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APPLICATION OF NUMERICAL SIMULATION FOR ANALYSIS AND OPTIMIZATION OF FORGING MANUFACTURING PROCESS

Abstract: The paper presents the use of numerical modeling results for multivariate simulation of the manufacturing process of a wheel hub forging made of 20 HG alloy. The QForm 3D program was used to analyze the issue, which allowed to analyze the forging process without the need for expensive tools and technological tests. Based on insights from several variants of numerical calculations, new technology solutions were proposed, reducing the number of deficiencies found in industrial practice. In order to obtain full information about the phenomena occurring in the deformation process, numerical calculations were carried out in the areas of material flow, the degree of filling of blanks, the distribution of deformations and stresses in the various stages of the forging process in the die, and the elimination of defects in products. The information obtained formed the basis for proposing the optimal technology for forging wheel hubs.

Keywords: physical parameters; numerical simulation; FEM

1. Introduction

Forgings are used for highly stressed machine components. Often, these components are also an important safety component, so they are required to have high strength properties, dimensional accuracy, absence of defects and correct fiber routing. The process of manufacturing forgings is still an incompletely solved problem, as the selection of appropriate process parameters plays a major role in their manufacturing processes. This is important when forgings are additionally required to have a certain structure and hardness, which are obtained not only as a result of the forging process itself, but also by appropriate heat treatment [1,2]. A large number of factors affecting the correctness of the forging process, especially multi-stage forging, and their interaction makes them difficult to analyze and optimize. For this purpose, numerical modeling based on FEM is very often used, mainly at the design stage of the manufacturing process. The use of numerical simulation in the analysis of die forging has many advantages over the traditional process of technology design, based on the performance of technological tests. These include, first and foremost, the relatively low cost of implementation, versatility, the possibility of repeated calculations to verify different variants of the technological process, and the short time to develop a new technology [3-6].

The most difficult issue is the modeling of forging with flow out, where the correct representation of the shape of the forging and flow out requires the analysis of a very large number of elements and technological parameters [7-9].

2. Numerical analysis with the use of FEM

The component analyzed was the wheel hub of an Ursus C-330M agricultural tractor, made of HG alloy 20, used for machine parts with high surface hardness and high core strength. This material is used for shafts, gears, worms, hubs, journals, which are subject to high pressures and variable loads. This steel is suitable for carburizing, nitrocarburizing and hardening. The hardness after machining is above 60 HRC.

The development of the technology for making the product in question was based on the guidelines used in the design of forgings [1,2], relevant industry standards and scientific publications [10-12]. The results presented here are the final stage of the project, involving the design of a blank for the production of an automotive component. All drawings, tooling and product geometry were prepared in SolidWorks [13].

QForm 3D software was used to model the forging processes [14]. Due to the course of the process, forging was

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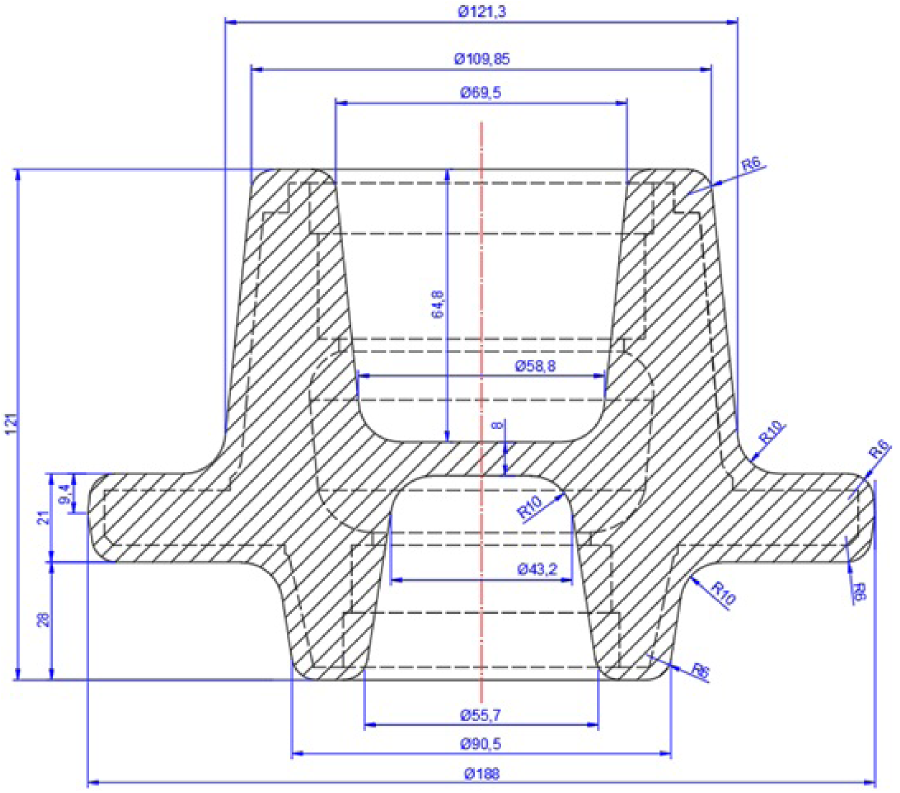

Fig. 1. Wheel hub – dimensions

performed in two stages: swelling and open die forging. The values of stresses created in the material during swelling were taken into account by the program in a further stage of simulation.

In order to perform the first stage of the simulation - swaging, the geometry of the tools and the initial material were imported and created in SolidWorks software. The batch material was a bar whose outside diameter was 89 mm and height was 214 mm. The imported 3D models included two flat dies. The bottom tool was restrained and the top tool made a downward motion along the Z axis swelling the 20 HG steel shaft to a height of 170 mm.

Figs. 2 and 3 show cross-sectional views of the upper and lower die.

The tools are made from AISI H13 (1.2344) steel for hot work. This material demonstrates superior mechanical properties especially in terms of high tensile and compressive strength.

The technological process presented in this paper is somewhat simplified in relation to the already functioning production process of the aforementioned part. The main objective of the work was the numerical analysis of the wheel hub die forging process and the greatest emphasis was placed on this aspect.

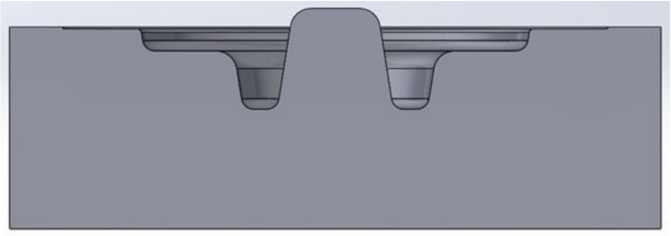

Fig. 2. Lower die

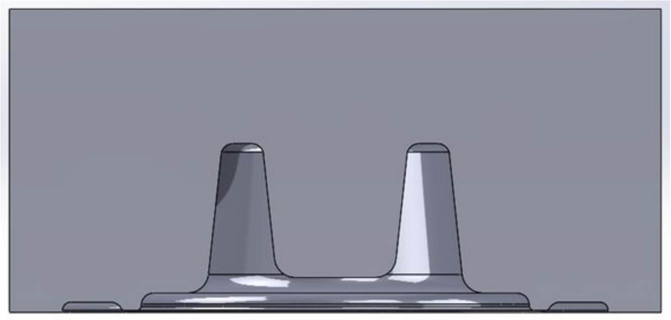

Fig. 3. Upper die

For the simulation, it was determined that the feedstock material was heated, reaching a temperature of 1040°C, while the tools were heated to a temperature that was 200°C. The material of the dies for swaging and shaping is H13 steel, which is commonly used for hot and cold working dies. The friction coefficient between the dies and the charge $m = 0.4$ (graphite + water) was adopted. The heat transfer coefficient between the tools and the charge was set at 30 kW/m^{2}K. The ambient temperature was 20°C. The swelling was carried out on a hammer, the mass of the falling part of which was 16 t, and the impact energy oscillated at 400 kJ. Fig. 4 illustrates the stress distribution after swelling.

After the swelling stage, the second part of the process was followed by die modeling. The tool temperature was assumed to be 200°C, the feedstock temperature to be 1040°C. The coefficient of friction was the same as in swelling

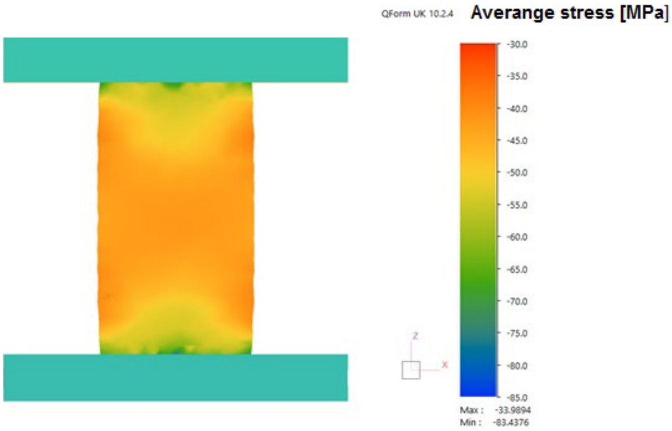

Fig. 4. Stress distribution after swelling

m = 0.4 (graphite + water). The mass of the falling part of the hammer was 21 t, and its impact energy was 624 kJ. As a result of the simulation, the forging presented in Fig. 5 was obtained. Unfortunately, partial unfilling of the blank of the groove for the spline was noted. This may indicate the presence of undercutting in the product. This defect disqualified the variant for further analysis. In order to eliminate the error, it was checked in the first variant whether increasing the impact energy (900 kJ) and the mass of the falling part (29 t), and in the second variant – increasing the temperature of the charge to 1150°C would allow to obtain a properly filled groove for the efflorescence.

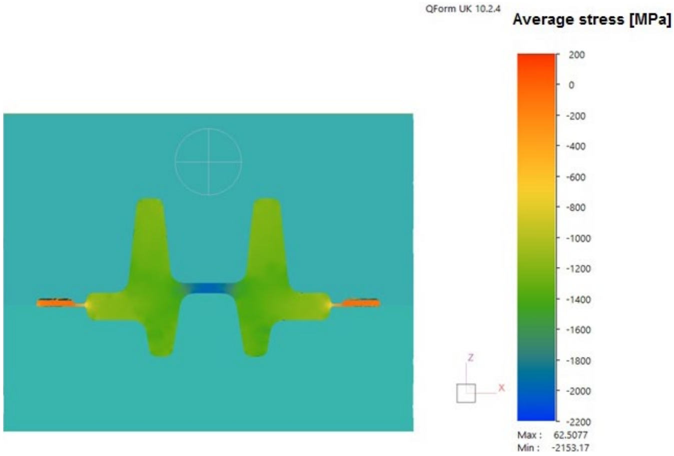

Fig. 5. Stress distribution in the resulting forging

Based on the simulation results obtained for the two variants, no satisfactory result was obtained.

Based on the simulation results obtained, a process adjustment was made to increase the volume of the feedstock. The outer diameter was left unchanged, while the height was increased by 3 mm to a level of 217 mm. Then the verification simulation was carried out again. It was assumed as before – a tool temperature of 200°C and a feedstock temperature of 1040°C. The friction coefficient *m* = 0.4 (graphite + water). The mass of the falling part of the hammer was 21 t. Fig. 6 illustrates the stress distribution in the forging with a filled groove for the dropout.

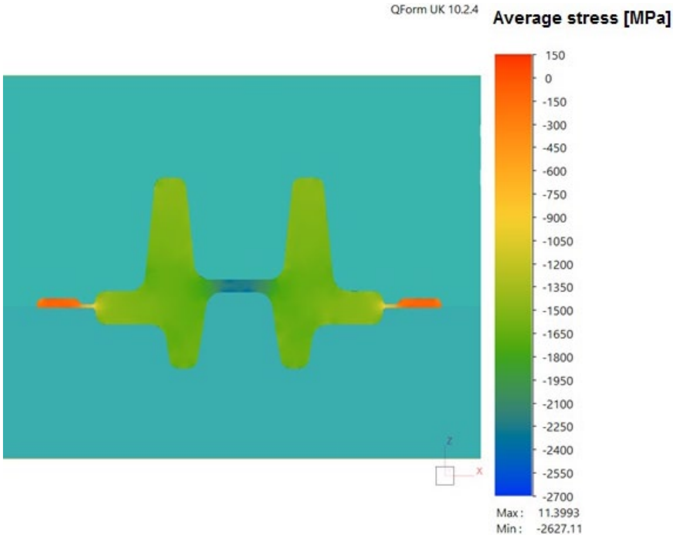

Fig. 6. Stress distribution in the forging

A satisfactory result was obtained – the groove for the efflorescence was completely filled. It was determined that the height correction resulted in the improvement of the prepared process. After the process correction, the shaped forging was the object of further analysis.

TABLE 1, presented below, shows three additional variants that are objects for further study. It was checked, the influence of various factors on the end result.

Fig. 7 shows an example of stress distribution for one of the cases.

Based on the results obtained from the average stresses, as well as the strain distribution, no significant differences were observed. For the first three cases, it was possible to obtain a properly made forging. For the fourth variant, it was not possible to obtain a properly made part. The forging had an undercut. The groove for the forging was not fully filled, which is presented in Fig. 8. The lack of lubrication has an adverse effect on the

TABLE 1

Summary of options analyzed

Variant	Hammer weight and impact energy	Feedstock temperature [°C]	Temperature of tools [°C]	Type of lubricant (coefficient of friction)
1 (a)	21t, 624kJ	1040	200	Graphite + water (0.4)
2 (b)	21t, 624kJ	940	200	Graphite + water (0.4)
3 (c)	21t, 624kJ	1040	300	Graphite + water (0.4)
4 (d)	21t, 624kJ	1040	300	lack of (0.6)

forging process, and thus it is not possible to obtain a properly made forging without lubricant.

TABLE 2 summarizes the simulation results. They clearly show that the highest compressive stress was obtained in the absence of lubrication. Similar stress values were obtained in all variants. Increasing the tool temperature by 100°C did not result in favorable changes, compared to the optimal variant (a). Lowering the charge temperature to 940°C resulted in a large increase in compressive stresses. The difference is about 270 MPa. On the other hand, the largest difference in stress was between the first variant (a) and the last variant (d). The values differed by 472 MPa. The values of strain intensity differed slightly. As could be predicted, the highest values occurred in areas of intense flow, i.e. in the upwelling. It was considered that the optimal variant was properly designed, and its parameters gave the best results compared to the others.

Figs. 9-11 illustrate the results of the analysis carried out for the optimal variant – the first one (a).

Thanks to the selection of appropriate process conditions, among others: lubrication, charge temperature, tools, forming force, but also a properly designed die, it was possible to obtain the desired forging. No anomalies were noticed, resulting in the possibility of defects. By analyzing the stress distributions, it is possible to identify the areas subjected to the greatest wear in the dies. The highest stresses were observed in the bottom of the forging, that is, the place where the greatest compression of the material occurs, caused by the longest time of forces, and at the same time contact on the shaped charge. The bridge of the die is a place that needs special attention due to the possibility of rapid damage.

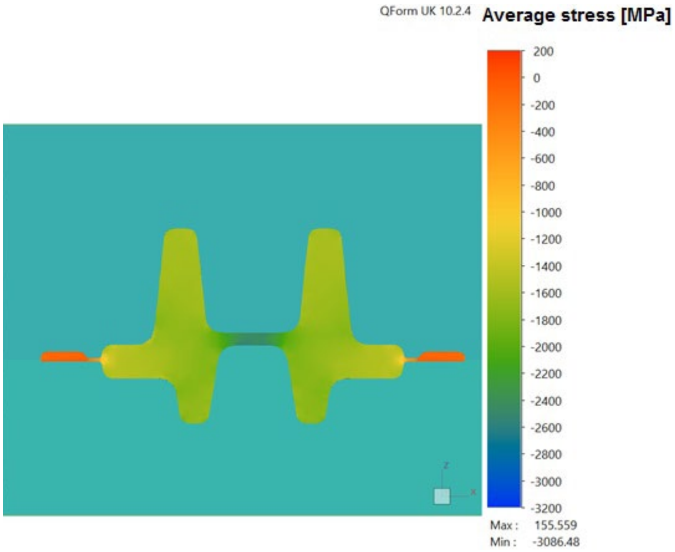

Fig. 7. Example of stress distribution for variant three

Fig. 8. Failure to fill the discharge groove in the absence of lubrication

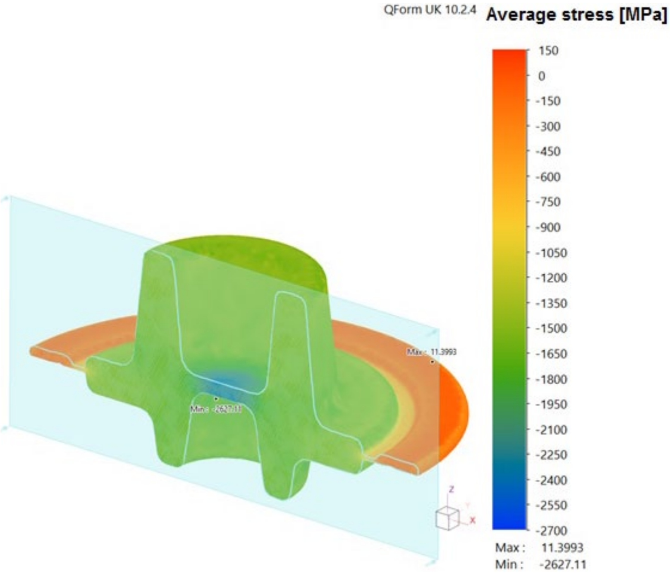

Fig. 9. Stress distribution in the analyzed case

As a result of the friction of the flowing material, there was an increase in temperature to a level of about 1350°C, which is about 310°C more than the originally heated charge. It is caused by the intensive flow of material in the inhibiting bridge (the place marked with an arrow). This phenomenon was observed around the entire circumference of the forging.

Fig. 12 shows the filling of the dies by the shaped material in four steps. At the beginning of forging, the highest deformation was observed near the hole (the central part of the forging).

TABLE 2

Summary of analyzed alternatives

Variant	Temperature of tools [°C]	Feedstock temperature [°C]	The smallest stress value [MPa]	The highest stress value [MPa]	Type of lubricant (coefficient of friction)
1 (a)	200	1040	11.4	2627,1	Graphite + water (0.4)
2 (b)	200	940	140,3	2999,7	Graphite + water (0.4)
3 (c)	300	1040	155,6	3086,5	Graphite + water (0.4)
4 (d)	300	1040	141,1	3099,9	lack of (0.6)

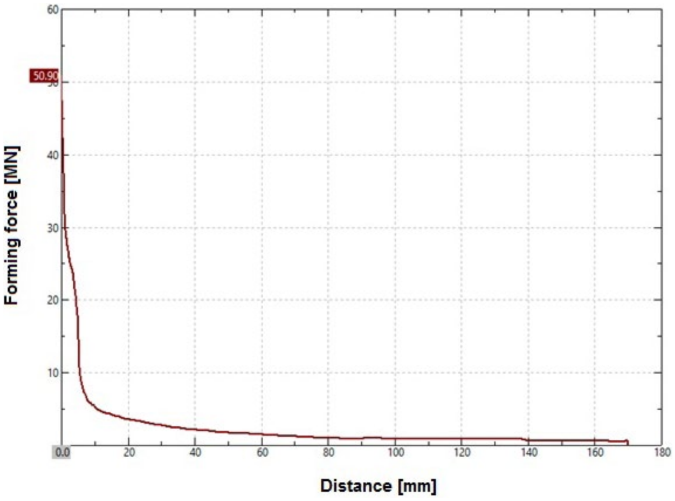

Fig. 10. Force distribution during forging shaping range 0-170 mm

With the further stage of shaping, the deformation appeared in the dividing plane of the dies (the center of the height of the bottom of the forging). In the final stage of tool filling, the largest deformation appeared. This was the bridge and a part of the outflow, places where the temperature of the charge also increased.

3. Conclusion

Based on the presented results of the analysis, the conclusions listed below are presented:

1. The process should be carefully designed taking into account all requirements for material, heating conditions and lubrication.

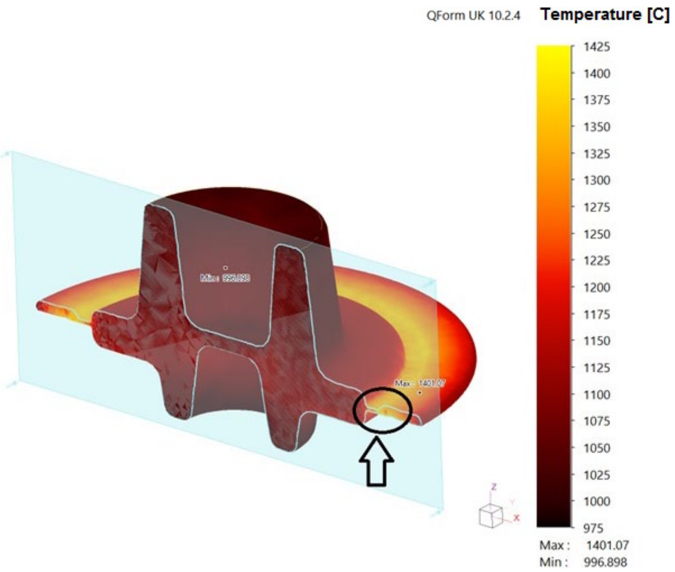

Fig. 11. Temperature distribution in the shaped forging

2. Modeling the course of the forging process with the help of tools using FEM allows to indicate possible errors made at the stage of process design.
3. The resulting shape of the forged part in QForm 3D is in line with the design.
4. It was shown that the calculated charge was insufficient and needed to be corrected.
5. The use of a lubricant in the form of graphite reduced the phenomenon of friction between the tools and the material being shaped.
6. The sharp increase in shaping force in the final stage of die forging can be caused by the strengthening of the material,

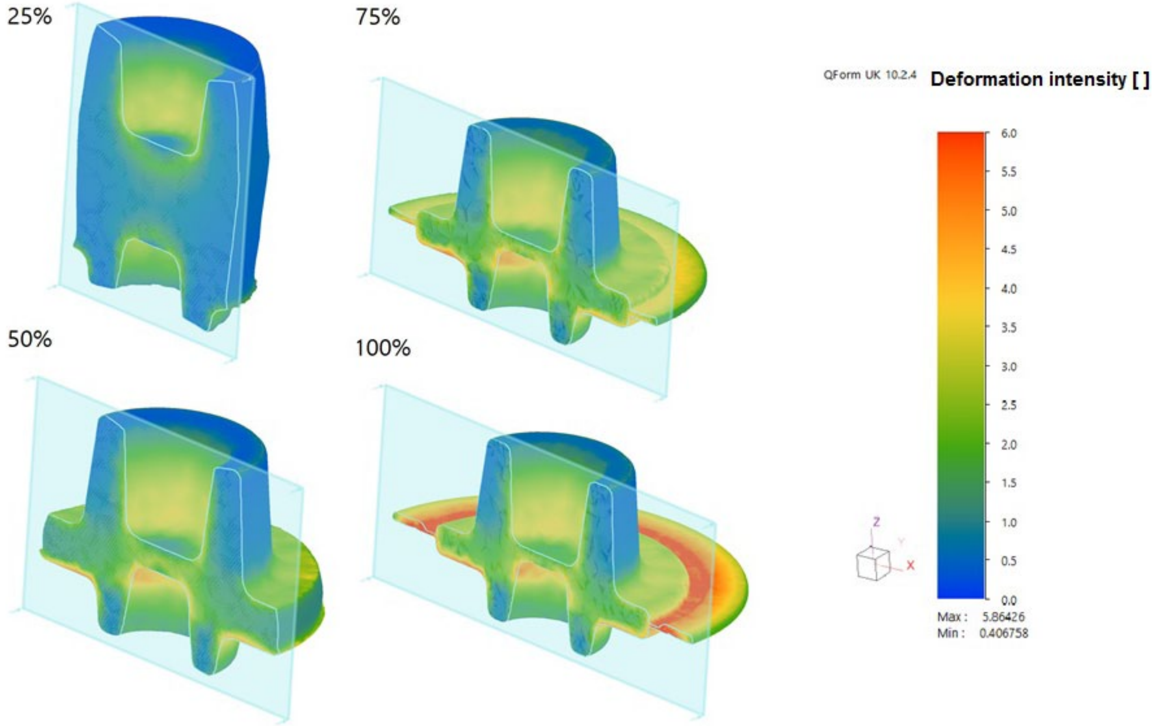

Fig. 12. Distribution of strain intensity in the cross-section of the forging

but also by the correct filling of the designed tools (final calibration of the forging).

7. Extensive and repeated analysis of a given forging process allows to obtain results that are the basis for the selection of appropriate lubricating, temperature conditions of the process.
8. The calculated value of the falling mass of the hammer of 21 t (impact energy of 624 kJ) at a die temperature of 200°C and charge temperature of 1040°C, also the use of lubrication in the form of graphite, provided optimal conditions, thanks to which the required shape and dimensions of the forging were obtained.

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