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INFLUENCE OF PREFOM SHAPE ON DIE LOAD AND PART ACCURACY IN HOT FORGING OF PNEUMATIC CLAMP

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ABSTRACT

Hot forging of parts with complex geometry often requires high external loads in order to ensure complete die cavity fill. Therefore, during hot-forging process, the tools are not only subjected to thermal stresses, but also to thermo-mechanical stresses. High external loads and working pressures cause lower toll service life and poor part accuracy. Therefore, one of the most important aspects of hot forging process design is to reduce working pressures and loads.
In this paper the influence of process sequence design and intermediate shapes on die cavity filing process, part errors occurrence, and contact pressures in hot forging of pneumatic clamp is discussed. Pneumatic clamp is a part with extremely complex geometry that is produced in large quantities for electro industry. Process modeling based on Finite Element (FEM) and Finite Volume (FVM) approach was performed using Simufact.Forming 8.1 commercial program package
Keywords: *Hot forging, contact pressure, FEM, FVM.*

1. INTRODUCTION

Hot closed-die forging of complex part often involves multi-axial material flow and large deformation and thus high forging load (working pressure) in order to achieve desired shape of forging component is required. But, forming load and compressive stresses within workpiece cause the die walls to deflect elastically, which, in turn, might produce forged part out of tolerance. Also, high contact pressures initiate die wear and mechanical cracks appearance at die surface that cause tool failure [1]. Therefore, the measures for reduction of contact pressures and die stresses are of great importance for improvement of quality and the dimensional accuracy of forged components as well as increase of tool service life. According [2] starting points for decreasing the forging load in hot forging are related to improvement of factors and properties like are: billet material, pre-heating, lubrication system, lay-out of die shape (radii, angels), and flash design., but optimization of the process sequence design and preform shapes offers the most possibilities. With proper number of preform steps and adequate preform shapes, die filling without defects, high quality of the surfaces and high accuracy of the forged part can be achieved, and material loses into the flash and die wear reduced [3].

Forming sequence design of hot forging process is time and cost consuming procedure in which many design possibilities should be considered as well as numerous process variables determined [4]. In the past this procedure was relied on activities strongly dependent on human expertise, intuition and creativity [5, 6] and performed by iterative trial-and-error approach which requires extensive experimental work. However in many cases, this trial-and-error procedure is neither optimal nor cost effective in terms of achieving the desired properties of the finished product. Recent development of computer-aided simulation techniques made it possible to upgrade efficiency of the process of forming-sequence design. Numerical simulations based on Finite Element Method (FEM) reduce time and man power in process design and enable simultaneously analysis of large number of process variables and preform solutions before actual try out [7,8,9, 10] Result of this is significant reduction of manufacturing cost and overall improvement of forging process and product quality.

This paper deals with contact pressure and die load in case of hot closed-die forging of a complex part such as pneumatic clamp. The pneumatic clamp shown in Fig.1 is a part of electric pole in transmission lines that is used as cable carrier and stretcher. Being exposed to heavy thermo-mechanical loads it requires both high strength and toughness and therefore this yoke-like part is traditionally manufactured by hot closed-die forging. However, its irregular geometry (combination of oblong body and yoke-like head with laminated elements) is very unfavorable for forging technology. There are many obstacles when forge the pneumatic clamp and similar yoke-like parts. Due to complex geometry forming process is being with difficulties resulting very often in non-uniform material distribution and cavity underfilling. In practice designers try to solve this by enhancing the volume of billet and creating dies with large flash area and minimal flash land thickness. This is not always optimal solution because it leads to an increase of forging load and dies wear occurrence. Cold forging is sometimes employed for modeling yoke-like parts in order to avoid subsequent trimming and machining operations necessary after hot forging. [11,12]. Additionally, cold forging offers possibility to produce yoke-like elements in net shape tolerances such as constant-velocity joint housing or steering yoke used in automotive industry [13]. In comparison to hot forging effects of material saving are up to 40% [11]. But cold forging of yoke-like parts is limited with dimension of final product and especially with material formability. Technical difficulties when cold forge complex yoke-like parts in some cases may be overcome by alternative procedures like one in which final products is obtained by welding of forged head and shaft parts [13]. But two separate forging operations and welding procedure significantly increase time and particularly manufacturing cost of products. Further due to welded zone the risk of fatigue cracks appearance raises.

Fig.1 - Pneumatic clamp

In the following sections the process of hot forging for pneumatic clamps is investigated by Finite Volume (FVM) modeling approach and using Simufact.Forming 8.1 commercial program package. The aim is to find the influences of the intermediate shape and preforming steps on material flow, die cavity filling, part accuracy, contact pressures, and die loads in the operation of final forging. Preforming operations were performed as open and closed (impression) die forging.

2. PROCESS DESCRIPTION AND MODELING

The process sequence in case of hot closed-die forging for the pneumatic clamp comprises following operations: preforming, final forging, flash trimming and plate punching. Starting bulk (billet) of proper size is firstly cropped from rectangular bars and then heated to forging temperature. It volume is about 20% larger from the volume of final part after machining because of loses into the flash, draft, radii, scrap and machining allowances that should be included in volume calculation. For small series flat upsetting (open die forging) is commonly applied in preforming of the billet. The goal is to obtain proper material distribution along longitudinal axis of workpiece. In this case the number of preforming stages necessary to attain an intermediate shape depends mostly on operator's skills. Usually it needs several blows of hammer to reach desired shape [14]. Such large number of the preforming stages increases manufacturing time and energy consumption. Also there is limitation in the form of cross section of the preform when used flat upsetting in preforming stages. Result of this could be cavity underfilling in the final forging and an overload of the finishing dies. To overcome these demerits dies with one or more impressions are normally employed in the performing stages.
Final shape of the pneumatic clamp is imparted by the final impression which is designed with flash. Complex form of the pneumatic clamp requires an optimization process of the geometry of the finishing dies and flash geometry. In that sense special attention should be paid to the design of the different sections in the final die cavity which have to be balanced in order to avoid extreme differences in metal flow as the flash dimensions should provide correct die cavity filing with reasonable forging pressures. Operations of flash trimming and plate punching should be carried out immediately after final forging to prevent workpiece bending which can occur due to unsteady cooling process.

2.1 Process modeling

The forging process for manufacturing pneumatic clamp has been analyzed by using Finite Volume Method and commercial program package Simufact.Forming 8.1. Finite Volume Method is widely used for analyze of forging process due to its capabilities to model the complicated geometries of tools and parts and to consider forming processes from many aspects. Compared with FE, simulations based on FV approach are both less time consuming and demanding in term of computer capabilities. The geometry of the dies and initial billets were set in SolidEdge V.18 CAD program and exported to Simufact.Forming 8.1. Modeling of the forging process was performed according process sequence design described in previous chapter. Both variants of the preforming operations (performing with open and closed dies) were included in the simulation and analyzed.
Dimensions of the forged pneumatic clamp (after trimming and punching) are given in Fig. 2. The material was steel C45. The material data necessary for simulation were adopted from the list of materials incorporated in Simufact.Forming8.1. In simulations, the following assumptions of the process variables are implied: the dies are considered as rigid bodies, fixed bottom die and

movable upper die, strain rate $\dot{\varphi}$=6.5 [s^{-1}]. As for boundary conditions the initial forging temperature is 1150°C, preheated dies temperature 400°C, constant friction model is applied and friction factor is assumed to be m=0.3 [15]. The capacity of pneumatic hammer which is used in simulations is limited to 80kJ in respect of the actual hammer capacity in industry.

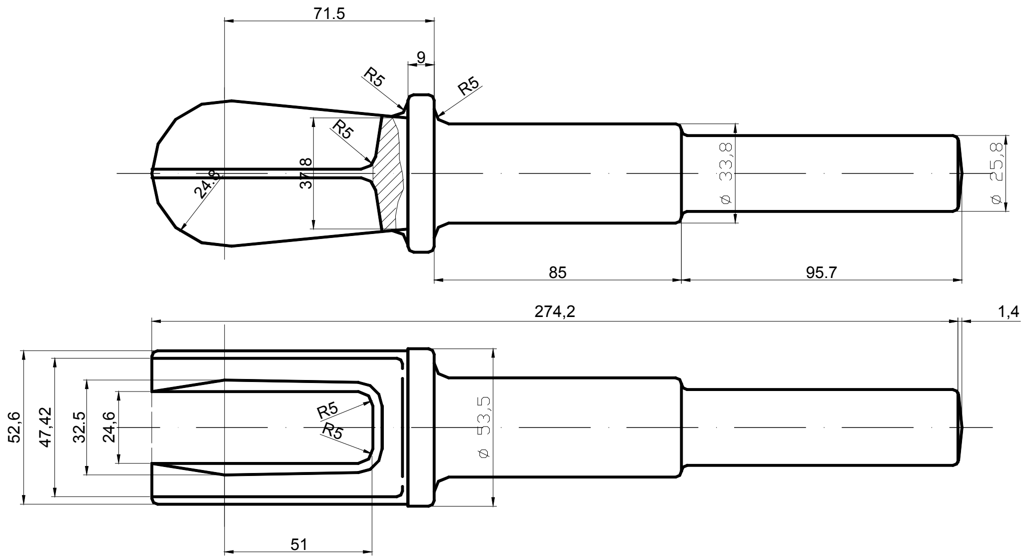


Fig.2 - Geometry of the pneumatic clamp after forging

Design of the finishing dies and selections of draft, fillets and radii is performed according recommendations given by experts [9, 15, 16]. Details of flash geometry in the finishing dies are depicted in Fig. 3. Thickness (s) and width (b) of the flash land are calculated according following empirical expressions [16]:

$$s = 0.017 \cdot d_1 + \frac{1}{\sqrt{d_1 + 5}} \tag{1}$$

$$\frac{b}{s} = \frac{30}{\sqrt{d_1\left(1 + \frac{2d_1^2}{h(2r_h + d_1)}\right)}} \tag{2}$$

where are:

d_1 – diameter of the forge at parting-line surface
h – maximal height of the forge in direction of forging
r_h – distance between the highest elements of the forge and parting line

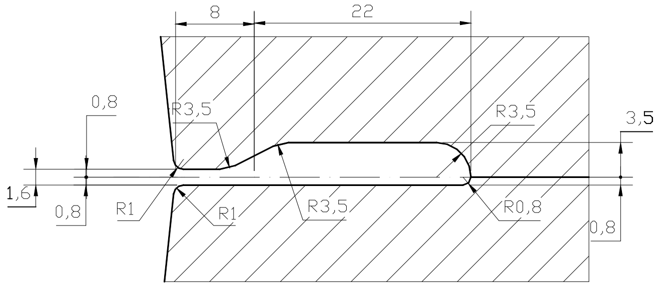


Fig.3 - Geometry of the flash in the finishing dies

3. RESULTS OF FVM SIMULATION

3.1 Preforming with open dies

Intermediate steps in preforming with open dies are schematically illustrated in Fig.4. Simulation is prepared according to an actual process design for forging of the pneumatic clamp which is performed in A.D Proleter- Arilje. Dimensions of the billet were 55x55x113mm [14]. It requires 6 blows while rotating the workpiece between upper and bottom die to obtain preform which is then forged into the final shape. Effective stresses during preforming operations are given in Fig.5.

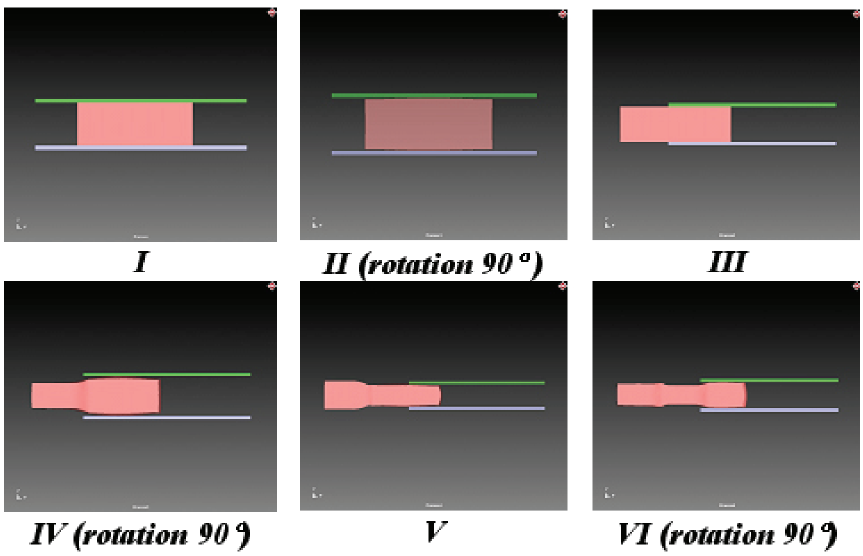


Fig.4 - Preforming stages realized with open dies

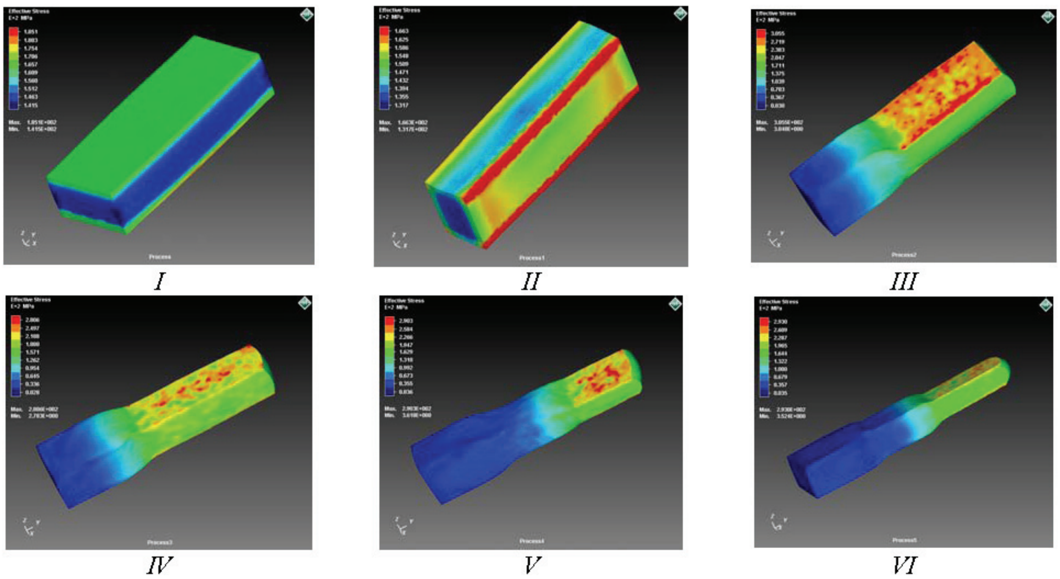


Fig.5 - Effective stresses in workpiece during preforming with open dies

Material flow and cavity filling process during final forging is shown in Fig.6. As it can be seen process of the cavity filling is non-uniform. At the beginning of the operation head modeling is dominant process. After full contact between dies and workpiece is established, the body section of pneumatic clamp starts to form. The die cavity filling in this zone is very difficult because of very low horizontal component of the total force. In the final phase material fills the dies corners in the head section.

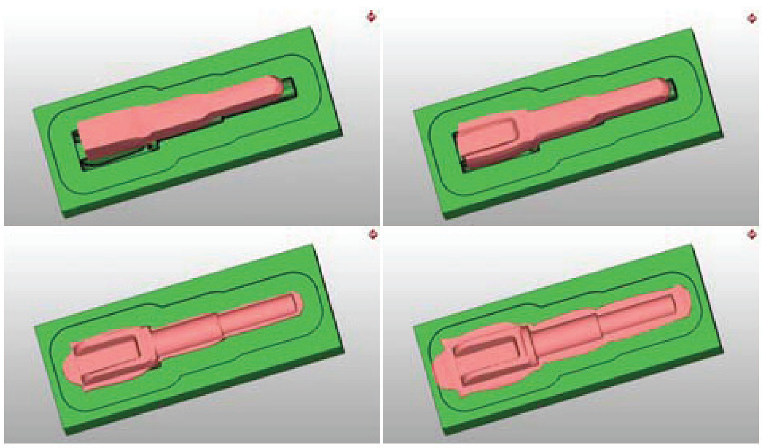


Fig.6 - Material flow in forging of pneumatic clamp

For complete cavity filling of the finishing dies, 3 blows are required when use 80kJ hammer. Fig.7 displays distribution of contact stresses at the end of forging. Predicted values of the contact stresses are pretty high 1800MPa in average and with maximum values of 3000 MPa. It means that finishing dies are overloaded in some sections which may reduce their service life significantly.

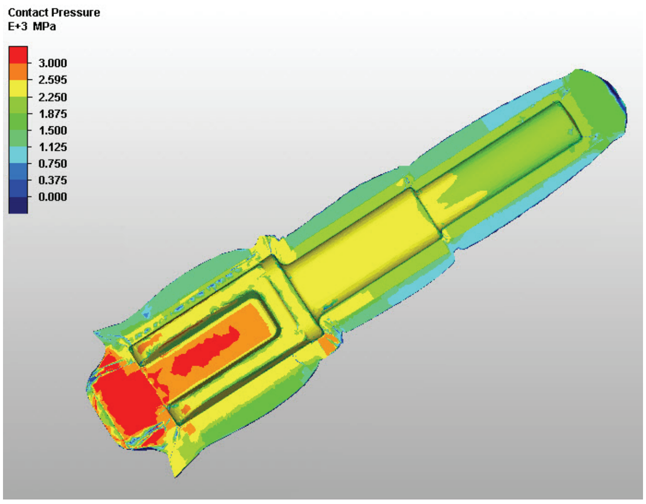


Fig.7 - Contact stresses in the operation of final forging (open-die preform)

Defects and poor geometry at head section of the pneumatic clamp as a result of insufficient cavity filling are reported from practice [14]. Investigated this problem it was concluded that even small dislocation of the preform from its optimal position in finishing dies lead to underfilling in this section. It is illustrated in Fig. 8 for case when the preform is set 15 mm away from it nominal position. Cooling of the workpiece and unallowable drop of the temperature may be responsible for cavity underfilling, too.

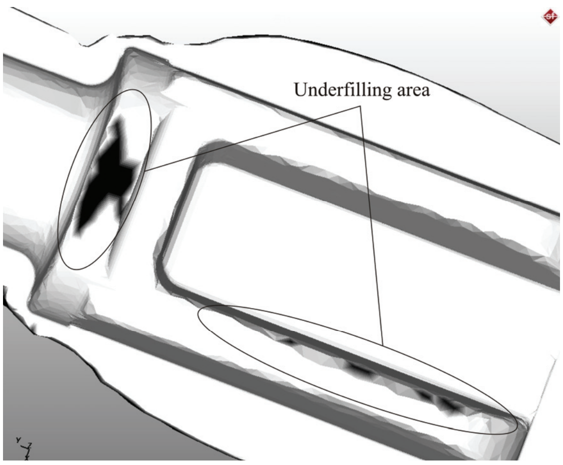


Fig.8 - Under filling areas in case of non-proper positioning of the preform in the finishing dies

3.2 Preforming with impression-dies

As it mentioned before, preforming with closed or impression-dies allows modeling of preforms with complex geometry and cross sections differ from rectangular. Additionally, closed-die forging ensures better control of material flow, good repeatability of the preform geometry, and brings the workpiece shape close enough to the finishing configuration of the forged part.
Two types of immersions could be employed for preform shaping. First type is applied with goal to distribute material into the rough shape in accordance to the needs of later cavities. Second type is a cavity for preliminary shaping in which the workpiece is processing into a shape that more closely resembles the final product. In some cases, preforming steps for preliminary shaping might be omitted and in that case workpiece is directly moved to final impression. It reduces forging time, but increases die load in final forging. Required number of preforming stages which depends upon the forging mass. There are different approaches used in engineering practice, but the questions what is optimal number of the intermediate steps and what is the best design of them do not have correct answers yet [9].
Here, in line with previous, two preforming procedures performed with impression dies are analyzed. In the first case, only impression for rough shaping is employed in preforming steps, as in second there are two preforming impressions (for rough and preliminary shaping). In both cases, the geometry of the impression for rough shaping is identical.

3.2.1 Preforming in one operation

Fig.9 shows starting position of the billet in the die impression which is used for rough shaping. In accordance with the results of simulation the cross-sections of this impression are made elliptical in order to increase the portion of horizontal forces which are crucial for proper material flow along workpiece axis.

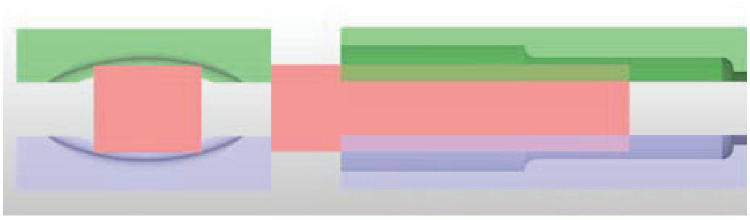
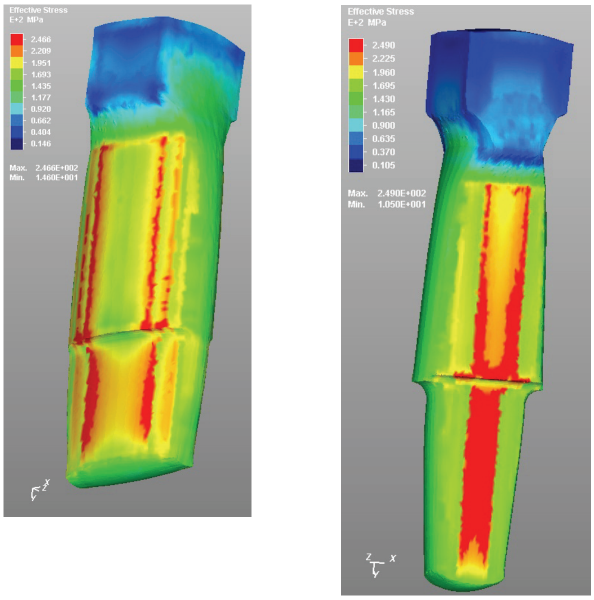


Fig.9 - Elliptical impression for operations of mass distribution

In this case, bulk 40x50x170mm is used as the billet. The volume of the billet is identical to one used in flat upsetting, but starting height was chosen smaller with goal to avoid an operation of upsetting for billet elongation. Intermediate shape for final forging is obtained by 2 blows and 90°rotation of the workpiece around longitudinal axis after first blow. Intermediate shapes during preforming steps and effective stresses within workpiece are depicted in Fig.10.
Material flow in operation of final forging is similar to the process illustrated by Fig.6, but predicted contact pressures (Fig.11-left) are lower in average for about 50% in comparison to previous case, as the maximal contact pressure was 1900MPa. Moreover, only 2 blows of 80MJ hammer are needed for complete die cavity filling (Fig11-right). Considering part accuracy, simulation revealed that cavity underfilling problem in the head section may also occurs in case of poor workpiece positioning, but here the positioning problem is less emphasized.



I step II step

Fig.10 – Preforming steps and effective stresses in preforming operation for rough shaping

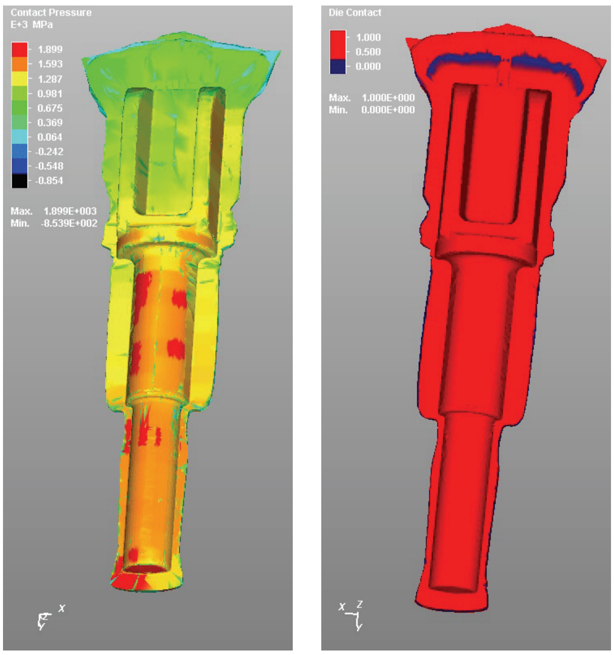


Fig.11 - Contact stresses (left) and die-material contact (right) in the operation of final forging (roughly-shaped preform)

3.2.2 Preforming in two operations

3D model of the tool and layout of low die which consist impressions for mass distribution, preliminary shaping and final forging is given in Fig.12. In this case after operation of rough shaping the workpiece is moved firstly to impression for preliminary shaping, and then to the final impression. Preliminary shaping is commonly applied when forging part with complex geometry to ensure complete die cavity filling in final forging. At the same time it helps to reduce contact pressures and die load. The preform shape after preliminary forging as well as effective stress and effective strain within workpiece are displayed in Fig.13.

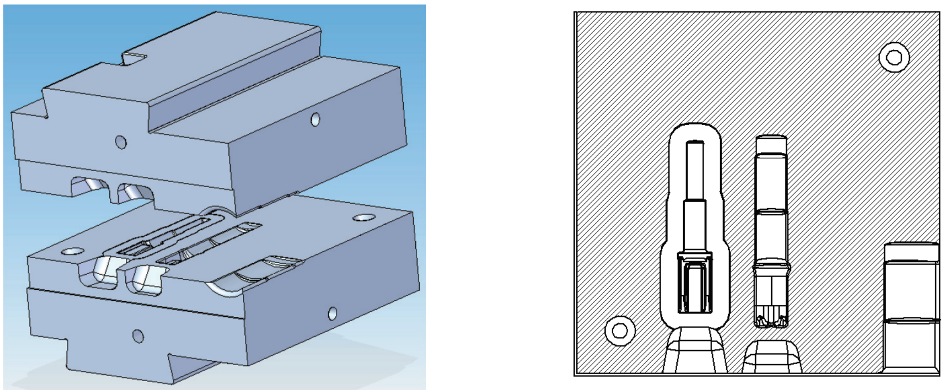


Fig. 12 - 3D model of the dies with two preforming and the final impression

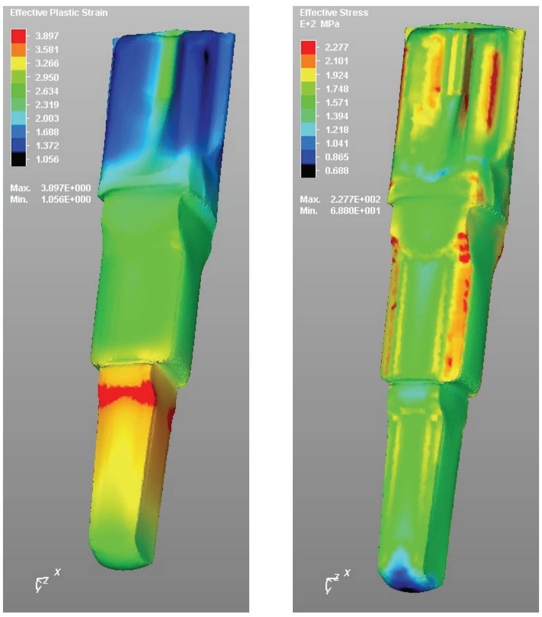


Fig. 13 – Effective strain (left) and effective stress (right) after prelimiray shaping

Final forging requires 2 blows of 80MJ hammer (Fig.14) for complete die cavity fill. Simulation shown that in this case defect free part is obtained and the amount of material into the flash is reduced compared to forging process without preliminary shaping (Fig.15-right). Also, contact pressures are significantly lower with maximal predicted value of 850MPa (Fig.15-left).

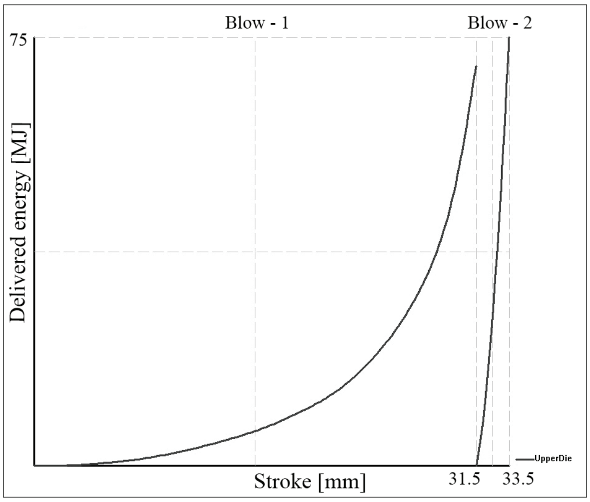


Fig. 14 - Energy consumption in final forging (roughly and preliminary shaped preform)

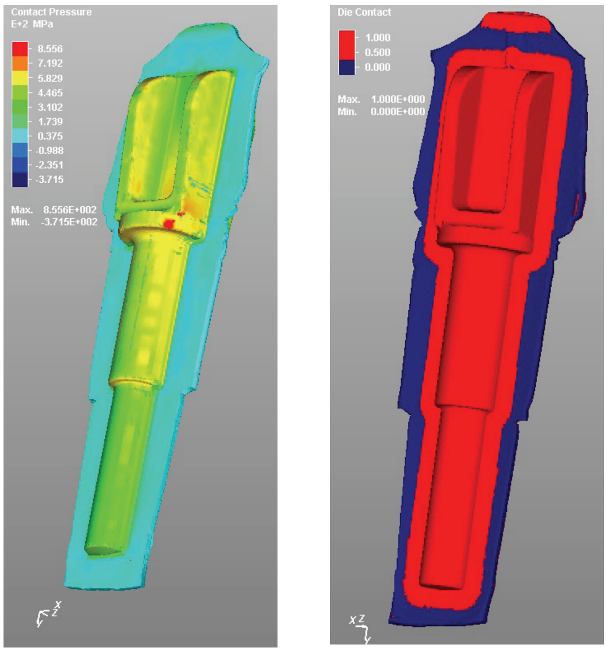


Fig.15 - Contact stresses (left) and die-material contact (right)t in the operation of final forging (roughly and preliminary shaped preform)

4. CONCLUSION

In this paper hot forging of the pneumatic clamp is analyzed by FVM simulation with goal to reduce contact pressures in the operation of final forging and to improve geometrical accuracy of the forged part. In that purpose tree different performing sequences are designed. From obtained results following can be concluded:

- Preform stages and intermediate shape influences very much both: accuracy of final part and die load
- Preforming stages realized with open dies are very time and energy consuming
- Part accuracy is very sensitive to the positioning and centering of the preform in the finishing impression.
- Underfilling may occurs at upper surface of the head section
- Contact pressures in the operation of final forging are very height in case when use the preform obtained by flat upsetting
- Preforming with impressions for mass distribution and preliminary shaping ensure defect-free, complete die fill and small metal loses into flash

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UTICAJ MEĐUFAZNOG OBLIKANA OPTEREĆENJE ALATA I TAČNOST DELA KOD TOPLOG KOVANJA PREUMATSKE SPOJNICE

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REZIME

U procesima toplog kovanja delova složenog oblika često je neophodno primeniti velike deformacione sile kako bi se obezbedila potpuna popuna kalupa. Zbog toga ovi alati nisu izloženi samo termičkim, već i značajnim termo-mehaničkim naprezanjima, koji negativno utiču na radni vek alata i tačnost otkovaka. Jedan od primarnih ciljeva pri projektovanju procesa toplog kovanja je redukcija kontaktnih pritisaka, odnosno smanjenje opterećenja alata
U ovom radu razmatran je uticaj operacija predoblikovanja, odnosno, međuoblika na proces popunjavanja kalupa, pojavu grešaka na finalnom otkovku i veličinu kontaktnih pritisaka pri kovanju pneumatske spojnice. Pneumatska spojnica je deo kompleksne geometrije koji se za potrebe elektro industrije izrađuje u velikim serijama. Proces kovanja analiziran je pomoću metode konačnih zapremina i Simufact.Forming 8.1 programa namenjenog za simulaciju postupaka zapreminskog oblikovanja.
Ključne reči: *Toplo kovanje, kontaktni pritisci, metod konačnih zapremina*