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THE INFLUENCE OF PHYSICAL PROPERTIES OF C55 ALLOY ON GEOMETRY OF FLOW IN THE PROCESS OF SHAPING

The paper presents analysis of influence of change of physical parameters such as: temperature, friction coefficient and load, during the process of die forging. Optimization of the process effects in achieving high quality products, decreasing shaping resistance, and what follows – lower energy consumption. Temperature is the basic factor affecting the process of plastic working. Analyzing that influence in individual die fragments, allows to engineer the flow of shaped material. The QForm3D commercial program for finite element method calculations was used for numerical simulations. The paper presents multi-variant analysis of forging process with the usage of numerical simulation, which provided many valuable information concerning changes of key parameters, such as: temperature, stress and strain distribution and variations of technological parameters, as well as their mutual influence, difficult to obtain in analysis of industrial process.

Keywords: Die forging; FEM; drop forging; simulation methods; QForm3D

1. Introduction

Forged products are one of the most important and most common types of parts used in mechanical engineering. Elements made in this way play an important role in the construction of all kinds of machines and devices. Due to their quality, forgings are used in machines transmitting high values of stresses and forces. Among all the forgings produced, the main part are die forgings, which account for about 50-80% of all forged products.

Die forging is a technological process with many advantages. It is used for forgings with complex shapes, especially in large-scale processes, in order to save large amounts of material. Examples of such die-forged elements are gears, crankshafts, axles, high pressure valve bodies or various types of hooks that carry enormous loads [1,2]. The method also grants high quality of the forgings obtained, significant process efficiency and optimal use of the starting material with a small amount of production waste. The quality of final elements by drop forging is significantly better compared to elements obtained by other technologies. Here are some other advantages of drop forging that should be mentioned:

- high profitability of making die forgings in larger series,
- high accuracy of the forgings made,
- dimensional and shape repeatability of the parts made,
- possibility of making complex forgings with complex shapes,
- the ability to accurately determine production costs,
- the possibility of reducing the loss of material intended for technological allowances,
- the possibility of optimizing the forging process [3-8].

Optimization of forging processes, the aim of which is to obtain the best results, must be carried out at the design stage of the forging. It can be provided by modeling method, which allows to predict the behavior of a given type of material in subsequent operations and technological processes. With the use of simulation methods, it is possible to indicate the best, optimized parameters of each process, the filling of the die, the degree of forging, the occurrence of flow defects and the resulting mechanical properties of the material. Advanced post-processing techniques allow you to visualize the analyzed process [9-12].

2. Numerical analysis with the use of FEM

The aim of this article is the numerical analysis of stresses and strains, based on the finite element method (FEM), using the QForm 9.0.10 3D program [13,14]. The presented results are the final stage of the project, which involves the design of

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a semi-finished product for the production of an automotive component. All drawings, tooling and product geometry were made in the SolidWorks program.

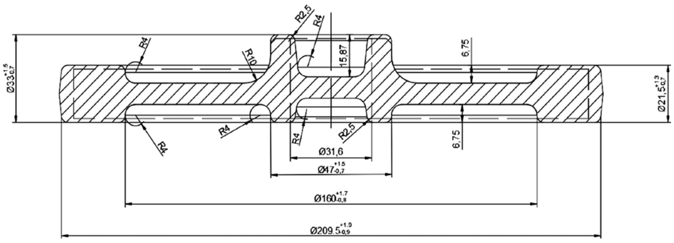

Fig. 1. Drawing of the shield type forgings

The material of the forging is C-55 steel, which is used for moderately loaded machine and equipment components, including spindles, axles, shafts, unhardened gears, electric motor shafts and discs. These products can be surface hardened achieving a hardness of up to 50-60 HRC. Taking into account tool life, hammer size, and technological guidelines, it was assumed that the process would be performed using a double-bender die. Numerical analysis was performed in the QForm 3D program.

The billet is a bar with an outer diameter of 80 mm and a height of 122 mm made of C-55 steel. The simulation assumed that the material was heated to 1100°C. The tool temperature during the operation was 200°C. The tool material was X30WCrV93 steel. The friction coefficient between the contact surfaces of the feedstock and tools was assumed = 0.4. The heat transfer coefficient between the feedstock and dies is 30 kW/m2K. The swaging was carried out on a hammer with a mass of 11.3 t, and impact energy of 250kJ. The calculations are based on a load model, where the impact force of the hammer is put to the upper surface of the top die. In numerical simulation was modeled the contact area 3-D between elements of the shaped dies and the feedstock.

All the models were constructed in the Qform 3D program based on the Finite Elements Method. The program allows simulation of metal flow in different dies on any kind of equipment to predict possible defects (non-filling of a die impression, laps, flow-through defect, etc.)

3. Results of numerical analysis

Figs. 2 and 3 show the distribution of stresses during forging. The highest values occur in the central part of the forging and are a maximum of 259.665 MPa. The approaching dies caused the material to flow radially from the center toward the outside of the dies.

In the second stage, finishing shaping simulations were carried out. The simulation assumed that the bar was heated to 1100°C. The tool material was X30WCrV93 steel. In order to correctly represent the process, previously made dies in SolidWorks were imported. The geometric parameters of the previously swelled batch, along with the stress distribution, were imported from the final swaging stage. Nine calculation variants for different tool temperatures and sizes of selected hammers were analyzed. The individual variants are presented in TABLE 1. The simulation assumed that the rod was heated to 1100°C.

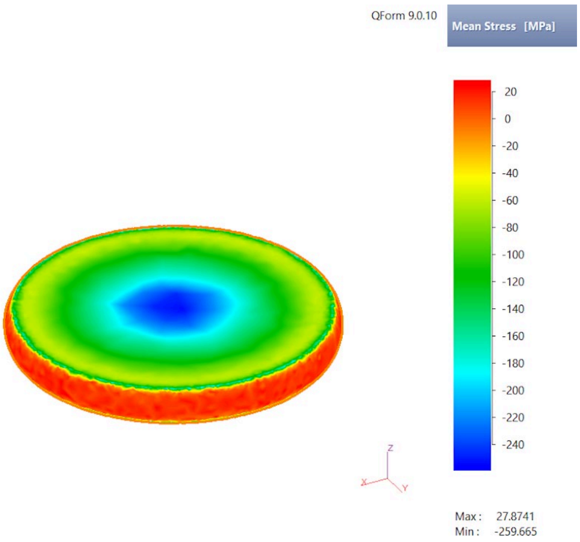

Fig. 2. Stress distribution during charge upsetting, view of the entire element

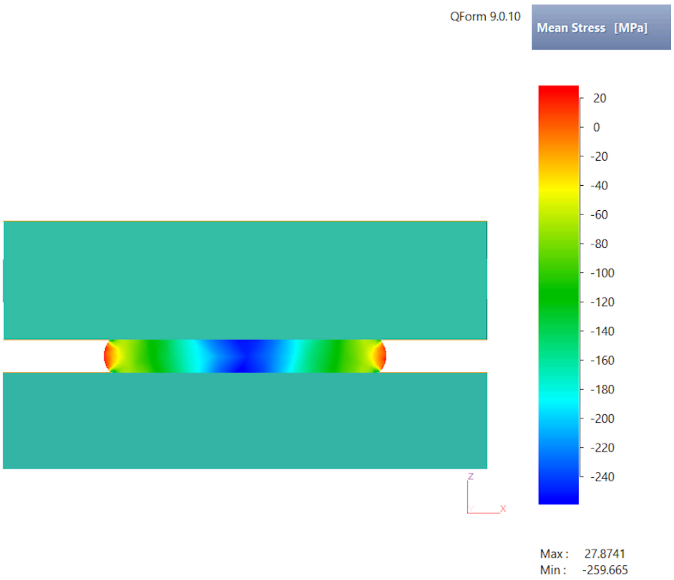

Fig. 3. Stress distribution during charge upsetting, element cross-section

The friction coefficient between the contact surfaces of the feedstock and tools was assumed = 0.4. The heat transfer coefficient between the billet and dies is 30 kW/m2K. The following assumptions were made:

a) hammer 11.3 tons, impact energy 250 kJ,
b) 8 tons hammer, 190 kJ impact energy,
c) hammer 4 tons, impact energy 100 kJ.

Figs. 4-6 show examples of stress distributions occurring in the forged material visible in the cross-section.

Based on the simulations, the results of which are the maximum stress values included in TABLE 2, it is noted that

TABLE 1

Variants adopted for the simulation of the process.

Variant	Hammer mass [t]	Tool temperature [°C]	Type of lubricant
1 (a)	4	20	Graphite + water
2 (b)	8	20	
3 (c)	11,3	20	
4 (d)	4	200	
5 (e)	8	200	
6 (f)	11,3	200	
7 (g)	4	800	
8 (h)	8	800	
9 (i)	11,3	800	

a significant increase in tool temperature from 200°C to 800°C did not significantly affect the magnitude and distribution of stresses (when comparing variants with the same hammer weight). The effect of significantly lower values (than for higher die temperatures) was brought by lowering the temperature of the dies to 20°C (ambient temperature). The differences are most pronounced between variant 1 and 4 bring more than 600 MPa. For variants 2 and 5, the difference is almost ten times smaller at about 66 MPa. Reducing the weight of the hammer by about 65% resulted in the occurrence of undercutting. It was concluded that it was not possible to make the presented forging on a 4 t hammer even with high die temperatures.

TABLE 2

List of maximum stress values

Variants	Maximum stresses [MPa]
1 (a)	996.4
2 (b)	1967.7
3 (c)	2159.4
4 (d)	1608.4
5 (e)	2034
6 (f)	2234.5
7 (g)	1613.4
8 (h)	2052.6
9 (i)	2205.8

In order to maintain dimensional accuracy, it is necessary to control die wear, already at the process design stage. Options 5 and 6 were considered for further analysis. The others were not included, that due to too high or too low tool temperatures. It was investigated how the magnitude and distribution of stresses change for the above-mentioned variants when the dies are lubricated with graphite with water and when there is no lubrication. For the absence of lubrication, the coefficient of friction between the contact surfaces of the feedstock and tools was assumed = 0.8. The heat transfer coefficient between the feedstock and dies is 50 kW/m2K. The obtained results of numerical calculations correspond with the ones obtained by other authors [8-12].

TABLE 3 illustrates the list of analyzed cases.

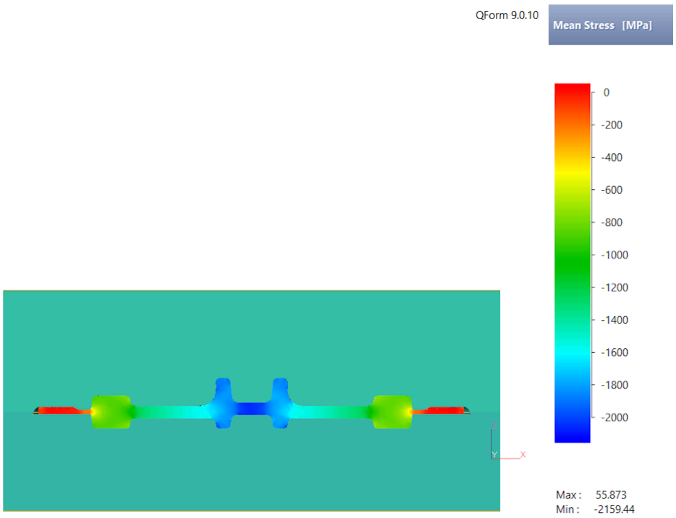

Fig. 4. Stress distribution in the forging using a hammer with a weight of 11.3 tons and a tool temperature of 20°C

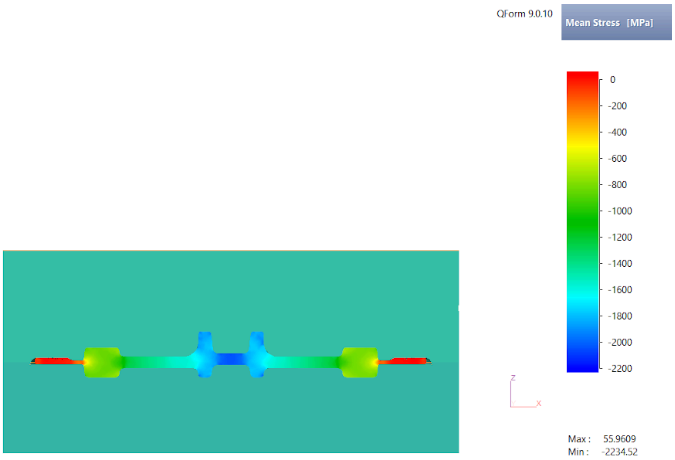

Fig. 5. Stress distribution in the forging using a hammer with a weight of 11.3 tons and a tool temperature of 200°C

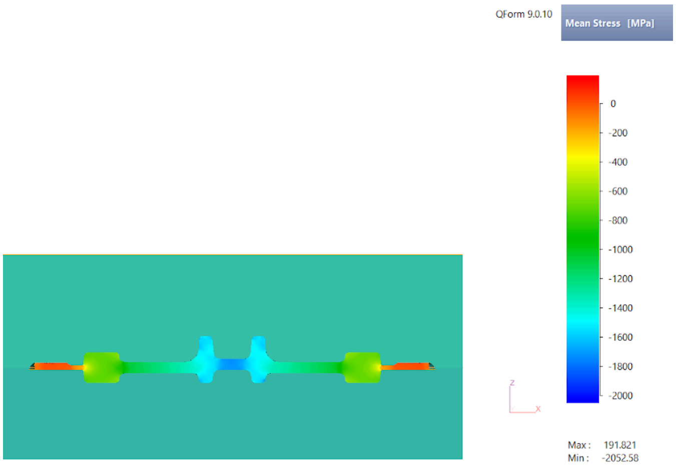

Fig. 6. Stress distribution in the forging using a hammer with a weight of 8 tons and a tool temperature of 800°C

Fig. 7 illustrates an example of stress distribution in a forging for a setup: an 8t hammer with die lubrication using graphite and water.

TABLE 3

List of the analyzed computational combinations

Number of the drawing	Hammer mass [t]	Tool temperature [°C]	Type of lubricant
9.11a	8	200	graphite + water
9.11b	11.3	200	
9.11c	8	200	lack
9.11d	11.3	200	

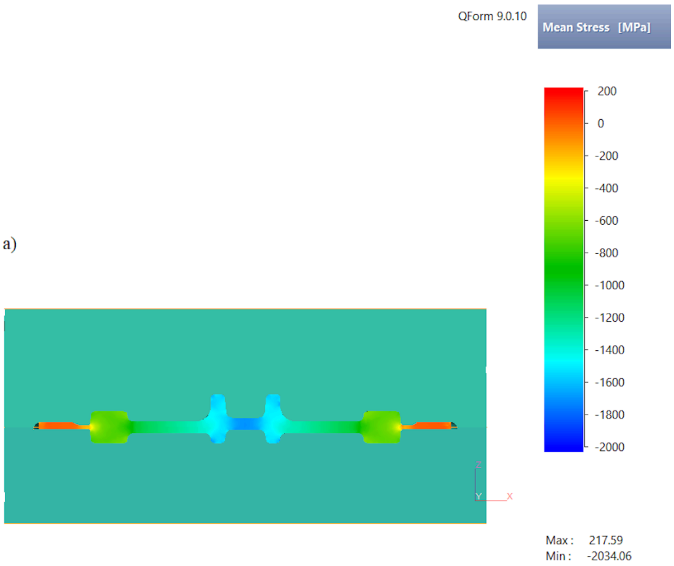

Fig. 7. An example of the stress distribution in the forging for the combination: 8 tons hammer with die lubrication

Based on the simulations, it can be concluded that the lubricant has a significant effect on the amount of stress. For a hammer with mass of 11.3 t for the situation of no lubrication, the value increased up to 2539 MPa. Forging is not possible when the hammer's mass is 8 t and no lubrication is applied. It is apparent that the forging is not properly forged.

It was concluded that the introduction of lubrication, and thus the provision of appropriate tribological conditions to the forging process, significantly reduces tool wear, and allows us to make forgings without defects. The use of a lubricating and cooling agent is helpful to reduce friction and thus better fill the die by the deformed material.

The optimal combination of forging parameters was demonstrated by the combination:

- hammer's mass: 11.3 t,
- die temperature: 200°C,
- lubricant: graphite grease with water.

Fig. 8 shows the stress and temperature distribution in the forging for this setup. No undercutting or deformation was observed. Appropriate rounding radii were selected. The outflow is evenly distributed around the circumference of the part. The stresses in the cross-section are a maximum of 2234 MPa. They are located in the central part of the forging (the bottom location), where the tools have the greatest contact with the shaped material. These are the areas, as can be presumed, where the greatest tool wear will occur. The lowest stress value occurs at the bridge of the forging, at the location marked by the arrow (Fig. 8a).

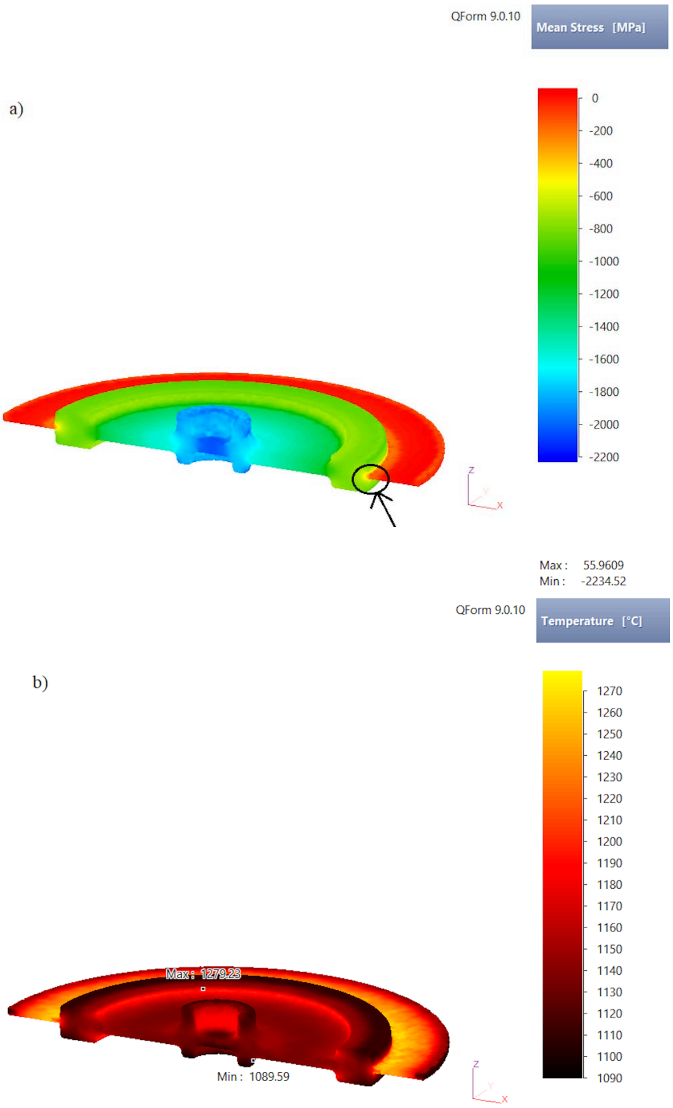

Fig. 8. Sample stress distribution (a) and temperature (b) in a forging

Fig. 9 presents selected stages of filling the finishing blank. In the initial stages, the largest deformations occur near the hole. In subsequent stages, such a place is the bridge. After the middle part of the tool is filled, a significant increase in the size of the blank appears.

4. Conclusions

1. Temperature is the basic factor having a significant influence on the course of the plastic working process. It was found that while increasing the temperature of the tools from 200°C to 800°C did not significantly affect the size and distribution of stresses (when comparing variants with the same weight of the hammer), lowering the temperature of the dies to 20°C had a negative effect on the forging process.
2. The largest temperature increase during forging was observed at the protrusion, around the forging.

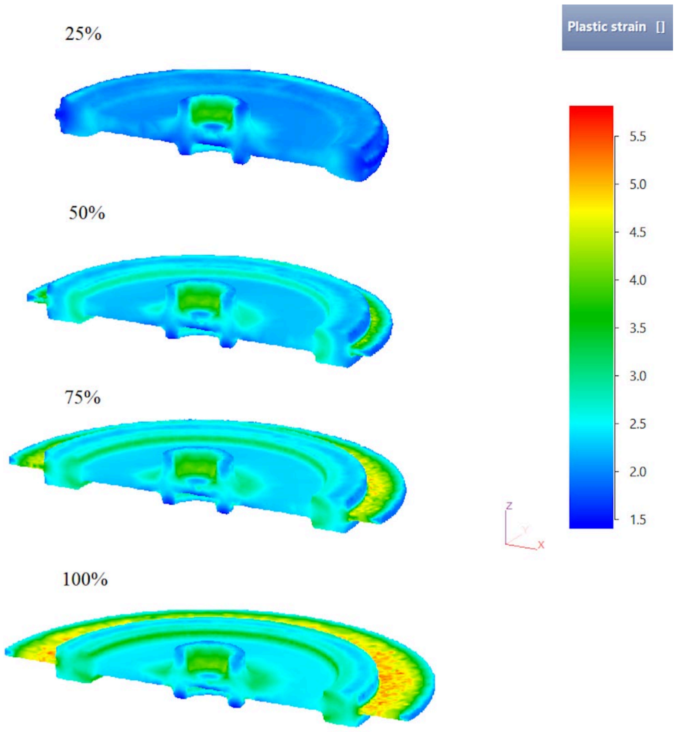

Fig. 9. Distribution of plastic strains in the cross-section of the shaped forging

3. The use of a lubricating and cooling agent resulted in a beneficial reduction of friction between the dies and the forged material.
4. The high quality of the forged element is the result of the correct stress distribution.
5. The results obtained can be helpful in optimizing forging processes.
6. The finite element method allows for various types of strength simulations and computational analyses carried out during the design process on virtual models (close to real ones), which eliminates the need to perform tools, which require a lot of time and tests at research stations.
7. Numerical analysis will help explain a number of phenomena occurring during the plastic deformation process and provide a wealth of data to assist in the design of this type of tool.

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