

Finite Element Analysis of Gear Like Form by Using Lateral and Forward Extrusion

Tahir ALTINBALIK¹, Önder AYER²

¹Assoc. Prof. Dr., Trakya University, Faculty of Engineering, Edirne TURKEY

²Dr., Trakya University, Faculty of Engineering, Edirne TURKEY

Abstract – The aim of this research is the reduction in deformation load, improvement of the mechanical properties of the product by means of an optimum forming process and die profile. Forward extrusion and lateral extrusion were chosen as two different forming methods to manufacture a spur gear form. Four different die geometries were chosen for the forward extrusion; including straight tapered transition profile and cosine transition profile with having two different die lengths. Al 1070 was used as workpiece material in the experimental study. Experiments using five sets of dies with spur gear form were performed, and the measured forming load results were compared with the predictions of the finite element method for the same deformation situations by using DEFORM-3D. The state of stress and strain was also determined for two forming methods by means of DEFORM-3D. Finally, a series of fatigue tests were carried out for four teeth gear forms produced by both processes to evaluate influence of the forming processes.

Keywords – Extrusion, spur gear, DEFORM 3-D, optimal die profile, fatigue

1. Introduction

A gear is a machine element designed to transmit power and motion from one mechanical unit to another. Spur gears are the simplest types of gear and mainly manufactured by metal cutting, or by the combination of conventional hot forging with metal cutting which is expensive and requires much more manufacturing time [1]. Metal forming is a favorable manufacturing method of gears and gear-like components due to their longer lifetime, higher fatigue strength and cost effectiveness when compared to machined gears when it is made of the same material. Extrusion process is the technique used to transform cast billet of solid metal into products with a definitive cross-sectional profile for a wide range of uses. The manufacture of high strength products with good surface finish is maintained to use cold shape extrusion in a large extent. The cold extrusion is used in areas of application from simple axisymmetric products to complex shapes such as gears and splines [4]. As it is known, cold extrusion of a solid spur gear has some advantages such as

better wear and fatigue properties compared to conventional machining [2]. The most important factor that affects the quality of extrudate is the material flow: the optimum die surface design will produce a smooth material flow during the extrusion process and, therefore gives a high quality extrusion product. Recently, a serious experiment has been carried out by Çan and Mısırlı [3] choosing a gear-like section for comparative evaluation of the methods of lateral extrusion and closed-die forging. Altınbalık and Ayer [4],[5] performed serious studies for extrusion of clover sections which are used for trochoidal gears of external gear pumps. The new kinematically admissible velocity fields for three dimensional extrusion were suggested for both to obtain the optimum die length of shaped inlet dies and to determine the extrusion load in the mentioned study. As known, to prevent expensive evaluation of tooling design based on trial-and-error which often leads to high development cost and long time-to-market, FEM simulation and modeling is used in product design and development for many metal forming areas [6]. Qamar [7] used FEM for investigation of shape complexity, metal flow and dead metal zone in cold extrusion. FE simulation of porthole die extrusion process has been investigated by Jo et al [8] by using DEFORM-3D. Process simulation using DEFORM-3D has been instrumental in cost, quality and delivery improvements for the last two decades. Chen et al.[9] performed DEFORM-3D finite element code to examine the separate influences of the die semi-angle, the extrusion ratio and the friction factors on the plastic deformation behaviour of an aluminum billet during its axisymmetric extrusion through a conical die. Fang [10] aimed at combining the considerations on die design and process optimization for the alloy to manufacture a complex solid profile with large differences in wall thickness, by means of DEFORM-3D and experimentation instead of the traditional trial and error approach. In another study, Fang et al [11] attempted to apply FEM to simulate the extrusion process to manufacture profiles of industrial significance through multi-hole pocket dies. He et al. [12] carried out a theoretical investigation to understand the non-

steady state extrusion process by means of the behaviour of metal flow, the extrusion load and the velocity field based on the FEM simulation called DEFORM-3D.

On the other hand, lateral extrusion was introduced as a branch of extrusion in which the material, placed in an injection chamber, is injected into a die cavity in a form which is prescribed by the exit geometry and is characterised by combined axial and radial flow of material to fill the die cavity [13]. Lateral extrusion has several advantages, such as less load requirements, comparing to closed die forging in producing parts with radial geometries. Studies about metal flow in lateral extrusion mostly cover the simple shaped flanges. Balendra [14],[15] has studied the effects of process parameters on metal flow and load requirement for complete flanges. Recently, the FEM was also employed to simulate the lateral extrusion of solid billets for different geometries by several researchers. Jafarzadeh et al.[16] performed a theoretical and experimental study for analysis of lateral extrusion of gear-like parts. In another study Jafarzadeh et al.[17] studied the forming characteristics of radial-forward extrusion by using FEM. On the other hand, research on the lateral extrusion of the segmented flanges such as splines and spur gear forms are very limited in the literature. So far, the load requirement of lateral extrusion of segmented flanges has been carried out by Plancak et al.[18], Çan et al.[19] and Altınbalık[20] by using the Upper Bound Method.

In the presented study, a theoretical and experimental investigation of spur gear form is performed. Gear forms of the same dimension were produced by forward extrusion and lateral extrusion. 1070 aluminium alloy were extruded through two different die inlet profiles, namely straight tapered transition and cosine transition and the die lengths of them were selected as 15 mm and 20 mm in the forward extrusion experiments. The material used for the billet in the lateral extrusion experiments was the same as 1070. Then, two manufacturing processes were simulated by a commercial FEM programme called DEFORM 3-D in order to predict the extrusion load requirement. Furthermore, the states of stress and strain were determined for two forming methods by means of DEFORM-3D. Finally, a series of fatigue tests were carried out to tooth of the gear forms to evaluate influence of the forming processes.

2. Experimental Study

a) Sample Preparation and Die Design

Although the straight tapered dies were preferred to curved dies for their easy manufacture in the past,

nowadays, the manufacture of curved dies has become an easy operation process by using the capabilities of CNC machines. Especially in the last two decades, researchers have performed many studies on curved dies such as linearly converging die profile and cosine die profile. Curved dies cover an area of application from simple axisymmetric products to complicated sections such as gears and splines [2].

In this study, two different forming methods have been used to obtain gear form, namely forward extrusion and lateral extrusion. Gear form has been defined mathematically as shown in Fig.1 and the inlet and exit geometry of the dies were obtained as;

$$R_{inlet}(\theta,z)=14 \quad (1)$$

$$R_{outlet}(\theta,z)=8.7+3.5\cos(6\theta) \quad (2)$$

In forward extrusion the die inlet geometry has been design by two different type as straight tapered transition and cosine curved transition. Transition equations are given as;

$$R_{cos}(\theta,z) = \frac{(R_{inlet} + R_{outlet})}{2} + \frac{(R_{inlet} - R_{outlet})}{2} \cos\left(\frac{\theta z}{L}\right) \quad (3)$$

$$R_{tap}(\theta,z) = R_{outlet} + (R_{inlet} - R_{outlet})\left(\frac{L-z}{L}\right)$$

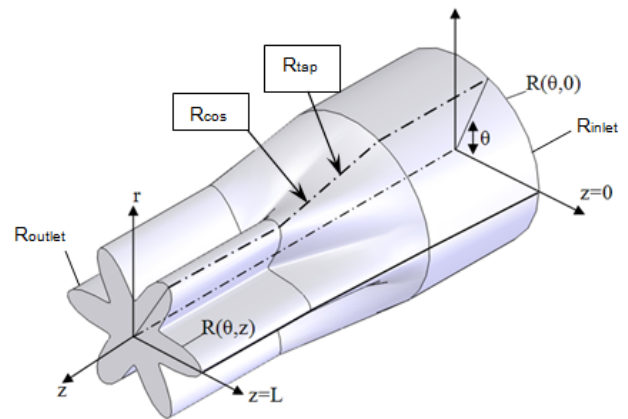


Figure 1. Schematic representation of the curved extrusion dies with the axes of reference and profile functions

The lengths of the dies have been determined to be L=15 and L=20 mm for the purpose of studying the effect of the die length on the extrusion load. Schematic illustrations of the die assembly and profiles of dies for forward extrusion are shown in Fig.2.a and Fig.2.b. and the die assembly for lateral extrusion is shown in Fig. 2.c. The dies have been designed in flexible manner, and both the forward extrusion experiments and also the lateral extrusion

experiments have been realized with similar arrangement. The exit geometry given in Equation 2 for the lateral extrusion experiments have been machined on a die having a length of 15 mm and the die shape has been obtained. Photographical view of the experimental set-up is shown in Fig.2.d.

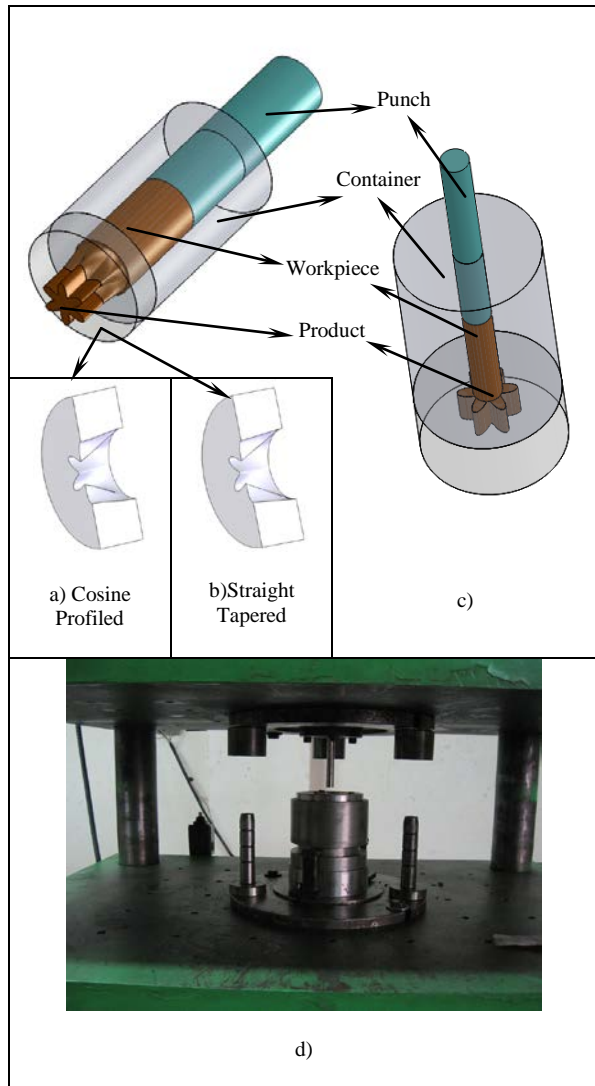


Figure 2. Schematic illustration of the die assembly for both extrusion processes

a) Die assembly of forward extrusion for cosine profiled die
 b) Die assembly of forward extrusion for straight tapered die
 c) Die assembly of lateral extrusion
 d) Photographic view of the experimental set-up

Al1070 was selected as an experimental material for investigation. For the forward extrusion, aluminium specimens have been cut from the bar and machined to 28 mm diameter and 45 mm in length. An extrusion container with internal diameter of 28.2 mm having 60 mm outer diameter and a punch having 28.2 mm diameter were machined. For the lateral extrusion, the initial diameters of specimens

were chosen as 10mm, which is assumed to be the dedendum circle of the gear. The height of the lower die was 15 mm. The dies were made by W-EDM because of their geometrical complexity and the other die parts were machined at CNC. Dies, containers and the punches were made from 1.2344 DIN hot worked tool steel and hardened to 54 HR_C. After simple compression test was performed to obtain the stress-strain relationship of the material and the equation was determined as follows:

$$\sigma = 144 \epsilon^{0.162} \text{MPa} \quad (4)$$

Forward extrusion and radial extrusion experiments were done on the 150 metric ton hydraulic press with constant ram speed of 5 mm/sec. The aluminum specimens were cleaned with acetone before deformation in order to ensure the similar friction conditions. A pressure transmitter has been placed on the hydraulic press with a PLC system. The load values were obtained by transforming the pressure signal that was received from the PLC system. The movement and the position of the press are determined in accordance with the information coming from the digital linear ruler. Thus, the upper plate of the press reached the adjusted position of 28 mm punch stroke, the experiment was stopped by means of the software. Data files about load versus stroke were stored.

b) Fatigue Test

As it is known, the fatigue strength of teeth of a gear is an important design consideration and affected by service conditions and manufacturing methods as well. On the other hand, “the single tooth bending test” is one of the rapid testing methods to obtain the fatigue behaviour of a gear tooth [21]. The mentioned test is very useful to determine the effect of some parameters such as manufacturing methods, heat treatments and finishing operations on the strength of the products. In the presented study, single tooth bending fatigue test was applied using three point loading method for determining the cycles of failure on the tooth which were produced from 1070 Al by both the forward extrusion and lateral extrusion. Bending tests were carried out on a 50 kN capacity of servo-hydraulic material testing machine called INSTRON 8501 having a frequency range of 0.5-50 Hz. The three point bending test equipment is given in Fig.3 and the upper and lower parts of the equipment were machined from 1.2344 DIN hot work tool steel and hardened to 54 RC. Although two teeth are loaded, each loaded tooth is assumed a cantilever beam, as explained in detail [22]. So, this situation can be considered as single tooth test.

Needle elements having 2 mm. diameter were attached to V-shaped grooves that were machined on the upper part of the equipment. The distance between two loading points is calculated by means of highest point of single tooth contact (HPSTC) which is given in detail in literature [22] and also determined as 20 mm. As seen in the figure the gear was set on a lower part of the equipment and bending loads were applied to the gear via its upper part by way of needle elements fitted on the equipment. The predetermined compression load values used in the fatigue experiments vary between 1.65 to 4 kN for each test. Fatigue tests were carried out on the gear tooth until complete fracture took place at the root of the tooth and tests were stopped and number of cycles was saved.

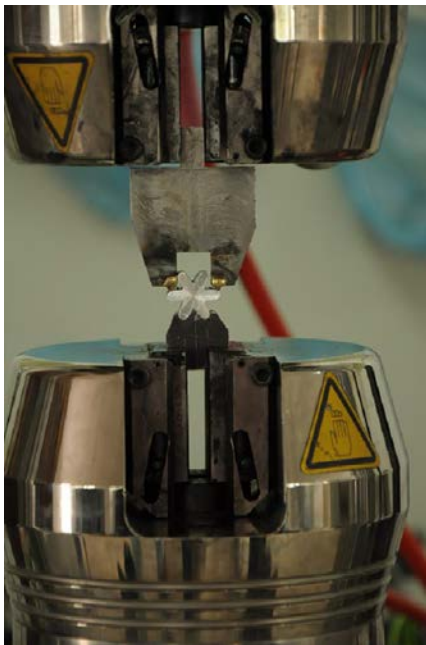


Figure 3. Photographic view of fatigue test fixture

c) 3D FEM Simulation Procedure

Finite Element Method (FEM) has been widely used in the modelling and simulation of profile extrusion processes in recent decades. DEFORM-3D is a useful FEM based process simulation programme designed to analyze the three-dimensional flow of complex metal forming processes such as open-closed die forging, extrusion, rolling, machining etc. In the presented study, as a finite element based software, DEFORM-3D v10.2 was used to simulate the forward and lateral extrusion of the aluminum billets. DEFORM-3D developed by Scientific Forming Technology Corporation (SFTC) in the US.

In the present simulations, the complete models of each extrusion experiment were modeled to obtain more intensive simulation results. In finite element simulations, remeshing of the workpiece is necessary due to large deformation in extrusion process. Therefore, tetrahedron elements were assigned to the workpiece and the die due to easily discrete mentioned the objects with complex shapes. The simulations in the present work, the different mesh density distributions were used to save calculation time and data storage space. Finer meshes were generated in the areas near the gears cavity of the dies and coarser meshes were generated in the other areas of the workpieces and the dies. Then, load requirements of the processes and state of stress and strain were obtained for both forward and lateral extrusion simulations. The present analyses comply with the following assumptions: (1) both the container and the dies are rigid bodies; (2) the extrusion billet is a plastic material; and 3) the friction factors (m) between the extrusion billet and the ram, the container, and the die components are constant and selected as 0.4. The velocity of the ram was 5 mm/s and the stroke was 28 mm same as in the simulations and in the experiments also. The extruded billet was modelled using approximately 6000 nodes and 30000 elements.

3. Results and Discussion

Fig. 4-7 show a comparison of forming load versus the punch stroke between experimental and theoretical results which obtained from DEFORM-3D for different die profiles and different extrusion processes. As seen in figures, the forming load increases with the increasing stroke due to the increase in frictional surfaces. As the process continues the forming load decreases until the last stage of extrusion process and then increases again sharply as shown in figures because of the upper and lower dead zones are facing each other. The theoretical predictions are somewhat lower than experimental ones but the differences are in acceptable ranges. In Fig.4 calculated load values and experimentally recorded load values are shown for straight tapered profiled die having 15 mm die length to obtain the gear section. As known, prediction of the maximum extrusion load is important to design all forming parameters such as die design and tool material selection. According to Fig.4 a good agreement can be seen between the theoretical results and the experiments.

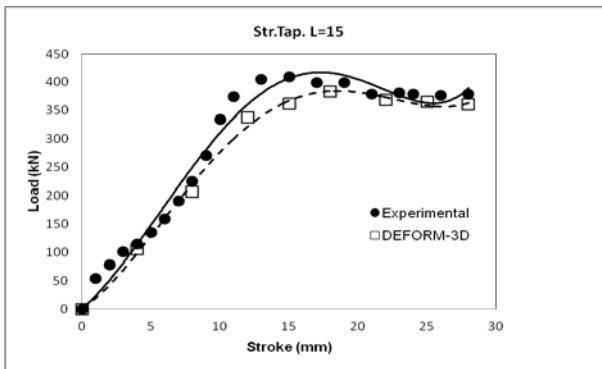


Figure 4. Comparison of theoretical and experimental forward extrusion load versus punch stroke for straight tapered profile $L=15$ mm.

The value of the maximum load estimated by the DEFORM-3D, which is crucial for determining the press capacity, deviates from the value obtained experimentally only with 6.5% and this discrepancy is acceptable one. This difference can be explained that material properties which are defined in the DEFORM-3D software do not entirely comply with the actual material properties which were used in the experiments. Similar conditions were observed on the other die types. The loads versus punch stroke obtained as a result of the experiments with cosine profiled die having 15 mm die length are given together with the DEFORM-3D solution results in Fig.5. The value of the maximum load that the FEM calculated deviates from the value obtained experimentally only with 6%. In order to investigate the effect of die length on deformation load the number of experiments were repeated for each die sets for $L=20$ mm. As seen from the Fig.6 and Fig.7, for the $L=20$ mm die length conditions, the differences between the experimental results and the ones obtained from FEM values at the max is 6.8% for straight tapered transition die and 7.9% for cosine curved transition die. In regard to the Figs 4-7, curves obtained from the DEFORM-3D are considerable suitable with the experimental data for whole processes. So, the FEM analysis is assumed to be valid. As the diagrams are examined together the extrusion load for straight tapered die having 15 mm die length is a little lower than the other die sets. It has been observed that the die transition geometry does not have a significant effect on the load for the same die length in forward extrusion. The difference of the measured load values between the cosine curved transition profile and the straight tapered transition profile in the experiments that have been carried out with die having a length of $L=15$ mm is only about 1%. The similar situation is also valid for the dies having lengths of $L=20$ mm. whereas, the load difference between the cosine curved transition profile and the straight tapered transition profile dies are 2%. It is clear that the effect of the die transition geometry on the forming load will be observed in a

clearer manner as the die length increases. A difference at a considerable value has not been observed between the measured load values, since the differences of the die lengths in the presented work are rather small.

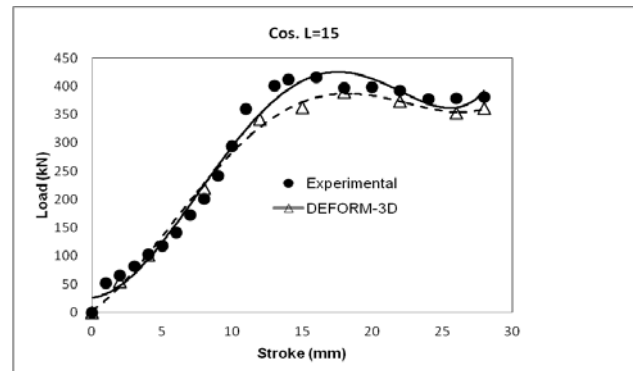


Figure 5. Comparison of theoretical and experimental forward extrusion load versus punch stroke for cosine curved profile $L=15$ mm.

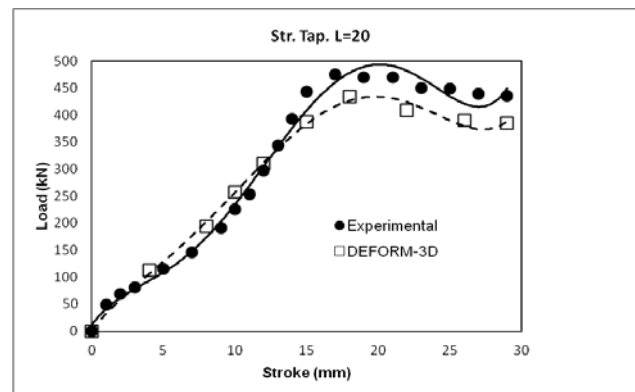


Figure 6. Comparison of theoretical and experimental forward extrusion load versus punch stroke for straight tapered profile $L=20$ mm.

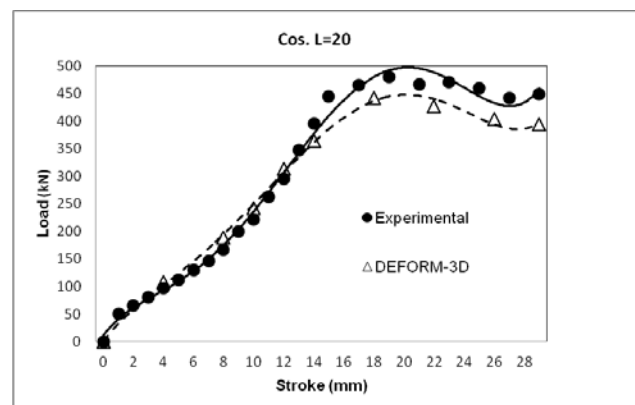


Figure 7. Comparison of theoretical and experimental forward extrusion load versus punch stroke for cosine curved profile $L=20$ mm.

Fig. 8 shows theoretical extrusion loads versus experimentally measured against the punch movement for lateral extruded parts from the billets

having 10 mm diameter and 65 mm in length. The three stages of extrusion can be seen in the diagram, namely, the simple lateral extrusion, the tooth formation and the corner filling. The tooth formation starts at 4 mm of the punch stroke and continues until the front wall of the gap. The corner filling stage starts at 21 mm of the punch stroke and finishes end of the process. According to diagram it is clearly seen that lateral extrusion requires less deformation load than that of the forward extrusion process for manufacturing the same geometry. Maximum deformation load was measured as 113 kN and this value is 3.5 times less than the forward extrusion. On the other hand, FEM solution gives more suitable results comparing the forward extrusion solutions. The value of the maximum load estimated by the DEFORM-3D differs from the value obtained experimentally only with 5% and this deviation is better than the results of the forward extrusion.

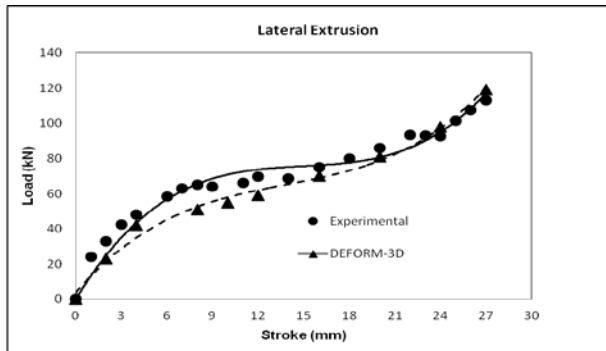


Figure 8. Comparison of theoretical and experimental lateral extrusion load versus punch stroke

Figs 9.a-9.e show how the effective stress distribution values change with forward extrusion for different die inlet geometry and die length and the lateral extrusion parts. In all cases, it increases from the rear side to the die inlet. What leads to this difference is the fact that the different material flow in the die and friction at the die interface. It may be observed that the lowest effective stress value is for the straight tapered transition and is at L=15 mm die length when the figures 9.a-9.e are considered as a whole. The dies with straight tapered transition have given lower effective stress values for the same die length. However, the differences between the stresses are rather close to each other, since the difference between the die lengths is not much. Lateral extrusion has given approximately 15% higher effective stress value compared to forward extrusion. Another interesting point is that the ratio of effective stress values at just before the die entrance and at the die inner surface is about %50 for all die applications.

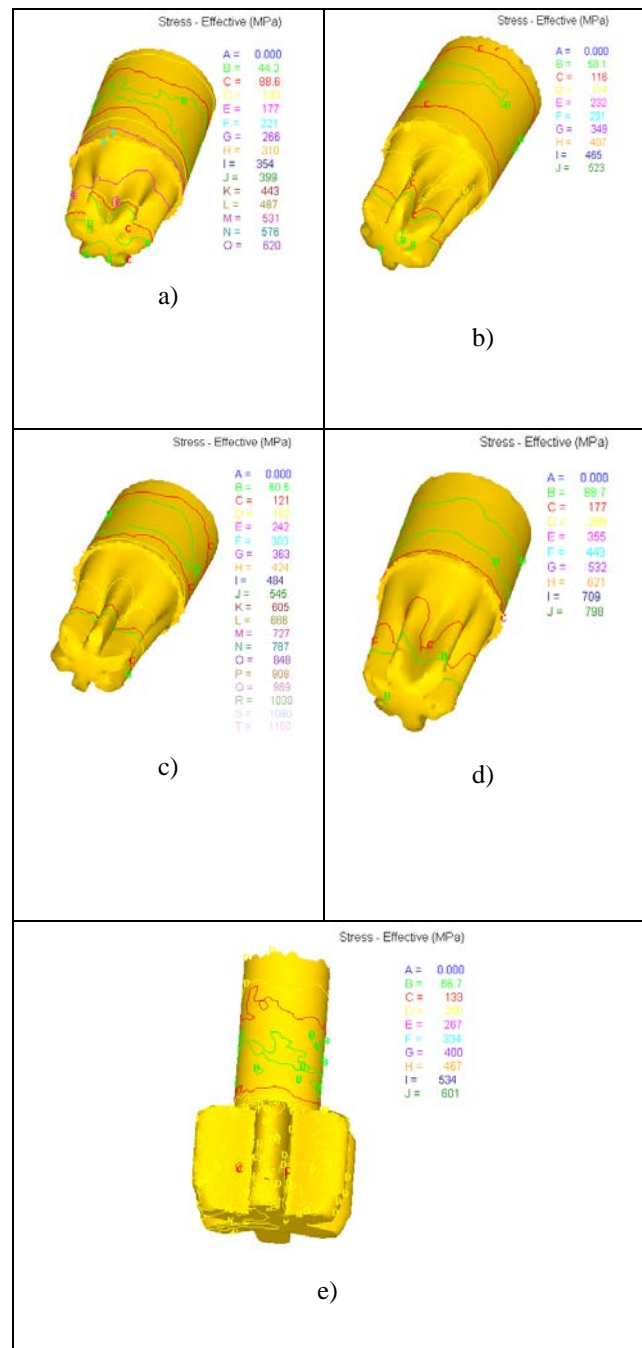


Figure 9. Effective stress distribution of the parts

- Forward extrusion cos. curved die L=15
- Forward extrusion straight tapered die L=15
- Forward extrusion cos. curved die L=20
- Forward extrusion straight tapered die L=20
- Lateral extrusion part

Figs 10.a-10.e show the effective strain distributions of Al billets under the same experimental conditions of all die profiles. In all cases, high strain values concentrated at the deformation zone as expected. As seen in the figures, there is a large strain concentration near the die entrance. Although the numerical values are nearly closer to each other, higher effective strain values were obtained for longer die lengths. Uniform mechanical properties can be obtained as a major advantage for such a

homogeneous distribution of strain. The maximum average strain value varies between 1.72 - 3.43 for straight tapered die profile with L=15 mm die length and maximum average strain value varies between 4.86-7.29 for cosine profiled die with L=20 mm because of the more intensive deformation. All the diagrams show that the cosine profiled die having 20 mm die length for the forward extrusion is worse than the other die applications.

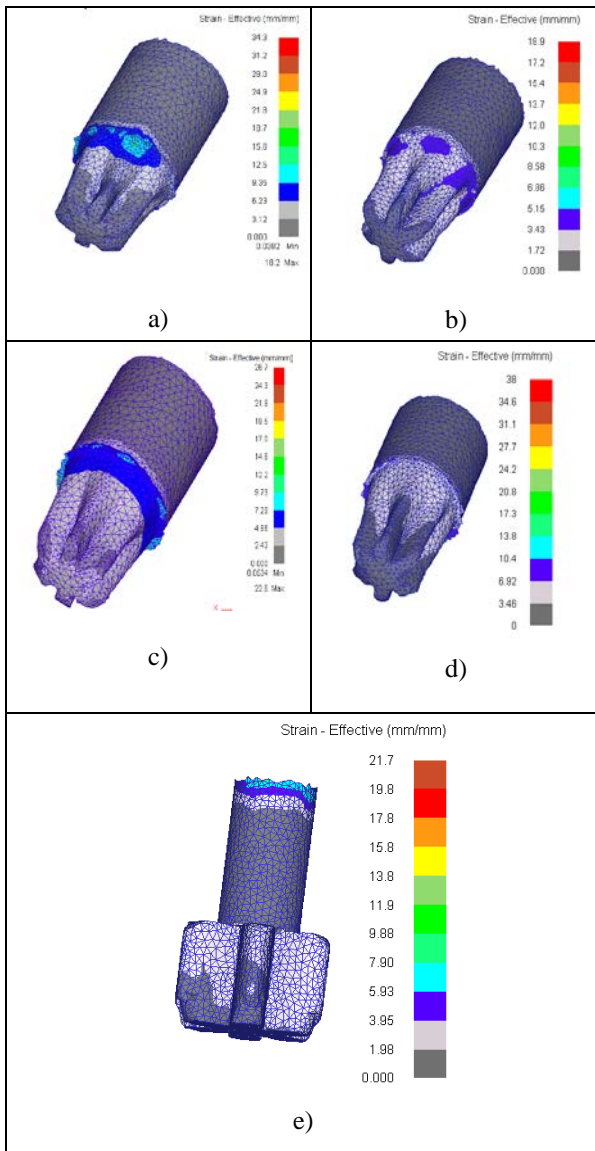


Figure 10. Effective strain distribution of the parts

a) Forward extrusion cos.curved die L=15 b) Forward extrusion straight tapered die L=15 c) Forward extrusion cos. curved die L=20 d) Forward extrusion straight tapered die L=20 e) Lateral extrusion part

Fatigue experiments have been carried out on spur gear parts for the purpose of more detailed studying of the effects of the production methods on the product. It has been observed that the die transition form in the forward extrusion does not have an important effect on fatigue strength when the results

are examined from the point of view of the fatigue strength. However, the increase in die length for the same die transition form has changed the number of cycle approximately by 2%. The fatigue strengths of the parts that are produced by lateral extrusion are considerably higher compared to parts which are manufactured by forward extrusion. The number of cycle for the parts that have been formed by forward extrusion using the cosine profiled transition die and with L=15mm die length together with the number of cycle for the parts that have been formed by lateral extrusion are given in Figure 11. The proportional difference in between two is in favor of the lateral extrusion at a ratio of 25 % approximately for the same number of cycle. For the 10^6 cycle this difference is at the level of 21 %.

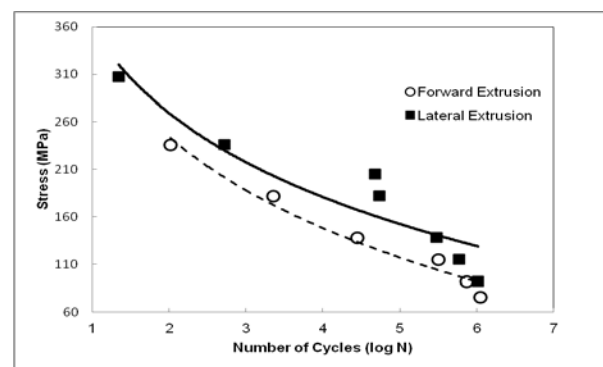


Figure 11. Fatigue tests results of gear forms produced by lateral and forward extrusion

4. Conclusion

In the presented study detailed experimental and theoretical investigations have been carried out to obtain optimum forming process for two chosen deformation processes in terms of the lower load requirements and higher mechanical properties of spur gear form. This has been performed for the two forming process: lateral extrusion and forward extrusion. Besides, in addition to the experimental work, the process has also been simulated by using DEFORM-3D.

The followings are obtained by regarding to the detailed DEFORM 3-D analysis and experimental results;

- 1) Load requirement for straight tapered transition die in forward extrusion is about only 1% less than that of cosine curved transition die for L=15 mm die length and 2% for L=20 mm die length. So, there is no considerable difference between the load values obtained by forward extrusion in terms of die length.
- 2) Comparing the forward extrusion with the lateral extrusion by means of the load requirements, as

expected, lateral extrusion required 72% less deformation load than the forward extrusion.

3) DEFORM-3D solution gives slightly lower results for the forward extrusion and slightly higher results for the lateral extrusion. The differences between the experimental results and the ones obtained from FEM values are about 6% for the forward extrusion and 5% for the lateral extrusion.

4) The fatigue strength of gear profile produced by lateral extrusion is about 25% higher than that produced by forward extrusion. On the other hand, the increasing of the die length in the forward extrusion process changes the fatigue strength only at a ratio of 2%.

References

- [1] Alves, M. L., Rodrigues, J. M. C., & Martins, P. A. F. (2001). Cold forging of gears: experimental and theoretical investigation. *Finite elements in analysis and design*, 37(6), 549-558.
- [2] Song, J. H., & Im, Y. T. (2004). Development of a computer-aided-design system of cold forward extrusion of a spur gear. *Journal of materials processing technology*, 153, 821-828.
- [3] Can, Y., & Misirli, C. (2008). Analysis of spur gear forms with tapered tooth profile. *Materials & Design*, 29(4), 829-838.
- [4] Altınbalık, T., & Ayer, Ö. (2008). A theoretical and experimental study for forward extrusion of clover sections. *Materials & Design*, 29(6), 1182-1189.
- [5] Altınbalık T, Ayer Ö. (2009). A theoretical study for optimum die length for forward extrusion of clover sections from circular billets through curved dies, paper presented at UNITECH'09 International Scientific Conference Gabrovo, Bulgaria, 2, 160-165.
- [6] Chan, W. L., Fu, M. W., & Lu, J. (2008). An integrated FEM and ANN methodology for metal-formed product design. *Engineering Applications of Artificial Intelligence*, 21(8), 1170-1181.
- [7] Qamar, S. Z. (2010). Shape complexity, metal flow, and dead metal zone in cold extrusion. *Materials and Manufacturing Processes*, 25(12), 1454-1461.
- [8] Jo, H. H., Lee, S. K., Jung, C. S., & Kim, B. M. (2006). A non-steady state FE analysis of Al tubes hot extrusion by a porthole die. *Journal of Materials Processing Technology*, 173(2), 223-231.
- [9] Chen, D. C., Syu, S. K., Wu, C. H., & Lin, S. K. (2007). Investigation into cold extrusion of aluminum billets using three-dimensional finite element method. *Journal of materials processing technology*, 192, 188-193.
- [10] Fang, G., Zhou, J., & Duszczyk, J. (2009). Extrusion of 7075 aluminium alloy through double-pocket dies to manufacture a complex profile. *Journal of materials processing technology*, 209(6), 3050-3059.
- [11] Fang, G., Zhou, J., & Duszczyk, J. (2009). FEM simulation of aluminium extrusion through two-hole multi-step pocket dies. *Journal of Materials Processing Technology*, 209(4), 1891-1900.
- [12] He, Y. F., Xie, S. S., Cheng, L., Huang, G. J., & Fu, Y. (2010). FEM simulation of aluminum extrusion process in porthole die with pockets. *Transactions of Nonferrous Metals Society of China*, 20(6), 1067-1071.
- [13] Balendra, R., & Qin, Y. (2004). Injection forging: engineering and research. *Journal of materials processing technology*, 145(2), 189-206.
- [14] Balendra, R. (1987). Considerations in the modelling of injection upsetting. *International Journal of Production Research*, 25(6), 889-906.
- [15] Balendra, R. (1993). Injection-chamber to die-cavity interface for Injection forming. *International Journal of Machine Tools and Manufacture*, 33(6), 753-760.
- [16] Jafarzadeh, H., Faraji, G., & Dizaji, A. F. (2012). Analysis of lateral extrusion of gear-like form parts. *Journal of mechanical science and technology*, 26(10), 3243-3252.
- [17] Jafarzadeh, H., Zadshakoyan, M., & AbdiSobbouhi, E. (2010). Numerical studies of some important design factors in radial-forward extrusion process. *Materials and Manufacturing Processes*, 25(8), 857-863.
- [18] Plancak, M., Bramley, A., & Osman, F. (1992). Non-conventional cold extrusion. *Journal of Materials Processing Technology*, 34(1), 465-472.
- [19] Çan, Y., Altınbalık, T., & Akata, H. E. (2005). A study of lateral extrusion of gear like elements and splines. *Journal of materials processing technology*, 166(1), 128-134.
- [20] Altınbalık, T., & Can, Y. (2006). An experimental study of lateral extrusion of splines. *Materials & design*, 27(9), 727-734.
- [21] Altınbalık T, (2000). *Investigation of load and material flow of gear blanks in closed-die forging*, Ph.D. Thesis, Graduate School of Natural and Applied Sciences, Trakya University, Edirne (in Turkish).
- [22] Akata, E., Altınbalık, M. T., & Can, Y. (2004). Three point load application in single tooth bending fatigue test for evaluation of gear blank manufacturing methods. *International Journal of fatigue*, 26(7), 785-789.

Corresponding author: Tahir ALTINBALIK
Institution: Trakya University Engineering Faculty, Edirne-Turkey
E-mail: tahira@trakya.edu.tr