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OPTIMIZATION AND DESIGN OF MULTISTAGE HOT FORGING PROCESSES BY NUMERICAL SIMULATION AND EXPERIMENTAL VERIFICATION

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ABSTRACT

Multi stage hot forging processes make possible to produce variety of components with different shape, size and different materials. In these processes it is essential to design forging steps in optimal way. In previous times set-up of forging steps in multi stage processes was mainly conducted based upon experience gained in the forging practice. Nowadays, software packages based on FE (finite elements) and FV (finite volumes) method, are developed which enable creation of forging process optimization in more effective and more reliable way.
In this paper insight is given in the optimization of hot forging of wheel hub as well as in the design of the multi-step forging process of joint socket. Optimization criteria were minimal number of forging stages, die filling and stressing of the top and bottom die by contact pressures. Simulation and optimization results are verified in practical, industrial environment.

Key words: *Multi stage forging process, Technology design, Optimization, Numerical simulation*

1. INTRODUCTION

Forging and related bulk metal forming processes are key industrial production technologies since they can create parts that are stronger than those manufactured by any other metalworking processes. Components produced by forging (“forgings”) are characterized by structural integrity, impact strength, fracture toughness, fatigue life and uniformity. Due to these features forgings are always specified and required where reliability and human safety are highly demanded. High flexibility of this process lies in the fact that forgings can be manufactured from great variety of different metal materials (steel, aluminium, titanium, alloys,…) in almost any size and shape.

Every year around 10^{10} different forged components are produced in Europe. In most cases those components are assembled into automobiles, airplanes, vehicles, ships, missiles and others. Modern car design includes 250 forged components. In average, large airplane contains over 18000 high precision forged components [1].
Current state-of-the-art in the field of forging technology is characterized by intensive research work in a number of different areas such as metallurgy, material science, heat transfer and hear treatment, tooling design, environmental issues, etc. Number of papers have elaborated the problem of forging-set up and forging optimization by numerical methods [7,8,9,10,11,13].
Complex forgings geometries are produced in multi-stage processes. In such cases it is essential to determine optimal multi-stage process design which has minimum number of forging steps. For a long time set-up of process sequences has been based upon experimental generated trial and error method which is time and cost consuming. This inevitably reflects on forging quality and costs. Opposed to such solutions, numerical simulation and optimization, which has been growing rapidly in the last years, offers the possibility to perform forging process design in more efficient and qualitative way.
In this paper optimization and design of hot forging processes of wheel hub and joint socket are presented in terms of minimal number of forging stages, complete die filling and minimum material waste. Verification of the obtained and optimized solution has been performed in production environment forging plant, using pneumatic hammer.

2. OPTIMIZATION OF HOT FORGING TECHNOLOGY OF WHEEL HUB

Initial practical process design of wheel hub hot forging at "Proleter" Arilje forging plant was created based upon trial and error method and upon experience. This forging variant was unsatisfactory in terms of forging component quality (insufficient die filling). Therefore, more advanced numerical analysis, process planning and process optimization was conducted.
Process of wheel hub hot forging was simulated by Finite Volume Method (FVM) and commercial program package Simufact.Forming 9.0. Initial data for the simulation are:

- Material of the wheel hub: c53
- Friction factor: m=0,4
- Hammer with 80KJ available energy
- Initial length of the element: 1,5mm
- Die preheating temperature: 400°C
- Billet heating temperature: 1100°C

Forging die was assumed to be a rigid body which thermal features were taken into account (heat convention and heat radiation to the environment as well as heat transfer from forged material to the forged die). Axi-symetric shape of the wheel hub (Fig.1) enables analysis of only one quarter of the wheel hub cross section in the simulation process.
Two variants of forging process simulation were developed.

Variant 1
Schematic illustration of wheel hub forging is given in Fig. 1.

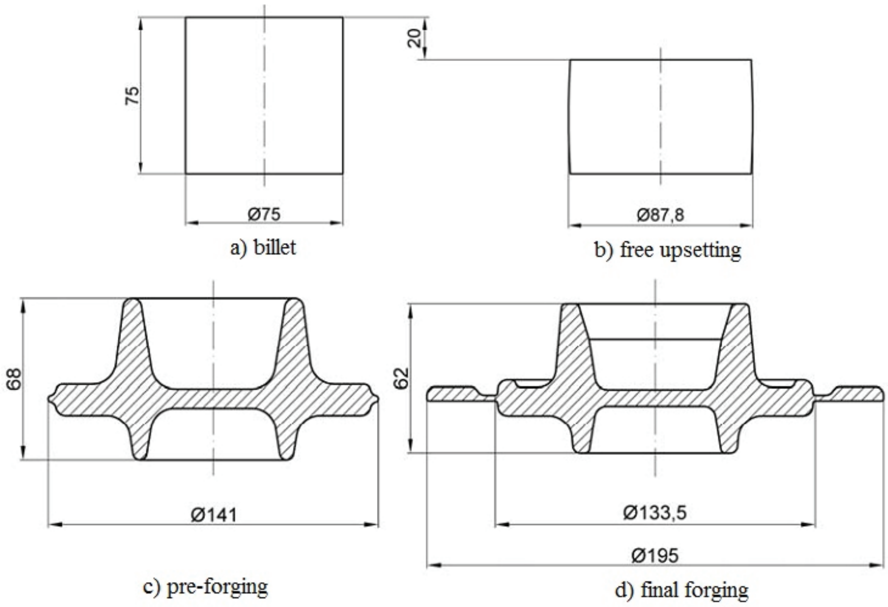


Figure 1 - Schematic illustration of wheel hub forging

In most cases it is not possible to obtain final forging in only one step, but one or more intermediate steps are necessary. In current case of wheel hub forging one preparation step and one perform step are planned before final step is performed.

Preparation step (flat upsetting at small high reduction) is scheduled in order to remove the scale from the billet surface and to improve metal flow in further forging operations.

Next step is preform forging carried out in the close forging die. The main purpose of this step is mass distribution and to prepare forged part for final forging step. This is done by transforming workpiece shape close enough to the final shape. In this way final step is made easier and more effective in term of die filling and in terms of contact stresses reduction.

In simulation of multi stage forging process, Simufact Forming makes possible to use foregoing workpiece shape in the creation of succeeding steps. In this way the data regarding stress-strain state and temperature field, from previous steps, are kept preserved.

Figure 2 illustrates the workpiece after preforming step. It can be seen that after forging step there is incomplete die filling at the edges of wheel hub (black color, Fig.2a and 2b). This unwanted effect may influence die filling in next, final forging step which, as a consequence, would result in incomplete and incorrect final product. Maximum contact pressure in this preforming step is around 670MPa.

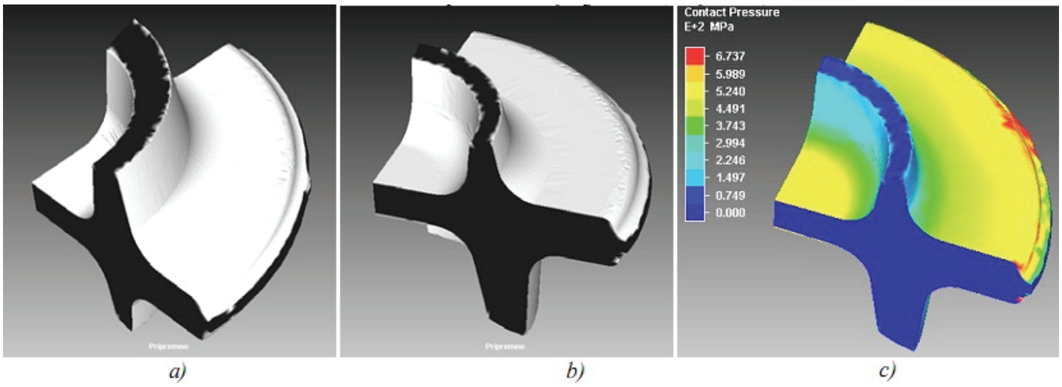


Figure 2 - Forging part after preforming step
a) die filling at the top side, b) die filling at the bottom side, c) contact stress distribution

In the final step preform shape is transformed into final workpiece shape, with final dimensions. In current case die filling is still not complete, as it can be seen in Fig. 3. Also, contact stresses are quite high (≈1400MPa, Fig 4b) which can lead to the premature die failure.

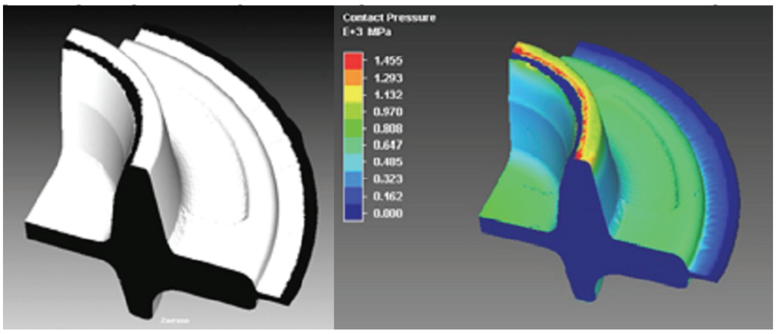


Figure 3 - Final forging part
a) die filling, b) contact stress distribution

Variant 2
In the variant 2 preparatory step (flat upsetting) initial billet is compressed for the amount of 12mm (unlike in variant 1, where this amount is 20mm) – Fig.4.

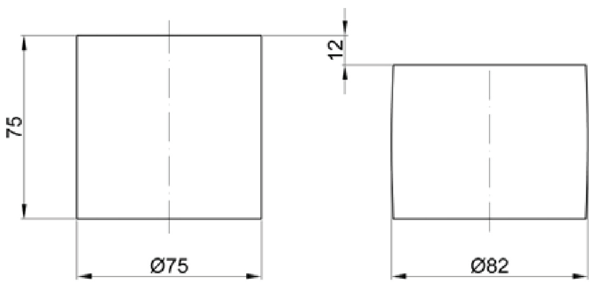


Figure 4 - Preparation step, variant 2

After preparation step preform forging is carried out in the same die as in the first variant. Process simulation shows that in this case complete die filling has been achieved and that maximum contact pressure are less than 1000 MPa (Fig.5).

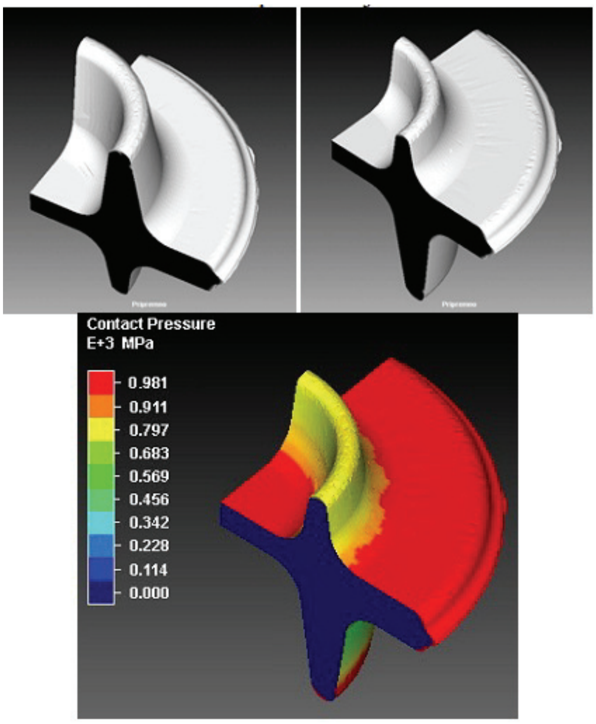


Figure 5 - Preform forging, variant 2
a) die filling – top view, b) die filling – bottom view, c) contact stress distribution

Final forging simulation indicates that complete die filling has been achieved and that final workpiece with correct geometry and dimensions has been produced (Fig.6). Contact pressures are lower than in the first variant and their values are around 1100MPa.
Preformed simulation of wheel hub forging showed that the most influential factor for the correct forgings is the flat upsetting amount in first operation. Complete die filling and error free product is obtained in the case when this amount is 12mm (variant 2).
Practical verification of the improved wheel hub forging had been carried out in the forging plant "Proleter" Arilje. Error-free forging components have been produced (Fig. 7).

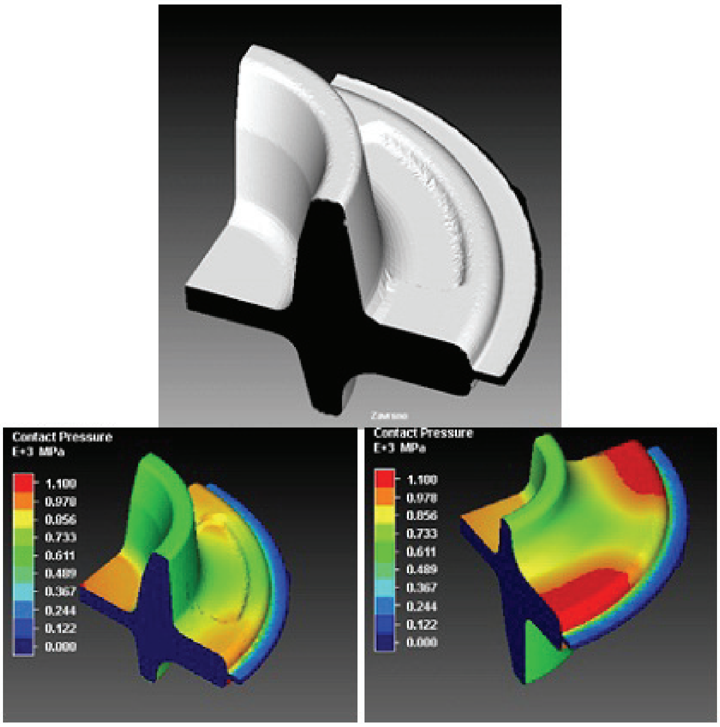
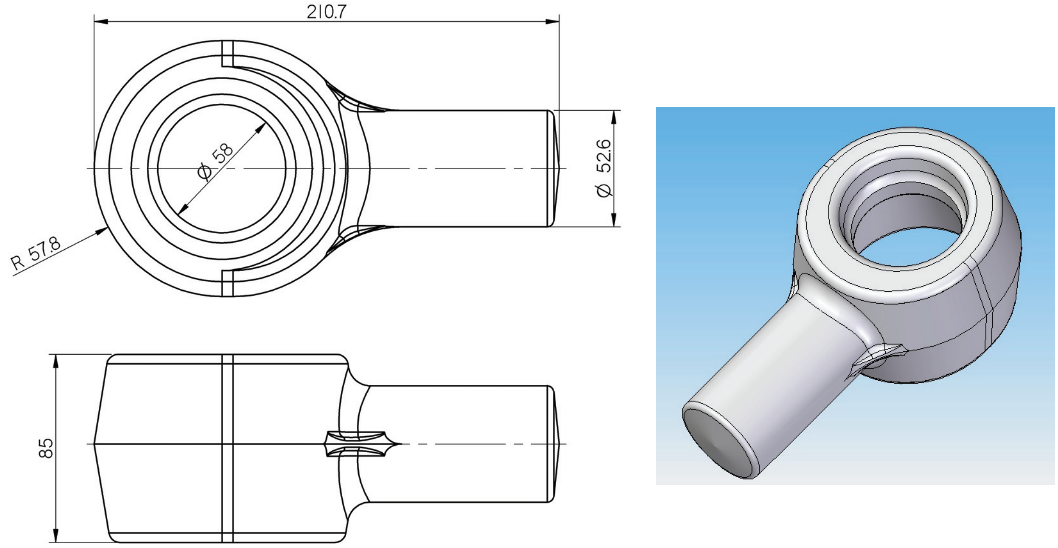


Figure 6 - Final forging, variant 2
a) die filling, b) and c) contact stress distribution

Figure 7 - Component produced according to improved process design and optimization

3. HOT FORGING TECHNOLOGY OF JOINT SOCKET

Joint socket (Fig.8), made from steel material C 4732 (JUS standard), is liable machine component within a steering mechanism of vehicle. Due to high dynamic loading in exploitation, this part is produced by forging and by additional metal cutting operations.



a) b)

Figure 8 - Joint socket: a) drawing, b) 3D model

Preliminary forging process design of joint socket was performed according to classical approach which is based upon the diagram of mass distribution and calculated perform shape. (Fig.9). Material amount predicted for flash was 5% of forgings volume. Based upon calculated shape of perform, cylindrical billet with the dimensions ∅80x160 mm was adopted.

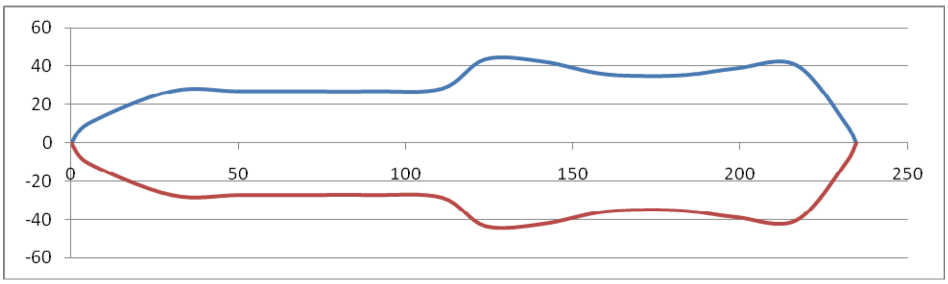


Figure 9 - Mass distribution diagram

Based on forging geometry and on calculated billet shape and based upon experience in forging of similar components at Arilje forging plant, thee forging operations are adopted:

- free upsetting for mass distribution along the longitudinal axis
- preforming forging (open die forging)
- final forging in open die with flash.

For the realization of join socket forging operations required dies are designed and made according to the multi-stage principle, i.e. complete die in one single body.
Process of joint socket hot forging was simulated by Finite Volume Method (FVM) and commercial program package Simufact Forming 9. Initial data are:

- Billet: rod 80mm in diameter and 160mm long
- Preheating temperature of the billet: 1150°C
- Die preheating temperature: 400°C
- Hammer capacity: 80KJ

OPERATION 1 – Free upsetting
This is a preparatory step in which billet (rod) is compressed on one side for the amount of 30mm (Fig.10).
This operation is foreseen for the mass distribution along the longitudinal axis of the workpiece in order to enable better die filling in successive, following operation.

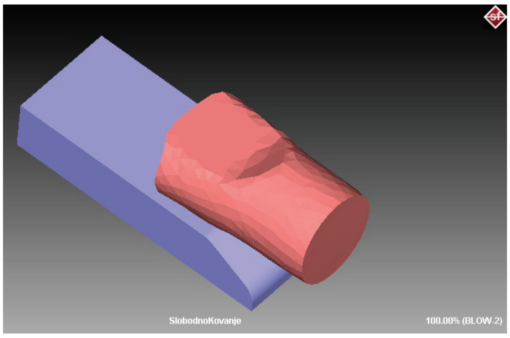


Figure 10 - First forging operation – free upsetting

OPERATION 2 – Preforming forging
This operation is designed in order to prepare the workpiece for the final forging step, i.e. for the creation of transitory forging shape. In this way in final die cavity only minimal correction of the workpiece geometry is needed. Die cavity for preforming operation of workpiece cross-section is obtained by reduction of the shapes of the specific cross-section areas of the final forging component, and by recommendation from the literature.
Preforming operation is performed in special preforming die (Fig.11). Operation is completed after 4 strokes of hammer. Die filling after this operation is 100%.

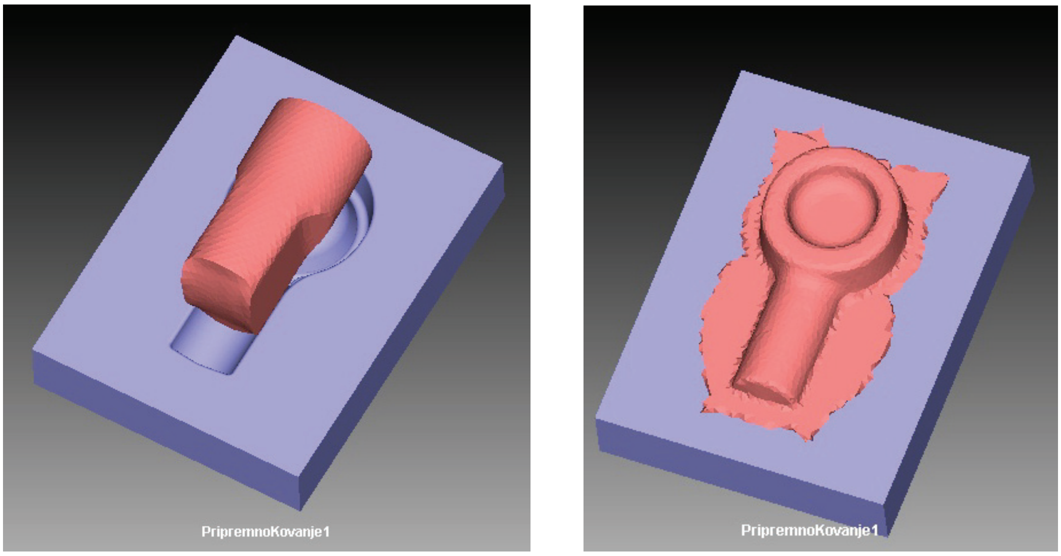


Figure 11 - Preforming forging
a) initial position, b) final preforming shape

In Fig.12 die filling of upper and bottom die is presented (white color – 100% die filling)

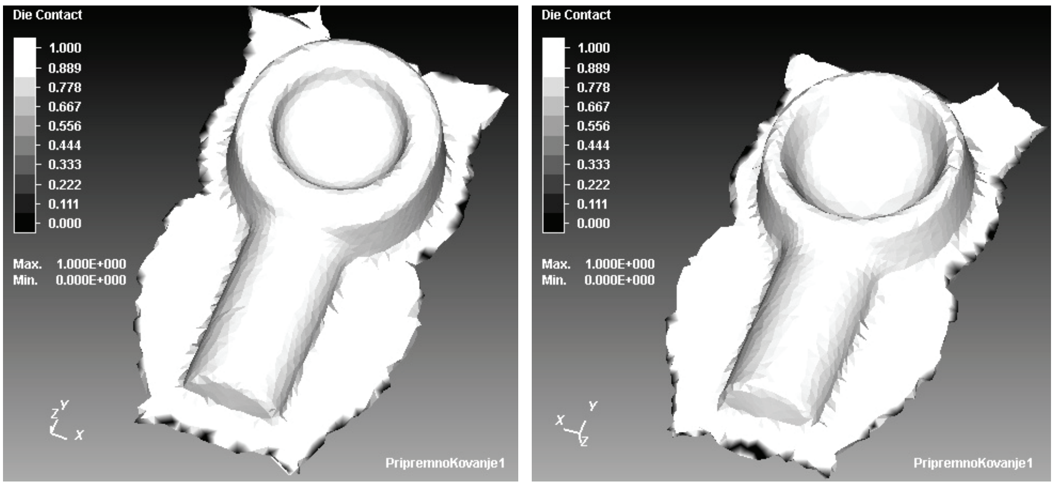


Fig. 12. Die filling of upper (a) and bottom die (b) in preforming operation

Contact stresses at the workpiece after preforming operation of cross-section (Fig.13) are significantly lower than the allowed values (maximal 786 MPa), which is a good starting point for final forging. Maximal allowed values of contact stresses in hot forging are 2000 MPa.

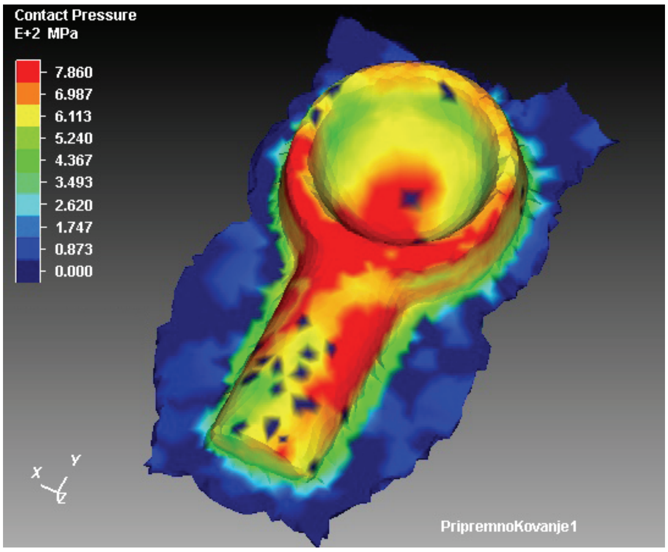


Figure 13 - Constant stress distribution at operation preforming forging

OPERATION 3 – Final forging
In final forging operation workpiece obtains its final shape and dimensions (Fig. 14.). To achieve this, three strokes are needed.

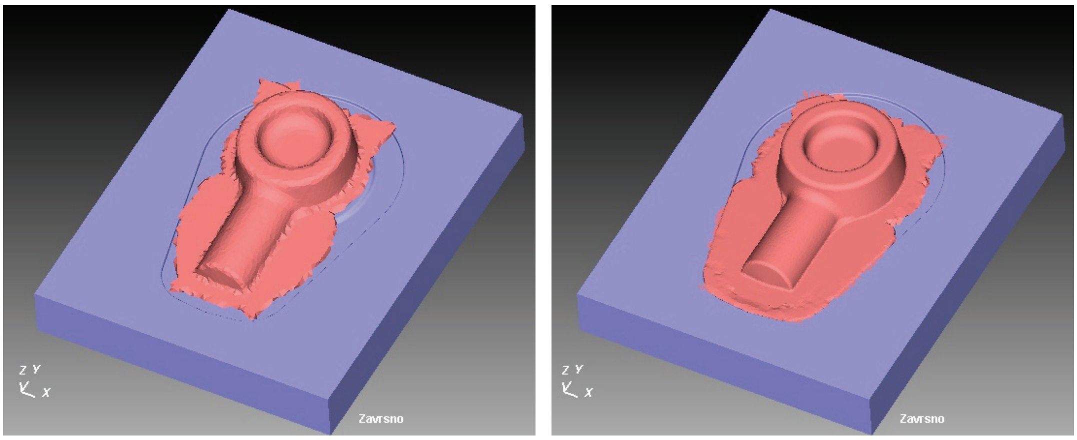


Figure 14 - Initial and end configuration in final forging operation

Simulation results show that maximal contact pressures in final forging operation are lower than 900 MPa (Fig.15). Also, die filling is complete (Fig.16).

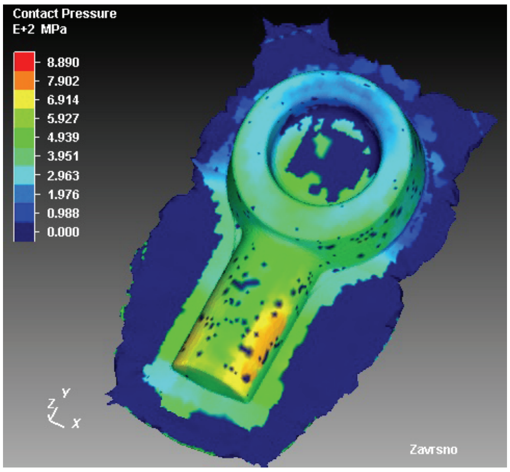


Figure 15 - Constant stress distribution at final forging operation

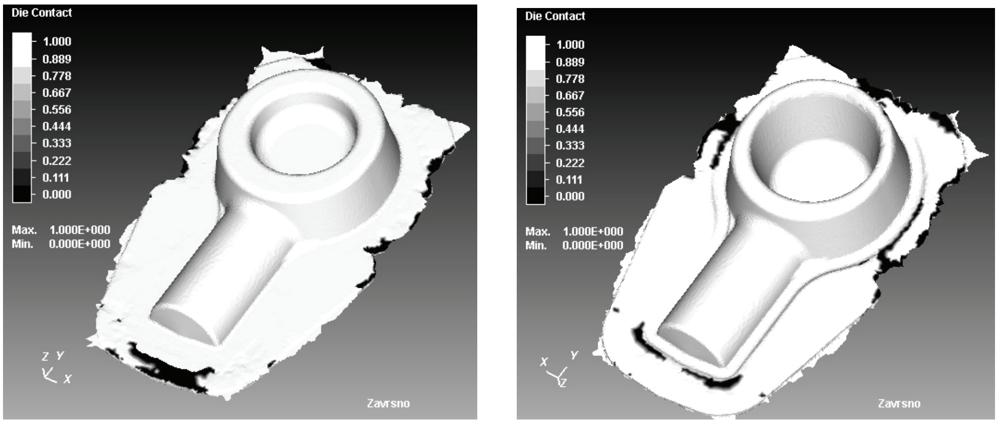


Figure 16 - Die filling of upper (a) and bottom die (b) in final forging operation

Based upon above facts it can be concluded that by implementation of presented manufacturing of joint socket component of high quality can be obtained. Also, die stressing is significantly lower than allowed.

Conducted numerical simulation of joint socket hot forging has been verified in practical industrial environment, in forging plant "Proleter" Arilje. Hammer used in forging process was Huta Zygmund MPM-3150 B with capacity of 80 kJ, weight of the top die (tup) was 3150 kg (Fig.19). Applied lubrication: graphite.

In Fig.17 3D model of both halves of the forging die, modeled using Solid Edge software, are shown.

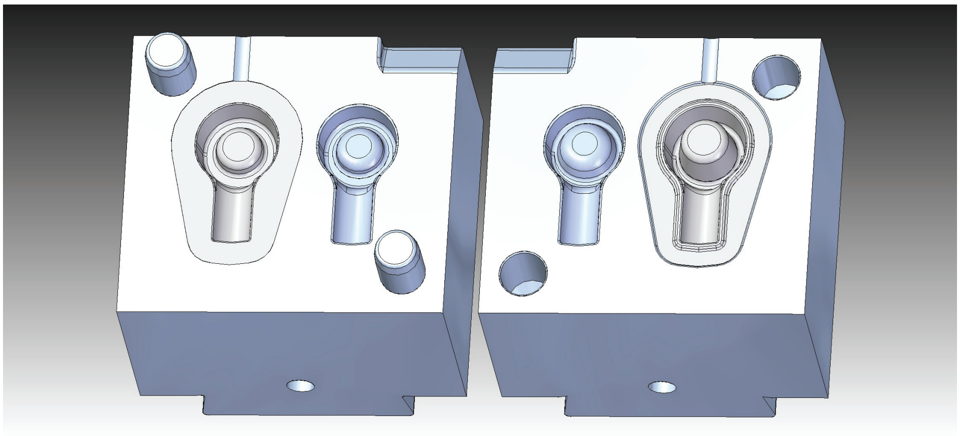


Figure 17 - CAD version of the bottom and upper die

Final shape of the forged joint socket positioned in die is given in Fig. 18.

Figure 18 - Final shape of the forged joint socket

Forging parameters were identical with those applied in the numerical simulation. Results obtained in practical forging experiment confirm simulation results, i.e. complete die filling and relatively low contact pressure between the die and forging component.

Figure 19 - Hammer Huta Zygmund MPM-3150 B

4. CONCLUSION

Hot forging technology is indispensable process for producing high quality parts for different applications. This technology is applied for the manufacture of automotive components, turbine discs, gears, bolts, structural components for machinery, railroad and other transportation equipment. Due to its comparative advantages, hot forging finds wide spread implementation in metal industry all over the world.
Effective and qualitative design of forging technology requires application of modern informational technologies in all stages, starting form workpiece design, multi –stage forging design, optimization of the process, die design, etc. Numerical simulation of the forging process makes possible to perform optimization of forging phases, die wear, material structure, elastic deformation of die and machine, essential for the precision of forgings.
Current paper enlightens the optimization and process design (forging steps set-up) of hot forging process for the production of wheel hub and joint socket. The aim was to determine all relevant parameters which result in correct forged part (complete die filling) and low die stressing.
Results obtained in numerical simulation were verified in practical industrial environment. By inspection of final forging component it has been concluded that they posses high quality and dimension accuracy. Also, those forgings are free of surface cracks, material overlapping and insufficient die filling.

Acknowledgement

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PROJEKTOVANJE I OPTIMIZACIJA PROCESA VIŠEFAZNOG TOPLOG KOVANJA PUTEM NUMERIČKIH SIMULACIJA SA EKSPERIMENTALNOM PROVEROM

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REZIME

Višefazno toplo kovanje omogućuje proizvodnju raznovrsnih delova različitih oblika, dimenzija i materijala. U ovim procesima suštinski problem je optimalno definisanje faza kovanja. Ranije, projektovanje faza višefaznog kovanja bilo je zasnovano na iskustvu i tkz. „trial and error“ proceduri. Danas, sa razvijem softverskih paketa baziranih na metodi konačnih elementa i konačnih zapreminama, postupak projektovanja i optimizacije procesa kovanja vrši se na mnogo efikasniji i pouzdaniji način.

U ovom radu, dat je prikaz optimizacije procesa toplog kovanja glavčine točka kao i faza višestepenog kovanja kućišta zgloba. Optimizacioni kriterijumi bili su minimalan broj faza kovanja, popunjavanje alata i naprezanje gornjeg i donjeg kalupa kontaktnim pritiscima.

Rezultati simulacije i optimizacije su provereni praktično, u industrijskom okruženju.

***Ključme reči**: Višefazno kovanje, Projektovanje tehnologije, Optimizacija, Numeričke simulacije.*