OKÜ Fen Bilimleri Enstitüsü Dergisi
5(Özel Sayı):96-107, 2022

OKU Journal of The Institute of Science and Technology, 5(Special Issue):96-107, 2022

Osmaniye Korkut Ata Üniversitesi
Fen Bilimleri Enstitüsü
Dergisi

Osmaniye Korkut Ata University
Journal of The Institute of Science
and Technology

An Investigation for the Performance of the Design of Hot Forging Die and Workpiece

Ece Destina BEKLETENLER[1*], Simge İRIZALP[2], Murat DELİBALCI[3]

[1,3] İZELTAS İzmir El Aletleri Sanayi ve Ticaret Inc., 35070, İzmir
[2]Manisa Celal Bayar Universitesi, Mühendislik Fakültesi, Makine Mühendisliği Bölümü, 45140, Manisa

[1]https://orcid.org/0000-0003-2384-1307,
[2]https://orcid.org/0000-0002-0339-5699,
[3]https://orcid.org/0000-0002-9537-3920
Corresponding author: ece.bekletenler@izeltas.com.tr

Research Article

Article History:
Received: 06.12.2021
Accepted: 15.01.2022
Published online: 23.02.2022

Keywords:
Hot forging
Process cost
Die and workpiece design
Finite volume analysis

ABSTRACT

Hot forging is a metalworking process in which metals are plastically deformed above their recrystallization temperature, allowing the material to retain its deformed shape as it cools. In today's industry, the performance of the tools used during the hot forging process has always been a subject of interest. Although it is known that, the tool life used affects 10% of the design costs of the total budget, 80% of the total production costs are determined during the design stages. For this reason, minimizing mechanical stress and changing the die design, so as to optimize the tool life and reduce the cost, have been attractive. In this study, finite volume analysis was performed on 31CrV3 steel using the multi-stage forming process of hot closed die forging using Simufact Forming v16 software. 56NiCrMoV7 hot work tool steel was used as die material and X153CrMoV12 as template blade raw material. In this article, 3 state variables, effective plastic strain, equivalent stress and temperature were evaluated for two different die designs of multi-stage forming processes such as pre-forming, final forging, and cutting. The results were compared for cost for single and dual dies. For both die designs, the initial temperature of the billet is 1100-1200 ºC and the die temperature is 100-110 ºC. Finally, comparative analyzes of both die designs for three state variable parameters were performed in terms of mechanical properties and cost. The main focus is on calculating mechanical properties and cost based on available process parameters using subroutines during the incorporation of different die designs. According to the results obtained from the simulation study, the manufacturability of the product has been proven, the effect of the changes in the die and workpiece design on the cost have been investigated, and the final performance has been revealed by evaluating the profit rate.

Sıcak Dövme Kalıp ve İş Parçasının Tasarımının Performansı Üzerine Bir Araştırma

Araştırma Makalesi

Makale Tarihçesi:
Geliş tarihi: 06.12.2021
Kabul tarihi:15.01.2022
Online Yayınlanma: 23.02.2022

Anahtar Kelimeler:
Sıcak dövme
Proses maliyeti

ÖZET

Sıcak dövme, metallerin yeniden kristalleşme sıcaklıklarının üzerinde plastik olarak deforme edildiği ve malzemenin soğudukça deforme şeklini korumasını sağlayan bir metal işleme sürecidir. Günümüz endüstrisinde sıcak dövme işlemi sırasında kullanılan takımların performansı her zaman ilgi konusu olmuştur. Kullanılan takım ömrünün toplam bütçenin tasarım maliyetlerinin %10'unu etkilediği bilinmesine rağmen, toplam üretim maliyetlerinin %80'inin tasarım aşamalarında belirlendiği bilinmektedir. Bu

Kalıp ve iş parçası tasarımı
Sonlu hacimler analizi

nedenle, takım ömrünü optimize etmek ve maliyeti azaltmak için mekanik stresi en aza indirmek ve kalıp tasarımını değiştirmek cazip olmuştur. Bu çalışmada, Simufact Forming v16 yazılımı yardımıyla, kapalı kalıpta sıcak dövmenin çok aşamalı şekillendirme prosesi kullanılarak, 31CrV3 çeliği üzerinde sonlu hacim analizi yapılmıştır. Kalıp malzemesi olarak 56NiCrMoV7 sıcak iş takım çeliği, şablon bıçak hammaddesi olarak X153CrMoV12 kullanılmıştır. Bu makalede, ön şekillendirme, son dövme ve kesme gibi çok aşamalı şekillendirme proseslerinin iki farklı kalıp tasarımı için 3 durum değişkeni, efektif plastik gerinimi, eşdeğer gerilmesi ve sıcaklık değerlendirilmiştir. Sonuçlar, tekli ve ikili kalıplar için maliyet açısından karşılaştırılmıştır. Her iki kalıp tasarımı için de iş parçasının başlangıç sıcaklığı 1100-1200 ºC ve kalıp sıcaklığı 100-110 ºC'dir. Sonuç olarak, üç durumlu değişken parametre için her iki kalıp tasarımının mekanik özellikler ve maliyet açısından karşılaştırmalı analizleri yapılmıştır. Ana odak noktası, farklı kalıp tasarımlarının dahil edilmesi sırasında alt rutinler kullanılarak mevcut proses parametrelerine dayalı mekanik özelliklerin ve maliyetin hesaplanmasıdır. Simülasyon çalışmasından elde edilen sonuçlara göre ürünün üretilebilirliği ispatlanmış, kalıp ve iş parçası tasarımındaki değişikliklerin maliyete etkisi araştırılmış ve elde edilen kar oranı değerlendirilerek nihai performans ortaya konmuştur.

To Cite: Bekletenler ED., İrizalp S., Delibalcı M. An Investigation for the Performance of the Design of Hot Forging Die and Workpiece. Osmaniye Korkut Ata Üniversitesi Fen Bilimleri Enstitüsü Dergisi 2022; 5(Özel sayı): 96-107.

Introduction

Hot forging is one of the popular methods in which the workpiece is deformed under impact or pressure by means of tools called dies. Closed die hot forging is one of the most adopted methods for creating complex shaped parts with satisfactory geometric accuracy. More than 60% of industrial parts are produced with this method, due to its high strength and part production speed (Kumar and Kumar, 2019). Parameters such as temperature, raw material geometry and die design are effective in reducing production costs and increasing part quality. If the design and manufacture of parts are based on experience, the process can result in time loss and high costs. Optimizing the design of the part and die is essential to reduce the cost of the forging process and make it suitable for other production methods. (Maarefdoust and Kadkhodayan, 2010). The closed die hot forging process and the process affecting the cost improvements are shown in Figure 1 (Campi et al., 2020).

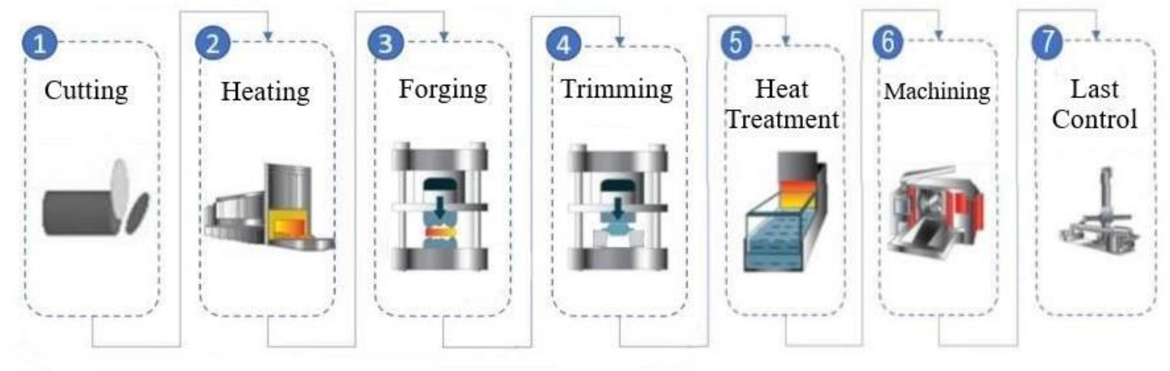

Figure 1. Hot forging process in a closed die (Campi et al., 2020)

Tool costs in hot forging can constitude 30% of the total process cost. Besides, tool production costs (die production cost) can directly affect the process parameters (repair, press downtime, scrap, rework, etc.). The most important factors to determine the tool life are die material, heat treatment and hot forging process control. In the production of hot forging dies, the material constitudes 5-15% of the total process cost and 5-15% of the heat treatment cost (Chander and Chawla, 2017). Figure 2 shows the die steel and machining costs according to the total tooling costs.

Figure 2. Tooling cost illustration (Chander and Chawla, 2017)

Cost estimation is a design task that provides the classification of cost items of both materials and processes prior to the manufacturing process (Campi, 2020). Today, companies have to provide product, and tool costs in a quality manner at competitive prices. With the advancement of technology and the development of computer-aided engineering (CAE) technology in the forging industry, production efficiency and product quality have been increased by reducing the product development cycle and product cost (Jha, 2016). Hot forging method can be simulated with two different methods as finite element method (FEM) and finite volume method (FVM). Santos et al. (2001) used FEM to determine the size of the billet material of the workpieces and the forces to be applied. The authors argued that, numerical simulation can actually aid modification and reduce the trial and error step in preparing tools for forging. The FVM and FEM method can also provide an important answer in predicting the process and defects. The place of die design and FEM analysis in the hot forging process flowchart are shown in Figure 3. Takemasu et al. (1996) designed the optimum preform die for the flashless forging of a connecting rod and proving the manufacturability by simulating with FEM by reducing pre-process trials. Meng et al. (2010) simulated the forging process combined with an optimization procedure to obtain optimal parameters of the geometry of the forging dies. Such forging processes are affected by material waste, die design, energy-saving, lubricant design, etc. Many different studies have been conducted on parameters. In this study, the manufacturability of the 25 × 28 mm double ended open-jaw wrench short pattern product, which was currently produced by using the single workpiece hot forging method, with dual workpieces in the simulation environment using CAE software, and the effect of die and workpiece design on the product cost were investigated.

The cost of single and dual forging methods was calculated by considering the effect of die and workpiece design on cutting, heating, and forging processes in the hot forging process, and both their mechanical properties, unit product costs and tool costs were investigated.

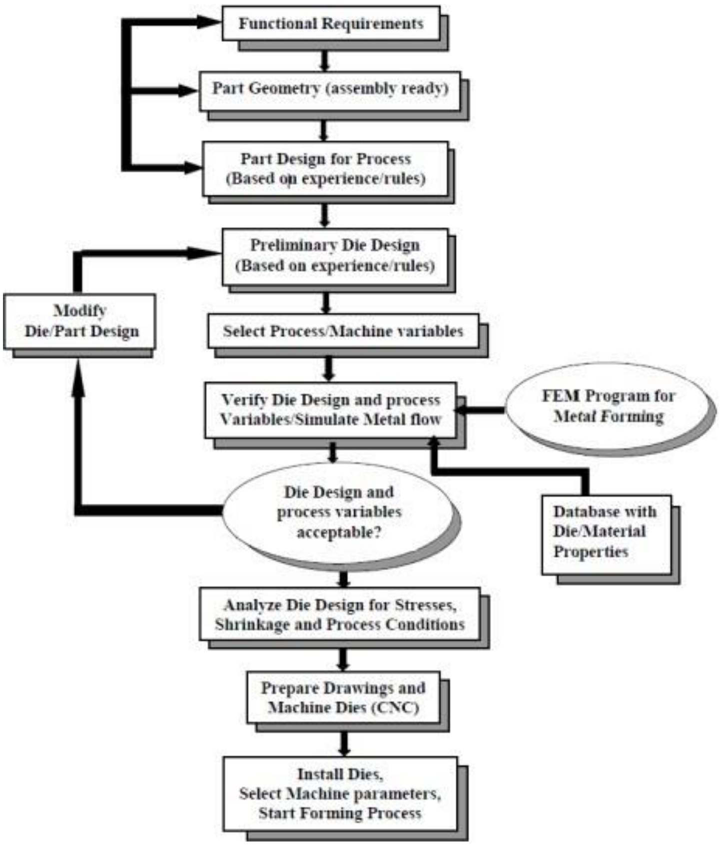

Figure 3. A flowchart illustrating forging process design (Altan and Shirgaokar, 2008)

Material and Method

In the study, a comprehensive research was conducted to understand the die design and forging process. For the short length product of the 25 × 28 mm double-edged wrench shown in Figure 4, 3D models of the dual die and workpiece were created. The workpiece forging temperature was 1100-1200 ℃ and the die temperature is 100-110 ℃. DIN 31CrV3 was used as workpiece raw material, DIN 56NiCrMoV7 hot work tool steel was used as forging die raw material, DIN X153CrMoV12 was used as template blade raw material. The chemical compositions of raw materials and die steels were determined by spectrometry analysis, which was shown in Table 1. A hammer with a capacity of 1200 kg was used as a forging bench. Machine capacity, workpiece forging temperature, die temperature and stroke numbers were kept constant and forging was carried out in single and dual dies. Only cutting and forging processes were based on cost estimation. Table 2 shows the parameters affecting the cutting and forging process costs.

Figure 4. 25 × 28 mm double ended open jaw wrench short pattern

Table 1. DIN 31CrV3, 56NiCrMoV7 and X153CrMoV12 chemical composition

STEEL	C%	Si%	Mn%	Cr%	Mo%	Ni%	V%
DIN 31CrV3	0.33-0.36	0.25-0.40	0.40-0.60	0.40-0.70	0.027	0.145	0.07-0.12
DIN 56NiCrMoV7	0.50-0.60	0.10-0.40	0.60-0.90	0.80-1.20	0.35-0.55	1.50-1.80	0.05-0.15
DIN X153CrMoV12	1.45-1.60	0.10-0.60	0.20-0.60	11.0-13.0	0.70-1.00	-	0.70-1.00

Table 2. Process parameters required for cost estimation

PROCESS NAME	PARAMETERS AFFECTING OF PROCESS COST
CUTTING	CUTTING BLADE RAW MATERIAL CUTTING BLADE PRODUCTION WORKPIECE RAW MATERIAL HOURLY WORKPIECE CUTTING CUSTOMS
FORGING	FORGING DIE RAW MATERIAL FORGING DIE PRODUCTION HOURLY LABOR COSTS

The products were produced by the multi-stage hot forging method. In multi-stage forging, the final shape of the product was obtained by deforming the initial geometry of the workpiece at various stages. In Figure 5, single and dual forging die models (upper and lower dies) and workpiece initial geometries are shown comparatively. Preforming, straight stroke, first and second shaping and finishing stages for multiple die forging simulations of 25 × 28 mm double-ended open jaw wrench short pattern product were simulated using Simufact Forming V16 and the manufacturability of the product was investigated. Besides, the cost estimations of cutting and forging processes, which were affected by the change in die and workpiece design were made. It is possible to classify the cost estimation methods as heuristic, analogical, parametric and analytical methods. Heuristic methods are based on past experiences. Analogical methods start from other products whose costs are calculated and make cost estimation using common parameters. Parametric methods, on the other hand, estimate the cost from the parameters used by the designers. Finally, analytical methods such as the activity-based forecasting method (ABC) allow the evaluation of the total cost of a product by decomposing the product's production steps into key tasks, operations, or activities with known (or easily calculated) costs (Rezaie et al., 2008). In this study, cost estimation was carried out with the activity-based costing software used in Izeltas. The effect of die and workpiece design changes on unit product cost and tool cost was calculated and compared for single and dual die forging.

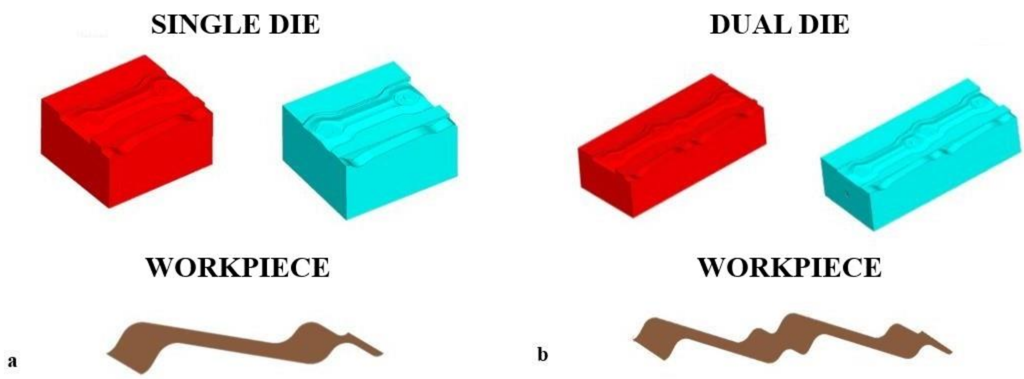

Figure 5. a) Single die and workpiece b) Dual die and workpiece

Results and Discussion

FVM is the underlying method of commercial simulation software, mostly derived for the solution of computational fluid dynamics and closed die forging with flash processes. Just like in FEM, the basic principle in FVM is to divide the geometry to be solved into parts and to find the general solution by combining the solutions, after making a solution for each of these parts (Kilerci, 2017). The simulation is used to study the flow of metal in the die cavity and to determine the energy required for the forming process. As a result of the simulation studies, the 25 × 28 mm double-ended open-jaw wrench short pattern length final product obtained after forging is shown in Figure 6. The final shape of the 25 × 28 double-ended open-jaw wrench short pattern product, which is forged in single and dual dies, is shown in Figure 7.

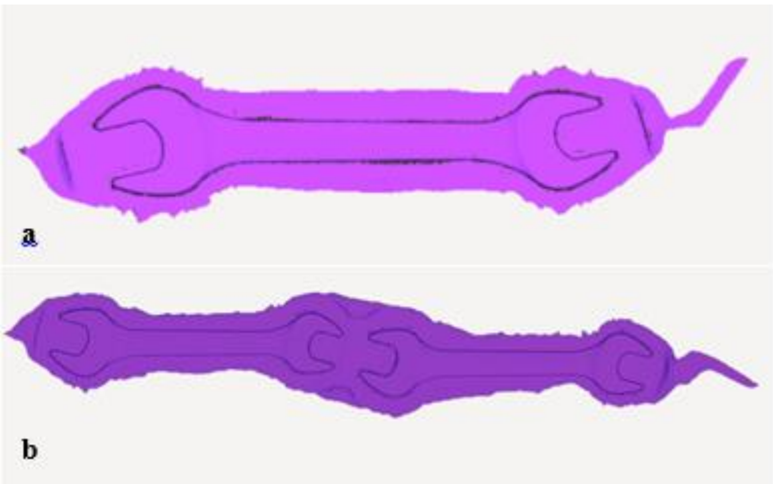

Figure 6. Single (a) and dual (b) 25 × 28 mm double-ended open-jaw wrench short pattern final shape obtained from simulation

Figure 7. Single (a) Dual (b) 25 × 28 mm double-ended open-jaw wrench short pattern final shape after hot forging

The press currently used has a total energy of 12936 J. The simulated force required for the single and dual die forging process is plotted in Figure 8, as a function of the press stroke. In the results shown in Figure 8, it was determined that, the dual forging die workpiece design was faultless, and the forging energy was within the energy limits of the currently used press. The peaks of the curves seen in the graphs show the energy transferred by the stroke of the press during the forging process. The rises correspond to the beginning of intensive material flow into the lateral openings − formation of the open-jaws After reaching the maximum value, the load sharply drops. This is known as the calibration step in which there is no vertical motion of the lower die (Milutinović et al., 2017). The fact that, the second curve is high in the product forged with a single mold is entirely at the discretion of the operator, therefore the energy percentages of the strokes are entered according to the program system according to the actual process applied in the company. Due to the deformation of the workpiece, the impact energies are assigned differently in single and dual forging. The differences in the stroke values vary depending on the plastic deformation in the material. With the changes made in the dual workpiece design, the force required for deformation has been reduced, due to the increase in the contact area and lateral loads. Since this is the opposite of a single workpiece, the stroke distance had to be increased in order to obtain the desired part properties.

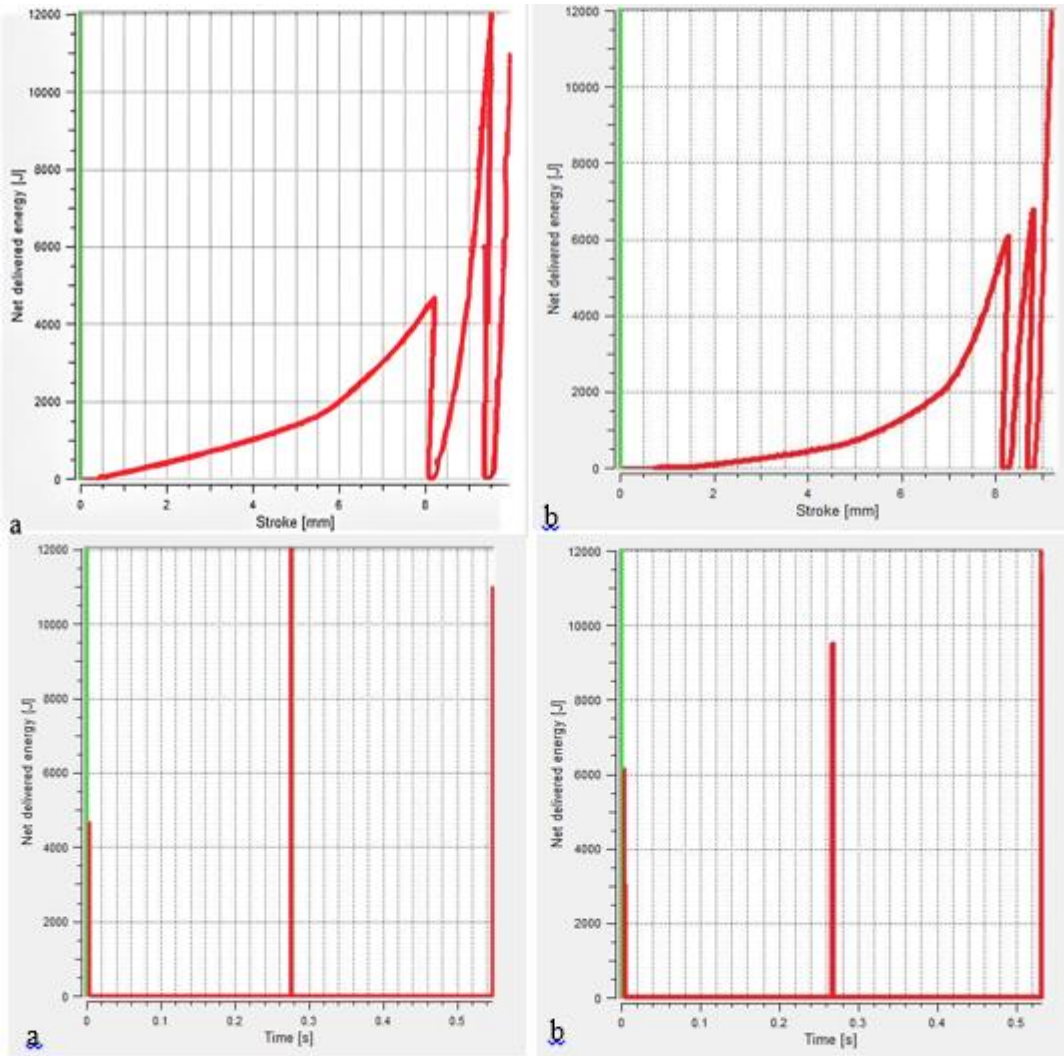

Figure 8. Net delivered energy from the hammer from the hammer depending on time and distance (a) single die (b) dual die

Equivalent stress and effective plastic strain results for both single forging and dual forging are shown in Figure 9, comparatively. Equivalent stress is slightly higher for single forging compared to dual forging. The gradual increase in die force, the reduction in effective plastic strain leading to minimal plastic deformation were present during the final forging stages for double forging as compared to single forging. This may limit grain structure improvement. According to the results shown in Figure 9, higher effective plastic strain values were obtained in the key body and burr region. The areas that undergo the most deformation are the burr line and the body part. High effective plastic strain values are seen where the deformation is high (plastic deformation). The reason why the effective plastic strain values are slightly higher in the dual forged product can be explained as the increase in the surface area of the workpiece geometry. Temperature values of workpieces for single and dual forging were given in Figure 10. The temperature field is more uniform in single forging. However it is noteworthy that, the part that affects the homogeneity is the burr region with a large surface area. In this case, the tendency of crack propagation may be in question for the circumference region, it is clear that, the temperature distribution in the main workpiece is also homogeneous in dual forging (Milutinović et al., 2017).

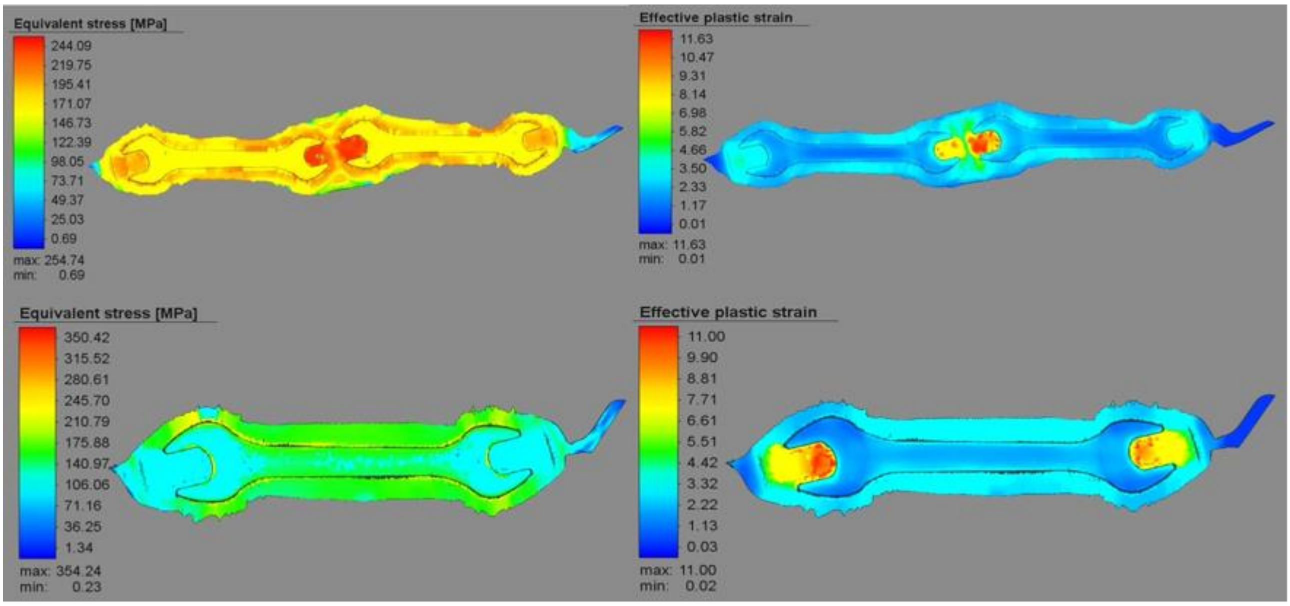

Figure 9. Comparison of equivalent stress and effective plastic strain for single and dual forging

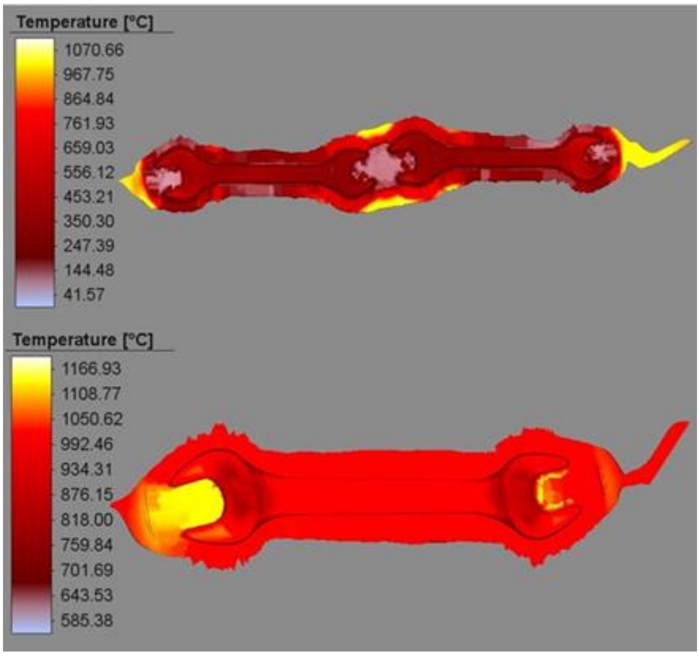

Figure 10. Temperature values for single and dual forging

The total costs of forging die, workpiece and cutting blade are calculated for single and dual forging die and given in Table 3. In line with the results, it was calculated that, 153000 products were produced during the total tool life with a single forging die and 544000 items could be produced with a dual die forging. According to the results, the dual forging dies increases the production of 25 × 28 mm double-ended open-jaw wrench short pattern products by 255% in the same cycle time. A similar study was investigated by Shirgaokar (2008). The author developed an FEA-based design and optimization sequence to improve material yield in multi-stage hot forging processes, using volume distribution analysis and achieved a 15% improvement in material yield for a sample process with preforming optimization alone. An additional 3-4% improvement is envisaged through the optimization of the blocking die design.

Table 3. Single and dual forging die, cutting blade and workpiece total cost

PROCESS DETAILS	TOTAL COST (€)
SINGLE DIE+WORKPIECE+CUTTING BLADE	160.930,42
DUAL DIE+WORKPIECE+CUTTING BLADE	271.907,73

In addition to these, the effect of the total die cost on the unit product cost was calculated and examined by considering the parameters given in Table 2. According to the data presented in Table 4, a profit of 0.052 € is obtained per unit product. The average life of a tool is two years, if it is used continuously. With the dual die, 391000 products will be over-forged in two years. The projected profit amount is foreseen as 20,332 € for 391000 products. Considering that the annual sales volume for the product under investigation is 50000, it will be possible to produce these products in 11 batches with a single die, while annual sales can be produced in 3 batches with a dual forging die. In this way, the forging machine will be freed, and an extra production bench will be provided for other products.

Table 4. Profit per unit product

SINGLE DIE UNIT COST	1,051 €
DUAL DIE UNIT COST	0,99 €
UNIT PROFIT	0,052 €

Conclusion

The main purpose of this study is to investigate the effect of the hot forging process stages on the mechanical properties and the product cost, and to prove the feasibility of design changes in the forging die and workpiece with a 3D simulation program. It has been researched that, production can be carried out with newly designed dies and workpieces without trial production costs in the virtual environment created before real production. As a result of the simulation studies, it has been proven that, production can be made by simply changing the die and workpiece design by using the same hammer and technique with the dual forging die. Equivalent stress is maximum during the final forging stages for single forging compared to dual forging. With the gradual increase in die force, a decrease in effective plastic strain leads to minimum plastic deformation, which thusly may limit grain structure refinement during final forging stages for dual forging compared to single forging. The final temperature distribution is homogenous in both forging processes. Burr region is also affected and gradually increases in dual forging. After the simulation studies, the effects of cutting and forging parameters on tool and unit product costs were calculated. The products are actually produced with the newly designed die and workpiece. The results showed that this complex production process can be produced with the help of the software mentioned above, with less cost and time loss. As a result of the study, it is presented by proving that, high profitability can be obtained by simply changing the die and workpiece design using the same hammer and technique with dual forging dies. When the unit product profit obtained is calculated over the annual product sales, it is estimated that it will reach a high figure.

Acknowledgement

The authors would like to thank IZELTAS Izmir El Aletleri Sanayi ve Ticaret A.S. support of the study.

Conflict of Interest Statement

The authors of the article declare that there is no conflict of interest between them.

Contribution Rate Statement Summary of Authors

The authors declare that they have contributed 100% to the article.

*This study was presented as a summary paper at the International Conference on Engineering, Natural and Applied Sciences (ICENAS'21) held online on 24-26 November 2021.

References

Altan T., Shirgaokar M. Simulation based process design for improvement of profitability in the hot forging industry. In 19th International Forging Congress 2008; 615.

Campi F., Mandolini M., Favi C., Checcacci E., Germani M. An analytical cost estimation model for the design of axisymmetric components with open-die forging technology. The International Journal of Advanced Manufacturing Technology 2020; 110(7): 1869-1892.

Chander S., Chawla V. Failure of hot forging dies–an updated perspective. Materials Today Proceedings 2017; 4(2): 1147-1157.

Jha SK. Cost optimization of a forged steel crankshaft in global manufacturing environment. International Journal of Mechanical Engineering Research and Technology 2016; 2(2): 16-28.

Kilerci İ. Computer aided investigation of the effect of mechanical properties on metal forming production parameters. Manisa Celal Bayar Üniversitesi, Manisa, Doctoral Dissertation 2017.

Kumar OP., Kumar V. Optimization of the process parameters of forging of pitman arm. International Journal of Engineering Science Invention 2019; 8(08): 01-11.

Maarefdoust M., Kadkhodayan M. Simulation and analysis of hot forging process for industrial locking gear elevators. 14th International Conference on Applied Mechanics and Mechanical Engineering 2010; 14, 1-10.

Meng F., Labergere C., Lafon P. Methodology of the shape optimization of forging dies. International Journal of Material Forming 2010; 3(1): 927-930.

Milutinović M., Baloš S., Plančak M., Movrin D. Comparison of some mechanical properties and micro-topography of a component with non-axisymmetric geometry manufactured by cold orbital and hot forging. Journal of Materials Processing Technology 2017; 249: 179-192.

Rezaie K., Ostadi B., Torabi SA. Activity-based costing in flexible manufacturing systems with a case study in a forging industry. International Journal of Production Research 2008; 46(4): 1047-1069.

Santos AD., Duarte JF., Reis A., Rocha B., Neto R., Paiva R. The use of finite element simulation for optimization of metal forming and tool design. Journal of Materials Processing Technology 2001; 119(1-3): 152-157.

Shirgaokar M. Technology to improve competitiveness in warm and hot forging: Increasing die life and material utilization. The Ohio State University, Ohio Doctoral Dissertation 2008.

Takemasu T., Vazquez V., Painter B., Altan T. Investigation of metal flow and perform optimization in flashless forging of a connecting rod. Journal of Material Process Technology 1996; 59: 95-105.