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Original article

FEM analysis of the stress strain rate during hot forging of steel non-rotational form

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ABSTRACT

The simulation of the clutch lever forging process was carried out using Qform software, which is based on numerical and finite element methods, while the tool itself was modeled in SolidWorks CAD software. The stress-deformation state of the workpiece in the process of hot forging in an asymmetric dies for forging with excess material, which represents one of the most common technologies in modern industrial processes of the metalworking industry was analyzed and monitored in this paper.

Key words: *Hot forging, FEM, Stress, Strain, Die;*

1. INTRODUCTION

The process of forging involves changing the initial dimensions of the heated metal into desired shape with the help of dies. The resulting finished piece is transformed into the final product with minimal additional processing, and in some cases it is the final product [1].

Today, from the total number of parts produced by forging, 50% to 80% of them are produced by forging in tool, which allows as to obtain parts of complex geometry that, with little or no additional processing, give the finished product [2].

The technology of forging in moulds is justified in cases of serial or mass production due to the need to make robust and expensive tools that can withstand the large deformation forces that occur in the production process, as well as the need for machines that need to have high power [2, 3].

In order to achieve the desired mechanical characteristics of the product, phenomena that occur during the deformation process that affect and leads to inhomogeneity must be taken into account. Inhomogeneity originates from shear stress in the material of workpiece that cause heat generation which results in stress and deformation inhomogeneity during forging that can lead to a reduction of mechanical characteristics of the product [4].

Software tools that are used in the process of simulating the forging process use numerical methods that are based on the finite element method. By applying numerical methods in the process of simulating the forging process, it is possible to monitor material flow processes, analyse loads during forging, detect defects and monitor them, as well as monitoring and analyse the stress and strain [4].

Software solutions allow us to optimize the forging process by monitoring key parameters and simulating the process to identify the defects during forging process, and the results obtained within the simulation are almost identical to those that would be obtained experimentally with a significantly lower time and money spent [5].

Numerical simulation methods can in principle answer questions such as "how many machining steps are required for a given product", "can the finished product be obtained only by forging, and can be avoid the post-machining process", " will the tools withstand cyclic load stress that is unavoidable in high-volume hot forging',

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whether the final product will have the required grain structure and mechanical properties' and so on [6]. In the work of M.R.Rahul and others [7], a finite element simulation was performed, which was used to examine the deformation distribution and material flow during hot deformation, which helps in predicting the actual material flow in the forging process. In the work of J. O. Obiko et al. [8] three-dimensional finite element analysis in Deform 3D software was used to investigate the behaviour of plastic deformation during forging of Ks20CrMoV121 steel. The focus of the work was on examining the influence of forging temperature on the distribution of deformation, stress and particle flow rate during the forging process.

2. FEM PREPROCESING SIMULATION

The dimensions and geometry of the forged part at the end of the forging process are defined by the tool geometry (Fig.1), which plays a decisive role in the process of plastic deformation [1, 9].

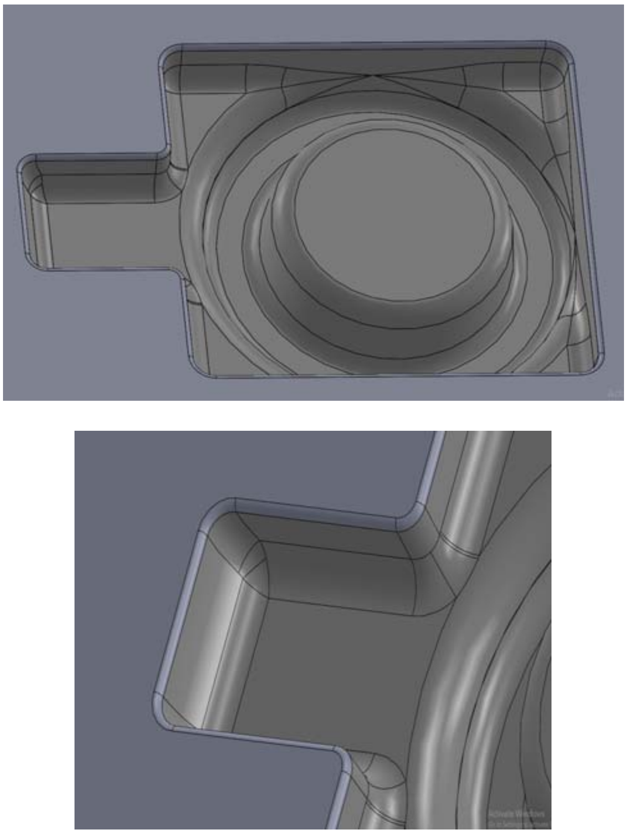

Fig.1 *Geometry of forging tool with detail*

The pre form in the process of hot forging is dimensioned so that it has an additional volume, in order to ensure filling of the engraving of the tool and the excess of material into the flash gutter. This ensures that even the outermost parts of the tool volume are filled in the forging process. The workpiece in the simulation is cylindrical in shape with a diameter of 65 mm and a length of 75 mm made of steel S355J2.

The simulation process of the hot forging process of the crankcase is simulated in the software QForm v10.1.0, which is based on the finite element method. The input data used in the crank case forging simulation process are:

- Workpiece temperature 1100 °C,
- Dies temperature 200 °C,
- Workpiece material S355J2,
- Dies material H13 6408,
- Forging machine - hammer with available energy of 69 kJ,
- The lubricant used is a salt solution, which has the following characteristics: friction law according to Levanov, which is 1.25, heat transfer coefficient 45000 W/(m2K), pause coefficient 0.05,
- Ambient temperature 20 °C.

The characteristics of the material in the simulation are determined as follows. The flow stress of the material is given by the diagram in Fig.2 while the Poisson coefficient is given as a constant value of 0.3. The material characteristics data are taken from the QForm v10.1.0 software database, which can be modified according to the needs of the user.
The yield stress of the material, or the stress-strain curve, is the area in which the forging process itself takes place and as such it is important for understanding and implementing the forging process of bulk forging. Based on a given diagram, we can understand how the metal behaves when it is deformed and how it hardens under those deformations and from this we can predict what force is necessary to apply so the material continues with plastic flow [10]. The flow stress of the material and its behaviour at the processing temperature of 1100 °C is given in Fig.2, on the basis of which the simulation was performed.

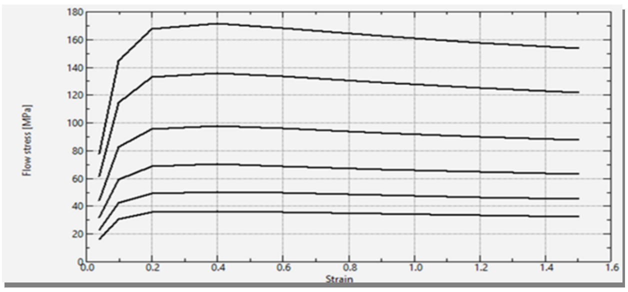

Fig.2 *Flow stress for material S355J2 at temperature of 1100 °C*

In the simulation, the workpiece is defined as a deformable body, while the tool is defined as a non-deformable rigid body. By using this approach, where the dies is taken for a non-deformable body, the processing time is greatly reduced, while having little or no significant impact on the quality of the obtained results. During discretization, the real continuous object is replaced by a set of a finite number of smaller domains (finite elements), and in each of them the required function is approximated by a collection of polynomials of a lower degree [11].

3. FEM SIMULATION RESULTS

The dies load itself starts from 0 N, which represents the state before the dies comes into contact with the workpiece, and then increases until the end of the process when reaches its maximum value of 11.72 MN at the end of the forging process. The dies load increases evenly and slightly up to 6 $\times 10^{-3}$ s of the forming process at the amounts to 0.66 MN, after which it increases rapidly until the end of the forming process (Fig.3).

Based on the obtained results, it can be concluded that the highest concentration of critical stresses occurs in the areas of the formation of the flash as well as in the places of sudden changes in the geometry of the dies. Based on the obtained results, the maximum stress appears at the place where the flash is formed and it is 181.537 MPa while the minimum effective stress is 46.3731 MPa.

At the place of formation of the flash a sudden change in the geometry of the die chases the intensive flow of material in those areas which is observed [11, 12]. At the observed yield area, five points were monitored where can be seen a jump in the effective stress of the material, point number 1 has a effective stress value of 154.475 MPa at the beginning of material flow and reaches a value of 173.756 MPa at point number 3 and, at the very exit point number 5 the stress drops to value of 141.326 MPa (Fig4.).

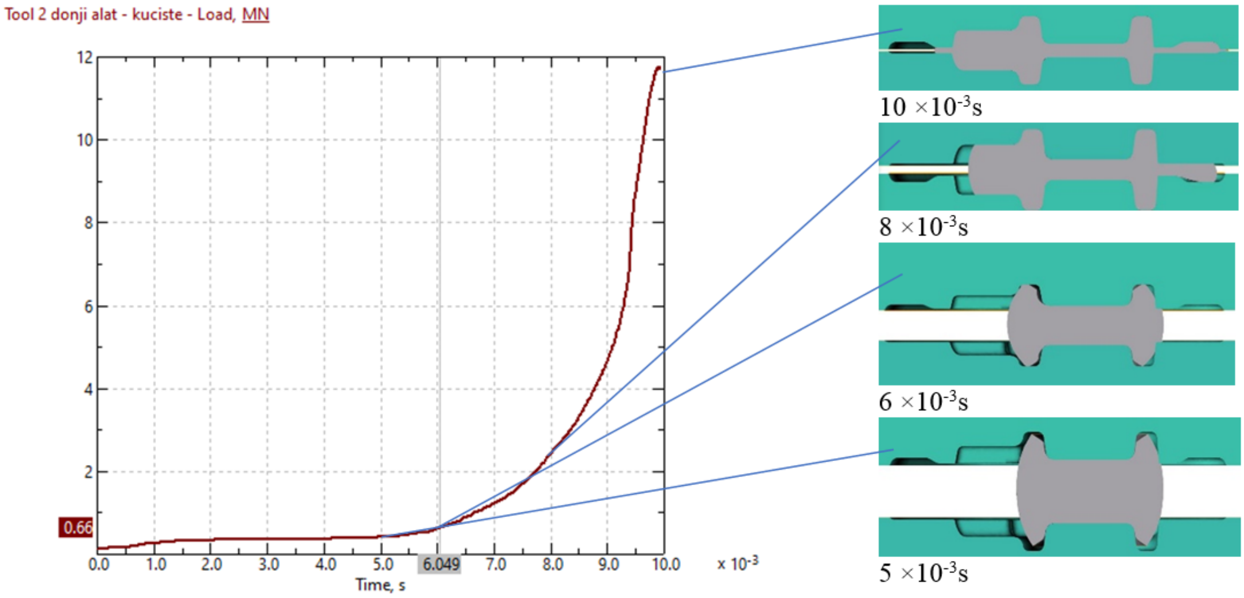

Fig.3 *Dies load chart*

The highest effective stresses are found in the zones of formation of the flash of the material witch is in contact with the tool, where there is a high concentration of load forces on the forging part, as well as due to sudden changes in the geometry of the tool. The shape of the tool in those areas is designed to prevent excess material from flowing into the flash gutter until the die cavity is completely filled so it can be achieved the desired quality of forged part.

The highest concentration of stress occurs in the central part of the forging part due to the reduction of the amount of volume of material in forged part, while in the parts where a larger amount of material is present, lower stress of the material occur. The die geometry engraved cavity of the tool based on the simulation indicates that it is fully filled and that the forging part has excess material that has entered in the flash.

The plastic strain that occur during hot forging process can be seen in Fig.5 where the highest degree of plastic strain can be seen in the areas of the formation of the flash of the forged part and its value is 13.4518. While in the areas where the material has filled the cavity of the dies the material is not in a plastic state.

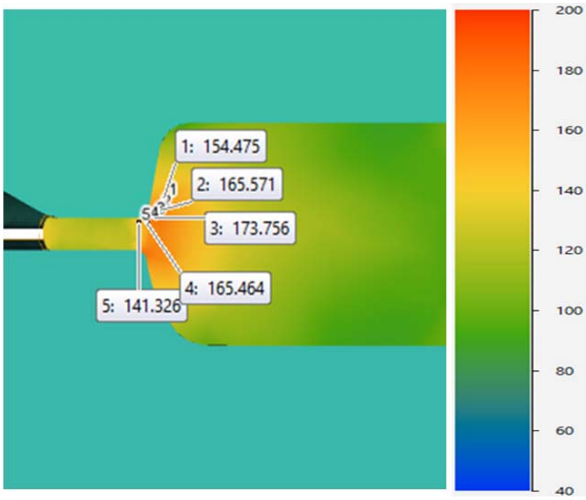

Fig.4 *Field of effective stress at cross section near transfer radius of forging part*

Fig.6 shows the rate of deformation across the wortkpiece. The highest are observed in the areas where the material continues to flow and in the areas where the flash is formed in contact with the tool [11, 12]. The rate of deformation in the monitored area ranges from 651.767 1/s at the beginning of the radius of the curve of toll, while in the middle of the radius of the curve its most intense effective stresses are located witch value is 2924.23 1/s, and at the exit of the radius value drops to 1156.79 1/s.

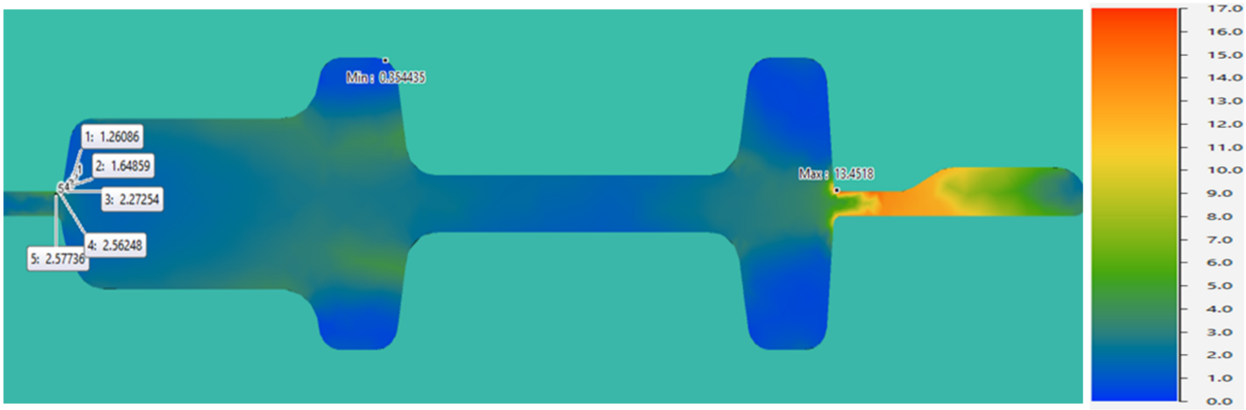

Fig.5 *Plastic strain in cross section of the workpiece*

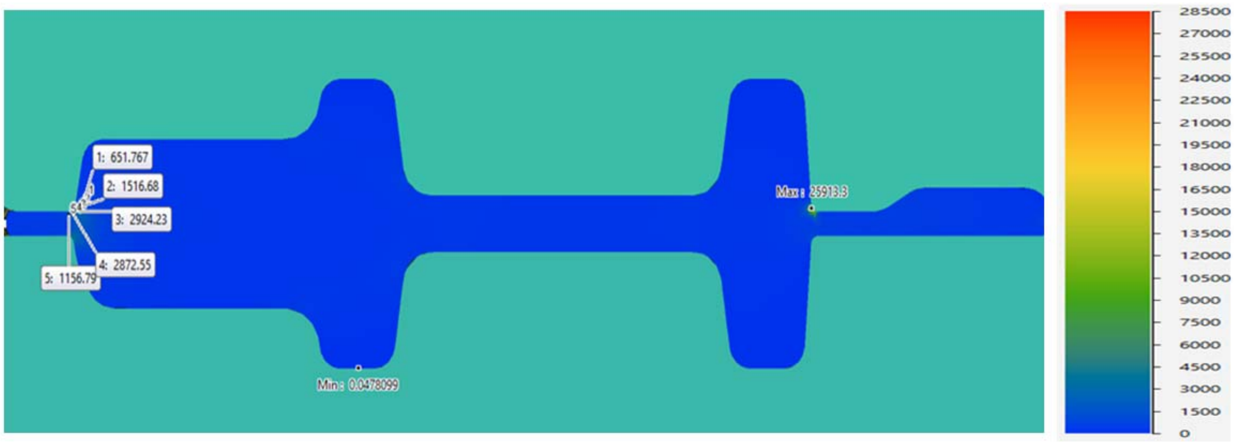

Fig.6 *Strain rate in cross section of the workpiece*

The geometry of finished part obtained by the simulation well matches to the geometry of real finished part obtained in real industrial conditions. The real finished part can be seen in Fig.7.

Fig.6 Photo of the real *finished part*

5. CONCLUSION

In the paper, the stress-strain state during forgings of part made of S355J2 material were monitored by FEM simulation based on numerical methods. The monitored die indicates that there is a sudden increase in the tool load in the forging process which can be seen in Fig.2, which occurs due to the occurrence of large degrees of deformation and hardening of materials, which is accompanied by a greater resistance of the material to further deformation during forging process.

Based on the obtained results, it is possible to conclude that the forging process itself can be improved in terms of reducing the input material by making the flow of material harder in the field of occurrence of maximum stress, i.e., the lowering flow of material into the right part of the excess material flash according to Fig. 5, by making the opening of the excess material further reduced and to direct the flow of excess material to the left part of the tool. During the analysis of the parameters of the results of the stress-deformation state, it was determined that there are no breaks in the material during flow and that there is no occurrence of material laps during forging process.

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NOTE

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