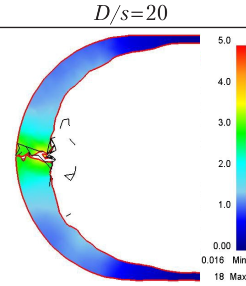
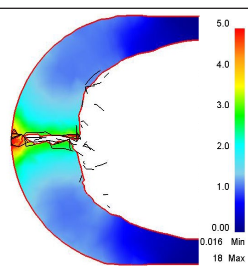
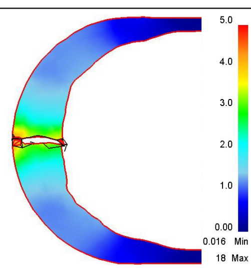
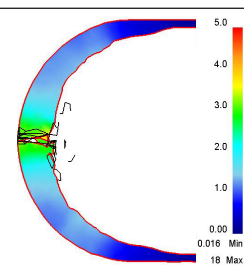
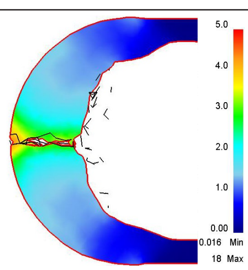
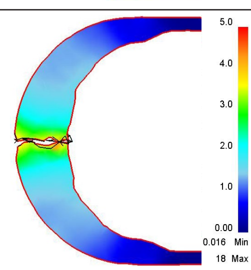
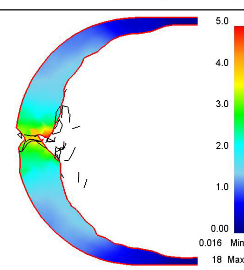
t, °C	D/s=10	D/s=15	D/s=20
900			
1050			
1200			

Table 2

Distribution of the intensity of logarithmic strains in workpieces with different initial temperatures and relative wall thickness with constant feed of the workpiece to the friction tool

t, °C	D/s=10	D/s=15	D/s=20
900			
1050			
1200			

5. 2. Experimental verification of welding the axial hole

Based on finite element modeling of the processes of tangential roughing with FT, rational parameters of workpieces were established for defect-free production of bottoms from pipe blanks:

– relative pipe wall thickness for manufacturing a defect-free bottom $D/s=20$;

– relative feed of the workpiece to FT $l/D=0.925$;

– homologous temperature $0.8{\cdot}T_m$ (T_m – temperature of a melting).

To devise a technological process and the possibility of implementing our results, it is necessary to carry out experimental verification under conditions close to industrial ones.

The pipe diameter was 90 mm, the pipe wall thickness was 4.5 mm, the absolute feed of the workpiece into the tool was 82 mm, and the heating temperature of the pipe was 1200 °C. Thus, the following established technological recommendations were subject to verification.

The specified parameters fall within the recommended intervals for roughing pipe blanks. The process of induction heating of a pipe blank with high frequency currents (2.4 kHz) is shown in Fig. 2. The heating time was 70 s. Pipe material – steel 34XH.

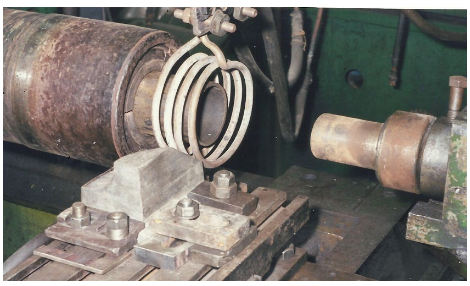


Fig. 2. Induction heating of a pipe blank before roughing

The second important indicator of the quality of the bottom is its continuity. The integrity of the metal can be established on the basis of metallographic studies – analysis of the macro- and microstructure in the axial zone of the bottom. To do this, the cut bottoms were polished, after which a macro-section was prepared from the resulting templates (Fig. 3).

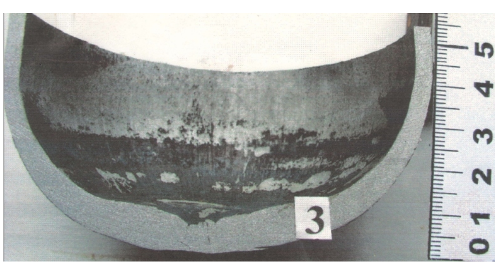


Fig. 3. Macro-sections of bottom after roughing

When the image is magnified by 2 times, the remains of the axial defects of the bottom can be clearly identified (Fig. 4). In Fig. 6, these remains are highlighted in red.

Based on a macrostructural analysis of the shape and location of axial defects in the bottoms, it was established that there are defects in the bottom (Fig. 4). The length of the defect is 4.2 mm, which is 2/3 of the thickness of the bottom wall, the location of the defect is axial. This location of the defect will lead to its increase with increasing pressure and the appearance of elastic deformation of the walls in the cartridge case. The defect extends to the inner surface of the bottom, which will reduce the tightness of the cartridge case. Macro defects located away from the axial zone were also identified. This defect can be explained by the formation of folds during roughing, due to the accumulation of metal in the axial zone.

The final conclusion about the quality of the axial zone of the bottom can be drawn based on the results of microstructural studies. The cut templates after polishing and etching were examined on an optical microscope with a magnification of 50 times. The microstructure results for a spherical bottom with an arrangement of internal defects are shown in Fig. 5.

Fig. 4. Remains of axial defects of bottoms after roughing

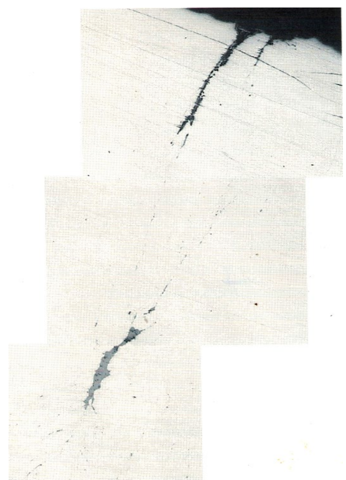


Fig. 5. Microstructure of axial defects of spherical bottom after roughing (×50)

Analysis of the microstructural study has made it possible to establish that the metal structure of the bottom contains oxide films that did not contribute to the complete welding of the axial hole of the bottom.

6. Discussion of results of investigating the possibilities of using the proposed technique for the production of cartridge case parts

Our temperature distribution results (Table 1) are explained by the fact that there is no need to heat the pipe blank during the tangential roughing process. Moreover, the results are explained by the fact that during the roughing process, with the initial heating of workpieces with different wall thicknesses to temperatures of 900...1200 °C, there is no cooling of the workpiece, nor a sharp increase in temperature. This made it possible to explain the technological recommendation on the heating temperature of the workpieces, which is important for the practice of FT tangential roughing process. This temperature is 1200 °C ($t_{hom}=0.8$). This temperature level is sufficient for maximum ductility of the metal, minimal roughing force, welding of the walls of the axial zone of the bottom, as well as preventing the formation of overheating and burnout of the metal.

The maximum level of deformation is localized in the bottom hole area. The results can be explained by the fact that this volume of the workpiece undergoes a significant change in the shape of the metal. The quantitative difference in the distribution of the deformed state of the workpiece along the longitudinal section is explained by the fact that when roughing hollow workpieces with a thick wall (first column, Table 2), the maximum level of deformation is located on the outer surface of the bottom. Roughing thin-walled workpieces leads to the appearance of maximum deformations on the inner surface of the bottom (third column, Table 2). This result is a new scientific observation, explained by the different stress state of the pipe when roughing thin-walled and thick-walled hollow billets.

Simulation of the tangential roughing process has made it possible to establish that the relative supply of the workpiece to FT does not lead to complete closure of the pipe walls in the axial zone of the bottom, which is explained by the small amount of volume of the workpiece metal.

The features of the proposed roughing technique in comparison with previously known ones are that parts such as cartridge cases can be obtained from pipe blanks, rather than from solid ones [7, 12], which will reduce metal consumption.

The limitation of this roughing technique is the narrow range of relative wall thicknesses of the pipe blank, which is 15...20.

Analysis of the results of macro- and microstructural studies has made it possible to identify the disadvantages that are characteristic of this roughing technique, namely, the structure of the metal of the bottom contains oxide films that do not contribute to the complete welding of the axial hole of the bottom. This clearly explains the appearance of two elongated inclusions (films), which are separated by a dense layer of metal. The results of metallographic studies on full-scale products explain the results of a theoretical study on the insignificant effect of roughing a spherical bottom on the support in the axial zone and its complete welding.

The indicated disadvantages can be eliminated by improving this technological process to eliminate the formation of defects in the bottom of the cartridge case through the use of an additional operation of refilling the bottom. Or you should use the proposed technique for cartridge cases that have an axial hole in the bottom, by drilling which these defects can be removed.

The development of this research is the study of the operation of refilling the bottom to weld internal defects. This research will require the inclusion of an additional operation in the technological process and the manufacture of an appropriate deforming tool.

7. Conclusions

1. The effective initial homologous temperature for heating the workpieces before roughing should be 0.8. This temperature will facilitate welding of the bottom hole and will not lead to overheating and burnout of the workpiece metal. The relative feed of the workpiece to FT before roughing should be set in the range of 0.9...0.95, which will facilitate closing and welding of the bottom hole. It is advisable to choose the relative thickness of the pipe wall in the range of 15...20, for the manufacture of bottoms with lower metal costs.

2. A new technological process of tangential roughing of a spherical bottom was tested. The results of metallographic studies on full-scale products confirm the results of a theoretical study about the insignificant effect of roughing a spherical bottom on the support in the axial zone. This technological process should be improved to eliminate the formation of defects in the bottom of the cartridge case, or this technique should be used for products that have an axial hole (artillery cartridges, hydraulic cylinders, etc.), which will ensure drilling out the axial defect.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

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