Questions process simulation of metal forming

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Abstract. Today, enterprises are faced with the problem of reducing the terms of design and technological preparation of production, which ultimately has a significant impact on the cost of production. In reducing time, CAD / CAM / CAE systems and CAD processes help today. In this regard, the aim of the article is to develop a model that allows you to choose the main technological equipment with a sufficient degree of reliability for hot forming processes. Research method, finite element method, which is used to analyze the stress-strain state of the forging. The results of the study are expressed in the obtained dependence, which allows you to choose the main technological equipment by weight of forgings. The conclusions obtained from the study are based on multivariate calculations by the finite element method for forgings of varying degrees of complexity, covering the most common range of crank hot stamping presses with a nominal force of 6.3 to 40 MN. The practical significance of the research results is to reduce the time of design and technological preparation of production by 15%. The proposed methodology and / or its results can be applied at enterprises engaged in the manufacture of parts by metal forming.

1. Introduction

Currently, more than one high-precision production is not complete without computer-aided design (CAD) systems and computer modeling. This is especially true for such sectors of the economy as the space industry, aviation, automotive, engineering, materials science, etc. These technologies bridge the gap between engineering manual calculations and full-scale finite element analysis. For example, the Autodesk Helius Composite software package provides analysts and designers with permanent, detailed information about the behavior of composite materials and laminates, allowing you to interactively explore the many different “what-if” scenarios that make up most of the design and analysis process. This program is actively used by the company – NASA’s Goddard Space Flight Center in order to develop new materials for the next generation of space agency heavy launch vehicles [1].

So, in the work of Shibaev, various approaches were used that are used in materials science and materials technology, in modeling, predicting and calculating sintering diagrams, predicting the physicomechanical properties of polymeric materials, metallurgical processes and the problems they
encounter. Associated, according to the author, with the need to take into account a number of features of materials science. Since several levels of the structure are distinguished in the material, it is necessary to take into account all these levels of the structure, starting with the electron-nuclear (microstructure) and ending with the macrostructure, so that the mathematical model used for calculations adequately describes the properties of materials, the technological processes for their preparation and have the smallest error [2].

Equally important for the real sector of the economy is the use of CAD systems for technological processes (TP) of metal forming; they have wide capabilities associated with the modeling of processes of hot volume and sheet stamping. The use of CAD TP is associated with the need to predict the flow of metal and a preliminary assessment of the stress-strain state of the workpiece during deformation, which is the initial data for the design of a technological tool [3].

2. Purpose and objectives of the study
The purpose of the study is to verify the adequacy of mathematical models used in modern CAD based on the finite element method. To do this, let us analyze a fairly wide range of parts and forgings manufactured by various methods of metal forming from various materials (structural and alloyed steels, non-ferrous metals and alloys, etc.).

3. Methodology
The analysis of the adequacy of mathematical models is carried out on the basis of the finite element method, for which purpose CAD, CAM / CAE systems create models of parts, forgings and technological tools in accordance with the adopted process flow diagram. Further calculations are carried out in CAD software using standard techniques for these systems in terms of data preparation and analysis of the results.

4. Results
4.1. Sheet stamping
The main problem of manufacturing parts by sheet metal stamping is that as a result of the combined force on the metal, in most cases it is necessary to obtain the final shape of the part, which does not require any modification. It is known that sheet stamping operations are classified according to the degree of deformation into dividing and forming.

Optimization of energy-power parameters of sheet metal stamping processes requires studying the question of the possibility of combining technological operations in order to reduce the required number of technological transitions. In this case, the most complex from the point of view of the stress-strain state are the form-changing operations of sheet stamping, which we will consider using the example of parts shown in Figure 1.

Figure 1. Details of stamping: (a) cover, (b) disc, (c) terminal, (d) strap, (e) bracket (f) cover.
After analyzing the technological features of the parts, we can distinguish a number of operations that can be obtained in one technological transition. These operations include:
- shallow hood;
- punching;
- cutting down;
- bending.
Examples of the data obtained are shown in Figure 2.

![Figure 2](image1)
![Figure 2](image2)

Figure 2. Viewing simulation results using the basic functions of a post-processor: (a) deformation, (b) stress, (c) temperature distribution.

![Figure 3](image3)

Figure 3. The results of modeling parts manufactured by cold stamping: (a) the results of modeling a part of the Link type, (b) the results of modeling a part of the Planck type.
After performing the calculation, the data obtained are used to optimize the technological tool and refine tool models. In this case, the strain rate, which is determined by the design features of the applied technological equipment, is also taken into account. Similar parts are manufactured on single-crank mechanical presses with a force of up to 1.6 MN (160 tf), which is shown in Figure 4 [4].

![Figure 4](image)

**Figure 4.** Presses of cold sheet stamping with a simple action: a) KD2324, 250 kN, b) KI2126, 400 kN, c) KI2328, 630 kN.

4.2. *Hot stamping*

Parts obtained by hot volumetric stamping are characterized by an axisymmetric and three-dimensional stress-strain state and have more diverse shapes and degrees of complexity and are presented in Figure 5.

![Figure 5](image)

**Figure 5.** Parts made by hot forging: (a) bevel gear with teeth, (b) cup, (c) crown nut, (d) bracket, (e) roller.

Due to the obvious complexity of the forgings of parts made by hot forging, their modeling presents certain difficulties, associated primarily with the high cost of machine time required to obtain optimal results.

Therefore, there is a need for the initial design of crank hot stamping presses (CHSP) or when buying it in a quick expert assessment of the magnitude of the required effort and the work of plastic
 deformation. Based on the experience gained by the forging plants, there are indicative data for choosing the press force $P$ depending on the weight of the forging, the values of which are given in Table 1 [5].

**Table 1.** Press forces depending on the weight of the forging.

| Weight of forgings, kg | 0,5 | 0,5-3 | 2-3 | 3-8 | 8-12 | 12-20 | 20-25 |
|-----------------------|-----|-------|-----|-----|------|-------|-------|
| Press force, MN (tf)  | 6,3 (630) | 10 (1000) | 16 (1600) | 20 (2000) | 25 (2500) | 31,5 (3150) | 40 (4000) |

![Figure 6. An experimental plot of the press force versus the forging mass.](image)

It is possible to more accurately predict the magnitude of the effort, focusing on the data of calculations of technological processes of hot die forging based on the finite element method. The purpose of these experiments is to establish the adequacy of the results obtained by theoretical methods.

At the beginning of the analysis of multivariate calculations, we obtain pictures of the stress-strain state, which are presented in Figure 7.

![Figure 7. Results of modeling parts manufactured by hot forging: (a) results of modeling a part of the type “Bevel Gear”, (b) results of modeling a part of the type “Glass”, (c) results of modeling a part of the type “Crown nut”.](image)
5. Discussions
The mathematical dependencies obtained on the basis of the results of calculations of a wide range of forgings presented in Table 2 make it possible to determine the accuracy of the press selection. Given that the initial data in the design is often only the mass of forgings, these diagrams will allow you to lay the rest of the parameters. The appearance and accuracy of the graph shown in Fig. 8 is determined by the number of numerical experiments, the more data there is, the more accurate the shape of the curve. The data in Figure 8 show a high degree of adequacy of mathematical models used in the finite element analysis, especially for parts of relatively simple forms.

Table 2. Energy efficiency of hot forming processes.

| №  | Product name | Weight of forgings, kg | Estimated force, MN (tf) | Area surface blanks, mm² | Area surface forgings, mm² | Technological work, N·mm |
|----|--------------|------------------------|--------------------------|--------------------------|----------------------------|--------------------------|
| 1  | Coupling     | 0.19                   | 240                      | 3864.16                  | 24387.14                   | 3.14·10⁶                 |
| 2  | Puller       | 0.939                  | 450                      | 20725.01                 | 22008.52                   | 2.56·10⁷                 |
| 3  | Spider       | 1.756                  | 679                      | 29891.54                 | 35759.06                   | 2.14·10⁸                 |
| 4  | Nut          | 4.852                  | 304                      | 41363.07                 | 83199.28                   | 3.634·10⁸               |
| 5  | Glass        | 4.959                  | 1430                     | 44017.04                 | 95859.54                   | 1.4408·10⁸              |
| 6  | Pulley       | 10.78                  | 1990                     | 61462.03                 | 192070.4                   | 3.47·10⁸                |
| 7  | Rink         | 12.73                  | 3610                     | 74764.24                 | 200727.8                   | 9.26·10⁸                |

Figure 8. Functional dependences of power parameters: (a) function of the dependence of the press force on the mass of the forgings, (b) function of the change in electric motor power depending on the mass of the forgings, (c) function of the change in the press force depending on the power of the main electric motor, (d) function changes in the amount of technological work depending on the power of the main electric motor.
6. Conclusion
A further discrepancy with the experimental data can be justified by the fact that insufficient numerical experiments were carried out, and is also determined by the simulated scheme of the deformation process (the number of transitions and the degree of deformation). But focusing on the totality of the data presented, it is already possible to pre-select the press of the required technological effort in Figure 9.

![Figure 9](image)

Figure 9. Press KGS produced by OJSC Tyazhmehpress, Voronezh: (a) KA8538 6.3 MN (630 tf), (b) KD8040 10 MN (1000 tf), (c) KD8042 16 MN (1600 tf), (d) KD8042 16 MN (1600 tf), (e) KB8544A 25 MN (2500 tf).

References
[1] Autodesk (n.d.) Retrieved April 23 2020 from https://damassets.autodesk.net/content/dam/autodesk/www/products/simulation-composite-design/docs/pdfs/helius-nasa-coex-team-customer-story-en.pdf
[2] Shibaev P 2019 Professional communication in the scientific community is a factor in ensuring the quality of research. All-Russian Scientific and Practical Conference. Almetyevsk branch of Kazan National Research Technical University. A.N. Tupolev – KAI. (Moscow: Convert) pp 20-23
[3] Novokshchenov S 2006 In the collection: Innovative technologies and equipment of a machine-building complex. (Ed V M Pachevsky et al). Используйте «et al», Interuniversity collection of scientific papers. Federal Agency for Education, Voronezh State Technical University, Regional Board of Engineering NTO (Voronezh) pp 70-72
[4] Taloverov V and Titov Yu 2001 Equipment forging shops (Mechanical and hydraulic presses. Research methods): Textbook (Ed Yu N Berleta) (Ulyanovsk: UISTU) p 80
[5] Mikhailova N., Mikhailova O and Zavyalova G 2012 Production technology of blanks by the method of die forging: method. directions (Ekaterinburg: Publishing house of Ural State Transport University) p 46