Theoretical study of a new forging technology with additional macroshift using fem simulation in deform

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Abstract. In this paper the finite element method is used to simulate the process of forging round-section blanks in strikers of a new design. It is shown that the use of a radial joint of the faces has a positive influence on the hydrostatic pressure distribution along the entire length of the metal-tool contact. The comparative research of models with various values of flat zones inclination angles showed that the best variant is the tool with an angle value 30°. In this case a deep strain distribution over the cross section occurs in the billet with a significantly lower deformation force than when using tool with an angle value 0°. The simulation of the sequence of technological forging operations was also carried out. Two first compressions were performed with the workpiece turning at 90° to close possible internal defects. Then the angle of the turning is lowered to 45° and 30° in order to bring the cross-section shape closer to the round one.

1. Introduction

Despite the rapid development of metallurgical processes for the production of semi-finished products aimed at improving the modes of smelting, casting and crystallization, a significant improvement in the properties of any cast metal, ensuring its wide application in modern mechanical engineering, is achieved by hot metal forming. The main arguments for the use of hot metal forming, namely forging, are: giving the metal the necessary shape and dimensions as close as possible to the configuration and dimensions of the part with the least labor costs; eliminating defects in the cast structure; improving the quality of the metal by converting the cast structure into a deformed one; distribution of the properties of the metal in the volume of forging and workpiece according to the law that satisfies the operation of this part at the manufacturing stage by plastic deformation.

In classic metal forming methods, it is required to seriously change the billet size to improve the metal quality by structure grinding to a fine-grained state, which leads to large power and labor expenses. The technical solution of these problems is based on the implementation of shear and alternating deformations [1]. Therefore, in order to process the cast structure to obtain a high-quality metal with a homogeneous or directionally textured fine-grained structure in the whole billet volume, it is required to create the technological deformation process that significant shear and alternating deformations occur in the entire deforming volume [2]. Previously, this was most often achieved by increasing the total compression of the ingot or the initial billet. Now a number of new deformation processes and equipment for their realization have been produced [3-11], where additional shear or alternating deformations in addition to the usual compression during the deformation process occur.

Authors of paper [12] describe the forging technology, that allows to implement severe shear strain over the entire volume of billet metal, and also lock strikers as an equipment for this technology realization (figure 1,a). That deformation method showed positive results, the quality of forgings was improved by obtaining a more uniform and fine-grained structure and better welding of internal defects when forging in this tool compared to forging using the current technology in flat strikers. At the same time, this effect is achieved with a smaller forge coefficient, which allows reducing energy consumption for the production of high-quality forgings [13]. But at the same time, this technology has its own small drawbacks, and one of them is that this deformation method is applicable for forging of billets with square or rectangular cross-sections and due to the angles available in this design, small concentrators of additional tensile stresses still appeared.

With this purpose, described forging die was modificated to use it for round billets forging, and to remove the local zones of tensile stresses. The construction of this tool (figure 1,b) will allow to realize more significant alternating strains throughout the whole volume of billet.

a) b)

Figure 1. Tools for broaching: a – with an angular joint; b – with a radial joint.

The aim of this research is to investigate the influence of geometric factors (construction shape of a new forging tool, as well as the inclination angle of the striker faces shown in figure 1 on the stress-strain state of the metal.

2. FEM-modelling of forging process

FEM-modelling of the deformation process in Deform software was conducted. AISI-1035 steel was set as the workpiece material. The initial billet was round workpiece with diameter value 45 mm. The forging process was conducted at a temperature of 1200 °C with non-isothermal calculation. The vertical velocity of upper tool was 1 mm/sec. The friction coefficient value was set to 0.25 at the contact of billet and forging tools. A tetrahedral grid was created on the billet. The sizes of mesh elements were at range 0.3-0.6 mm, the grid remesing parameters were set by default.

At the first stage of simulation, the stress state was compared when using the striker constructions shown in figure 1, during which the influence of the joint shape of the internal faces was studied. It was found that when using strikers with an angular joint (figure 2), a region of tensile stresses of up to 80 MPa occurs in this zone. This effect is negative from the point of view of further deformation with the edging of the workpiece. The highest values of tensile stresses occur in the lateral zones, where there is no contact with the strikers and barrel formation occurs. When the workpiece is edged at 90°, these areas become in contact with the strikers and then large compressive stresses are created here, which annihilate the negative effect of the stretching action. But the considered metal zones from the area of angular joints after edging become contactless. As a result, tensile stresses also occur here during the subsequent deformation cycles. Therefore, these areas are potentially dangerous from the point of view of the occurrence of surface cracks.

The proposed design of the strikers (figure 2) creates a more uniform stress state over the entire length of the contact surface due to the radial joint of the faces. It is clearly seen that no areas of tensile stresses arise in this case, and the general level of the stress state is characterized by the action of only compressive stresses in the range of -90÷-100 MPa.

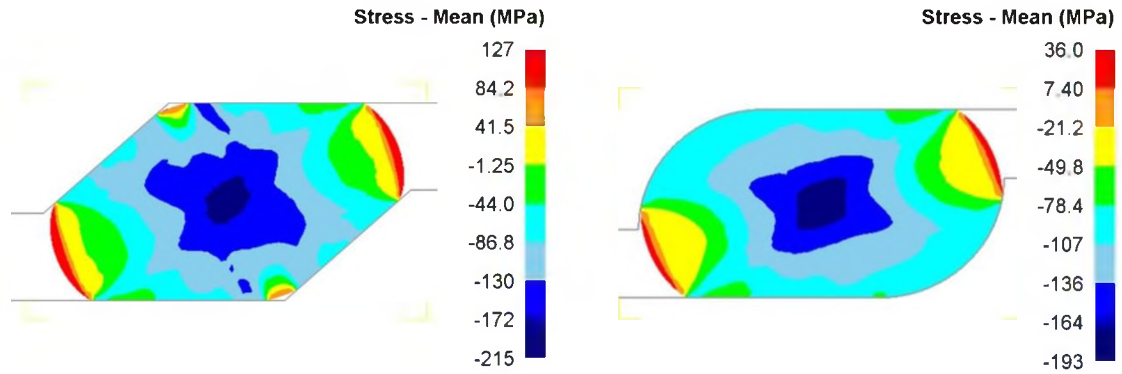

Figure 2. Average hydrostatic pressure in strikers with different types of joints: a – with an angular joint; b – with a radial joint.

At the same time, it is necessary to note another important distinguishing feature of these two constructions. In both cases, symmetrically arranged non-contact zones are formed at the deformable workpiece, where tensile stresses prevail. However, due to the change of the angular joint of the faces to a radial, the level of tensile stresses is significantly reduced from 120 to 35 MPa. This is a consequence of the change in the nature of the metal flow in these lateral areas. In both cases, the inclined faces of the strikers create a certain level of backpressure, which increases with an increase in the amount of compression. But if in strikers with an angular joint the increase in backpressure is linear, then in strikers with a radial joint it has a continuous increase until the metal touches the area of the striker that characterizes the horizontal position of the radius of rounding – here the amount of backpressure is the maximum possible.

Based on this comparative analysis, it was concluded that it is advisable to use strikers with a radial joint of the faces. Further, the influence of the inclination angle of a flat face on the stress-strain state was investigated. For this purpose, additional FEM-models with various values of inclination angle (15°, 30°, 45°) were created. Each model was calculated for 4 deformation passes with the billet turning at 90° after each pass.

It was decided to choose an equivalent strain as the studied parameter, since this characteristic of the strain state allows to assess the level of metal processing. The resulting deformation force was also considered. For analyzing these parameters, the consideration of models was conducted at the last pass.

The analysis of the equivalent strain (figure 3) showed that in all cases the highest level of strain occurs in the central part of the workpiece ($\varepsilon \approx 4.5$), and the nature of the strain distribution has the form of a forging cross. At the same time, it is noted that the most intense level of strain develops in the tool with an inclination angle of a flat face of 0°, covering almost whole cross-section of billet. This is a consequence of the action of normal stresses perpendicular to the movement of the punch over a sufficiently large length of metal contact with the strikers. As the angle increases, the level of normal stresses decreases, which, theoretically, should lead to a decrease in the deformation force. At an angle of 15°, the zones of strain development are the narrowest, an angle of 30° gives a picture of the strain distribution similar to strikers with an angle of 0°. An increase in the angle to 45° leads to a concentration of strain mainly in the central zone of the workpiece, significantly reducing it in the surface areas.

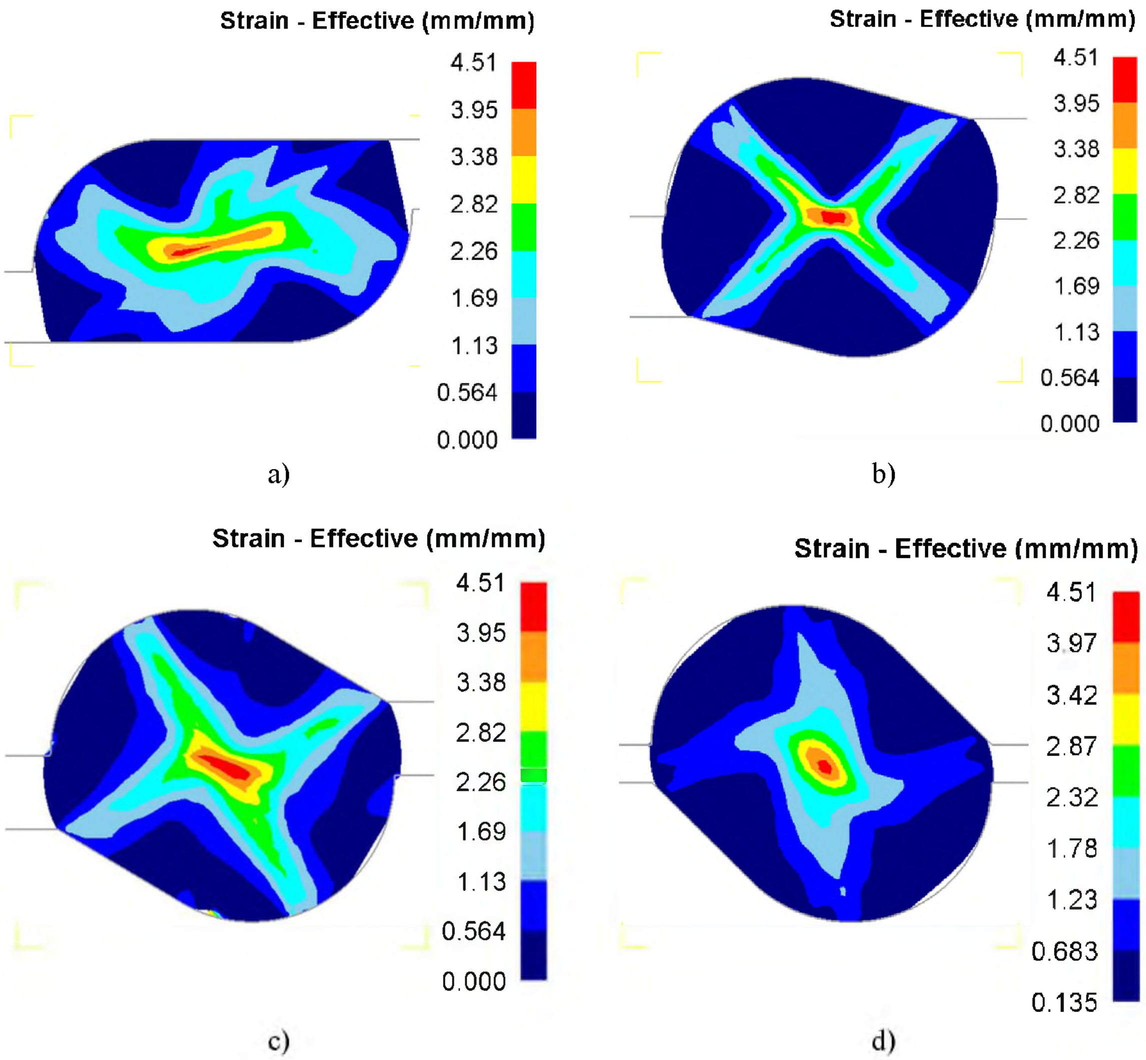

Figure 3. Equivalent strain: a – 0°; b – 15°; c – 30°; d – 45°.

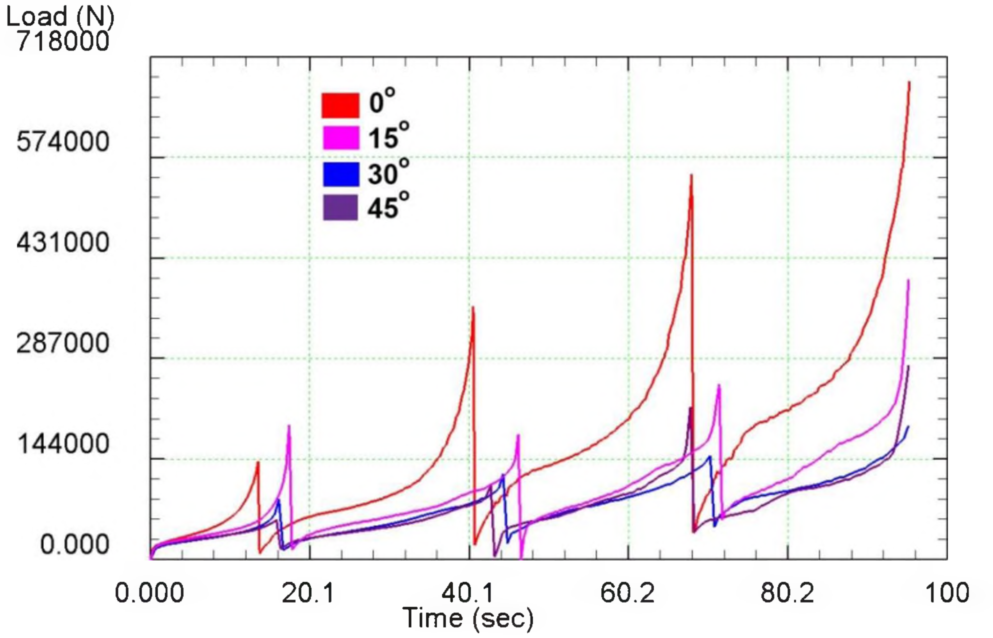

Figure 4. Deformation force.

The obtained graphs of the deformation forces (figure 4) confirm the previously stated hypothesis – the greatest values of the force occur when deforming in strikers with an angle of 0°, with an increase in the angle of inclination of the flat faces, the force decreases from 710 kN to 150 kN. So, the most rational variant is the tool with an angle value 30°, since in these strikers an enough deep strain distribution across the billet cross-section occurs (the second place after tool with an angle value 0°) with a lower deformation load.

3. Forging technology in a new tool

The strikers design considered in figure 1 with inclined faces will allow creating a favorable stress-strain state in the metal to obtain high-quality forgings with a fine-grained structure and without internal defects. However, for the practical application of these strikers, it is necessary to develop a forging technology.

When implementing the broaching operation, the workpiece undergoes the following shape changes: the cross-section over the area decreases, and the length increases. Moreover, often after broaching, the workpiece must have the same cross-sectional shape as before deformation. This is made possible by intermediate turning operations, i.e., turning the workpiece around the deformation axis. In this way, depending on the angle of the turning, you can get a square, a rectangle, a polygon, and even a circle. As shown by the studies of the stress-strain state of the metal carried out in this work, the most rational variant is strikers with an inclination angle 30°. Therefore, it was decided to use this particular design of strikers to develop a broaching technology, the ultimate goal of which will be to obtain a blank with a circular cross-section.

Initially, the workpiece must be compressed to close possible internal defects. From simulation results in [14] it is shown that one pass is quite enough for this. Then it is necessary to turn the workpiece by 90° and compress the workpiece again (figure 5).

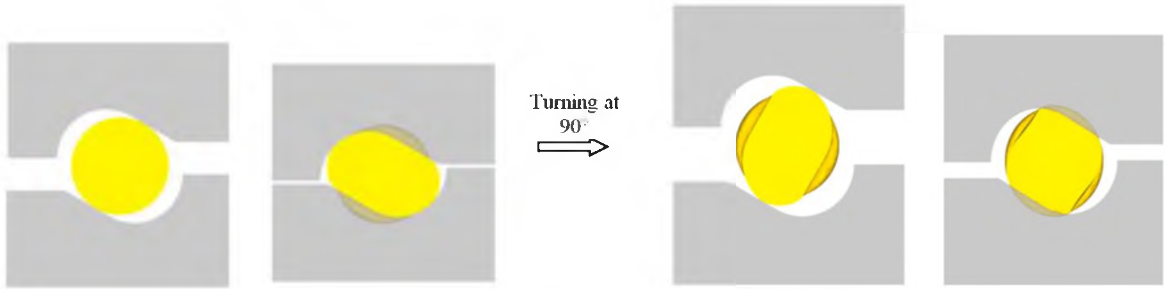

Figure 5. Forging scheme in strikers of a new design.

Next, it is necessary to lower the angle of the turning in order to bring the cross-section shape closer to the round one. For this, an alternating system of compression and turning at 45° is used, in the result an octagon shape is obtained. After that, the turning angle is reduced to 30° and also series of compressions with alternating turns is conducted. As a result, a blank with a cross-section shape that is close to a circle is obtained (figure 6).

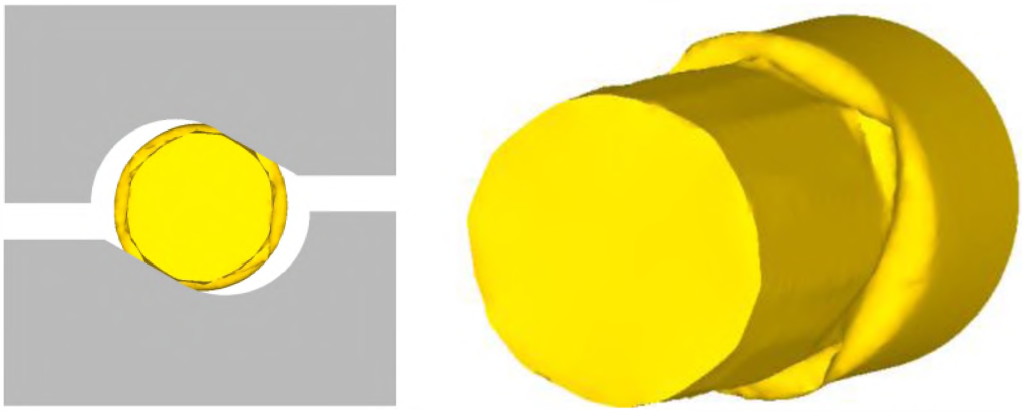

Figure 6. The shape of the workpiece after forging in the strikers of the new design.

4. Conclusion

The paper describes the FEM-simulation of forging process of round billets in the strikers of a new design. It is shown that the use of a radial joint of the faces has a favorable effect on the distribution of stresses along the entire length of the metal contact with the tool. The comparative research of models with various values of flat zones inclination angles showed that the best variant is the tool with an angle value 30°. In this case a deep strain distribution over the cross section occurs in the billet with a significantly lower deformation force than when using tool with an angle value 0°.

Acknowledgments

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