Al-Rafidain Engineering Journal (AREJ) Vol.29, No.1, March 2024, pp. 68-73

Simulation of Direct Extrusion Process of Aluminum Alloy Using the Finite Element Method

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Received: September 14th, 2023 Received in revised form: November 7th, 2023 Accepted: December 27th, 2023

ABSTRACT

Due to the intricate die design, the metal flow and stress distribution in the metal extrusion process are quite complex. This study successfully used the commercial finite element code Deform-3D to simulate the stress distribution in the direct hot extrusion of Al-AA7075 rods. The outcomes demonstrate that the ideal die angle reduces the effective stress intensity. The best die angle for the least effective stress is angle 15°, and the best die angle for the least maximum stress is angle 30°. Moreover, the least load is found at an angle of 15°; the load decreases with an increase in the diameter. Further more, careful design of the extrusion dies profile can therefore control and reduce the stresses, which cause a main defect in product structure, supported that it can be used to minimize the amount of in-homogeneity imparted in to the product, and therefore control the product quality.

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Keywords:

Die angle, Direct extrusion, Aluminum, FEM, AA7075 Aluminum alloy.

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1. INTRODUCTION

Metal forming is a very important manufacturing process, when metal is formed, a tool known as a die applies stresses beyond the metal's yield strength, causing the metal to take on the shape specified by the die's geometry. The effect of the temperature used in forming metal leads to a discrimination between cold extrusion, warm extrusion and hot extrusion [1]. We used in this study Aluminum Alloy (AA-7075), this alloy contains zinc as the primary alloying element. It is one of the most commonly used aluminum alloys for high-stress structural applications, mainly in aircraft structural parts. It has excellent mechanical properties, such as good ductility, high strength, toughness, fatigue resistance, and high corrosion resistance compared to 2000 series alloys[2] . Recent years , it has been noticed a significant increase in the usage of the extrusion method in the production of components for the aerospace and machine industries, as well as for mechanical manufacturing [3].Metalis compressed during the extrusion process and deformed plastically as it is pushed through the die to create the profile shape. Numerous variables, including: flow stress, friction at the tool walls, temperature rise owing to stress action, and die geometry, affect the quality of the extruded shape[4]. The extrusion conditions, including the initial billet temperature, ram speed, reduction ratio, deformation resistance of the billet material, as well as thermal properties of the billet material and the tooling, are complicatedly related to both the state of stress and the temperature [5]. In order to prevent work hardening and facilitate the material's passage through the die, hot extrusion is performed above the material's recrystallization temperature [6]. The current study looked into the viability of simulating the steady-state aluminum hot extrusion process with the Deform 3D program. The simulation model has been created and analyzed using the FEM tool DEFORM-3D. It was intended to make predictions about the process parameters for hot extrusion of 7075 aluminum alloy shaft using Deform 3D simulation. Many studies and research have been conducted on this subject, In 2013 Ambati Vijay Kumar [1] conducted an experimental investigation to determine the effect of die angle on extruded product properties such as product surface finish and hardness on cold extruded Nano Sic reinforced aluminum alloy. The results are compared with cold extruded 6060 aluminum alloy. The die angles are 12°,15° and 25°. The extrusion load found to decrease with the increase in die angle, 25° die angle has shown least resistance against extrusion compared with other two die angles in both experiments.In 2013 also R. Mayavaram et al [2] presented a numerical algorithm to improve it is length of bearings that cause the die to exit with a consistent velocity to handle the problem of material flow during extrusion, this is based on a finite element model to solve material flow

During extrusion. The solution approach involves iteratively computing velocity, temperature, and strain fields during extrusion and updating the bearing lengths until balanced flow is achieved.In 2014 Rafid Jabbar Mohammed [3] studied the effect of the die angle on the stress distribution in the direct extrusion process of the Al-1100 and used the Deform3D program.The results showed that the finite element model was successfully simulate the stress distribution in the direct rod extrusion of Al-1100,besides that the optimum die angle reduced the magnitude of normal, shear, and effective stresses.In 2016 S.N.Ab Rahim et al [4] used the three-dimensional simulation program Deform 3D to attempt to estimate the extrusion speed and temperature during the hot extrusion process of aluminum alloy chip type 6061by using Deform 3D simulation without lubricant. Ram speed 2 mm/s at 500°C affected the amount of heat generated, the amount of heat loss to the extrusion tooling and made insufficient on quality bonding. In the FEM code, the results of the simulations were compared and confirmed successfully by the experimental results. In 2018 Rajesh V and Anupama Francy K [5] studied the effect of oilers and Die angles on the cold front extrusion process of aluminum alloy type AA6063 by using the Taguchi based gray relation analysis method in the analysis of the extrusion process, in the analysis, two control factors were taken namely oilers and die angles. Accordingly, a suitable orthogonal array was selected in Minitab software and experiments were conducted. After conducting the experiments, the load, surface roughness and hardness were measured. With the help of graphs, the optimum parameter was obtained and experimental analysis has been employed to optimize the effects of lubrication and die angle on the deformation of aluminum work piece by using Grey relation analysis. The effects of lubrication and die angle on forming loads, surface finish, and hardness were evaluated between die- work piece sliding surfaces. Grease, Engine oil and Castor oil with same amount were used as test lubricant. The lubricant and die angle on the work piece were used as inputs for the experimental work. The resultant optimal parameters combination was determined as Engine oil at 25 0 die angle. In 2019 Syed Zahid Qamar et al[6] studied how extrusion pressure, metal flow, and product faults affected by profile complexity. Extruding cold three solid forms with various degrees of complexity were the subjects of experiments that performed on three solid profiles of different complexities. Simulations were carried out for these three shapes using the commercial, finite element package DEFORM-3D. After verifying against experimental results, numerical work was extended to six more profiles of varying complexity. It was found that profiles of higher complexity usually result in more inhomogeneous metal flow, require larger extrusion forces, and more susceptible to product defects. Current complexity definitions need to be improved for consistent ranking of die profiles. Factors such as extrusion ratio and die profile symmetry may also play a significant role in the distortion of metal flow through an extrusion die. These findings can be of direct utility in extrusion die design improvement and reduction of extrusion defects related to metal flow. In 2022 M.M. Saeed et al [7] Studied the inclusion of the extrusion force value depending on the die shapes, materials, and the type of forward or backward extrusion process on the value of extrusion force. Three types of material’s die used steel, copper and brass, as well as the use of two shapes to extrude the work piece made from lead in the cavity of the die square and circular outputs product and two kinds of extrusion processes used forward and backward cold extrusion. The results revealed an acceptable result for both experiments and numeric values. These values were clearly observed with die made from copper material compared with other selecting materials, where a good indication was obtained when using backward extrusion process with circular die. In 2022 T. L and M. N. Abdullah [8] calculated the study in two phases using the DEFORM 3D application to obtain a work piece with suitable dimensions used in the final stage of the forming process and, to prevent the defects of the forming process. Through the simulation process for all the proposed dies, the results of forming load, effective stress, strain

effective and movement of metal particles were compared for optimum die. Experimentally, the forging process was carried out on a mechanical forging machine for the optimal die according to the data obtained from the simulation program.
After visited previous studies on the subject, it was evident that the majority of them used the finite element technique (FEM) with different engineering programs for shaping in order to get the optimal extrusion die design. It was also observed that cold forming was used in the majority of real-world experiments on the extrusion process with various variables. The goal of the current study is to use the DEFFORM - 3D program to create and carry out a simulation of the direct hot extrusion process.

2. FINITE ELEMENT METHOD

Large plastic deformations occur during extrusion and other bulk deformation operations. Many commercial FE packages find it challenging to handle such deformations. FE modeling and simulation were carried out in this study utilizing the DEFORM-3D program. The variables and data used and implemented practically, as shown in Table (1), in terms of the type of metal and the shape and dimensions of the workpiece. With automatic remeshing (finer mesh in more crucial locations where the element shape can undergo severe distortion), this software can handle significant deformations.[6] . Benefits of the simulation test include time and money savings as well as avoiding any expansion of experimental trials before sending the model to the manufacturing stage. In this study, dies have been designed with different angles 15°, 30° and 45°,used three different output diameters for each angle 16, 18, and 20 mm. Although assembly pieces were designed such as billets, to be malleable to take into consideration for its plasticity, the punch and the container were hard elements when they were built [7]. To simulate the process of extrusion, a shaft of aluminum type 7075 was used. The extrusion process was computationally done by using the finite element method. Initially, using AutoCAD program, the required parts were designed in 3D for each of the work piece (billet) , die (bottom die), punch (top die) and stored in (STL) format. After that, each part was called to the simulation program, assembled together and made in preliminary contact with the upper die, work piece and lower die. Then the simulation was performed. A billet with (50mm length, and 30mm diameter) and a temperature of 450 ℃ for the billet and container were used. Figure 1 shows the shape of the die after assembly.

Table 1: Process parameters used in the simulation

Parameters	The name, Values
Billet material	Aluminum 7075
Billet length	50mm
Billet diameter	30mm
Billet temperature	450C^0
Top die temperature	22 C^0
Bottom die temperature	450 C^0
Shear friction coefficient	0.4
Speed	0.3mm/Sec
No. of mesh element	20000

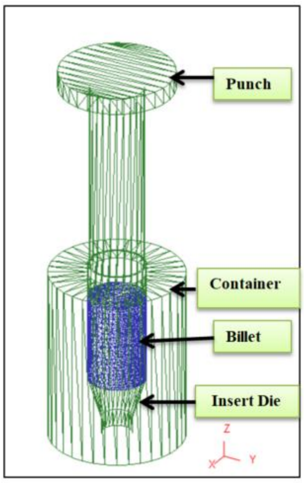

Fig.1 The parts of die after assembly

3. ALUMINUM ALLOY (AA-7075):

is an aluminum alloy, with zinc as the primary alloying element. It has excellent mechanical properties and shows good ductility, high strength, toughness, and good fatigue resistance. But it has much better corrosion resistance than alloys of the 2000 series. It is one of the most commonly used aluminum alloys for high stress structural applications and has been widely used in aircraft structural parts.

4.RESULTS AND DISCUSSION

After performing extrusion simulations, the following results are classified to groups as shown below:

4.1. The first group

Figure 2 and table 2 show the results of simulation of extrusion processes of Al – 7075 alloy when using extrusion dies with angle 15° and different diameters to produce product. From figure (2), it is noticed that the effective stress is as low as possible at an angle 15° and a diameter of 18 mm in the formation region and the land region, Because of the smoothness of this angle and the ease with the metal flows, the load put on the die is reduced. and it is also noticed that the maximum stress is as low as possible at a diameter of 20 mm for the same angle of the formation region and the land region. Because the dead metal zone at this diameter is as minimal as possible, and thus the force of sticking friction is smaller than at other diameters, the metal flows more smoothly. This was also observed and confirmed in research [9].

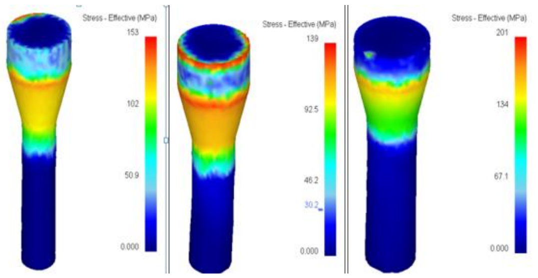

Fig .2 shows the effective stress of final product with die angle 15˚.

Table 2: results of simulation of extrusion for angle 15˚

Die angle (o)	Die outer diameter (mm)	Stress Effective (MPa) formation area	Stress Effective (MPa) land	Stress max. formation area (MPa)	Stress max. land (MPa)
15	16	119	39.1	-186	-277
15	18	118	30.2	-227	-238
15	20	134	39.4	-146	-203

4.2. Second group

Figure 3 and Table 3 show the results of simulation of extrusion processes of Al – 7075 alloy when using extrusion dies with angle 30° and different diameters to produce product. Figure (3) shows that the effective stress is as low as possible at an angle of 30° and a diameter of 16 mm in the formation area and the land area, while the largest stress is as low as possible at a diameter of 20 mm for the same angle in the formation area and the land area. This was also observed and confirmed in research [9].

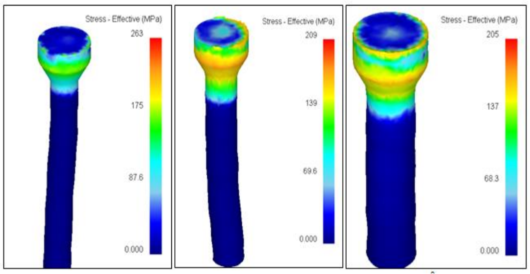

Fig .3 shows the effective stress of final product with die angle 30˚

Table 3: results of simulation of extrusion for angle 30˚

Die angle (o)	Die outer diameter (mm)	Stress Effective (MPa) formation area	Stress Effective (MPa) land	Stress max. formation area (MPa)	Stress max. land (MPa)
30	16	121	135	-178	-200
30	18	155	146	-218	-254
30	20	142	137	-147	-181

4.3. Third group

Figure 4 and Table 4 show the results of simulation of extrusion processes of Al – 7075 alloy when using extrusion dies with angle 45° and different diameters to produce product. Figure (6) that the effective stress is as low as possible at an angle of 45° and a diameter of 18 mm in the formation area and the land area, while the largest stress is as low as possible at a diameter of 16 mm for the same angle in the formation area and the land area. Because the dead metal zone at this diameter is as minimal as possible, and thus the force of sticking friction is smaller than at other diameters, the metal flows more smoothly. This was also observed and confirmed in research [9].

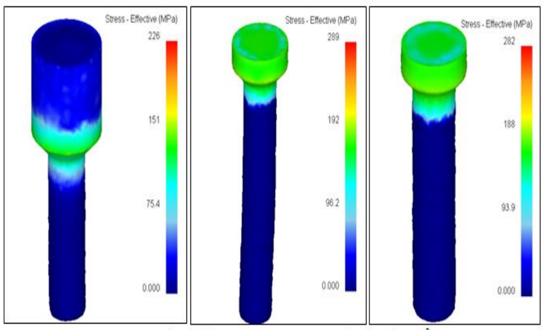

Fig .4 shows the effective stress of final product with die angle 45˚

Table 4: results of simulation of extrusion for angle 45°

Die angle (o)	Die outer diameter (mm)	Stress Effective (MPa) formation area	Stress Effective (MPa) land	Stress max. formation area (MPa)	Stress max. land (MPa)
45	16	112	69.7	123	-224
45	18	161	168	-220	-336
45	20	150	169	-176	-274

The final conclusions were documented, as shown in figures (5, 6 and 7) the figures show the relationship between the load (N) versus stroke (mm) for aluminum alloy AA7075 for different die angle. It is observed that the die with outer diameter 16 mm provides the maximum load. This shows that the load increases with decreasing diameter. Table 5 shows the extrusion average load in (N) for all die angles.

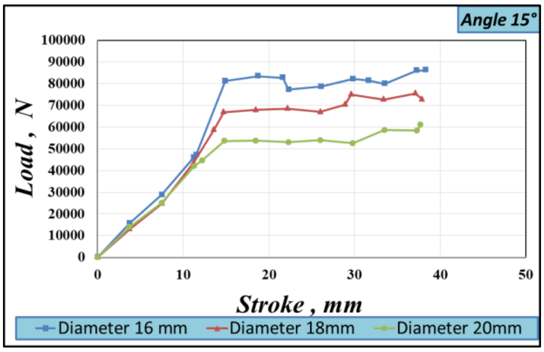

Fig 5. The load versus stroke curve for aluminum alloy AA7075 and die angle 15°

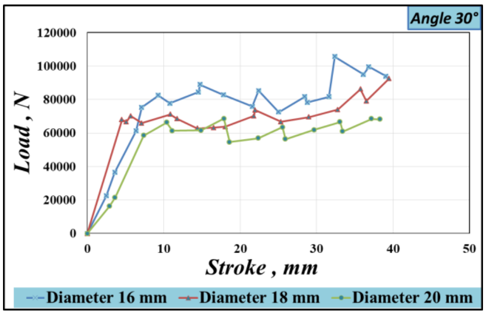

Fig. 6 The load versus stroke curve for aluminum alloy AA7075 and die angle 30°

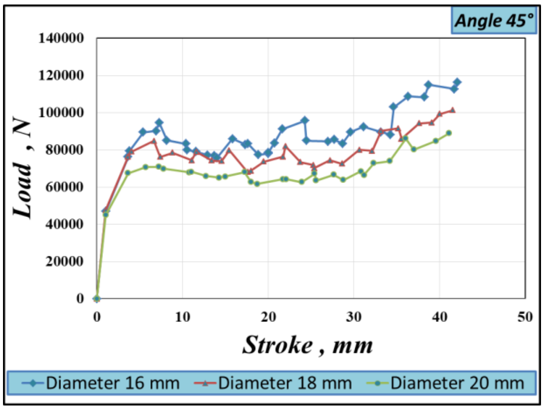

Fig .7 The load versus stroke curve for aluminum alloy AA7075 and die angle 45°

Table 5: the extrusion average load in (N) for all die angles.

Die angle (o)	Die outer diameter (mm)	Extrusion average load (N)
15	16	78772.73
15	18	67190.91
15	20	44500
30	16	84438.15
30	18	72608.86
30	20	62113.92
45	16	89354.42
45	18	80134.26
45	20	69615.68

5. CONCLUSION

The simulation examined the impact of die angle on stress distribution and extrusion load on AL-AA7075.

- It was found that the minimum load is at an angle of 15° .With an increase in the diameter, the load decreases.
- It was concluded that the best die angle for the least effective stress is an angle 15° and the best die Angle for the least maximum stress is an angle 30°.
- The commercial finite element code Deform-3D was successfully used to simulate the hot extrusion of Aluminum.
- Careful design of the extrusion dies profile can control and reduce the stresses, which cause a main defect in product structure, supported that it can be used to minimize the amount of in-homogeneity imparted in to the product, and therefore control the product quality.

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محاكاة عملية البثق المباشر لسبيكة المنيوم باستخدام طريقة العناصر المحدودة

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تاريخ الاستلام: 14 اوكتوبر 2023   استلم بصيغته المنقحة: 7 نوفمبر 2023   تاريخ القبول: 27 ديسمبر 2023

الملخص

نظرًا لتصميم القالب المعقد، فإن نوع تدفق المعدن وتوزيع الاجهادات في عملية بثق المعدن يكون معقدًا للغاية. في هذه الدراسة، تم استخدام برنامج Deform-3D *لمحاكاة عملية بثق سبيكة الألومنيوم نوع* AA7075 *. أظهرت النتائج أن توزيع الإجهاد في عملية البثق المباشر على الساخن تمت محاكاته بشكل مقنع باستخدام* Finite element method *، فضلا عن ذلك فإن زاوية القالب المثالية تقلل من شدة الاجهادات الفعالة. كما اشارت نتائج هذا البحث أن أقل حمل كانت عند الزاوية* 15° *، ومع زيادة قطر القالب في منطقة خروج المعدن المبثوق يتناقص الحمل، وأن أفضل زاوية قالب لأدنى إجهاد فعال هي الزاوية* 15° *وأن أفضل زاوية قالب لأقل أقصى اجهاد هي الزاوية* 30° *. وأخيراً تم استخدام برنامج Deform-3D بنجاح لمحاكاة عملية البثق الساخن للألمنيوم.*

الكلمات الداله :

*زاوية القالب، البثق المباشر، الألومنيوم، عناصر محدودة, سبيكة المنيوم*AA7075 .