COMPUTER MODELING AND INVESTIGATION OF THE DEFORMATION PROCESS IN CONVEX-CONCAVE AND TRAPEZOIDAL STRIKERS

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ABSTRACT

The article presents the results of a comparative analysis of the deformation process in convex-concave and trapezoidal strikers using computer modeling by the finite element method in the Deform program. In both designs, two variants are considered - with an equal and unequal ratio of the protrusion to the depression. For comparative analysis, equivalent stresses and strains, energy - power parameters are considered. Also, on the basis of computer modeling, the analysis of the microstructure evolution during the deformation in convex - concave and trapezoidal strikers was carried out. In the course of computer modeling, some advantage of the design of convex - concave strikers in comparison with trapezoidal strikers was proved.

Keywords: forging, strikers, modeling, finite element method, stress-strain state, grain size.

INTRODUCTION

When casting metal into molds in hardened ingots, various types of defects inevitably arise, such as: looseness, subcortical bubbles and captivity, and a number of other defects associated with both the casting process and the crystallization process of steel in molds. At the same time, the blacksmithing industry has always faced the task of obtaining high quality metal products in the form of forgings and blanks of various shapes with a fine grained structure evenly distributed throughout the volume and with welded internal defects with minimal energy consumption. At the same time, it has long been proven that using traditional forging technologies and tools for their implementation, it is possible to achieve the task only with a significant change in the initial dimensions of the ingot or billet, which leads to significant energy and labor costs [1]. It has also been proven for a long time that the successful solution of the task of a qualitative study of the cast metal structure with small changes in the initial dimensions of the workpiece (i.e. with a small forging), primarily based on the implementation in the forging process of additional alternating or shear strains in the entire volume of the deformable metal [2].

It is possible to achieve the implementation of additional alternating or shear strains in the entire volume of the deformed metal in the forging process in several ways, which include: torsion precipitation [3], deformation with an asymmetric load application [4], broaching of the workpiece in tools with complex movement of strikers [5 - 8] and many others [9 - 14]. Many of these methods, although they allow the development of additional alternating or shear strains in the deformation process, which make it possible to obtain forgings with a fine-grained structure, but many of them have a number of disadvantages. The main disadvantages are: high values of energy and labor costs; complexity of equipment design; complexity of implementation in practice; low productivity, etc. Therefore, the technologists of blacksmith shops give the greatest preference to such methods of implementing additional alternating or shear strains during forging, which are achieved by a simple change in the design of the working tool (strikers).

One of such methods is the technology of forging of rectangular cross-section billets and plates in trapezoidal strikers with the ratio of the trapezoidal protrusion to the depression equal to m/n = 1 and m/n < 1, where m is the length of the trapezoidal protrusion, n is the length of the trapezoidal depression (Fig. 1) [2]. This technology is very well proven in a practice, since this method of deformation during cyclic deformation allows to obtain rectangular blanks with a fine-grained structure and an increased level of mechanical properties with low energy consumption [2]. Unfortunately, this technology still had one small drawback that it was the appearance of dangerous stress concentrators at points 1 and 2. Thus, if the technological and geometric parameters of forging were chosen incorrectly (the human factor), it could lead not to an increase in the quality of the metal due to the implementation of significant shear strains, but to metal destruction. To eliminate this disadvantage, and in particular to eliminate the human factor to some extent, this technology has been improved, and for forging of rectangular cross-section billets and plates, convex-concave strikers have been proposed, which will avoid the appearance of dangerous stress concentrators.

In particular, convex-concave strikers were developed (Fig. 1) also with the ratio of the protrusion to the depression equal m/n = 1 and m/n < 1, the purpose of which was to improve the quality of the metal of the workpiece by localizing shear strains throughout the deformable body and avoiding the appearance of micro- and macro cracks in the metal [15, 16]. The technical result when using the proposed design of strikers for forging is achieved by the fact that the tool for broaching blanks of rectangular cross-section has an upper striker with a spherical protrusion, and a lower striker with a spherical depression.

This work is devoted to a comparative analysis of the deformation process in trapezoidal and convex-concave strikers. In addition, it is related to the evidence of the advantages of convex-concave strikers compared with trapezoidal strikers allowed to show that the application of convex-concave strikers allows to create a more favorable stress-strain state for obtaining in a deformable metal of a uniform fine grained structure without the danger of its destruction and with less deformation efforts.

To achieve this task, a computer simulation of the deformation process in trapezoidal and convex-concave strikers was carried out in a specialized DEFORM software package.

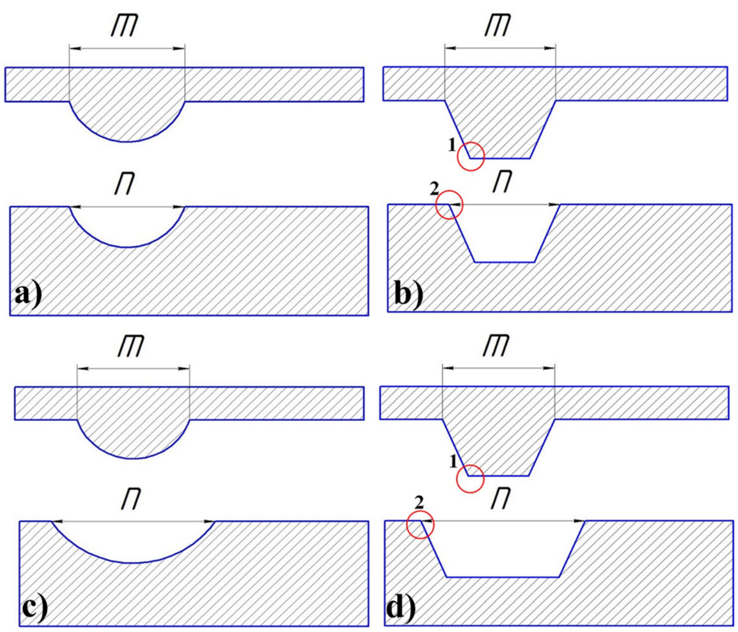

Fig. 1. Constructions of trapezoidal and convex-concave strikers: a - convex-concave strikers, m = n; b - trapezoidal strikers, m = n; c - convex-concave strikers, m < n; d - trapezoidal strikers, m < n.

EXPERIMENTAL

During the process of modeling, the following assumptions were made:

- the type of workpiece material was set as elastic-plastic, which allows more correctly simulating the flow of metal in real conditions; the type of strikers material was presented as a rigid body;
- AISI-1045 steel was chosen as the workpiece material;
- the deformation process was established as non-thermal, i. e. in addition to heat transfer to the tool, the workpiece also cooled in air in contact-free zones; the initial heating temperature of the workpiece was equal to 1100°C, the heat transfer coefficient from the workpiece to the tool was assumed to be equal to 5000 W m^{-2} deg^{-1}, which corresponds to the recommended data Deform for deformation models;
- the workpiece dimensions were 30 ´ 200 mm, a grid of 5000 finite elements with an equal aspect ratio was created on the workpiece (the length of the element face was 0.77 mm);
- the friction coefficient at the contact of the workpiece with the strikers was set to 0.3, as the average value for the polished surface;
- the movement speed of the upper striker was 1 mm s^{-1}
- during modeling, the condition was established that the calculation stops when a distance equal to the thickness of the workpiece of 30 mm is reached between the flat sections of the strikers;
- the initial grain size of AISI-1045 steel was assumed to be 80 microns.

The following parameters were selected as the parameters under consideration:

- components of the stress-strain state: equivalent stress and strain;
- deformation force;
- grain size.

RESULTS AND DISCUSSION

It was found that during the deformation process, the accumulation of equivalent strain occurs mainly on the side sections of the working surfaces. In strikers with a protrusion length equal to the length of the depression (m = n), the strain level is 0.786 in convex-concave strikers and 0.979 in trapezoidal strikers (Fig. 2(a-b)). At the same time, the widths of the deformation zones are quite different - in convex-concave strikers, these foci are wider, which is a consequence of the presence in each zone of only one corner on the lower striker. In trapezoidal strikers, two corners are present in each hearth, which significantly reduces the intensity of the metal flow.

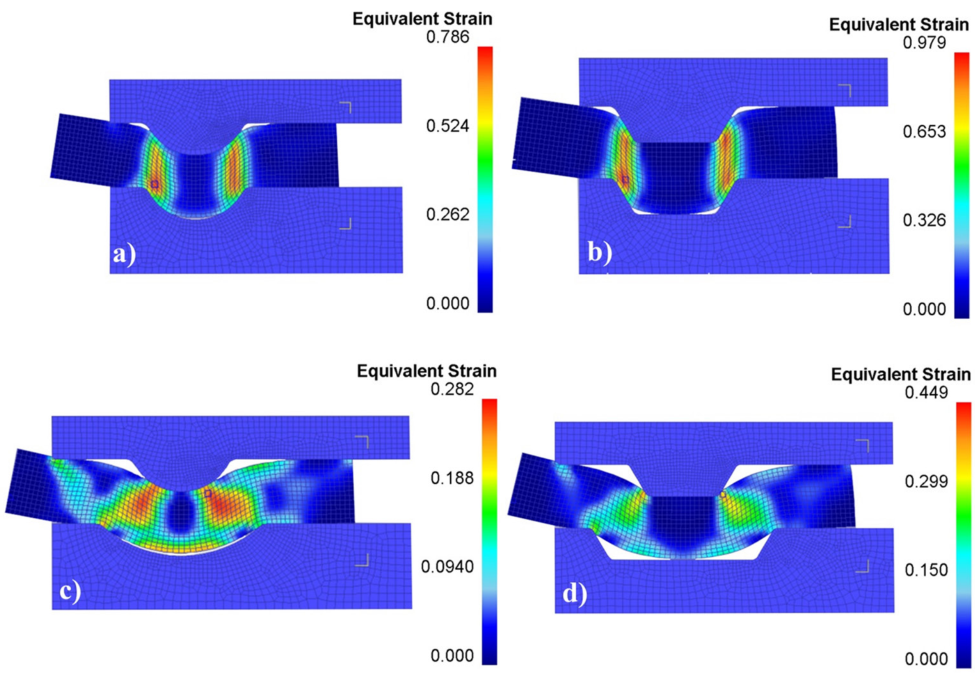

Fig. 2. Equivalent strain: a - convex-concave strikers, m = n; b - trapezoidal strikers, m = n; c - convex-concave strikers, m < n; d - trapezoidal strikers, m < n.

In strikers in which the length of the protrusion is less than the length of the depression (m < n), the strain level is 0.282 in convex-concave strikers and 0.449 in trapezoidal strikers (Fig. 2(c-d)). At the same time, the widths of the deformation zones become significantly larger than in strikers with an equal ratio of protrusion and depression - in these strikers, in both variants, the deformation zones cover almost the entire volume of metal located between the protrusion and the depression. Thus, the analysis of the deformed state showed that the deformation of the workpiece in convex-concave strikers proceeds with lower values of equivalent strain at the same level of compression compared to trapezoidal strikers. So, in the configuration of the strikers m = n, the difference in values is about 20 %, and in the case of m < n, the difference in values increases to about 37 %. At the same time, for each type of strikers, the strain level for the variant m = n exceeds by more than 2 times the strain level for m < n. This factor is explained by the fact that in both versions of the m = n type strikers on inclined sections, in addition to shear strain, a certain level of compression of the workpiece in thickness is realized, which, with further straightening of the workpiece on a flat section, will not allow to obtain the correct shape of the section.

Therefore, the optimal design is the strikers of type m < n, because, despite the fact that the strain value is less than in similar strikers with m = n, in this case, the workpiece is worked on almost the entire deformable area, and also is not subjected to additional compression in thickness.

The study of the behavior of the metal during its deformation is reduced to observing the inequality reflecting the strength condition, according to which the maximum stress should not exceed the permissible stress level:

$$\sigma_{EQV} \leq [\sigma], \quad (1)$$

where: σ_{EQV} - equivalent stress; [σ] - permissible stress.

In strikers with a protrusion length equal to the length of the depression (m = n), the level of equivalent stresses is 311 MPa in convex-concave strikers and 310 MPa in trapezoidal strikers (Fig. 3(a-b)). At the final stage of deformation, the value of equivalent stresses in convex-concave strikers becomes approximately the same as in trapezoidal strikers.

However, from Fig. 3, it can be seen that the concentration of maximum stresses in both versions of the strikers is different - in convex-concave strikers, maximum stresses are concentrated on the upper surface of the workpiece, and in trapezoidal strikers, maximum stresses are concentrated on all inclined faces of the workpiece.

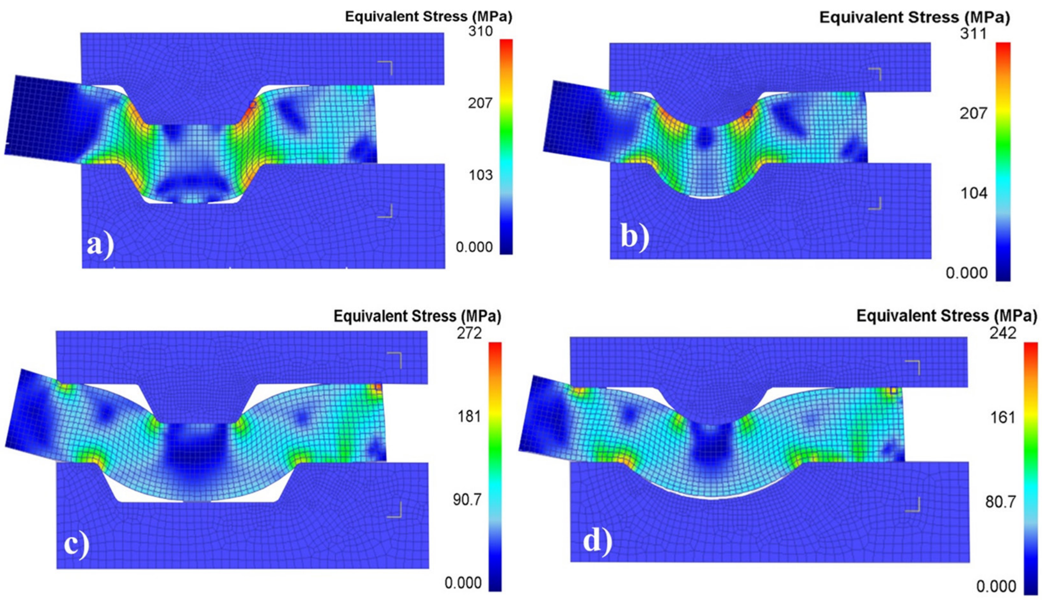

Fig. 3. Equivalent stress: a - convex-concave strikers, m = n; b - trapezoidal strikers, m = n; c - convex-concave strikers, m < n; d - trapezoidal strikers, m < n.

In strikers in which the length of the protrusion is less than the length of the depression (m < n), the level of equivalent stresses is significantly lower and amounts to 242 MPa in convex-concave strikers and 272 MPa in trapezoidal strikers (Fig. 3(c-d)). The reduction of the stress level in these blocks is a consequence of the absence of additional compression in thickness on inclined sections, which makes it possible to almost completely eliminate the occurrence of stress concentrators.

Analyzing the distribution of equivalent stress in different designs of convex-concave and trapezoidal strikers, the following conclusions can be drawn:

1) the highest values of equivalent stress are formed during deformation in trapezoidal strikers of both variants;

2) the maximum permissible value of the tensile strength for AISI-1045 steel is [σ] = 610 MPa. The values closest to this value throughout the deformation were the values during deformation in trapezoidal strikers. As a result, it can be said that the metal deformed in trapezoidal strikers is more susceptible to destruction than in convex-concave strikers.

The most important characteristic of the study when deforming workpieces in various tools is the study of energy-power parameters. The less energy the tool expends during deformation, the less time spent on deformation, and, consequently, the productivity is higher. It is very important that with a high quality study of the workpiece, the effort developed in the tool has a minimum value. The values of the developed force in trapezoidal and convex-concave strikers obtained during computer modeling show that the force developed by convex-concave strikers of any design (m = n, m < n) throughout the deformation cycle is less than when deformed in trapezoidal strikers.

The Cellular Automata 2.0 mechanism, introduced in the 13th version of Deform, was used to calculate the microstructure evolution. It improved the mechanism for calculating the shape of grains during deformation. The key parameters of this algorithm are the input of model constants, the values of which depend on the nature of the material. Table 1 shows the values of these constants for aluminum, nickel and steel. These constants are discussed in detail in [17 - 18].

The calculation essence of the microstructure evolution by this method is the use of a ready, calculated model. Calculation windows with a certain resolution are installed at the selected points, in which a change in both the grain size and their shape is observed. Taking into account that the initial grain size was set to 80 microns, a square window with a face size of 200 microns was selected.

Analysis of the results of computer modeling of the microstructure evolution of AISI-1045 steel showed that, both in trapezoidal and convex-concave strikers, there is a significant decrease in the size of the initial grain with an increase in the deformation cycles. But when comparing the changes in the microstructure of deformed metal in trapezoidal and convex-concave strikers, the advantage of trapezoidal strikers is obvious, since when using them, the metal structure evolves more intensively. Thus, when using trapezoidal strikers with m = n, the average grain size after 3 deformation cycles was 22 microns, trapezoidal strikers with m < n, the average grain size is 28 microns, in convex-concave strikers with m = n, the average grain size is 25, and with m < n is 33 microns (Fig. 4).

As can be seen from these results, in both cases there is a better processing of the initial structure when using trapezoidal and convex-concave strikers with m < n, compared to these strikers with m = n. At the same time, the best result of processing of the initial structure is observed when using trapezoidal strikers with m = n, and the least intensive change in the grain size of the initial workpiece is observed when using strikers with

Table 1. Constants of the Cellular Automata 2.0 model.

Material	ρ	ε_0	r_0	Q	K	h_0	m
Aluminum	0.01	1	2000	155000	6030	0.75	0.2
Nickel	0.04	1	1900	100000	85	0.75	0.2
Steel	0.01	1	7087	266616	6030	0.75	0.2

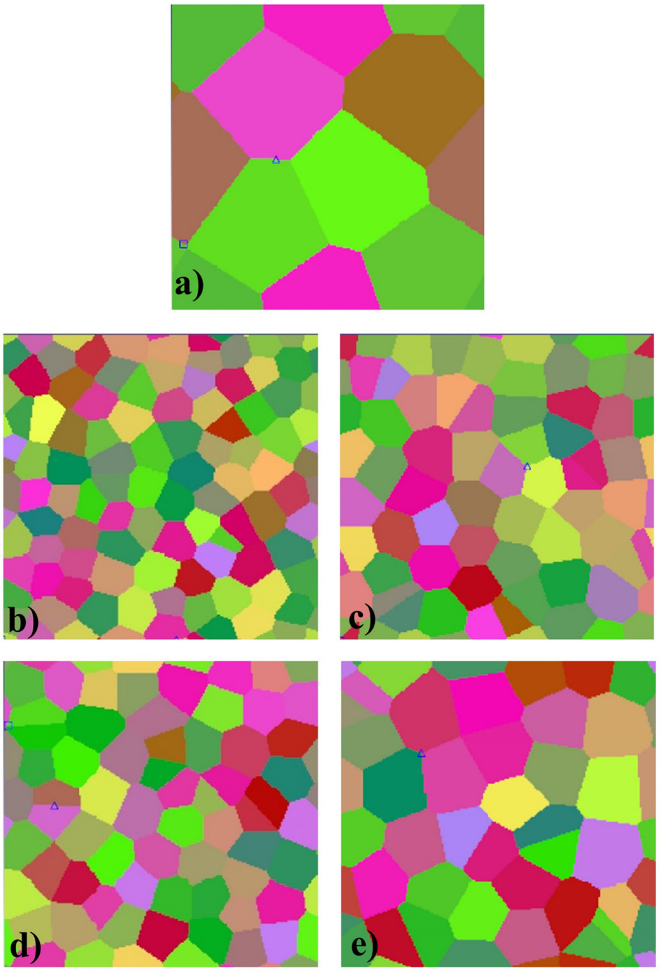

Fig. 4. Microstructure evolution: a - initial structure; b - after 3 cycles of forging in trapezoidal strikers, m = n; c - after 3 cycles of forging in trapezoidal strikers, m < n; d - after 3 cycles of forging in convex-concave strikers, m = n; e - after 3 cycles of forging in convex-concave strikers, m < n.

a convex-concave surface with a ratio of m /n < 1. But at the same time, the smallest change in the size of the initial blank, on the contrary, is observed precisely when using strikers with a convex-concave surface with a ratio m/n < 1, and the largest change in the initial blank was observed in trapezoidal strikers with m = n.

CONCLUSIONS

Analyzing the obtained results of computer modeling, we can draw the following conclusion: that when choosing a forging tool, i.e. trapezoidal or convex-concave strikers, for forging forgings of the type of plates and plates having a fine-grained structure, it is necessary to take into account the fact that when using convex-concave strikers, despite the lower level of metal processing, more favorable stress-strain state and there are no concentrators of dangerous stresses that occur when deforming workpieces in trapezoidal strikers. In addition, an additional advantage of convex-concave strikers is a wider deformation distribution zone, a smaller change in the initial dimensions of the workpiece, as well as a lower value of the developed deformation force.

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