Journal of Scientific Research & Reports
8(6): 1-10, 2015; Article no.JSRR.20398
ISSN: 2320-0227

SCIENCEDOMAIN *international*
www.sciencedomain.org

An Optimization of Hot Forging Process of Ti-6Al-4V for Non-isothermal Condition

F. Forouhandeh[1*]

[1]*Department of Engineering, Islamic Azad University, Shahrood Branch, Shahrood, Iran.*

Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

Article Information

DOI: 10.9734/JSRR/2015/20398
Editor(s):
(1) José Alberto Duarte Moller, Center for Advanced Materials Research, Complejo Industrial Chihuahua, Mexico.
Reviewers:
(1) Antonio Sergio Bezerra Sombra, Universidade Federal do Ceará, Fortaleza, Brazil.
(2) Siva Prasad Kondapalli, Anil Neerukonda Institute of Technology and Sciences, India.
(3) Anonymous, University of Missouri-St. Louis, USA.
Complete Peer review History: http://sciencedomain.org/review-history/11214

Original Research Article

Received 25th July 2015
Accepted 18th August 2015
Published 1st September 2015

ABSTRACT

Aims: Simulation and optimization of hot forging of Titanium alloys with validation.
Study Design: Modeling, simulation of the process using super forge package and analytical study
Place and Duration of Study: University of science and Technology and Islamic Azad University, Shahrood Branch.
Methodology: Hot forging of Titanium alloys for non-isothermal condition has been simulated. The process has been modeled for different conditions and parameters. The main objectives of simulation are optimization of die filling and perform design, load and material waste reduction and also providing a clear picture of material flow in the die cavity to avoid any defect. In the absence of experimental data, the calculated history of ideal work method has been compared with the available analytical results.
Results: Hot forging of Titanium alloy (Ti-6Al-4V) has been simulated using available finite volume software for non-isothermal condition. Appropriate condition has been found for the process. Analytical results have good agreement in comparison to simulation results.
Conclusion: Simulation, optimization of forging process along with validation using analytical study.

Keywords: Forging; Titanium; Ti-6Al-4V; isothermal; finite volume method; α layer.

**Corresponding author: Email: fariborzforouhandeh@gmail.com;*

1. INTRODUCTION

Ti-6Al-4V has a lot of special characteristics. Mechanical and metallurgical specifications of this alloy are the main reason for its application in aero space industries. Hot forging of Titanium alloys is very applicable method to manufacture the strong, light and complex products. Isothermal forging needs a lot of facilities and expenditure. Non-isothermal hot forging faces a lot of unpredictable problems and difficulties and products have different defects. In this case, the main problem is influence of atmosphere elements like O_2, N_2 and H_2 on the surface of work piece and therefore increasing of α layer of initial work piece/billet leads to brittleness of the final product [1]. An old research has been performed to find appropriate coating during hot forging of Titanium [2]. Die design and finding differences between forging of steels and Titanium has been reported [3]. More sensitivity of Titanium during non-isothermal forging like more possibility of cold welding has been reported [4].

Author has studied a wide research about the use of glass coating as the best protective during hot-non isothermal forging of Titanium alloys with special case study and it will be presented in the next publication.

In this paper, a finite volume method simulation has been performed to optimize the forging process of Ti-6Al-4V using super forge package. Different parameters have been studied and die filling, perform design, load and material waste reduction has been optimized.

In the absence of experimental data, the calculated history of ideal work method for the same condition has been compared. This paper follows BS (British Standard).

2. FINITE VOLUME SIMULATION

Detail drawing of forging die cavity corresponding to final part and 3D model of final product by Auto cad and Mechanical desktop has been shown in Figs. 1 and 2 respectively.

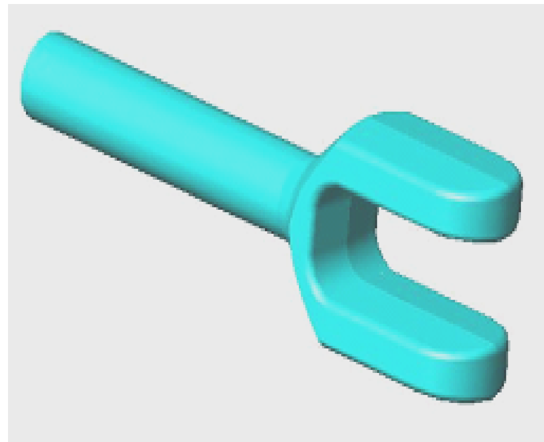

Fig. 1. 3D model of final product [1]

Geometric forging parameters are shown in Table 1. Table 2 shows elastic properties of forging material and Table 3 shows plastic properties of available Titanium in 930℃ (forging temperature). All the parameters have been set at working temperature for Ti-6Al-4V. Desirable microstructure is achieved between 900℃ to 980℃ Temperature range [4].

Shrinkage percentage should be applied to design of die cavity. 0.5% should be added for Titanium forging die [4]. The chemical composition of raw material is C around 0.08%, Fe: 0.25%, N_2: 0.05%, O2; 0.2%, Al: 6.67%, V: 3.5%.

Table 1. Applied forging parameters in die geometry [4]

Gutter width (mm)	Gutter height in upper/lower die (mm)	Fillet radius (mm)	Edge radius (mm)	Slope (degree)
6	1	4.8	1.5	5

Table 2. Elastic properties of material [5]

Young's modulus (M Pa)	Poisson's ratio	Density (Kg/m^3)	Thermal conductivity (Watt/m℃)	Specify heat capacity(Joule/Kg℃)
54220	0.4	4430	22	875

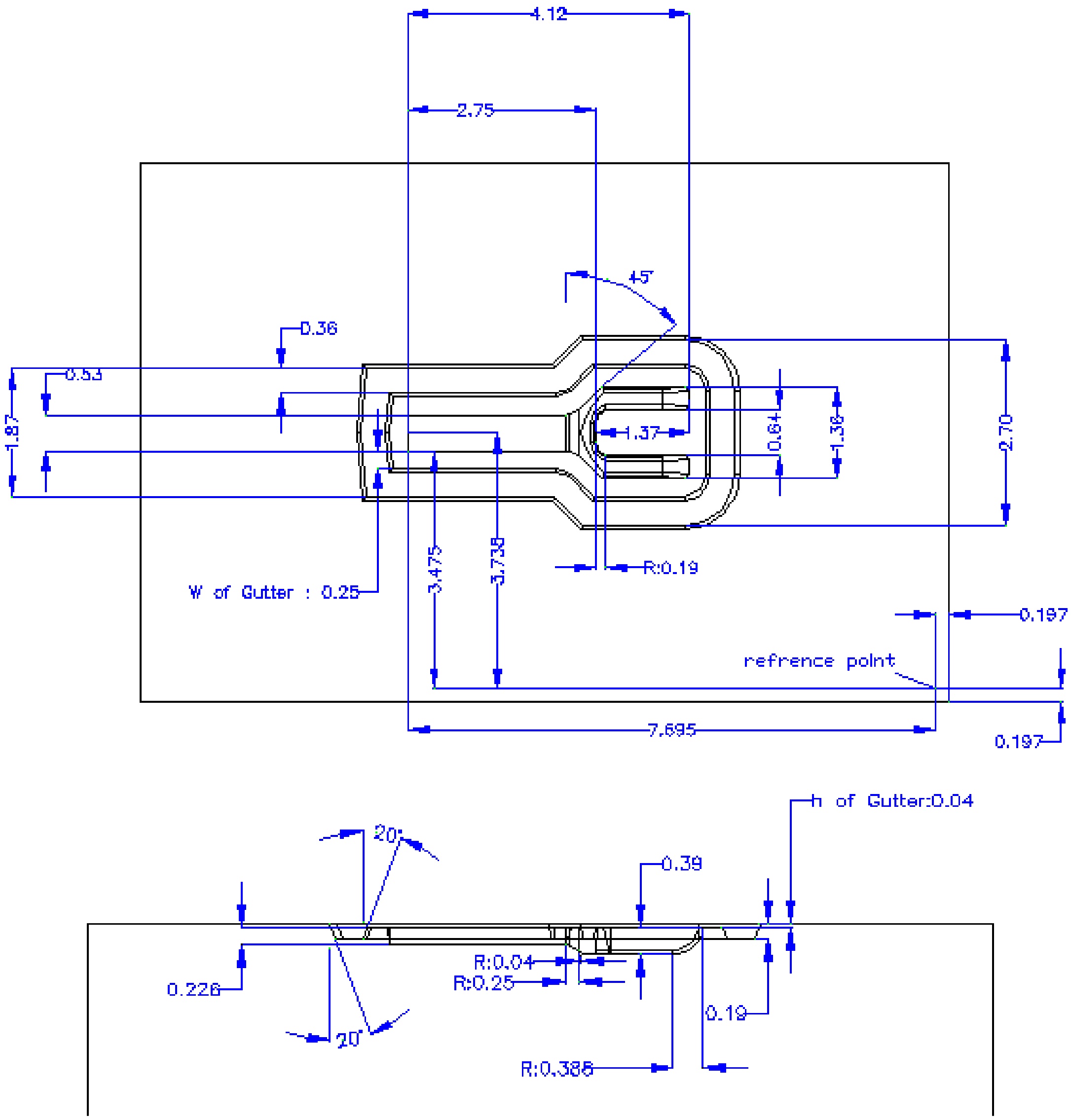

Fig. 2. Detail drawing of forging die cavity corresponding to final part (all dimensions are in inches except angles) [1]

Table 3. Plastic properties of material [5]

Minimum yield stress: S (MPa)	Yield constant: C (MPa)	Strain rate hardness: M
20	162	0.19255

Plastic behavior follows of equation 1 [4]:

$$\bar{\sigma}=max\ [S, C\dot{\varepsilon}^{M}] \quad (1)$$

Where S is minimum yield stress, C is yield constant and M is strain rate hardness. M and C are constant and depend to temperature.

Initial conditions for billet and die have been set; initial temperatures for die and billet have been 450℃ and 930℃ respectively. Initial temperature of ambient has been 25℃ and initial die temperature can be increased up to 650℃, w. r. t. the die material (H13) [4].

Friction coefficient depends on sliding conditions or type of lubricant, die temperature and strain rate in deformation time. In this work, graphite and glass coating has been used as the lubricant of the die and work piece respectively. In non-isothermal condition, friction coefficient (m) increases due to difference between die and work piece temperature. For current work, m is equal to 0.35 when die temperature is 400℃ and strain rate is 0.1 and reduction of height between initial billet and final product is 0.8 [6]. It appears that m decreases while die and working temperature increase. H13 steel has been selected as die material and in this case die can be heated up to 600℃. Initial die temperature is 400℃ while work piece/working temperature is 930℃. Hydraulic press with 15 mm/s speed has been selected for forging. Press should have speed controller. It should come down before deformation very fast to prevent of cooling the billet and should continue moving very slowly to prevent the brittleness and cold welding. Initial boundary conditions for heat transfer coefficient between die and ambient and between die and work piece are 52 and 1100 (Watt/ m2℃) respectively.

3. RESULTS AND DISCUSSION

To get the optimized preform different simulations has been performed. The main method to draw an appropriate preform is cutting the different places of final part and converting to the circle. In this case area of the circle should be equal to the corresponding cross section that has already been cut. Finally the preform shape is like Figs. 3 and 4. Any preform has been used as previous billet in superforge package and the corresponding result has been reported. Minimum forging load and waste material and getting the complete product is the main aim of simulation. Total forming/forging load also can be predicted. Figs. 3 and 4 show initial and optimized preform design respectively.

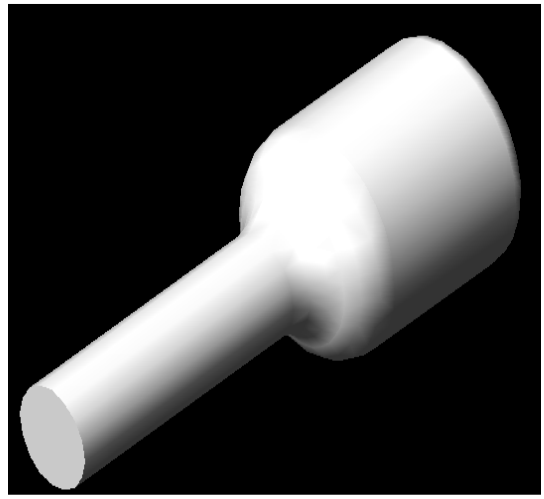

Fig. 3. Initial design of preform

A lot of simulations have been performed and in each group only one parameter like preform volume or press speed has been changed while other parameters have been kept constant. Table 4 shows a view of optimization process. Every parameter has been changed at least 5 times.

Initial design has been like Fig. 3 with 50342.6993 mm^3 volume and 35 mm diameter and 100 mm length and corresponding result after complete deformation has been reported in Fig. 5 that is not desirable due to high waste material and also rough surface. After more than 60 simulations optimized geometry of preform has been presented in Fig. 4 with 31135.4216 mm^3 volume and 25 mm diameter and corresponding result has been shown in Fig. 6.

Table 4. Procedure of optimization for size and shape of preform and waste reduction

Run No.	Dimension of perform (mm)	Volume of perform (in^3)	Friction coefficient	Stroke (mm)	Speed of press (mm/s)	Tonnage of press (ton)	Die filling	Amount of waste material	Result
1	Diameter:35 Length:100	3.072	0.3	0.033	100	330	Almost good	Too much	Not good
2	D:35 L:90	2.5	0.3	0.033	100	429.4	Not bad	Much	Better than 1
3	D:30 L:100	2.42	0.3	0.028	100	378.5	Very good	Much	Better than 2
4	D:27 L:100	2.28	0.3	0.025	100	397	Better than 3	Less	Not bad
5	D:25 L:100	1.9	0.35	0.023	15	312.4	Very good	Very less	Good

The main effective parameter on deformation is ram/press speed. As Titanium is very sensitive to strain rate different runs has been performed to find an appropriate speed.

Fig. 7 shows the best result of simulation with appropriate speed and preform geometry. Super forge can predict total forging load required as shown in Fig. 8. Fig. 9 shows effective stress distribution in final forged part. Load required for material entrance to the gutter area has been shown in Fig. 10. It is clear that in tonnage/load-stroke diagram, when the press moves down around 21 mm (gutter area is going to be started), corresponding required load is around 98 ton.

Fig. 11 shows effect of preform volume on waste material percentage. It appears that when preform volume is increased, keeping other parameters constant, waste material percentage is also increased.

Fig. 12 shows effect of number of element on tonnage/total forging load. It is clear that total forging load/tonnage increase gradually by increasing the number of element when the number of element is more than 20000 and also it decreases with high slope when number of element is less than 20000. It can be said that due to small volume of preform or final part, element size does not have high influence in total forging load.

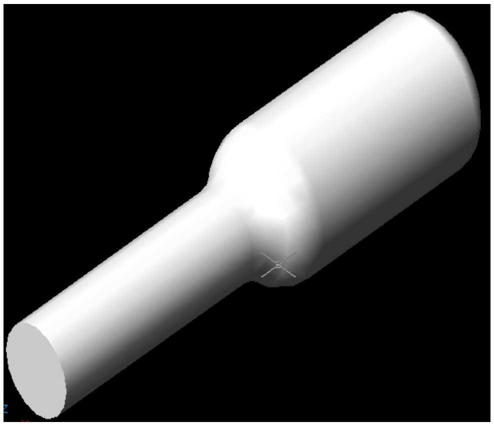

Fig. 4. Optimized design of preform

Fig. 13 shows effect of press speed on tonnage/total forging load. Due to sensitivity of Titanium, it appears that when the press speed increases total forging load/tonnage should also be increased. Also 15 mm/s is appropriate speed. To prevent of cooling the billet ram speed should be set in 100 mm/s from the start point up to touching the billet and as soon as touch the billet should be set in 15 mm/s up to the end of process. Hence, it should be noticed that billet will be cooled off for less than 15 mm/s speed and tonnage and brittleness possibility will be increased due to long working time [1].

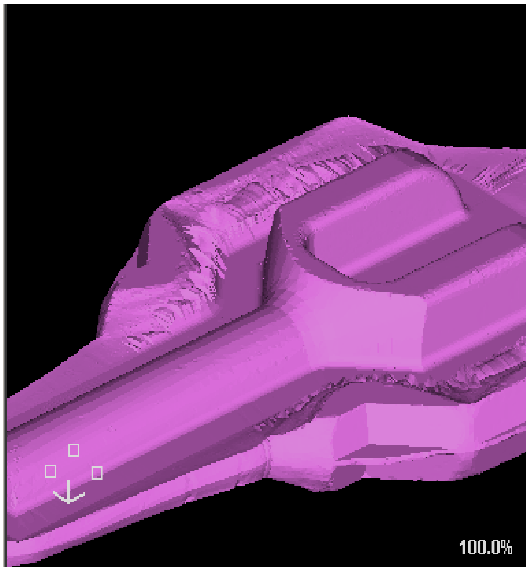

Fig. 5. Final forged part: Billet volume: 50342.6993 mm^3

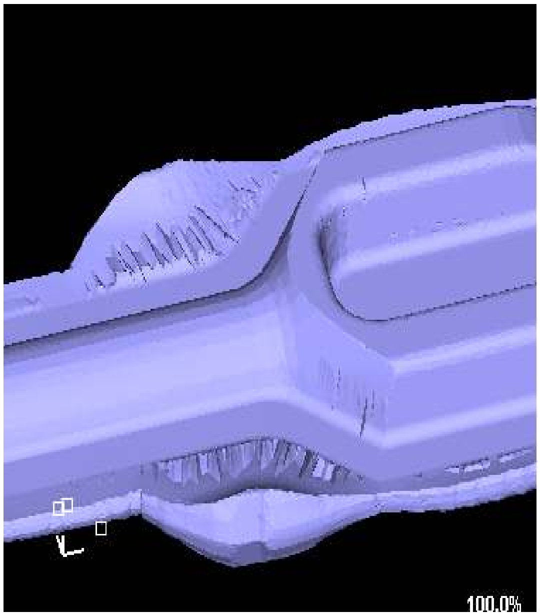

Fig. 6. Final forged part: billet volume: 31135.4216 mm^3, Press speed: 100 mm/s

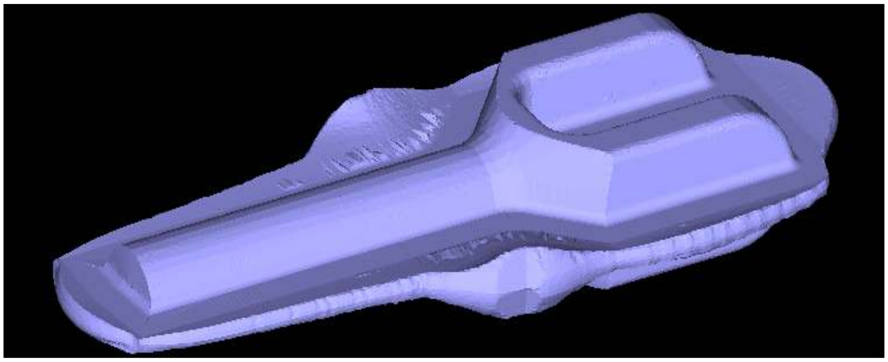

Fig. 7. Final forged part: billet volume: 31135.4216 mm^3, Press speed: 15 mm/s

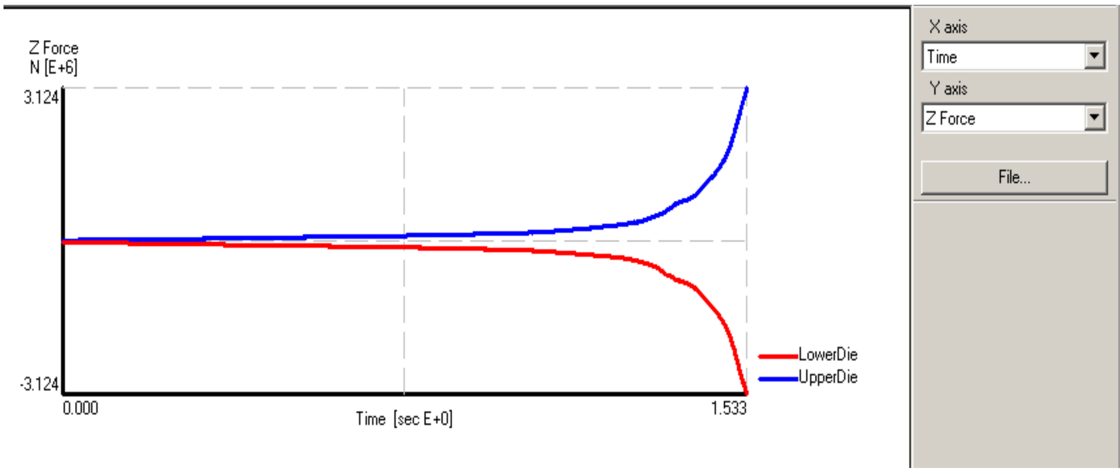

Fig. 8. Total forging load prediction

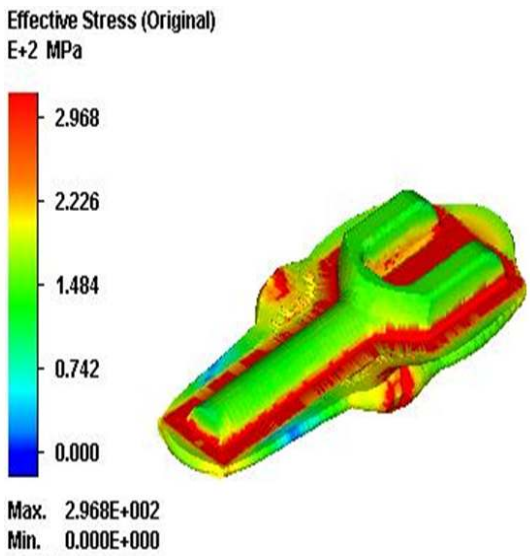

Fig. 9. Effective stress distribution

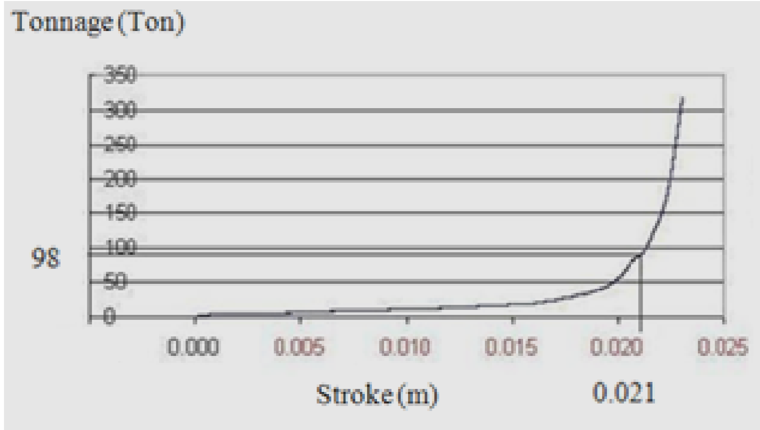

Fig. 10. Tonnage/load-Stroke diagram

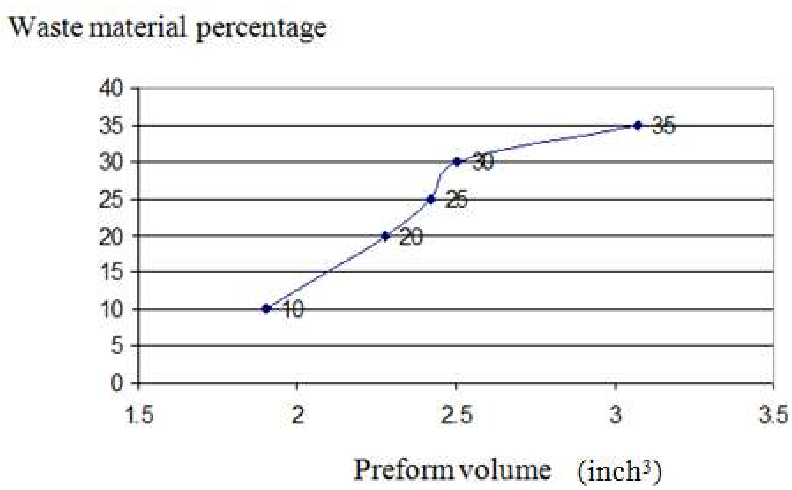

Fig. 11. Effect of preform volume on waste material percentage

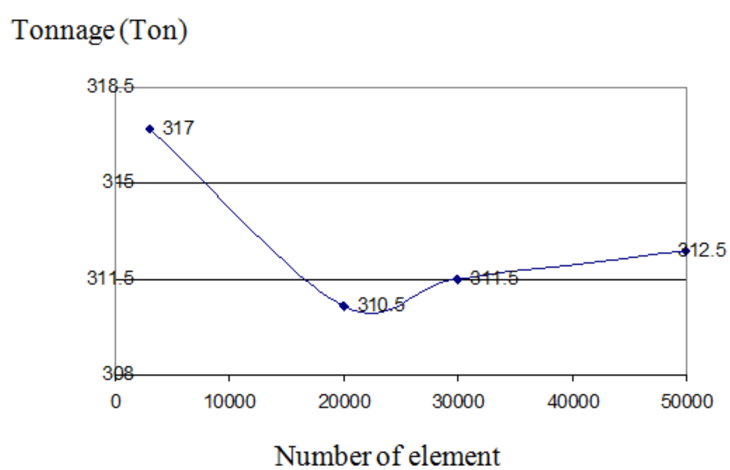

Fig. 12. Effect of number of element on tonnage/total forging load

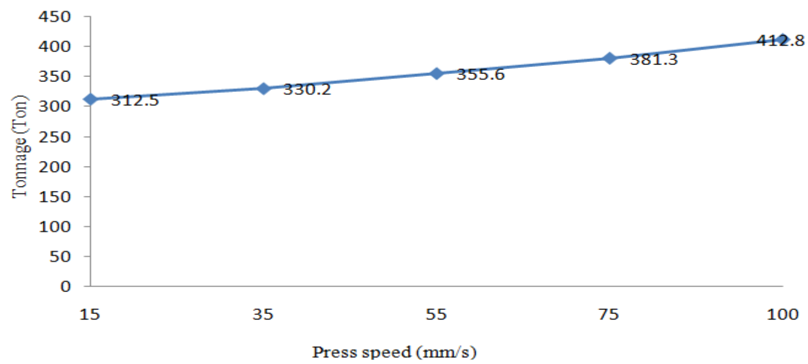

Fig. 13. Effect of press speed on tonnage/total forging load

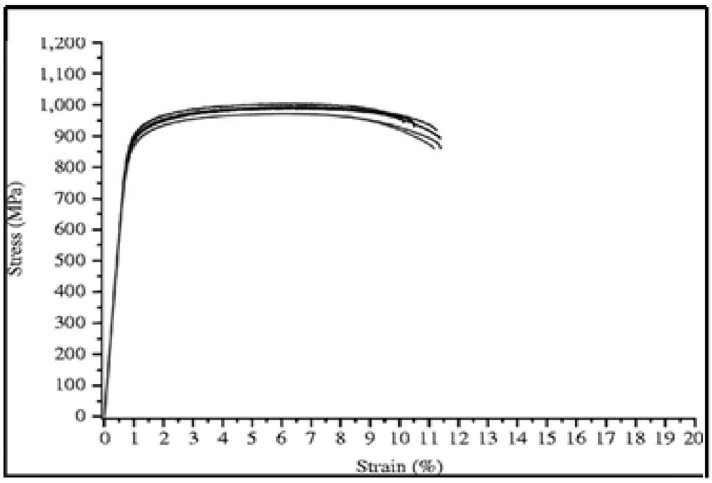

Fig. 14. Stress-Strain diagram of Ti-6Al-4V [5]

3.1 Calculation the Forging Load Required for Forging the Part as per Ideal Work Method and Validation

In ideal work method, it is assumed that material behavior is perfectly plastic, where yielding stress is Y, height is h_1 and corresponding area is A_1, F is corresponding load required, w is work per unit volume, Y_f is flow stress (yielding stress including work hardening), ε_1: Ultimate strain of part, K is strength coefficient, n is strain hardening exponent and $\bar{F}$ is average required force for deformation of part. Equations 2-8 show the steps to calculate of force in this method:

$$F = YA_1 \quad (2)$$

$$w = \int_0^{\varepsilon_1} \sigma d\varepsilon \quad (3)$$

$$F = Y_f A_1 \quad (4)$$

$$w = \bar{Y}(\varepsilon_1) \quad (5)$$

$$\bar{Y} = \frac{w}{\varepsilon_1} = \frac{K\int_0^{\varepsilon_1} \varepsilon^n d\varepsilon}{\varepsilon_1} = \frac{K}{n+1}\frac{\varepsilon_1^{n+1}}{\varepsilon_1} = \frac{K\varepsilon_1^n}{n+1} \quad (6)$$

$$\varepsilon_1 = Ln\frac{h_0}{h_1} \quad (7)$$

$$\bar{F} = \bar{Y}A \quad (8)$$

In this part, forging load required for material entrance to the gutter area is calculated. Working temperature has been set in 930℃. Equation 9 shows relationship between σ and ε [5,7,8,9].

$$\sigma = K\varepsilon^n \quad (9)$$

So that Ln σ=Ln K+ n Ln ε

According to stress-strain diagram of Ti-6Al-4V in Fig. 14, at the first point σ **=** 220 MPa, $\varepsilon = 0.2$ and at the second point σ **=** 190 MPa, $\varepsilon = 1$

Therefore K=190 MPa, n = -0.3

Now this part is divided to the four areas and strain is calculated for every area. Each area has different height and according to the corresponding area in the preform, height difference is determined so that strain can be calculated.

$$\varepsilon_1 = \ln(h_{01}/h_1) = \ln(15/13.5) = 0.095$$
$$\varepsilon_2 = \ln(h_{02}/h_2) = \ln(20/16.6) = 0.186$$
$$\varepsilon_3 = \ln(h_{03}/h_3) = \ln(25/19.7) = 0.238$$
$$\varepsilon_4 = \ln(h_{04}/h_4) = \ln(25/2) = 2.5$$

In this step average yielding stress ($\overline{Y}$) is calculated. Part geometry (Fig. 2) helps to calculate the different areas (A_i), corresponding work and force [3,7,10].

$$\overline{Y}_1 = 549969340.6Pa$$
$$\overline{F_1} = \overline{Y_1}A_1 = \overline{Y_1}.(13.5\times 58.75) = 436000N = 43.6Ton$$

$$\overline{Y}_2 = 449574508Pa$$
$$\overline{F_2} = \overline{Y_2}A_2 = \overline{Y_2}.(13.5+34.3)\times 12.9/2 = 140000N = 14Ton$$

$$\overline{Y}_3 = 417524989.6Pa$$
$$\overline{F_3} = \overline{Y_3}A_3 = \overline{Y_3}.(2\times 32.7\times 9.2) = 250000\,N = 25Ton$$

$$\overline{Y}_4 = 206192829.6Pa$$
$$\overline{F_4} = \overline{Y_4}A_4 = \overline{Y_4}.(15.9\times 33.5) = 109000\,N = 10.9Ton$$

Therefore forging load required for material entrance to the gutter area can be calculated:

F_{Total}=43.6+14+25+10.9=93.5 Ton

From Fig. 10 it is clear that when the press reaches to the 90% of its stroke (21mm moves down), material inters to the gutter area and total forging load/tonnage is equal to 98 Ton. Therefore error is (98-93.5)/98 ≅5% and a good agreement is found and super forge package is trustable for predicting the forging load required.

As the result of simulation and ideal work calculation have been compatible, Fig. 15 can be added to Fig. 2 to use as a conceptual design for relevant industries [1]. Fig. 15 shows 3D model of die cavity with gutter area.

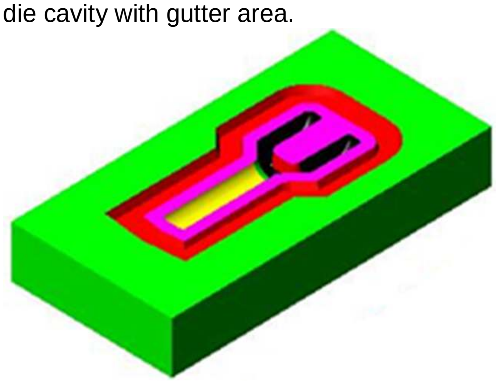

Fig. 15. 3D model of die cavity with gutter area

4. CONCLUSIONS

In this paper hot forging of Titanium alloy (Ti-6Al-4V) has been simulated using available finite volume software for non-isothermal condition. Different parameters have been studied and analyzed. An optimization for die filling and perform design, load and material waste reduction has been performed. In the absence of experimental data, the calculated history of ideal work method has been compared with the available analytical results and an appropriate agreement has been found. A good agreement has been found by comparison analysis and numerical results.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Forouhandeh F. Modeling of forging process of titanium alloys and using it in manufacturing a part, (Unpublished Master Thesis). Department of Mechanical Engineering. Iran University of Science and Technology; 2004.
2. Lresovani. Hot forging of titanium. Moscow Publication; 1975.
3. A Technical guide, ASM; 2000.
4. Lange K. Hand book of metal forming. SME. Dearborn. Michigan. 1996;20:40-43.

5. Boyer R, Welsch G, Collings EW. Materials properties hand book. Titanium Alloys. ASM. Materials Park, OH; 1994.
6. Hu ZM, Dean TA. Aspect of forging of titanium alloys and the production of blade forms. J. Mat. Proc. Tech. 2001;111:10-19.
7. Facchini L, Magalini E, Robotti P, Molinari A, Höges S, Wissenbach K. Ductility of a Ti-6Al-4V alloy produced by selective laser melting of prealloyed powders. Rapid Prototyping J. 2010;16:450–459.
8. Semiatin SL. Metals handbook. ASM. 1989;14:78-82,150-165.
9. Kalpakchian S. Manufacturing engineering & technology**,** McGraw-Hill; 1999.
10. Byrer TG. Forging handbook, ASM; 1985.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/11214