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THE CHOICE OF INITIAL CONDITIONS AND OF SOLUTION IN THE PROBLEM OF EFFICIENCY INCREASE OF PIPES CALIBRATION ON A MANDREL

This research work is devoted to the theoretical study of the pipe calibration on a mandrel. The aim of the study is to improve the precision of the calibrated pipes. As the paper shows, it is advisable to apply different methods of research depending on the purpose of the study of metal forming processes: mathematical, computer or physical simulation. Analytical review of existing mathematical models of the pipes calibration on a mandrel showed that the set of assumptions adopted in the mathematical modeling does not allow assessing the precision of the pipes during calibration. Therefore, finite-element method simulation package was used for this research. Research method and pipes precision index were developed on the basis of the computer simulation using Deform-3D package. The investigations have allowed us to get the dependence of the pipe precision on technological factors and to identify the root cause of reduced efficiency calibration – extrafocal deformation.

Keywords: hot-rolled pipe, pipe calibration on a mandrel, pipe precision index, extrafocal deformation, finite element simulation FEM

1. Introduction

The analysis of metal forming processes is aimed at solving specific technological problems: reduction of supplied energy and force parameters of the process, reduction of the contact pressure on the tool, increase of performance characteristics and dimensional precision of the product. In order to solve applied problems in the theory and practice of metal forming processes a variety of methods and techniques of research having their advantages and disadvantages are developed and widely used. Conventionally, these ones can be divided into methods of mathematical, computer and physical simulations. Continuous improvement of methods of mathematical and computer simulation allows us to solve most of problems without resorting to costly full-scale experiments.

The advantage of solving problems by mathematical simulation method is the ability to analyze the impact of technological factors on investigated parameters in a wide range of values, to find the optimum values of technological factors for manufacturing of products with specific dimensions quickly. However, when constructing a mathematical model of the process it is inevitable to adopt assumptions that simplify the solution, therefore accuracy of the results is reduced. Also, as it will be shown below, solution of some technical problems is not possible because of the adoption of certain assumptions.

Over the past decade, computer simulation of metal forming processes based on the finite element method (FEM) has been widely developed. Today there is a wide variety of FEM-simulation packages, both universal and narrowly focused: ANSYS, ABAQUS, PAM-STAMP, SOLIDWORKS, Q-FORM, DEFORM-3D, and others. Computer simulation allows us to avoid most of the assumptions and to obtain sufficiently accurate solutions. The solution accuracy is determined by applied boundary conditions and simulation parameters (the number of finite elements, mesh type, number of steps). The disadvantage of computer simulation is a necessity to set technological factors in the form of certain values, i.e. it is necessary to conduct a series of numerical experiments to obtain dependencies, which leads to a large amount of required time.

The choice of the method of solving the problem should be guided by the required accuracy of the solution. Rational choice of the method of solving and statement of the problem largely determine the success and results of investigation. As an example, you can consider papers containing new scientific results which were obtained through computer simulation of well-known metal forming processes and investigation of stress-strain state [1-3].

2. Problem statement

The task of the research work is to study the process of internal pipe diameter calibration on a mandrel in order to improve the precision of the calibrated pipe. Pipes with high accuracy of geometric dimensions are demanded for the nuclear power

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industry, the production of bimetallic pipes [4], so increasing efficiency of the calibration is a relevant objective. Pipe calibration is carried out by means of pipe expansion on a mandrel in a cold state. Thus an increase in the internal diameter, wall thickness reduction and the change in length of the pipe occur. Regularities of forming and common mathematical formulations are determined in mathematical simulation in a number of papers [5-9].

A simplified scheme of the pipe expansion process (Fig. 1a) was adopted in [5,6] with the use of assumptions about the size of the deformation region and the pipe forming pattern. Investigation of the process was performed with the use of the principle of possible changes of strain state for perfectly plastic material and with replacement of extrafocal elastic-plastic deformation regions by shear strain surfaces AB and DC. In this problem statement the aim was to study the force parameters of the process and relative thinning of the pipe. The disadvantage of this solution should be considered neglecting extrafocal plastic deformation and elastic unloading that effect on the internal diameter precision of the calibrated pipe. In applied problem statement, the internal pipe diameter is equal to the mandrel diameter under all conditions and precision investigation becomes impossible.

Further development of the calibration process research was obtained in [7], in which the problem statement is specified taking into account the elastic properties of the pipe material, the additional bending moments at the input and output of the deformation region, and the deformation region is presented in the form of five consecutive zones of the elastic and plastic deformation. The mathematical description of the process has become considerably more complicated, but it more realistically reflects the process mechanics. The scheme of the process shown in Fig. 1b. In this problem statement, authors also investigate δ – the value of extrafocal expansion (see Fig. 1b), however, in accordance with the solution, the extrafocal expansion δ does not depend on the degree of expansion ε.

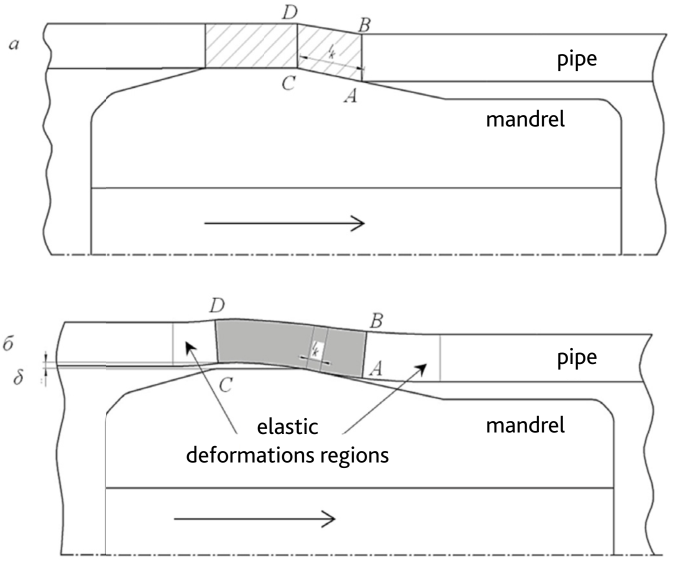

Fig. 1. The scheme of thin-walled pipe calibration on a mandrel ABCD – plastic deformation region, l_k – length of contact between pipe and conical mandrel

This is not verified by the experiment [8]. Among other disadvantages the assumptions should be noted which reduce the solution accuracy: the boundary between the elastic and plastic zones adopted in the form of flat sections, the pipe material properties correspond to properties of the perfectly plastic material, the strains and stresses are uniformly distributed over the wall thickness of the pipe. Based on these disadvantages, it follows that this solution does not satisfy the aim of this research work.

In the research works of foreign authors [8-14] the process of calibration was investigated in order to establish relationships between force and forming parameters of the process and stresses, however, some assumptions were used when solving the problem. This prevents adequate study of pipe precision under calibration on a mandrel.

In a recent paper [14] devoted to solving the problem of the pipe expansion on a mandrel, the mathematical model of the process taking into account the wall thickness and length changes in the process of pipe expansion, heterogeneity of tool pressure on the pipe and friction coefficient were adopted. An elastic-plastic hardening material was assumed as a model of pipe material. However, influence of extrafocal plastic deformation regions on forming of the pipe was neglected, which also does not allow assessing the precision of pipe size after calibration.

Review of available mathematical models of expansion process showed that most of them are developed in order to study the energy-force and forming parameters of pipe. It should be noted that the set of assumptions taken does not allow us to evaluate the precision of the internal pipe diameter after calibration (expansion) and its dependence on technological factors. An analysis of recent paper has shown that FEM simulation packages are becoming more widely used. These packages are used for verification of developed mathematical models and solving specific technological problems.

Achievement of the aim of this study is possible by means of FEM simulation of the calibration process. FEM simulation has greater information content in comparison with other methods, allows to avoid simplifying assumptions and to detect influence of certain technological factors. In this research work simulation was carried out using Deform – 3D software.

3. Research method of pipe precision

In the study of the pipe calibration as a model of pipe material elasto-plastic hardening material was used, as a material steel AISI-1045 was chose from Deform-3D material library. The taper angle of the mandrel working section is assumed to be 12°. This taper angle corresponds to the lowest level of expansion force[4]. The wall thickness of the pipe m was adopted as the two values: $m = 1.15$ and 1.2, where m is the ratio of the external diameter to the internal diameter.

Simulation with using Deform – 3D software revealed the following features of the deformation region under pipe calibration on a mandrel. Deformation region consists of several specific sections (Fig. 2): a section of direct contact between pipe and conical mandrel, which is the geometric deformation region and two curvilinear sections at the input and output, which are regions of extrafocal plastic deformation. The increase in internal pipe diameter 2δ at the output from the region of extrafocal plastic deformation is a characteristic of extrafocal expansion, while the decrease in the internal pipe diameter behind the section of extrafocal expansion characterizes the elastic unloading of the pipe.

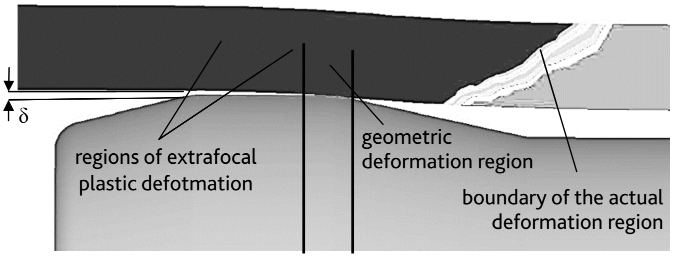

Fig. 2. Deformation region of the pipe calibration process in FEM-simulation

In the study of the pipe precision, we take into account that the initial pipes have spread of the geometric dimensions within the requirements of the standard by which these ones were manufactured (see Fig. 3 for example). When we set the initial condition of the problem, spread of pipe dimension was specified as a certain range of values.

To assess the pipe precision under pipe calibration on a mandrel, spread index of internal diameter values of the pipe array before and after calibration was used:

- before calibration

$$p_0 = (d_{in0max} - d_{in0min})/2d_{me0},$$

where: $d_{me0} = d_{in0\min} + (d_{in0\max} - d_{in0\min})/2$, $d_{in0\max}$ and $d_{in0\min}$ – the maximum and minimum possible value of the internal pipe diameter before calibration;

- after calibration

$$p_1 = (d_{in1\max} - d_{in1\min})/2d_{me1},$$

where $d_{me1} = d_{in1\min} + (d_{in1\max} - d_{in1\min})/2$, $d_{in1\max}$ and $d_{in1\min}$ – the maximum and minimum value of the internal pipe diameter after calibration.

The value of the mandrel diameter in the computational experiment was constant and equal to 64 mm, internal pipe diameter had a value in the range from 60.8 mm to 63.68 mm. The study was carried out for the Siebel frictional coefficient ψ, equal to 0.05, 0.15, 0.25. Input data and results of index of the precision increase p_0/p_1 when $\psi = 0.15$ are shown in Table 1.

After pipe calibration on a mandrel, the range of possible values becomes narrower therefore the precision of the internal pipe diameter increases. We investigate the change of six gradually expanding ranges with corresponding degrees of pipe expansion $\varepsilon = 0.5$, 1, 2, 3, 4, 5 % as a result of the calibration, where $\varepsilon = (d_{man} - d_{in0})/d_{in0}$, d_{man} – mandrel diameter, d_{in0} – internal pipe diameter. The effectiveness of calibration was evaluated by the ratio p_0/p_1 – index of the precision increase.

The results showed that in the pipe calibration with a small degree of expansion ε equal to 0.5%, the internal pipe diameter becomes smaller than the mandrel diameter due to the prevailing of the elastic unloading of the pipe, while with increasing the degree of expansion ε, internal pipe diameter becomes larger than the mandrel diameter. Fig. 4 is a graph of index of precision increase, which shows that in the range of values of the expansion degree ε = 0.5-2%, efficiency of calibration of the internal pipe diameter is highest, and with increasing the expansion degree ε to 5% efficiency decreases. With increase in the Siebel frictional coefficient ψ ratio p_0/p_1 becomes smaller. The decrease of calibration effectiveness at high expansion degrees ε results from a proportional increase in the degree of extrafocal expansion.

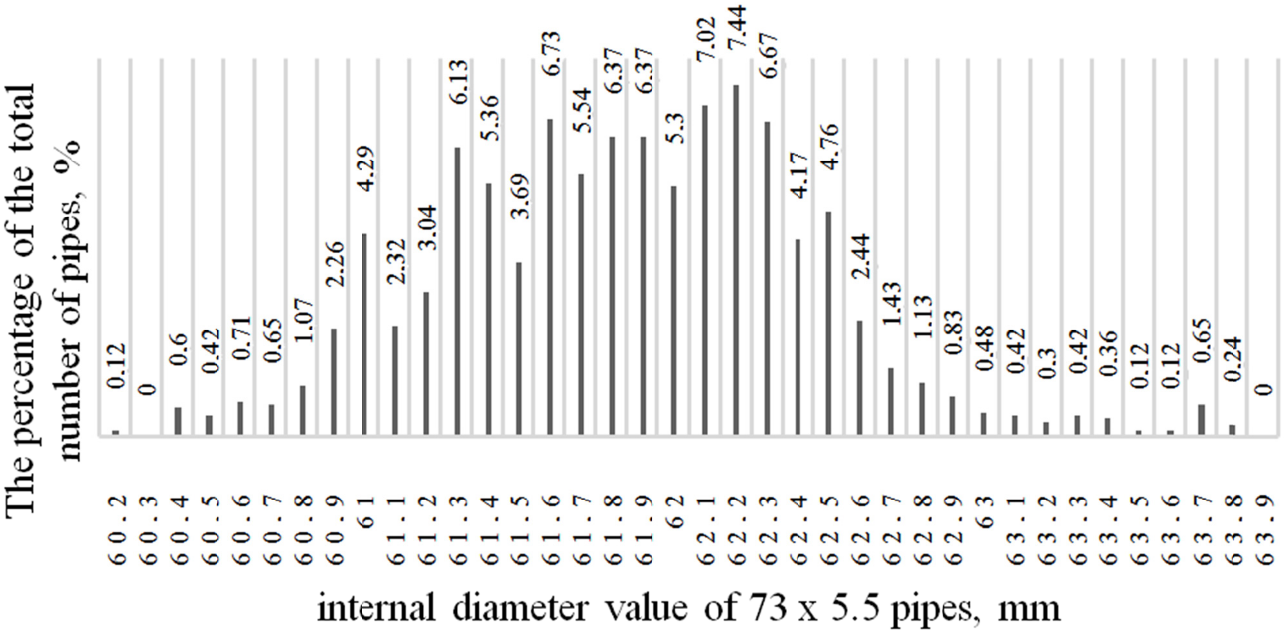

Fig. 3. The frequency distribution of internal diameter values of 73 × 5.5 pipes made according to State Standard GOST R 52203-2004

Using the FEM simulation, it was observed a feature of the pipe calibration process on a traditional mandrel with a conical working section, which consists in a small area of the contact between the pipe inner surface and the mandrel. Starting with an expansion degree ε equaling 1%, the internal surface of the pipe contacts with a small area of the working section of the mandrel, wherein the contact on the mandrel drawing cylinder is completely absent, as seen in Fig. 2. With that in mind, obtaining pipe with high precision of internal diameter is possible by means of the development of new designs of mandrels allowing minimizing extrafocal deformation.

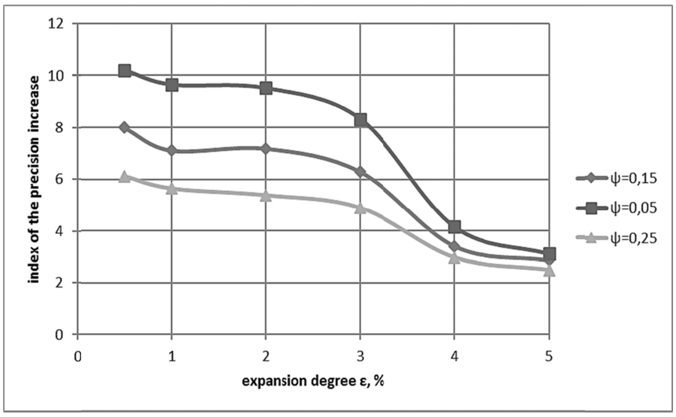

Fig. 4. Index of the precision increase

TABLE 1

Results of computational experiment

No	d_0 **mm**	m	p_0 %	ε %	d_1 **mm**	p_1 %	p_0/p_1
1	63.68	1.15	0.25	0.5	63.98	0.030	8.06
2	63.68	1.20		0.5	63.96		
3	63.36	1.15	0.50	1.0	64.05	0.055	9.09
4	63.36	1.20		1.0	63.98		
5	62.72	1.15	1.01	2.0	64.14	0.110	9.18
6	62.72	1.20		2.0	64.11		
7	62.08	1.15	1.52	3.0	64.27	0.210	7.24
8	62.08	1.20		3.0	64.23		
9	61.44	1.15	2.04	4.0	64.73	0.570	3.57
10	61.44	1.20		4.0	64.62		
11	60.80	1.15	2.56	5.0	65.07	0.830	3.08
12	60.80	1.20		5.0	64.90		

4. Conclusions

In the paper the existing analytical solutions of process of the pipe calibration on a mandrel have been considered. It is shown that a set of taken assumptions does not allow to investigate the precision in the pipe calibration process. So we used FEM-simulation package Deform – 3D for the theoretical study. To investigate the pipe precision, in the paper the method that takes into account spread of initial pipe values as the range of values has been developed. The results of the study on the proposed method showed the dependence of the pipe precision on technological factors. As was shown, the highest efficiency of the pipe calibration is achieved with an expansion degree ε in the range to 2%. Due to computer simulation the main cause of the calibration efficiency decrease at high expansion degrees ε was revealed – the extrafocal plastic deformation regions leading to additional increase in the internal diameter. Further direction of improving the process is associated with the development of new designs of calibrating mandrels.

Aknowlegement

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