PAPER • OPEN ACCESS

Analysis of the Impact of the Machine on the Forging Process of a Connecting Rod using Numerical Simulation

To cite this article: Marko Deli *et al* 2022 *IOP Conf. Ser.: Mater. Sci. Eng.* **1271** 012015

View the article online for updates and enhancements.

ANALYSIS OF THE IMPACT OF THE MACHINE ON THE FORGING PROCESS OF A CONNECTING ROD USING NUMERICAL SIMULATION

Marko Delić[1], Vesna Mandić[1], Filip Pavlović[2]

[1]Faculty of Engineering University of Kragujevac
[2]IMW institute

Corresponding author's e-mail: marko.delic@kg.ac.rs

Abstract. The application of numerical simulations of production technologies, using the finite element method or the finite volume method, is a widely used approach in advanced engineering design and research. Unlike industrial experiments, this approach allows the analysis of the influence of different process parameters on the output performance of a workpiece. The paper analyzes the influence of the choice of the machine on the forging process of the connecting rod, which is made, among other things, for the needs of the auto industry. For this purpose, numerical experiments were carried out, using the finite volume method and the Simufact.forming software package, with variations of three types of forging machines: drop forging hammer, crank press and screw press. Finally, the results of the numerical experiments and conducted analyses are presented, with concluding considerations and recommendations.

Keywords: Numerical simulation, Finite volume method, Forging

1. Introduction

Hot forging technology has an important role in modern industry. Forgings made by hot forging have good mechanical properties and are therefore widely used in the automotive and military industry.In hot forging processes, machines are used that differ according to their construction and mode of action. Hot forging machines are divided into several groups: forging hammers, crank, screw and hydraulic presses. Within this paper, the impact of the forging machine type on the hot forging process will be determined using numerical simulations. The impact of the forging hammer, crank press and screw press will be discussed.

Each of the listed types of forging machines has its own characteristics.The action of the forging hammer is impact, the velocity of the forging mallet can be up to 10m/s, and the filling of the forging engraving is better in the vertical direction due to inertial forces. According to their properties, screw presses are between forging hammers and crank presses and are used only when one forging operation is required for forging a part - final forging. Crank presses do not have an impact effect, so complex engravings are more difficult to fill than usinga forging hammer, because the material flow is more intense in the zone of the parting plane and more difficult in the vertical direction.

The hot forging process is the subject of numerous researches.The analysis of the hot forging process of aluminum 5083, previously deformed by the ECAE (Equal Channel Angular Extrusion) process, using the finite element method (FEM) is presented in [1]. In [2], two ways of determining the forming load were compared, analytically and using FEM. The process of hot forging of the connecting rod on the crank press was analyzed. The impact of the workpiece dimensions on the forming load and the effective stress in the process of hot forging of the pin on the screw press (1500kN) was discussed in the paper [3]. The aim of the research, which was carried out experimentally and numerically, is to reduce the forming load and the effective stress, and it was concluded that by reducing the volume of the workpiece, i.e. determining the optimal billet volume can reduce the value of the forming load. A detailed review of the materials processed by hot forging as well as the materials used to make dies for hot forging is given in [4]. Engineers have the goal to reduce material consumption by optimally determining the workpiece dimensions and thus preventing excessive filling of the flash [5], and FEM analysis plays a significant role in this process. The finite element method is used when defining the forging technology, primarily the workpiece dimensions and the choice of the forging machine [6]. For the successful carrying outof the forging process, the reliability of the press is very important, and the FEM analysis of the loaded componentsof the press and the heat impact can be important [7, 8]. The calculation of the workpiece dimensions and other production parameters can be automated using special software [9].

2. Description of the research methodology

The aim of the research presented in this paper is to determine the impact of machine selection on the process of hot forging of connecting rod, that is an important component for parts in the auto industry.In order to verify the obtained results, an analysis of the industrial process was carried out, so that CAD models of the connecting rod and corresponding engravings of the forging dies for two operations were obtained from the partner company Zastava Kovacnica.

In order to analyze the impact of the choice of forging machine on the forging process and the performance of connecting rod forging, three numerical experiments were performed on different machines (forging hammer, crank press, screw press). Numerical simulations of all analyzed forging processes were realized using Simufact.forming software and finite volume method (FVM) [10]. For all numerical simulations, the same parameters of the process were followed (filling of the engraving, material flow into the flash, homogeneity of the temperature field which affects the microstructure of the forging, required forming load, i.e. forging energy, as well as strainand stress fields in the forging).

The process of hot forging of the connecting rod consists of two operations, preliminary and final forging, and the design of the technology is based on the calculation of reduced forging for the preliminary forging operation, in order to perform an optimal redistribution of the mass of the workpiece and for the correct filling of the final engraving. The billet dimensions for forging the connecting rod is ϕ65x111mm, made of 42CrMo4 material, which is heated to a temperature of 1225°C. The dies were heated to 150°C, and the ambient temperature for process simulations was set to 50°C.

The design of the reduced forging is based on the shape and dimensions of the final forging. A preform (reduced) forging is a shaped perform of regular circular cross-section that is the same length as thefinal forging, where the cross-sectional area is equal to the sum of the cross-sectional area of the forging and the flash at a certain cross section.CAD models of the connecting rod forging and the calculated and modeled perform forging (shape after preforging) are shown in figure 1. The virtual perform forging for FVM analysis is discretized with 4mm facets.

Forging die engravings for both forging operations are shown in figure 2, as CAD models of hammer forging dies. The same engravings were used for the other two numerical experiments on other forging machines, in order to compare and analyze the results. The die material is H13, and rigid dies with heat conduction were used in the simulations.

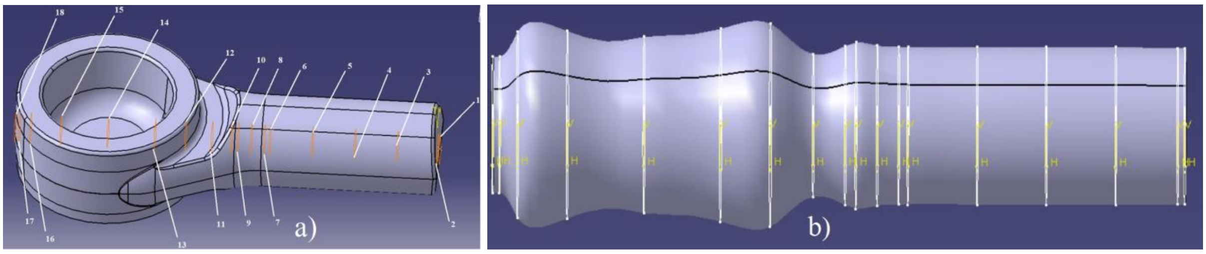

Figure 1. CAD models of forging a) and reduced forging, b) with characteristic sections

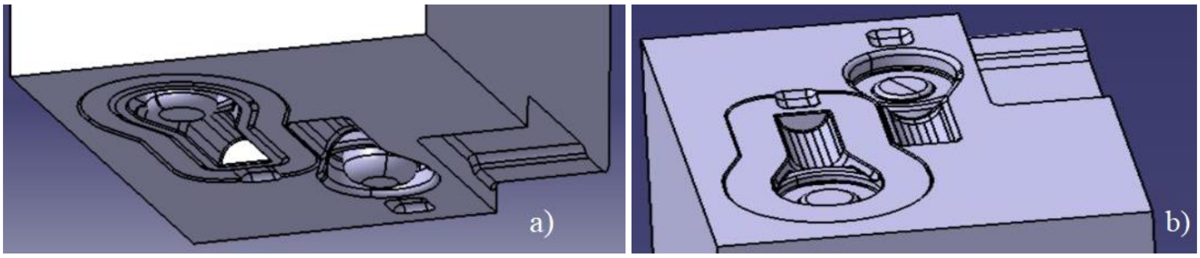

Figure 2. Tool engravings for preliminary and final connecting rod forging operations, a) upper die b) lower die

The properties of the considered presses (forging hammer, crank and screw press) are given in table 1. According to the data listed intable 1, in the Simufact.forming software i.e. in its press definition module "virtual presses" with given properties are defined.

Table 1. Press properties

Drop forging hammer	Crank press	Screw press
Max. impact energy: 9500 kGm Weight of falling part:3570kg Number of blows: 3	Crank radius: 300 mm Rod length: 1200 mm Revolution: 30 Rpm	Gross energy: 40000 [J] Maximum ram speed: 340 mm/s Efficiency during stroke [0-1]: 0,9

3. Research results and comparative analysis

The results of numerical simulations of the connecting rod forging process in the final forging operation were considered, namely the fields of effective plastic strain, effective stress and temperature in the forging, then forming load diagrams, and the material flow into the flash and filling of the engravings via the *Die contact option* (two-color display) were monitored.

The results of the numerical experiment when a forging hammer was used are shown in figure 3. The effective plastic strain is the highest in hammer forging process and in that case the strainfield is the least homogeneous compared to other used forging presses. The maximum value of the effective plastic strain is 2.93, but the area belonging to higher values is located on the flash of the forging, which is subsequently removed, while the maximum values on the forging itself have smaller values and amount to 2.2. The maximum value of effective stress is 315MPa. The highest values of the effective stress are inside the forging and such values are expected because the stress in the material depends on the strain rate because the viscoplastic behavior of the material is present. The temperature field is divided into several areas. The highest temperature is 1178ºC and belongs to the area located on the surfaces of the forging that were least in contact with the die (top of the forging and engraving). One of the most important things in the analysis of the forging process is to check the fulfillment of the die engraving, which is checked in numerical simulations with the *die contact option*.Figure 3.d shows that the engraving is completely filled, that confirms the success of the process.The protrusion of the material into the flash is uniform in the dividing plane. The maximum value of the forming load

IOP Conf. Series: Materials Science and Engineering 1271 (2022) 012015 doi:10.1088/1757-899X/1271/1/012015

is large and amounts to 32000kN. The value of the formingload increases sharply after reaching the forming stroke of 46 mm in the third blow of the hammer and corresponds to the moment when the material starts to protrude into the flash and the die closes.

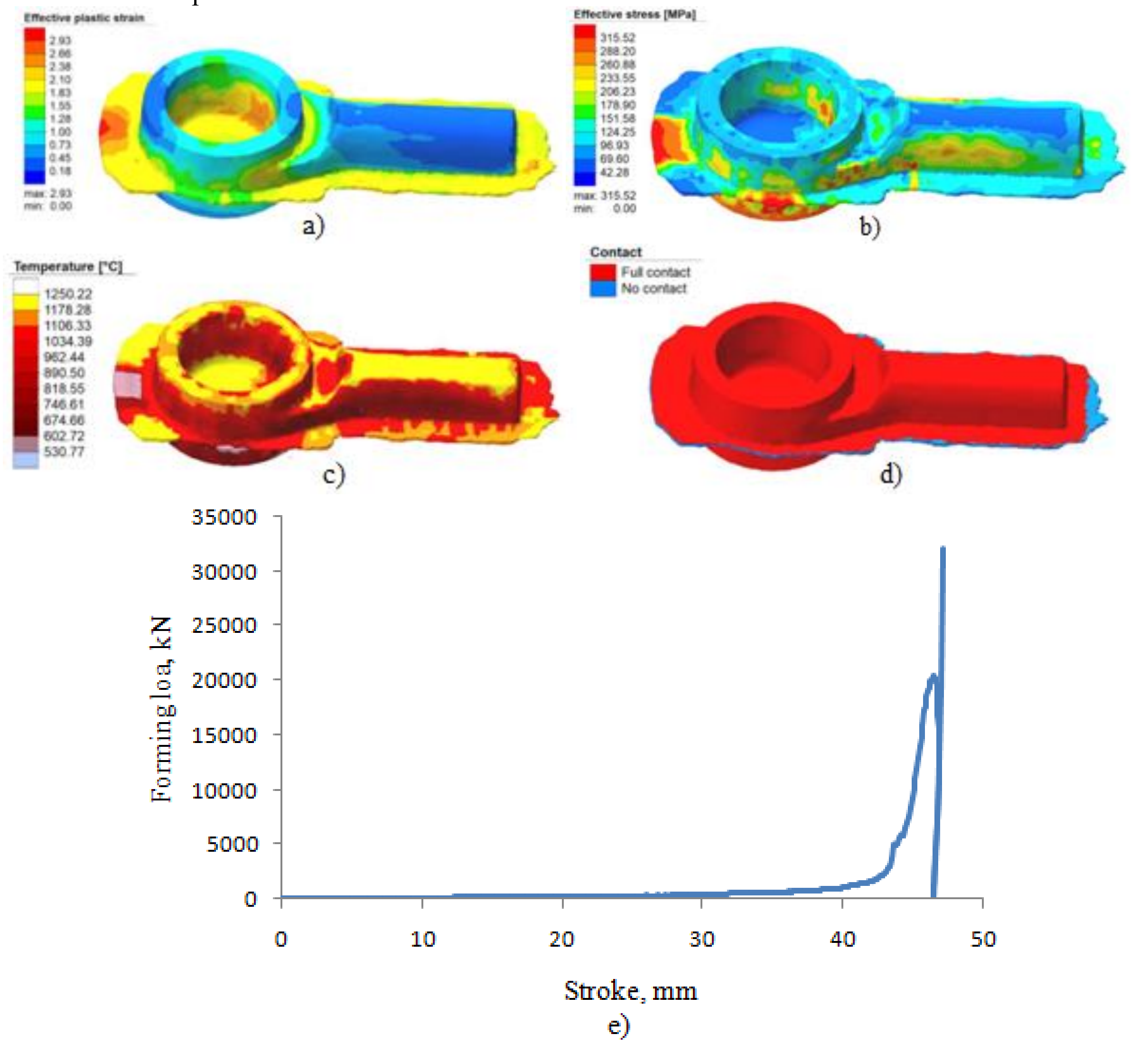

Figure. 3. Forging ondrop forging hammer a) effective plastic strain b) effective stress c) temperature d) die contact e) forming load diagram

The results of numerical simulation of the forging on crank press are shown in figure 4. The maximum value of the effective plastic strain is 3.88, which is a significantly higher value than in the case of forging ona forging hammer, and that in the zone of greater protrusion of the material into the flash in the part of the parting plane of the forging. The maximum value of the effective stress is 125MPa, significantly lower than for hammer forging, which is expected because the formingvelocityon a crank press is significantly lower than onforging hammer. The temperatureof the forging is lower than when forgingon a hammer, due to longer forging time and cooling of the forging in longer contact with the tool. The impact of the forming velocity on the temperature distribution in the forging is evident, so higher temperatures are achieved in hammer forging, because the process takes less time and the impact loads are the highest, so additional heat is generated due to forming. On the crank press, forming velocityis significantly lower, so the material in contact with the tool and the environment cools down during the longer duration of the forging process. Even in the case of forging on a crank press, the engraving of the die is adequately filled, but the shape of the flash is different than in forging on a hammer, namely in the cylindrical part of the connecting rod handle, which could have a lack of material for filling the connecting rod hub. The maximum forming load is more than twice as small as for forging on a forging hammer and amounts to 15000kN.

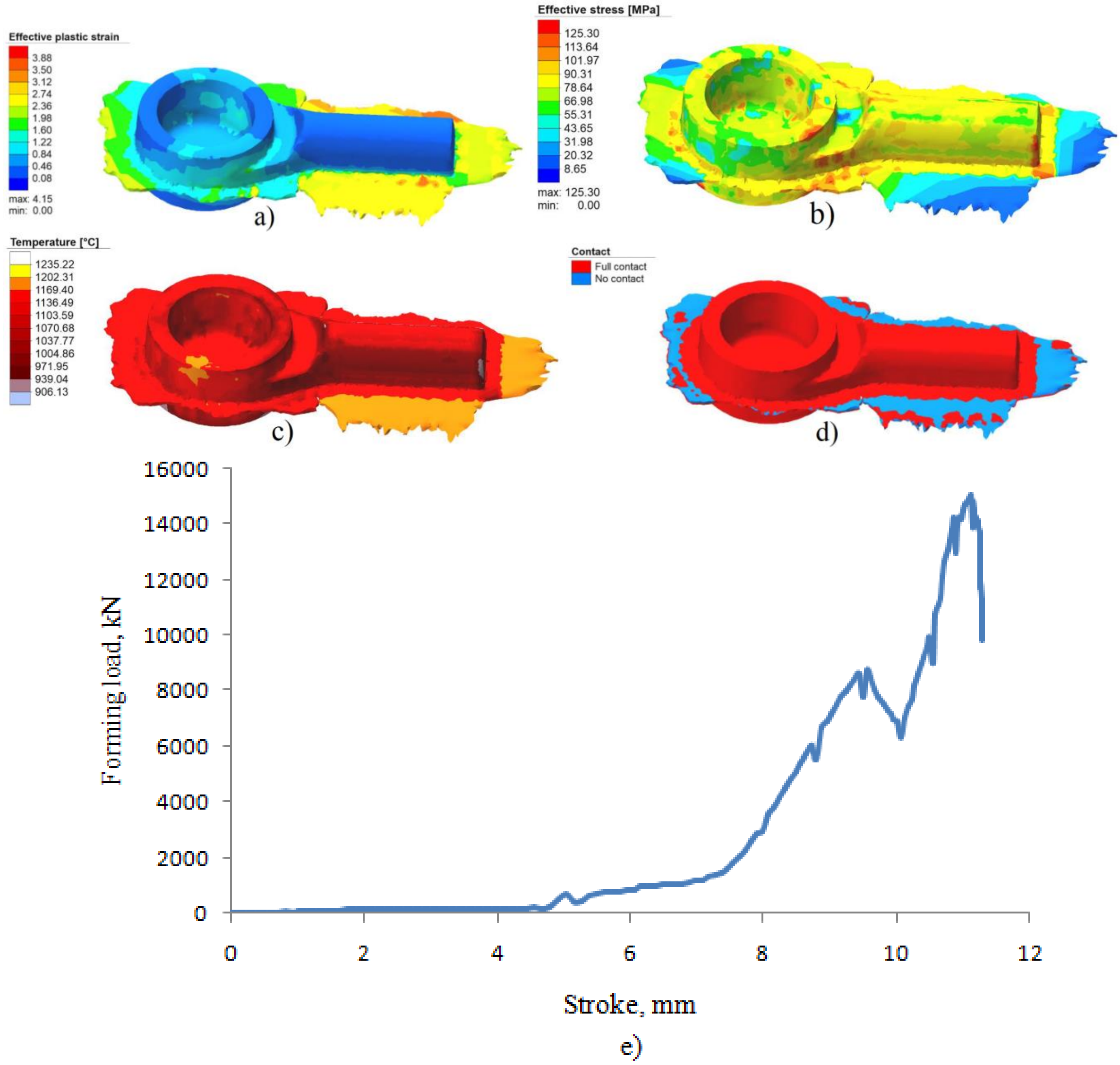

Fig. 4. Forging on crank press a) effective plastic strain b) effective stress c) temperature d) die contact e) forming load diagram

The results of the experiment usingthe last considered press, the screw press, are shown in figure 5. The value of the effective plastic strain in this case is the highest and amounts 5.8, but again in the area of the flash that is subsequently removed. The strain field in the forging itself is more homogeneous than in hammer forging, which was also the case in forging on a crank press, due to quieter operation of the press and lower forming velocities. The maximum value of the effective stress is 257 MPa, which is higher than for forging on a crank press and lower when using forging hammer. In the case of forging on a screw press, the temperature distribution is similar to that of a forging hammer.As in the previous two cases, the filling of the engraving is good, so the conclusion is that this forging can also be forged on a screw press.The extrusion of excess material into the flash is more even, as with a forging hammer, unlike forging on a crank press. The highest value of forming load

IOP Conf. Series: Materials Science and Engineering 1271 (2022) 012015 doi:10.1088/1757-899X/1271/1/012015

was recorded in forging on ascrew press and amounts 42000kN at the moment of closing the tool. Otherwise, the courseof the forming load diagram is different on all considered forging machines, which is expected and confirmed.

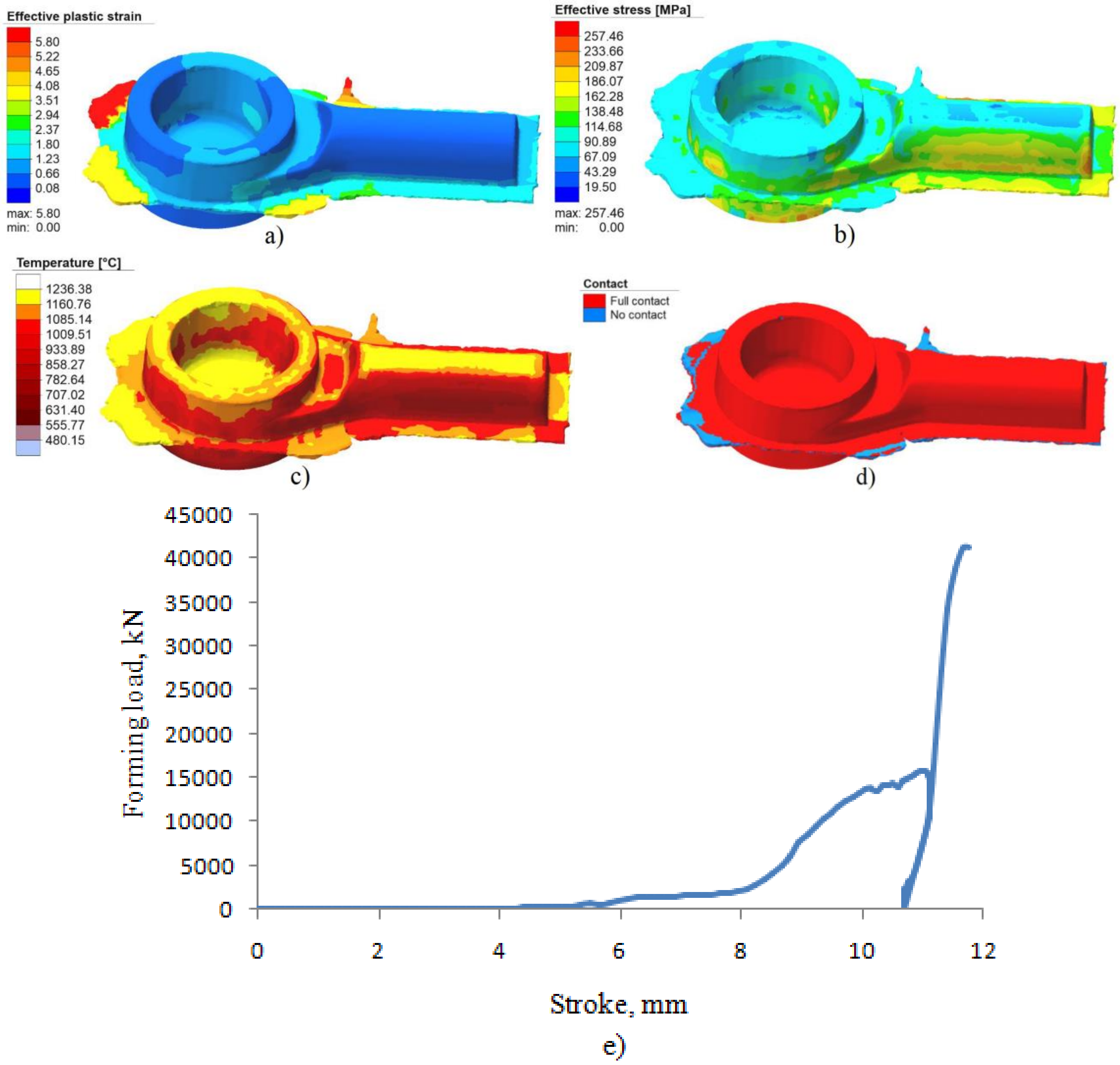

Figure. 5. Forging on screw press a) effective plastic strain b) effective stress c) temperature d) die contact e) forming load diagram

4. Conclusion

The impact of the choice of the forging machineon the forging properties and on the forging process itself can be analyzed using numerical methods and process simulations, as shown in this paper.Due to the exploitation propertiesof the forging, its microstructure, it is important that the strain field in the forging be as homogeneous as possible, and that the amounts of maximum strainsbe within acceptable limits for a certain material.

The results of numerical simulations showed that the highest effective stress is in the inner part of the forging, and it has significantly higher values in hammer forging than in crank and screw press forging. Such values of effective stress in the forging are expected, because the forming velocityisthe highest onthe hammer, then on the screw press, and the least onthe crank press. The stress in the forging material depends on the forming velocity, i.e. the achieved strain rate, because the viscoplastic behaviour of the material is presentat elevated forging temperatures. By comparative analysis of the field of effective plastic strain, maximum values were observed in the flash zone, which is not crucial from the aspect of forging quality, considering that it is removed after forging. However, for the quality of the forging, it is important to have as homogeneous a strain field as possible, which gives smaller variations in microstricture and resistance characteristics during exploitation. Highest strainsin the forging occurred during hammer forging, due to high forming velocities and impact loads. A more homogeneous strain field was obtained during forging on a crank press, and the most unfavourable distribution was obtained during forging on a hammer, due to impact loads and a high forming velocity. On the other hand, filling of the die and uniform protrusion of the material into the flash is evident in hammer forging, while in forging on the crank press, the protrusion into the flash is more prominent in the cylindrical part of the connecting rod shank, with the possibility of not filling the hub.

The temperature distributions in the forging are in similar proportions for these three forging machines, the highest temperatures are during forging on the hammer, and the lowest during forging on the crank press, again due to the different forming velocities of these forging machines, the duration of the forging process, and especially the time of contact with the die and environment and cooling of the workpiece.

Numerical process simulations provide the opportunity to review and analyze all aspects of the machine's impact on the complete forging process and forging quality, outside of the production environment, and to make correct decisions on the process parameters or on the selection of the most favorable machine based on the results.

References

[1] Luria R, Luisa C, Salcedoa D, Leóna J, Fuertesa J and Puertasa I 2013 *The Manufacturing Engineering Society International Conference, MESIC 2013*, FEM analysis of the isothermal forging of a connecting rod from material previously deformed by ECAE 63 540-546

[2] Zahálka M and Staněk J 2014*25th DAAAM International Symposium on Intelligent Manufacturing and Automation, DAAAM 2014,*Options of Advanced Simulations of Crank Presses Loading 891-898

[3] Vishal P and George P 2021*Materials Today: Proceedings*, Effect of preform design on forging load and effective stress duringclosed die hot forging process of pin 44 106-112

[4] Madhankumar S, Narayanan H, Harini V, Gokulraj K, Selvakumar S, Dharshini R, Dharshini K and Harikrishnan T 2021 *Materials Today: Proceedings*, Study and selection of hot forging die materials and hardness 45 6563–6566

[5] Vishal P and George P2021 *Materials Today: Proceedings*, Preform optimization for the anchor shackle during closed die forging process on one ton hammer 47 3256–3262

[6] Jayanthi A, Anilkumar M and Ravisankar B 2022 *Materials Today: Proceedings* Selection of forging process for compressor disc for aero engine using finite element analysis 60 2111–2116

[7] Zdenek C and Cechura M 2015 *ProcediaEngineering*Monitoring Extremely Stressed Points on Stands of Forging Presses 100 841-846

[8] Zdenek C 2014 *ProcediaEngineering* Effect of Heat Load on a Forging Press 69 897 – 901

[9] Bogoyavlensky A and Bogoyavlensky M 2019 *Materials Today: Proceedings*Calculation technological parameters of forging on hammers and presses

[10] Mandic V 2020 *Lecture Notes in Mechanical Engineering* Model-Based Manufacturing System Supported by Virtual Technologies in an Industry 4.0 Context, Springer, APM2020,ISBN 978-3-030-46211-6.