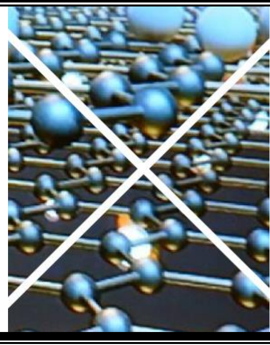
TIJMET, Vol. 004 (2021) 101-108

The International Journal of

Materials and Engineering Technology

ISSN: 2667-4033
TIJMET ID: 210402002 (8 pages)
Type of the Paper: Research Article
Received 11.04.2020 Revised: 23.11.2021 Accepted: 07.12.2021 Published (Online): 20.12.2021
Journal homepage: http://dergipark.gov.tr/tijmet



THE EFFECTS OF PUNCH SPEED ON THE FORGING LOAD OF HOT PRECISION BEVEL GEAR FORGING

MEHMET ALADAG[*1a], OMER EYERCIOGLU[1b], GULAGA TAS[1c]

[1]Gaziantep University Engineering Faculty Mechanical Engineering, Gaziantep, TURKEY.
*mmehmetaladag@gmail.com

Abstract

The mass production bevel gears is mainly realized by precision forging process. The process can be carried out cold, warm or hot conditions by using various forging presses (hydraulic or mechanical presses and High Energy Rate Forming machines). The process cycle time is changing with the type of forging press (i.e. the speed of punch). During hot forging, hot billet is in contact with the relatively colder die and heat is transferred to the environment. Therefore, the billet temperature is changing during deformation and the process time is an effective parameter of the temperature distribution of the billet. The flow stress of the material and the forging load are increasing with reducing billet temperature. In this study, the effect of punch speed on the forging load were investigated by finite element method. To simulate different forging presses, various punch speeds were chosen as 0.001 m/s, 0.01 m/s, 0.1 m/s, 1 m/s. and 10 m/s. In accordance with these punch speeds, the temperature distribution of the billet and the forging loads were determined. The results show that the temperature drop of the billet and the forging load are decreasing with the increasing punch speed. So that forging with HERF machines is advantageous than the hydraulic and mechanical presses in the precision hot forging process of bevel gears.

Keywords: Bevel gear, precision forging, finite element method, forging temperature, punch speed.

1. Introduction

Spur bevel gears are the most extensively used in the power transmission mechanism. To reduce cost and manufacturing time of spur bevel gears, the plastic deformation (forging method) which is one of the manufacturing process, is desirable to the other fabrication process (machining, hobbing, etc.) [1]. Hence, precision hot forging technology to spur bevel gear forging process has technological advantage with accompanying features. Also, precision forging, which gives the nearest shape to the final geometry after operation completed, therefore, is little or no further finishing processes are required [2,3]. Due to the

How to cite this article:
Aladag, M., Eyercioglu, O., Tas G., The Effects of Punch Speed on the Forging Load of Hot Precision Bevel Gear Forging, The International Journal of Materials and Engineering Technology, 2021, 4(2): 101-108.

ORCID ID:
[a]0000-0002-2484-7519, [b]0000-0002-9076-0972, [c]0000-0001-6149-935X

directional alignment of grains during the forging, the mechanical properties are significantly improved by this process [4]. In the previous studies, many features in hot forging process have been examined. Due to longer time and higher cost requirements of experimental studies on precision gear forging, computer aided numerical methods have been gained significant roles. In most of the numerical analyses, finite element or finite volume (FE - FV) methods have been widely used due to the success in prediction of the loads and stresses of forging process. In particular, FEM has been effectively used for large deformation problems.

Many researches successfully applied FE simulations in gear forging operations, such as Doege and Nale [5], Szentmihali et al. [6], and Mamalis [7]. Song and Im [8–10] have determined process design parameters by FE analyses. Zhuang et al [11] worked on tooth variation in hot forging of spur bevel gears. The effect of forming speed in precision forging with servo-press machine was evaluated by Kim et al.[12].

In present study, hot forging process of bevel gear in different punch speeds were examined by using Simufact Forming FE package. Defined press types and their velocities are hydraulic press, crank press and HERF (High Energy Rate Forming) machine, and 0.001 m/sec, 0.01 m/sec, 0.1 m/sec, 1 m/sec and 10 m/sec, respectively. Behavior of the material under subjected load and different velocities were presented. Moreover, the changing in the contact pressure between the workpiece and the die, and distribution of workpiece temperature were investigated.

2. Preparation of Model

2.1. Bevel Gear Model and Workpiece Preparation

The selected bevel gear model is used in the differential gear box of a passenger car. The solid model of the bevel gear was created by using Solidworks 3D Package. The tooth number, module and cone angle of the bevel gear are 11, 8mm and 113,4 degrees, respectively. The dimensions of the gear are given in Figure 1. The initial billet size is calculated by using the final gear dimensions keeping in mind that the volume is constant during forging.

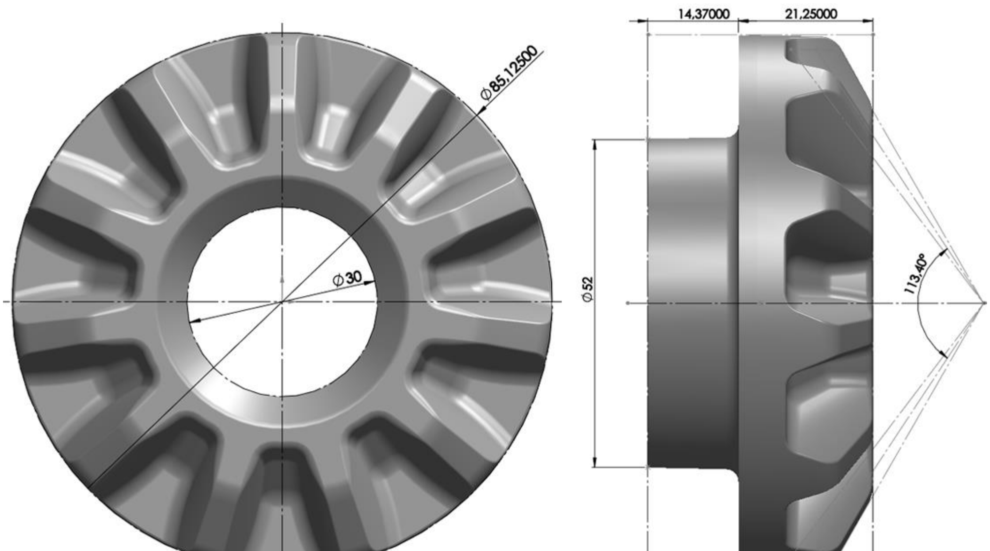


Figure 1. Representation of the bevel gear.

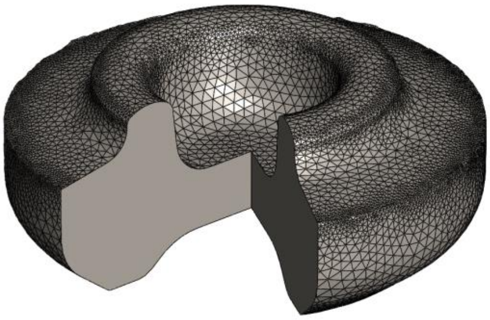


Figure 2. Representation of the workpiece after preforming process.

Because of the limited formability of the material, the forging operation is carried out in two steps. The first step is preforming the cylindrical billet and the second is precision forging of the bevel gear. The final shape of the preform is shown in Figure 2. However, preforming stage is not included to this study and precision forging stage which is critical is investigated.

2.2. Bevel Gear Precision Forging Die Set Design

The forging die is also created in Simufact Forming FE software environment. The geometry and dimensions of the die set are provided by the forging company. Thus, it was aimed to compare the results with the experimental study. The die set used in the simulations consists of 2 pieces for simplicity; punch and die as shown in Figure 3. Punch is the moving part which is attached to the ram of the press while the die is fixed on the press bed.

2.3. Finite Element Modeling For Precision Forging

In order to provide more accurate and consistent information as a result of the forging process, the selected material and the consistency of the defined parameters are very important. As the material flow changes according to the mechanical properties of the material under load and the direction of the fibers, the analysis results will also change. Thus, if a forging operation is to be carried out in the finite element analysis program, the operator must carefully select the basic parameters. In order to show the effect of different forging speeds on the load-stroke curve, the selected velocity values are given in Table 1. Also, in all models, the analysis time was calculated according to 99.5% filling of the mold so that the results can be compared with each other accurately.

In this study, the parameters defined in the workpiece to be forged are specified as the same for all finite element model. In this way, other defined parameters other than press speed as a result of the resulting changes will prevent the occurrence. Accordingly, the parameters defined in the FE analysis environment of the forging process are given in Table 2.

The analysis results are intended to be closer to reality, so the bevel gear mold is defined as elastic. Thus, the results obtained from the analysis are quite real. In addition, the mesh detail in the workpiece and in the bevel gear die is improvement in the detailed region, i.e., the tooth profile. Therefore, the number of mesh created on the model has increased significantly. This not only affected the results well but also extended the analysis time. The workstation computer used in the analysis, the "Dell Precision Tower 32GB memory with 2x Xeon 4114 processors" was completed in approximately 70 hours. The analyses results were discussed in 3th section.

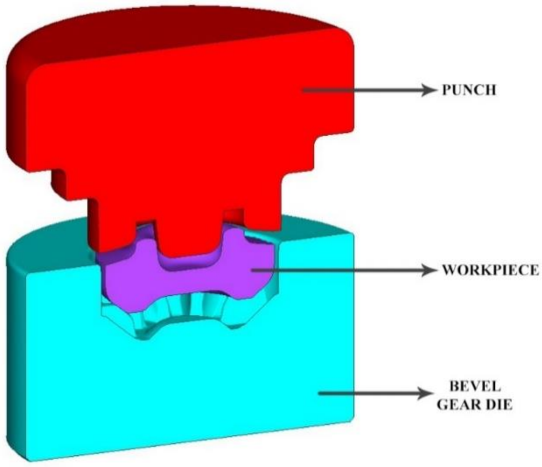


Figure 3. Bevel Gear forging die used in FE simulations.

Table 1. Forging models and selected forging speed [13].

Study	Punch Speed (m/sec)
Model 1 (Hydraulic)	0.001
Model 2 (Hydraulic)	0.01
Model 3 (Crank Press)	0.1
Model 4 (Crank Press)	1
Model 5 (HERF)	10

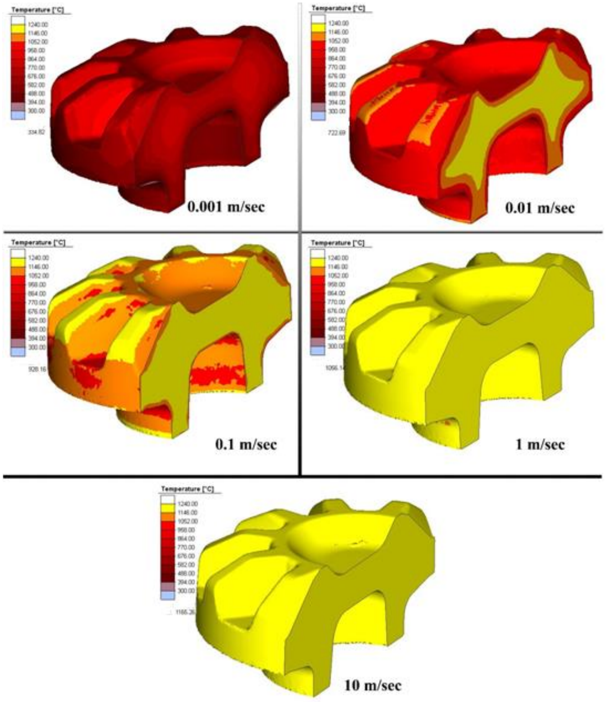
3. Results and Discussion

The temperature distributions on the forged gear at the final die filling stage (99.5%) are shown in Figure 4 for all punch speeds. The preform and the die were at 1200 °C and 100 °C respectively at the beginning of the forging operation. The heat is transferred from preform to the die and environment. Although some amount of heat is generated during deformation, the temperature drops by the time pass. As it is expected that the maximum temperature drop occurs for the lowest punch speed (longer forging time). The maximum temperature of the forging is found as 335 °C for 0.001 m/sec punch speed. Similarly, the maximum temperatures are 722 °C, 928 °C, 1056 °C and 1165 °C for 0.01 m/sec, 0.1 m/sec, 1.0 m/sec and 10 m/sec, respectively.

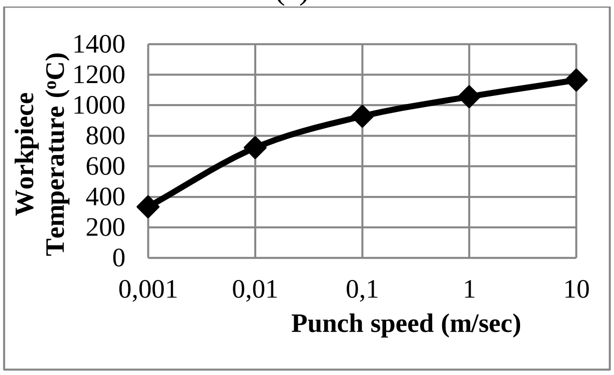
The effective (von Mises) stress distributions with respect to punch speeds are given in Figure 5. For high speed forming, there is a contradiction between temperature and strain rate effects in terms of flow stress. Lower forming time (higher punch speed) means less temperature drop, therefore lower flow stress. On the other hand, the flow stress increases with increasing strain rate and this is more affective at high temperatures (see flow stress-strain diagram of AISI 4340 in Figure 6). The results of FE analyses show that the maximum effective stresses are 334 MPa, 188 MPa, 96 MPa, 69 MPa and 62 MPa for 0.001 m/sec, 0.01 m/sec, 0.1 m/sec, 1.0 m/sec and 10 m/sec, respectively. The differences of effective stresses among higher punch speeds are smaller and this is due to strain rate effect.

Table 2. FE parameter settings table.

Parameters	Definitions
Workpiece Material	AISI 4340
Bevel Gear Die Material	H13
Workpiece Temperature T_w (°C)	1200
Die Temperature T_d (°C)	100
Behaviour of Workpiece Material	Elasto-Plastic
Behaviour of Bevel Gear Die Material	Elastic
Behaviour of Punch	Rigid
Frictrion Coefficient Shear and Columb	0.3 and 0.4
Workpiece Mesh Type	Hexahedral
Workpiece Mesh Size	219318
Bevel Gear Die Mesh Type	Tetrahedral 134
Bevel Gear Die Mesh Size	578816
Solver Machine	2 x Xeon 4114 CPU with 30 Solver Core – 32GB Ram

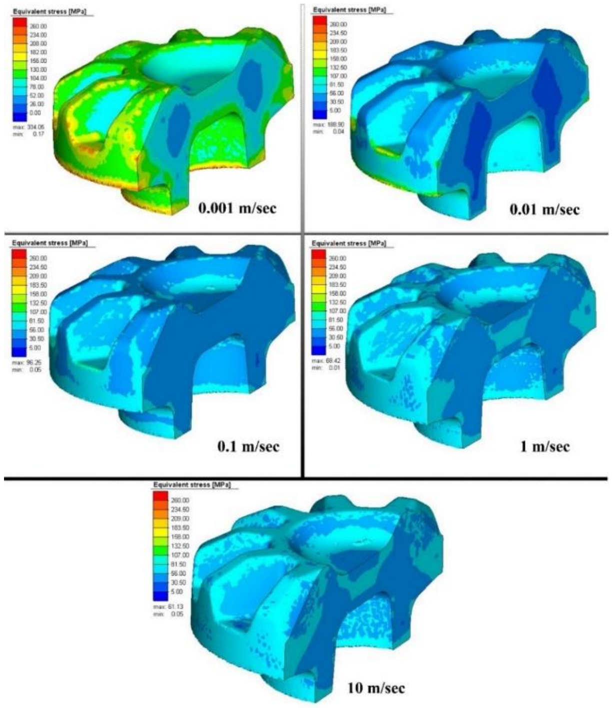


(a)

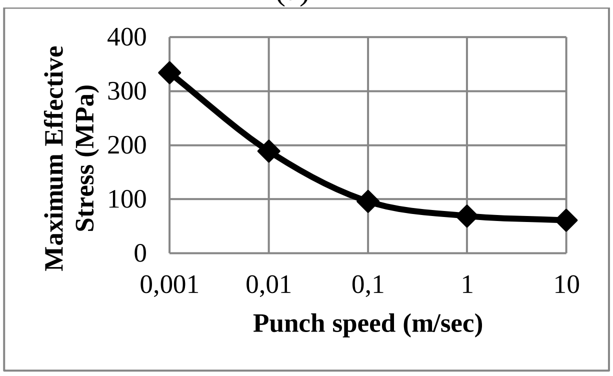


(b)

Figure 4. (a) Temperature distributions and (b) maximum temperatures at the maximum stroke of the punch for all models



(a)



(b)

Figure 5. (a) Effective stress distribution and (b) maximum effective stress at the maximum stoke of punch for all model.

The interference pressure between the workpiece and the die surface (i.e. contact pressure) is also investigated by FE analysis. As shown in Figure 7, the maximum contact pressure is obtained for the lowest punch speed (0.001 m/sec). The value of contact pressure is very near to the yield strength of the die material (AISI H13), therefore there is a danger of plastic deformation on the die surface for 0.001 m/sec punch speed. For other punch speeds the maximum contact pressures are not more than 650 MPa, so that the die is safe.

The load-stroke diagrams of all cases are plotted in Figure 8. The maximum forging loads are 445 tonf, 250 tonf, 235 tonf, 215 tonf and 216 tonf for 0.001 m/sec, 0.01 m/sec, 0.1 m/sec, 1.0 m/sec and 10 m/sec punch speeds, respectively. The change in maximum load with respect to punch speed is shown in Figure 9. Due to lower flow stresses at high temperatures, the corresponding forging loads are also lower. Although punch speed is increase from 1.0 m/sec to 10 m/sec (so as lower temperature drop), the forging load is not reduced. This is due to increasing flow stress due to higher strain rate.

An experimental study was carried out in the laboratory by using a crank press and the photograph of the forged bevel gear is given in Figure 10. The forging parameters taken as similar to the FE model 3; the preform and die temperatures were 1200 °C and 100 °C respectively, punch speed was 0.1 m/sec, the die set was lubricated by Molykote Longterm2. The maximum forging load was measured as 225 tonf which is slightly higher than the corresponding FE result (215 tonf). The slight difference may be encountered due to transfer time of the perform form the furnace to forging press. The result of experimental work validates the FE simulation models and the analyses.

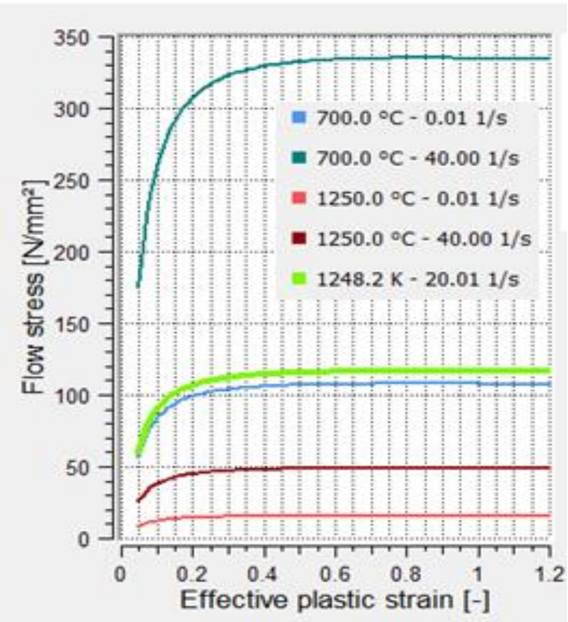
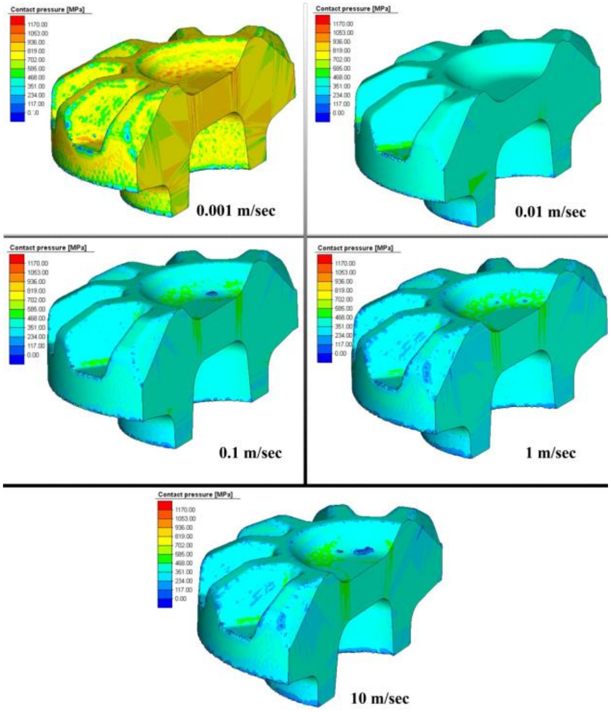
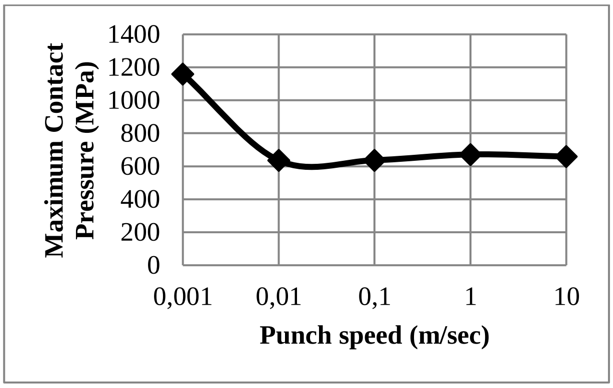


Figure 6. Flow stress-strain diagram of workpiece material (AISI 4340)



(a)



(b)

Figure 7. (a) Contact Pressure distribution and (b) maximum contact pressure at the maximum stroke of the punch for all model.

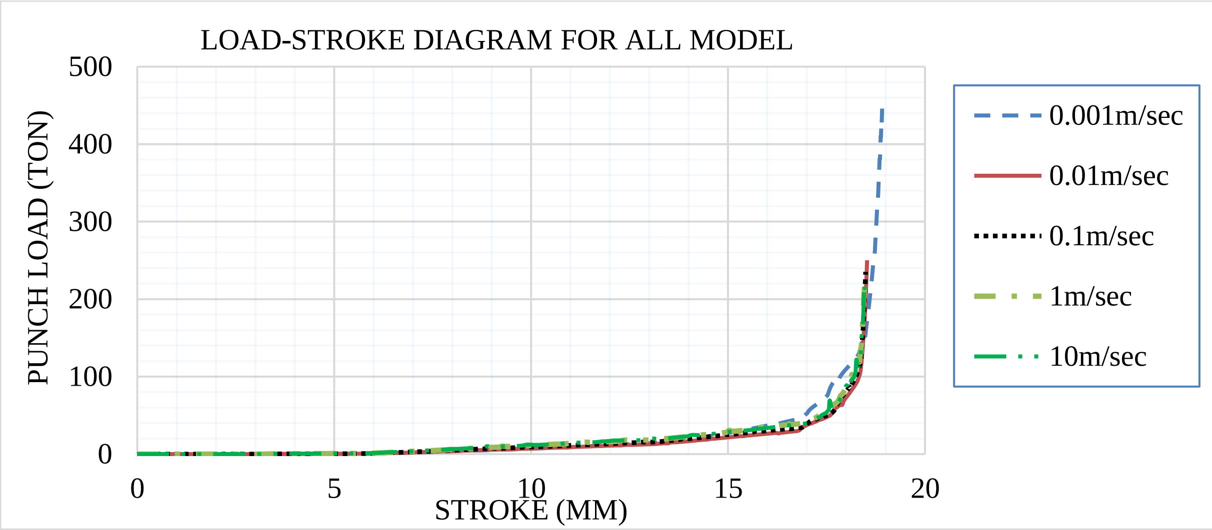


Figure 8. Load – Stroke Diagram for all models.

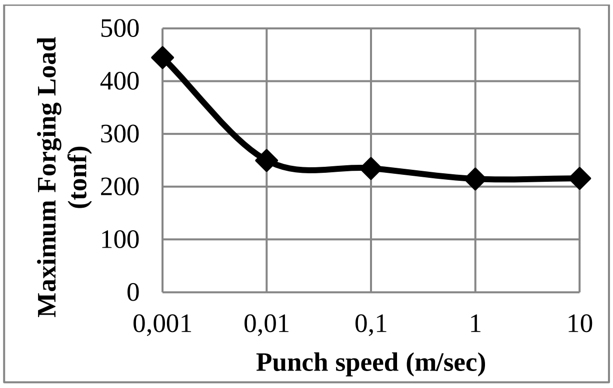


Figure 9. The change in maximum load with respect to punch speed.

Figure 10. The forged bevel gear by using crank press (0.1 m/sec press speed).

4. Conclusion

The results can be concluded as follows.

- The result of experimental study validates the FE model used in this study for gear forging simulations.
- The heat is transferred from workpiece to the die and environment during forging operation. Although some amount of heat is generated during deformation, the temperature drops by the time pass. As it is expected that the maximum temperature drop occurs for the lowest punch speed (longer forging time). For higher speeds (above 1 m/sec), the temperature drops are very small because of very short forging time.
- For high speed forming, there is a contradiction between temperature and strain rate effects in terms of flow stress. Lower forming time (higher punch speed) means less temperature drop, therefore lower flow stress. On the other hand, the flow stress increases with increasing strain rate and this is more affective at high temperatures. The differences of effective stresses among higher punch speeds are smaller and this is due to strain rate effect.
- When the forging process is carried out at low speed, the required press capacity is higher due to more cooling of the workpiece. At the lowest punch speed

(0.001 m/sec), the maximum forging load, effective stresses and contact pressure are all higher than the other cases. More cooling (so as higher forging load) may cause deformation of the die surface.

Acknowledgements
The authors would like to acknowledge the contributions of the Scientific Project Bureau (BAPYB) of the Gaziantep University and Kanca Forging Co. (Kanca Dövme Çelik ve Makina A.Ş.).

References

1. Behrens, B.A., Doege, E., Reinsch, S., Telkamp, K., Daehndel, H., and Specker, A. Precision forging processes for high-duty automotive components. J. Mater. Process. Technol., **2007**.
2. Eyercioglu, O., Dean, T.., and Wlaton, D. Precision Forging of Gears. Int. Mach. Des. Prod. Conf., **1996**.
3. Eyercioglu, O., Dean, T.., and Walton, D. Dimensional accuracy of hot precision forged spur gears. Int. Gearing Conf., **1994**.
4. Yilmaz, N.F., and Eyercioglu, O. Near Net Shape Spur Gear Forging Using Concave Preform. Mechanics, **2018**, 24(2):268–277.
5. Doege, E., and Nägele, H. FE Simulation of the Precision Forging Process of Bevel Gears. CIRP Ann. - Manuf. Technol., **1994**, 43(1):241–244.
6. Szentmihali, V., Lange, K., Tronel, Y., Chenot, J.-L., and Ducloux, R. 3-D finite-element simulation of the cold forging of helical gears. J. Mater. Process. Technol., **1994**, 43(2–4): 279–291.
7. Mamalis, A.G., Manolakos, D.E., and Baldoukas, A.K. Simulation of the precision forging of bevel gears using implicit and explicit FE techniques. J. Mater. Process. Technol., **1996**, 57(1-2):164–171.
8. Song, J.H., and Im, Y.T. Process design for closed-die forging of bevel gear by finite element analyses. J. Mater. Process. Technol., **2007**.
9. Kim, S.-Y., and Im, Y.-T. Three-dimensional finite element analysis of non-isothermal shape rolling. J. Mater. Process. Technol., **2002**, 127(1):57–63.
10. Kim, S.-Y., Tsuruoka, K., and Yamamoto, T. Effect of Forming Speed in Precision Forging Process Evaluated Using CAE Technology and High Performance Servo-press Machine. Procedia Eng., **2014**, 81:2415–2420.
11. Zhuang, W., Han, X., Hua, L., Xu, M., and Chen, M. FE prediction method for tooth variation in hot forging of spur bevel gears. J. Manuf. Process., **2019**, 38: 244–255.
12. Kim, S.Y., Tsuruoka, K., and Yamamoto, T. Effect of forming speed in precision forging process evaluated using CAE technology and high performance servo-press machine. Procedia Eng., **2014**, 81:2415–2420.
13. Bhaduri, A. Mechanical Properties and Working of Metals and Alloys.