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MODELING STAMPING TO DETERMINE THE IMPACT ENERGY OF THE HAMMER AND THE LOCATIONS WHERE DEFECTS FORM

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The operation of stamping is modeled in the software suite DEFORM-3D to determine the impact energy required of the hammer to completely fill the die in a single impact. The flow of the metal during stamping is analyzed and the probability of defect formation is estimated.
Keywords: *high-speed stamping, impact energy, modeling, DEFORM-3D, metal flow, formation of defects.*

Machinery manufacturers are finding it increasingly necessary to make new products of complex geometric form [1, 2]. In preparing to make such products, the manufacturers are realizing that they cannot rely on the existing reference literature to accurately determine the optimum parameters for the production process [3]. The use of computer-aided engineering (CAE) makes it possible to determine the locations where defects form in products, account for aspects of stamping operations that may adversely affect product quality, and reduce the amounts of time and money spent on preparatory tasks [4–6].

This article reports results obtained from numerically modeling high-speed stamping to obtain a “nozzle” part. Stamping regimes and the necessary deformation energy are determined and a quantitative estimate is made of the probability of the formation of defects. To obtain the required data, we designed the part that was to be made, the equipment for making it, and the stamping process in the program DEFORM-3D.

The stamped nozzle-like part is a cylindrical body with six external fins and two blind conical holes at both ends (Fig. 1*b*). The characteristics of the stamping: the material – tin-free silicon-bearing bronze BrKN1-3; weight 13.6 kg; volume 1625 cm^3; diameter 113 mm; height 177.5 mm.

One of the main challenges encountered in making such stampings is obtaining tall fins. The stamping operation needs to be carried out with a single impact, since the semifinished product cools quickly due to the rapid removal of heat from its lateral surface. Crimps and “channels” can form at the fins’ butt joints during the forming operation, and the die cavities that form the fins may not be completely filled with metal. Both the equipment used to make the stamped product and the product itself were first designed in the program Siemens NX. One distinctive feature of the equipment is the presence of six die sections. These sections are removed from the platen of the hammer stamp by the drive of the bottom pusher. Figure 2 presents a model of the equipment. The STL format was used to export models of the equipment from the program Siemens NX to DEFORM-3D. The different sections of the die were joined together and the structural elements smaller than 1 mm (bevels, rounded edges, etc.) were removed before the models were exported, which did not affect the results obtained by the modeling operation.

The following initial data was adopted in using DEFORM-3D to perform calculations for the high-speed stamping operation:

1. The initial semifinished product was a three-dimensional model of a bar having a diameter of 110 mm and a length L =171 mm.

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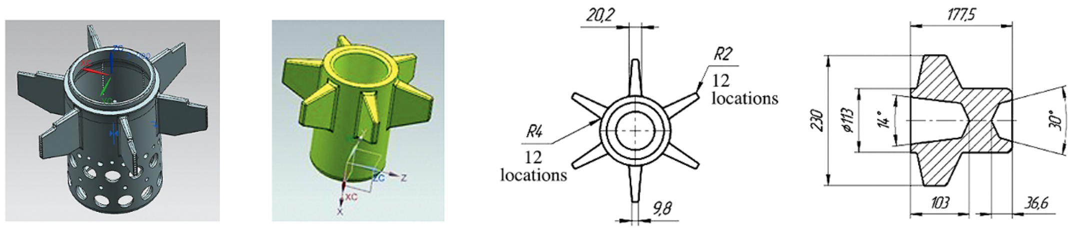
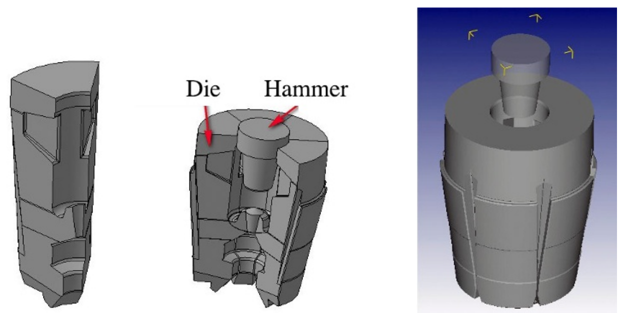


a *b* *c*

Fig. 1. Nozzle part (*a*), model (*b*), and drawing (*c*) of the stamping.



a *b* *c*

Fig. 2. Models of the equipment: *a*) section of the die; *b*) die in assembled form; *c*) die with the sections joined together into one unit (for modeling in the program DEFORM-3D).

2. The semifinished product was subdivided into 70000 finite elements in the DEFORM program (in accordance with the recommendations of the developer of the program).

3. The semifinished product was specified as being an object of the "plate" type, and its elastic deformation was not taken into account.

4. The material of the semifinished product was CuNi2Si (the analog of the material BrKN1-3).

5. The temperature of the semifinished product was 930°C.

6. The tool was specified as being a rigid body in light of the small elastic displacement of the tool's surface relative to the tolerance for the stamping operation and the fact that the sections of the die were rigidly fastened inside a massive casing. Flow of metal into the gap between the sections was ignored.

7. The tool was subdivided into 20000 finite elements in DEFORM (in accordance with the developer's recommendations).

8. The temperature of the tool was 200°C.

9. The material of the tool was SKD61 (the analogous Russian-made material is 4Kh5MFS).

10. Friction conformed to Coulomb's law. A value of 0.3 was taken for the friction coefficient (in accordance with the developer's recommendations).

In the first stage of the investigation, we performed a preliminary modeling to estimate the energy needed for the forming operation. It was assumed that the speed of the hammer along the *Z* axis was 20 m/sec.

Figure 3 shows the change in the form of the semifinished product at different stages in the modeling operation and Fig. 4 shows the angle of contact between the tool and the stamping. It is apparent from Fig. 4 that the material of the semifinished product completely filled the die. The useful impact energy for complete filling of the die was $3.15 \cdot 10^8$ N·mm. This can be seen on the graph that shows the dependence of impact energy on the displacement of the hammer (Fig. 5*a*). The modeling also showed that the hammer moves 137 mm before the die is completely filled. Figure 5*b* presents a graph showing the dependence of the hammer's displacement over time.

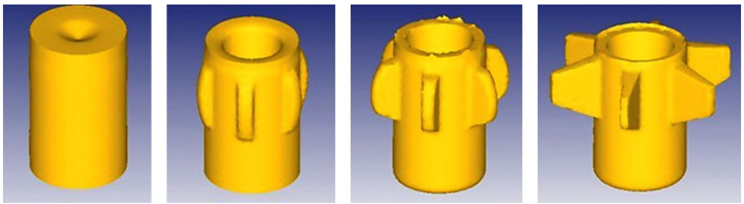


Fig. 3. Change in the form of the semifinished product at different stages of modeling.

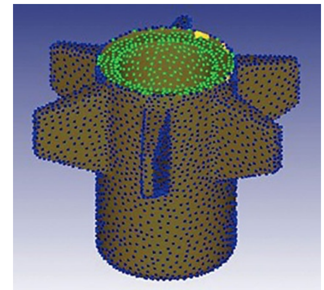
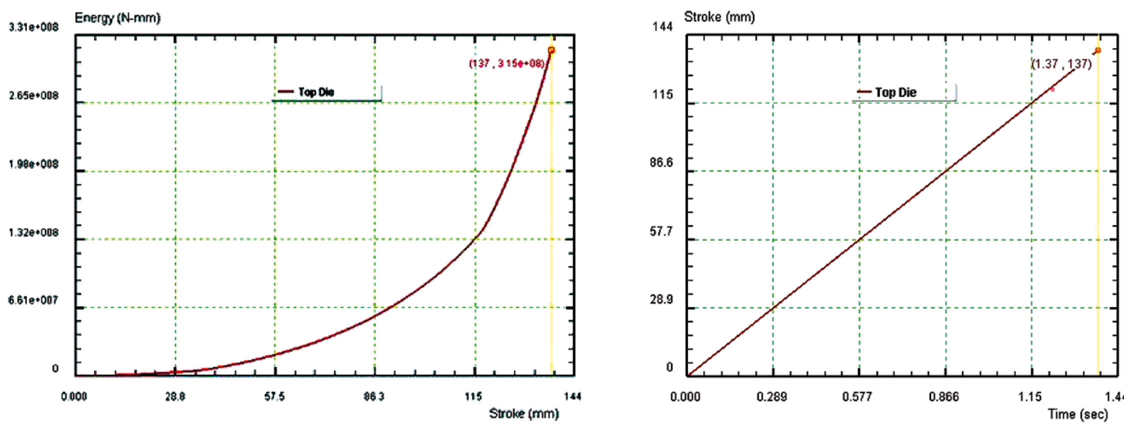


Fig. 4. Nodes where the stamping comes into contact with the equipment.



a *b*

Fig. 5. Graphs showing the dependence of impact energy on the displacement of the hammer (*a*) and the time dependence of the displacement of the hammer (*b*).

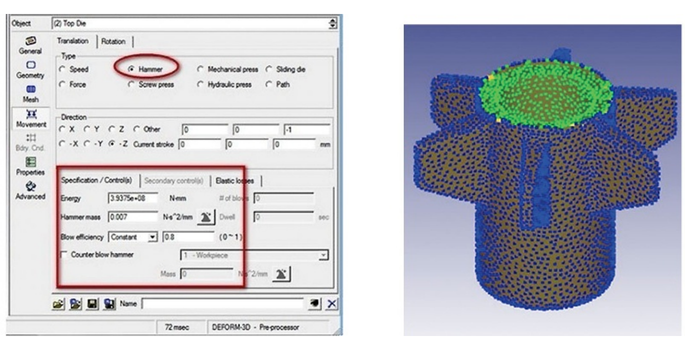
a  *b*

Fig. 6. Parameters characterizing the displacement of the hammer (*a*) and the nodes where the stamping comes into contact with the equipment (*b*).

After the modeling was done, it was necessary to determine the total amount of impact energy that was expended with allowance for the efficiency of the hammer. The average efficiency of high-speed hammers is 80% [3]. We determined hammer efficiency from the formula

$$\eta = E_{use}/E_{tot}, \tag{1}$$

where E_{use} is the useful energy necessary to form the product, and E_{tot} is the total impact energy.

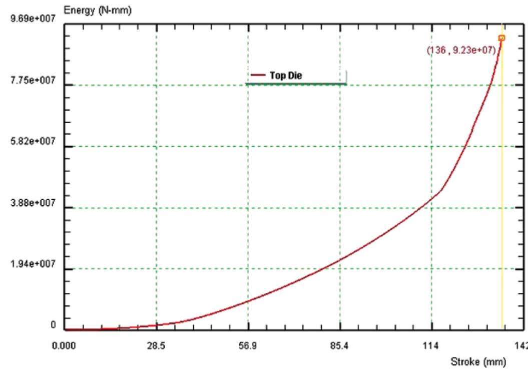
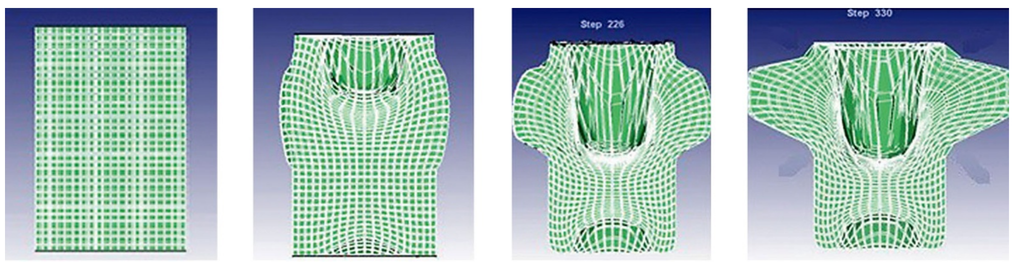
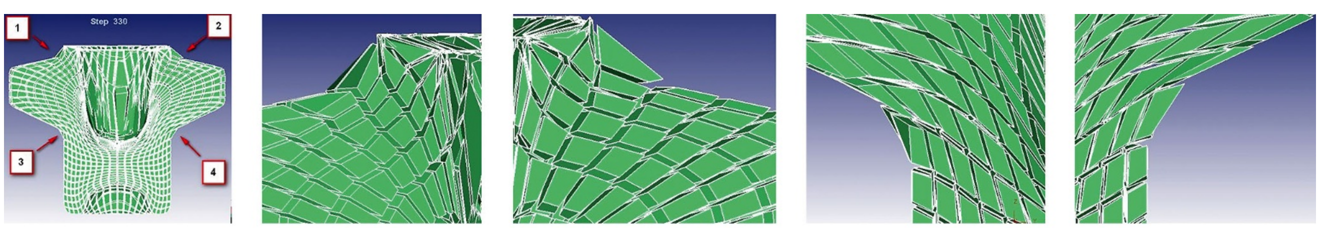


Fig. 7. Graph showing the dependence of impact energy on the displacement of the hammer during repeat modeling.



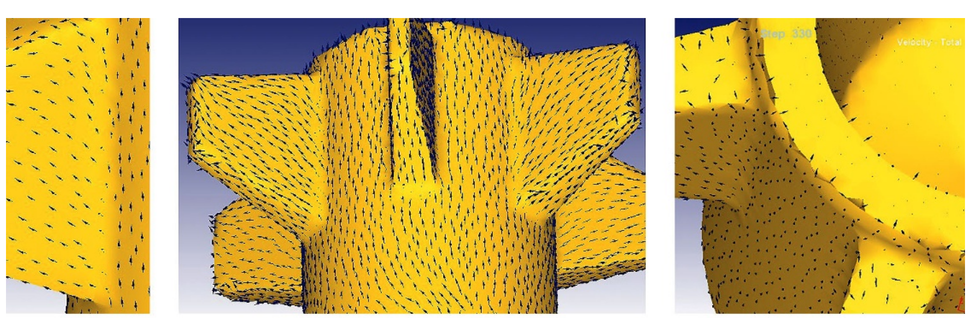
a *b* *c* *d*

Fig 8. Change in the Lagrangian mesh in one section of the stamping at different steps in the computation: *a*) No. 1; *b*) No. 100; *c*) No. 226; *d*) No. 330.



a *b* *c* *d* *e*

Fig. 9. Most probable sites of “channel” formation in the given section: *a*) most likely site for the formation of folds in this section; *b–e*) enlargements of the zones indicated by arrows 1–4.



a *b* *c*

Fig. 10. Vector fields of metal flow velocity at the sites where defects are most likely to form: *a*) at the butt joint of a fin; *b*) in the body of the stamping; *c*) on the radial fillets of the fins.

It follows from the above equation that the value of total impact energy

$$E_{tot} = E_{use}/\eta = 3.15\cdot10^8/0.8 = 3.9375\cdot10^8 \text{ N}\cdot\text{mm}.$$

To check the accuracy of the results, we performed a repeat modeling with the use of data that was closer to actual production conditions. We chose Hammer as the type of equipment in the preprocessor of DEFORM-3D when we were specifying the movement of the hammer. The value for the hammer's total impact energy and the efficiency value $\eta = 80\%$ were entered into the corresponding windows of the program (Fig. 6*a*). The remaining initial data was left unchanged.

The result obtained from the repeat modeling showed that the die is completely filled when the total amount of impact energy that is expended is at its theoretical value (Fig. 6*b*). The useful impact energy is $3.16\cdot10^8$ N·mm (Fig. 7), i.e., a difference of $0.01\cdot10^8$ N·mm from the result obtained in the first modeling. As in the first case, after coming into contact with the stamping the hammer travelled 137 mm before the die was completely filled. The results obtained from the repeat modeling confirmed the correctness of the approach taken to determining the total amount of energy which has to be expended to form the given product.

The options offered in FlowNet were used to analyze the flow of the metal. The semifinished product was subdivided into a Lagrangian mesh and the character of the flow during the forming of the semifinished product was followed based on nodes. Figure 8 shows the change in the mesh at different steps in the computation for one of the cross sections of the stamping.

The arrows in Fig. 9*a* indicate the most likely sites for the formation of channels in this section, while Fig. 9*b–d*, shows these regions in enlarged form. Since such defects can be formed during the final stage of deformation (if there is an excess of metal for forming the vanes), the data for the completion of the process is shown in the figure (see Fig. 3 for the sequence followed in filling the engraving). No signs of channel formation were seen either in examining the different stages of deformation. It is apparent from Fig. 9 that the layers which comprise the flow are not superimposed on one another and that no folds are formed at these locations. The same result was seen in other sections at the sites where defects were most likely to form.

The formation of folds and crimps was also evaluated on the basis of the vector field of metal flow velocity. The flow vectors did not intersect at the dangerous sites, which also means that no defects were formed. Figure 10 shows the vector fields of flow velocity at certain locations where defects can form during different stages of the stamping operation.

Conclusion. The above analysis of the stamping of a nozzle part in the software suite DEFORM-3D showed that the equipment which was designed and the regimes which were calculated for the production process prevent the formation of defects during the fabrication of the part. The given program was also used to determine the energy-force parameters of the equipment. Based on the data obtained from the modeling, it was decided to proceed with factory testing of the technology on a VSM4 hammer. The test results supported the modeling results. A defect-free stamping whose dimensions matched the dimensions in the drawing was obtained with a single impact of the hammer

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