Study of the microstructure evolution during forging in a new design strikers implementing alternating deformation by finite element method

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Abstract: *The study of the microstructure evolution during forging in a new design strikers implementing alternating deformation based on computer modeling by the finite element method was carried out. The influence of the flat face inclination angle was studied, for which models with an inclination angle of 0, 15, 30 and 45 degrees were studied. It was established that the most optimal option is the use of strikers with an angle of 30°. On this strikers configuration the influence of the workpiece heating temperatures and the punch movement speeds was studied. The analysis of these technological parameters on the microstructure evolution showed that both parameters affect the structure grinding intensity, while the influence of the heating temperature is more significant.*
KEYWORDS: *FORGING, BROACHING, SHEAR DEFORMATION, COMPUTER MODELING, MICROSTRUCTURE EVOLUTION.*

1. Introduction

In traditional metal forming operations, to improve the metal quality by grinding the structure to a fine-grained state, it is necessary to significantly change the workpiece sizes, which leads to significant energy and labor costs. However, it is often necessary to obtain a blank, the dimensions of which differ slightly from the initial one. The implementation of these two principles in practice is possible due to the intensification of shear and alternating deformations [1]. At the same time, for a high-quality processing of the initial structure, it is necessary to ensure such a technological process of deformation that sufficient shear or alternating deformation occurs in the entire deformable volume [2]. Currently, to solve this problem, a number of new forging processes and tools for their implementation have been developed [3-7], which allow implementing a high level of shear or alternating deformations.

In the work [8] the technology of broaching in lock strikers was developed and studied, which allows to realize intensive shear deformation over the entire volume of metal, and a forging tool for its implementation was proposed. This technology showed very good results, which consisted in improving the quality of the metal of forgings [9]. But this technology has its own small drawbacks - this technology is mainly applicable for forgings of only rectangular cross-section, and there are concentrators of tensile stresses due to the angles in this design.

Therefore this tool has been improved so that it is possible to use it for round forgings and to avoid the occurrence of even small concentrators of tensile stresses. At the same time, the design of this tool (Fig. 1) will allow for more significant alternating deformations over the entire volume of the deformed workpiece.

The purpose of this work is to study the influence of the faces inclination angle of the strikers shown in Figure 1, as well as kinematic and temperature factors on the microstructure evolution.

2. Computer simulation

Computer simulation of the forging process with an additional macroshift was carried out using the Deform software package. 5HV2S steel was chosen as the billet material. The initial billet had a diameter of 45 mm. The deformation was carried out at a temperature of 1000 °C. A non-isothermal calculation type was set for the simulation. The vertical speed of the upper striker was 1 mm/sec. When the workpiece came into contact with the strikers, the value of the friction coefficient was set to 0.25. An absolute tetrahedral grid was built on the blank, condensed on the surface for better rendering of the round shape. The minimum size of the element was set to 0.3 mm, the maximum size of the element was set to 0.6 mm, the parameters for the grid remesing were set by default.

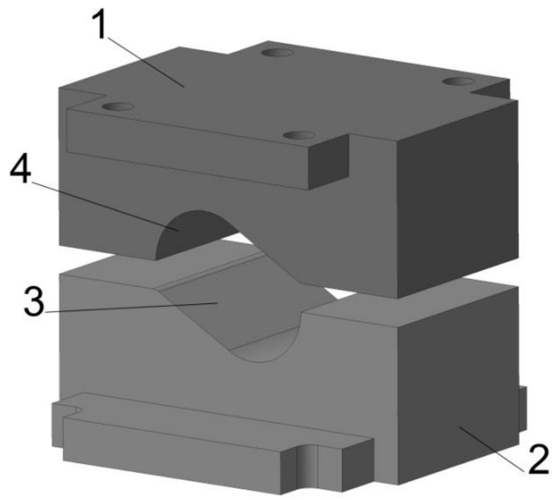
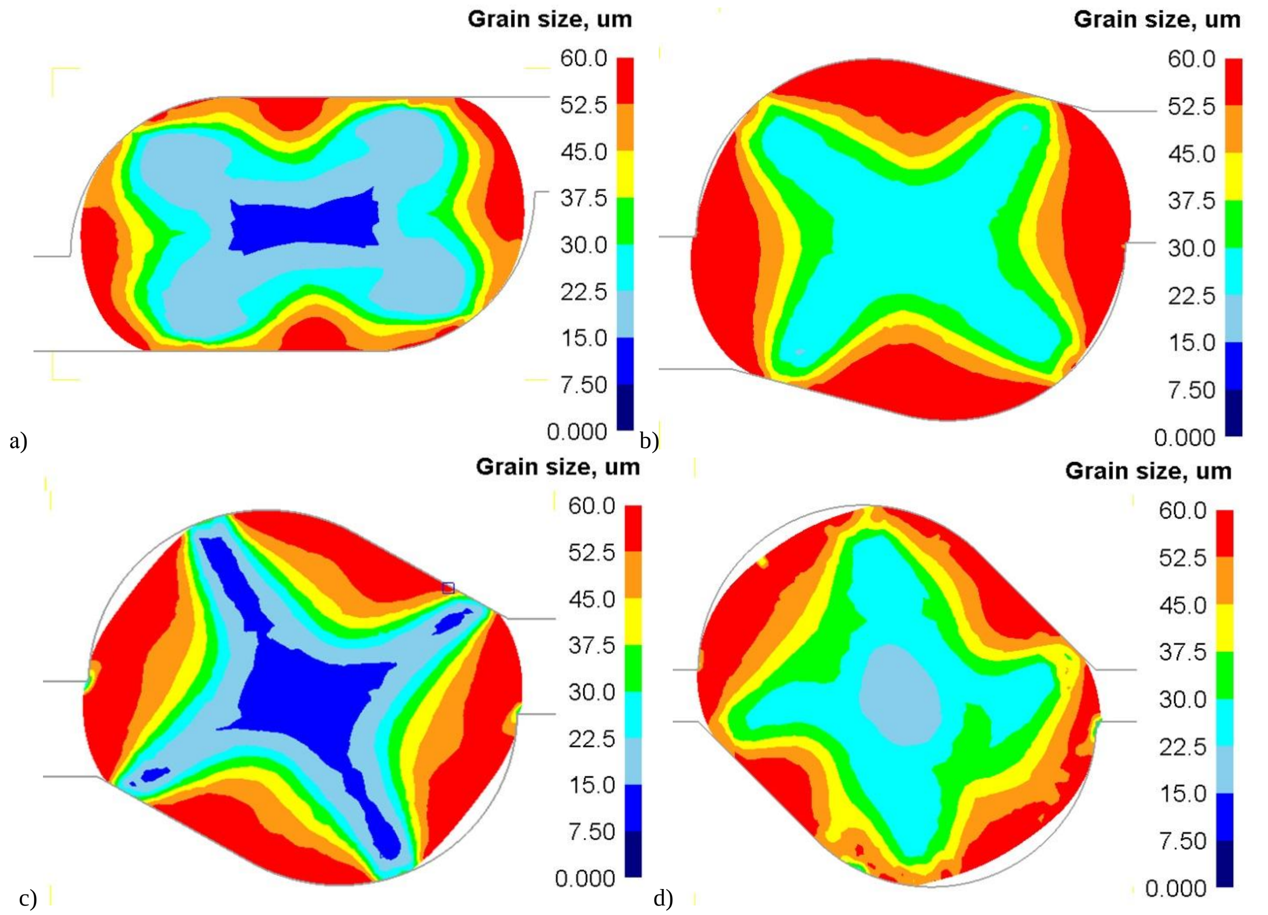


Figure 1 *- Tool for broaching: 1 – upper striker; 2 - lower striker; 3 - flat working surface of the striker; 4 - working surface of the striker, made in the form of a circle segment*

During computer modeling, the influence of the flat face inclination angle, as well as kinematic and temperature factors on the microstructure change was studied. The value of 60 microns was taken as the initial grain size. 4 deformation cycles were carried out with the workpiece turning at 90° after each compression. When analyzing each model, the study of the selected parameters was carried out on the last cycle.

First, the influence of the flat face inclination angle was studied. For this purpose, models with an inclination angle of 0, 15, 30 and 45 degrees were built. In order to identify the most rational strikers design, it is necessary to introduce a criterion of optimal values. The following criterion for grain size was adopted - "less is better".



a – 0°; b – 15°; c – 30°; d – 45°

Figure 2 – Grain size change in strikers with different inclination angles of a flat face

The analysis of the microstructure evolution (Figure 2) showed that in all variants the grain grinding area covers most of the cross-section of the workpiece. At the same time, the initial grain is crushed most intensively in strikers with flat face inclination angle of 0° (11 microns) and 30° (13 microns). Based on the accepted optimality criterion of the grain size "less is better", the following sequence was identified in descending order: 15° → 45° → 30° → 0°.

Thus, the most optimal option would be to use strikers with an angle of 30°, since in this case there is a fairly extensive distribution of strain across the cross-section in the workpiece (the second in terms of cross-section coverage after strikers with an angle of 0°) with a significantly lower deformation force [10]. The result is the second most intense level of grain grinding.

For further analysis of the influence of the technological parameters in the new strikers on the microstructure evolution, it was decided to use strikers with an inclination angle of flat faces of 30°. The temperature of metal heating and the speed of the punch movement were chosen as variable parameters, since the values of these parmeters are easy to change in real conditions. The resulting model is shown in Figure 6b at a temperature of 1000 °C and the upper striker speed of 1 mm/s was taken as the base model. As a result, to study the influence of the technological parameters in new strikers on the microstructure evolution, the following models were additionally constructed:

- with heating temperatures of the workpiece up to 1200 °C and up to 800 °C;
- with upper striker speeds of 0.1 mm/s and 10 mm/s.

Figure 3 shows the results of calculating the change in grain size for various technological parameters. When considering models with different values of the heating temperature (Figure 3 b-c), it was found that this parameter has a very significant effect on the grinding intensity of the structure. When the heating temperature increases to 1200 °C, the grain grinding intensity decreases significantly, which is the result of an increase of static and dynamic recrystallization. When the heating temperature decreases to 800 °C, on the contrary, the intensity of structure grinding increases significantly. This is due to the fact that for steel 5HV2S, the temperature of the beginning of recrystallization is 775 °C (point AC1). Heated to 800 °C, the workpiece gradually cools down, bypassing the AC1 point, as a result, the recrystallization processes are completely suppressed.

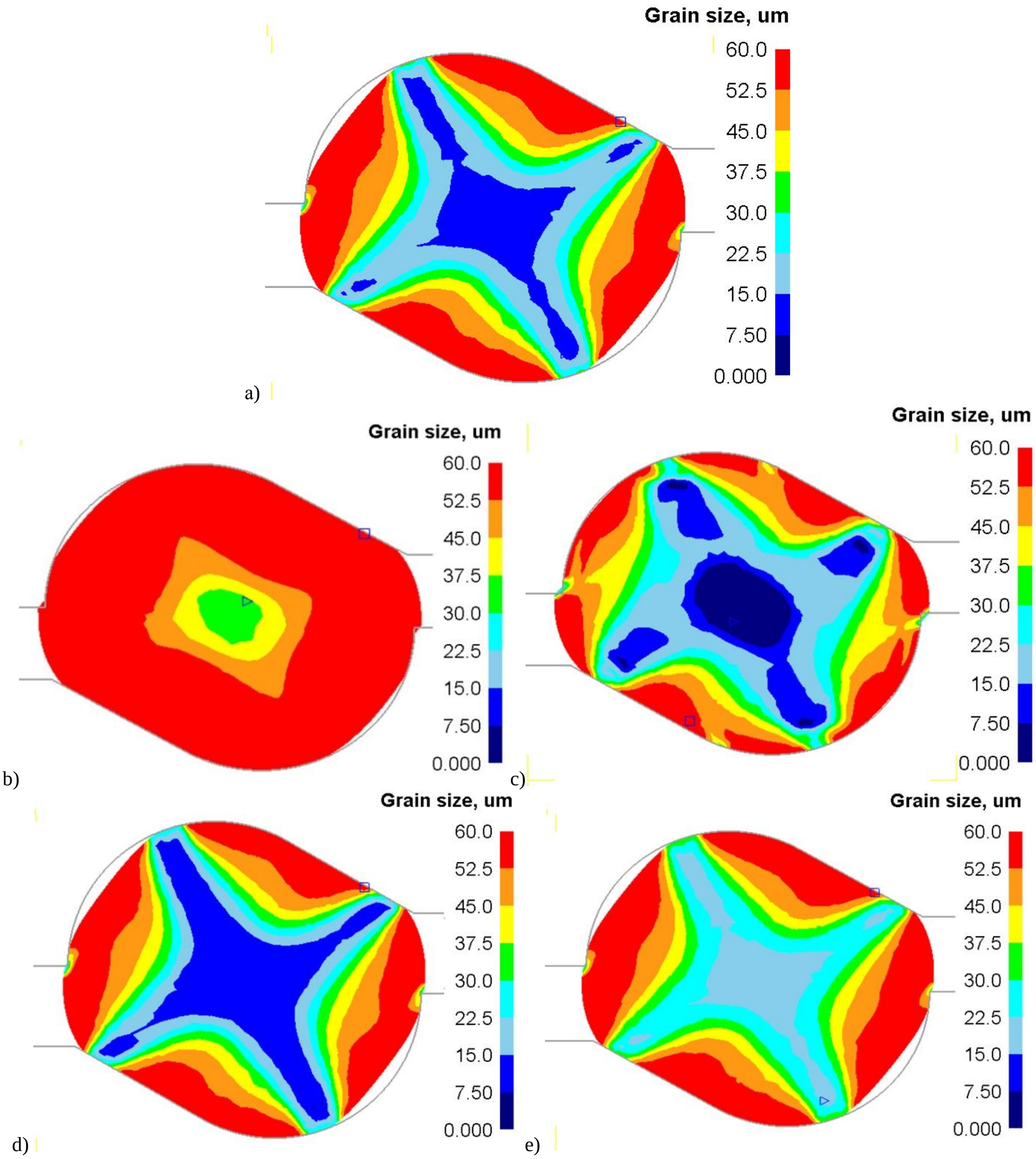
When considering models with different values of the upper striker speed, it was found that this parameter affects the intensity of structure grinding, although not as significant as the heating temperature. When the upper striker speed increases to 10 mm/s, the intensity of grain grinding decreases, and when the upper striker speed decreases to 0.1 mm/s, the intensity of structure grinding increases. This phenomenon is also associated with recrystallization processes. The recrystallization intensity depends on the workpiece temperature, the intensity of change of which depends on the strain rate. At a reduced upper striker speed, the total duration of the deformation process increases. As a result, the workpiece has time to cool down more, which affects the level of grain grinding. At an increased strain rate, the intensity of cooling of the workpiece decreases, which leads to a decrease in the level of grain grinding.

Based on the data obtained, the most optimal conditions from the point of view of the final grain size are the heating temperature 800 °C and the upper striker speed 0.1 mm/s. However, in order to approve these parameters, it is necessary to evaluate the resulting deformation forces in the models under consideration, since this parameter is critical at the stage of implementation of the developed technology. Summary data on grain size and deformation force are presented in Table 2.

It can be seen that despite the minimum grain size obtained, the option of lowering the heating temperature of the workpiece to 800 °C is not optimal, since in this case, due to cooling and lowering the plasticity of the metal, the force level increases almost 2.5 times compared to the basic level. At the same time, all three options for the upper striker speed can be recommended for the implementation of this process in practice. The key factor in choosing the speed here will be the rated power of the pressing equipment. With a sufficient margin of safety, it is desirable to conduct the deformation process at reduced deformation rates, which will lead to additional grinding of the initial grain.

Table 2 *- Grain size and deformation force in models with different technological parameters*

	Base model	1200 °C	800 °C	0,1 mm/s	10 mm/s
Grain size	13 μm	36 μm	6 μm	10 μm	19 μm
Force	202 kN	164 kN	495 kN	278 kN	185 kN



a - base model; b – at 1200 °C; c – at 800 °C; d – at 0,1 mm/s; e – at 10 mm/s
Figure 3 *- Grain size change in models with different technological parameters*

Conclusion

The paper presents the results of computer modeling of the microstructure evolution during forging of round-section blanks in new design strikers. The analysis of models with different inclination angles of flat faces showed that the most optimal option is to use strikers with an angle of 30°. The analysis of the influence of technological parameters on the microstructure evolution showed that both parameters (upper striker speed and heating temperature) affect the structure grinding intensity, while the influence of the heating temperature is more significant. The most optimal heating temperature of the workpiece in terms of grain size and the resulting force is the base value of 1000 °C, while all three options for the speed of movement of the punch can be recommended for the implementation of this process in practice.

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