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Investigation of the Deformation Behavior of 7075 Aluminum Alloy under Backward Extrusion Process for Producing Conical parts

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ABSTRACT

In this study, the producing of conical parts through backward extrusion has been numerically investigated. The finite element method has been used in order to extract the deformation behavior of 7075 aluminum alloy under this process for manufacturing of conical parts. The effect of friction on the process load has been investigated. The strain distribution has been studied and it was observed that in this process, the amount of plastic strain applied to the deforming part has reached above 2, which indicates that in this process, suitable mechanical properties can be expected from the manufactured part.

Introduction

The backward extrusion process is similar to direct extrusion, except that the moving direction of punch and material is against each, and this difference changes the friction status and the material deformation behavior, which is generally the case for producing nanostructured alloys for use in sensitive industries such as aerospace. The 7000 series aluminum alloys are based on a combination of Al-Zn-Mg-Cu, which offers high compressive strength, high toughness and cracking resistance. Among the advantages of this extrusion method is the reduction of the required force compared to the direct type due to the reduction of friction and also the lower cost in terms of dimensional accuracy and better surface smoothness. The backward extrusion process has been widely used in recent years to produce circular hollow parts with custom-shaped billets, for various industries such as automobile and aircraft parts.

As one of the initial researches in this field, Kudo [1] has done several analytical and experimental studies on the backward extrusion process to produce parts with axial symmetry, and it can be said that this study is the first serious research work on this process. Kudo, founded the research activities in the field of backward extrusion. Using upper bound theory, Avitzur et al [2] investigated this process to produce thin-walled, thick-walled circularly shaped wall sections from a circular billet. Luo [3] examined the limitations of the above method and tried to overcome these limitations by presenting a new method. Choi and Hwang [4] investigated the formation characteristics of the inverse radial extrusion process. In this research, they used rigid plastic finite element method for quantitative analysis of the combination of radial extrusion and reverse extrusion processes and considered various parameters such as groove size, die corner radius and friction conditions as related design parameters. In 2006, numerical analysis and experiments on the optimum die profile in backward extrusion were performed by Hosseinpour, Bakhshi and Saboori [5]. The aim of the project was to reduce the forming load in backward extrusion by optimizing the die profile. Stresses and loads are obtained with finite elements. By considering the curved profile for the die, this profile is optimized by minimizing the stresses. Then the force-displacement diagrams of finite elements and experiments are compared and then it was observed that this modeling has reduced the deformation load by 11% [8]. The backward extrusion process was studied and analyzed in combination with direct extrusion by Farhoumand and Ebrahimi [6]. They used the finite element method and Abaqus software to investigate the effect of geometric parameters such as die corner radius and frictional conditions on the process. In this study, strain distribution and its relationship with hardness were shown. Backward extrusion was used in a new method for the production of fineness in AZ31 magnesium alloy by Fatemi-Varzaneh et al [7]. In this method, in which the extruded sample piece was inverted back and forth, strains of up to about 4 to 5 were obtained. They called this method stacked reverse extrusion.

Shatermashhadi et.al [8] invented a new method of backward extrusion using small diameter billet. In their method, the system consists of three main parts includes the fix-punch, the moveable punch and the matrix. The fix-punch has been used to decrease the cross section of applied billet and finally reducing the total force of the process. They utilized experimental and numerical methods for proving the applicability of this method. They eventually showed that the process load is reduced to about lessthan a quarter in comparison with the conventional backward extrusion process.

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They also showed that this process imposed higher level of plastic strain into work piece and this process is appropriate for producing products with higher level of mechanical properties.

In the recent years various studies [9-15] focused on the backward extrusion process and it is a very remarkable process for researches in the area of metal forming science. Pasynkov [12] studied the backward extrusion of pipe work pieces from non-ferrous alloys with a cone-shaped punch. In their studies, the pipe work pieces were processed by backward extrusion in order to fabricate hollow thin-walled products while the cross-sectional area changes in the longitudinal direction. They worked on the pipe work piece extrusion from 6Al-4V non-ferrous titanium alloy. Their results recommended the manufacturing of cylindrical hollow products through implementation of backward extrusion.

In the present study, the deformation behavior of 7075 aluminum in reverse extrusion process to produce conical parts has been investigated. The process friction parameter on the amount of strain applied to the material and the process force is also investigated. In this regard, the finite element method has been used to evaluate the process numerically.

Materials and methods

Table 1. Physical ad mechanical properties of Al 7075

Physical Properties	Metric	Comments
Density	2.81 g/cc	AA; Typical
Mechanical Properties	Metric	Comments
Hardness, Brinell	60	AA; Typical; 500 g load; 10 mm ball
Tensile Strength, Ultimate	228 MPa	AA; Typical
	<= 276 MPa	Sheet and plate
Tensile Strength, Yield	103 MPa	AA; Typical
	<= 145 MPa	Sheet and plate
Elongation at Break	>= 10 %	Sheet and plate
	17 % @Thickness 1.59 mm	AA; Typical
	16 % @Diameter 12.7 mm	AA; Typical
Modulus of Elasticity	71.7 GPa	AA; Typical; Average of tension and compression. Compression modulus is about 2% greater than tensile modulus.
Poissons Ratio	0.33	
Shear Modulus	26.9 GPa	
Shear Strength	152 MPa	AA; Typical

Alloy 7075 is one of the series of aluminum alloys in which zinc is considered as the main element of it. This alloy has comparable strength to many steels, good fatigue strength and a medium level of machining. One of its disadvantages is its low corrosion resistance compared to many aluminum alloys. Also, due to its high production cost, its use in special industry is limited. 7075 Aluminum Alloy is one of the most important high-strength alloys that are widely used to make various components in the aerospace, defense and military industries. Among the twentyfive commonly used aluminum alloys, 7075 is the most difficult alloy for extrusion.

To connect parts made of this alloy, it is recommended to use rivets, screws or glue instead of welding, because it has low weld ability. Therefore, making conical parts, such as the nose of an aircraft, is usually a difficult task, and the beginning of making these parts by backward extrusion will be a revolution in the aircraft industry. The properties of the alloy which used in this study are listed in the table 1.

Finite element modeling

ABAQUS software is used for finite element modeling. ABAQUS has the ability to solve problems from a simple linear analysis to the most complex nonlinear modeling. This software has a very wide set of elements with which any type of geometry can be modeled. It also has many behavioral models that make it possible to model a variety of materials with different properties and behaviors such as metals, rubbers, polymers, composites, reinforced concrete, spring and brittle foams, as well as geotechnical materials such as soil and rock.

The model used to simulate the process consists of three parts: billet, punch and die. The shape of the die is curved, which is designed in two dimensions. It should be noted that all dimensions are in millimeters. Apart from the billet, other parts are considered rigid. Due to the axisymmetric nature of the process, only half of the 2D geometry has been modeled. Aluminium 7075 alloy has been used which the mechanical properties of this alloy are given in Table 1.

The standard option is used for the elements, although it is more appropriate to use the explicit option for a more accurate numerical simulation. This option has been selected to increase the speed of the simulation solution. The geometric order of the element is considered as linear to reduce the solving time. The element is from the axial symmetry stress family and the quadratic element type is of the reduced integral type. The distortion control option is activated. Also the boundary conditions are such that the die is fixed and all its degrees of freedom are closed and the punch can only move freely in the y direction. The value of the friction coefficient is considered to be 0.05. The mesh sensitivity test was performed to obtain acceptable results, and finally the element value of 2000 was found to be appropriate.

Then the simulation is continued to investigate the friction on the process load and also to study the strain changes in the direction of thickness. For this purpose, 4 distinct numbers have been selected for friction coefficient, which include 0, 0.05, 0.1 and 0.15. For each finite element analysis, the strain distribution along the thickness as well as the maximum extrusion load due to friction changes are investigated.

Initially, the element sensitivity test was evaluated using the number of 1000, 2000, 3000 and 4000 elements. As shown in Table (2), after the number of 2000 elements, the maximum force value converges and the relative error value decreases sharply to less than 1%. The table shows that the number of 2000 elements was suitable and reliable for this model.

Table2.relative error percentage obtained from element sensitivity test

Elements	Maximum Force	Relative Error Percentage
1000	38600.7	
2000	38155	%1.17
3000	38249.7	%0.25
4000	*38181.5*	%0.18

Results and Discussion

As was mentioned before, the finite element method has been used to numerically model the backward extrusion process.

Figure (1) shows the plastic strain contour between the middle of process (a) and the end of process (b). Plastic strain assessment is very important in this process. due to this fact that high strain values are associated with improved mechanical properties [8]. It can be seen that the maximum value of plastic strain in this process has reached above 2. This amount of strain is very good and shows that very good mechanical properties can be expected from this process. It should be noted that the amount of plastic strain in the pressing process in parallel channels per pass is about 1, and this comparison is a good reminder of the high value of the reverse extrusion process in producing suitable parts with desirable mechanical properties.

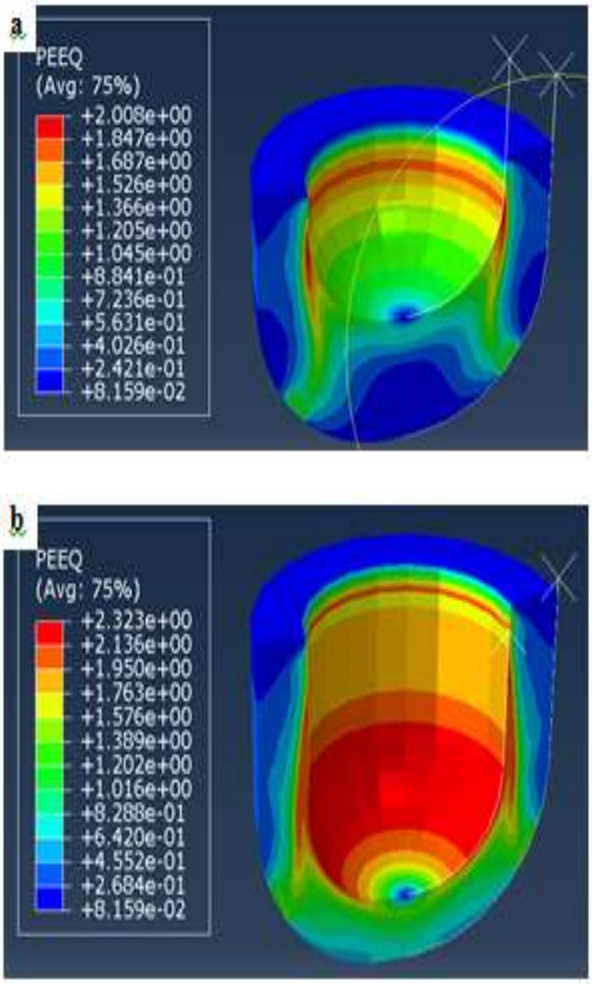


Figure 1. Plastic strain distribution in the work piece a) during the process. b) at the end of the process

The strain distribution in the billet is deformed in such a way that almost most parts have the lowest plastic strain, but the inner edges of the cone have maximum strain points, which change after the complete deformation of the work piece.

The obtained diagrams of process load changes in terms of time for this process follow the pattern that the load increases over time and reaches its maximum in some stages and then reaches a relative stability. The amount of process load (N) per punch displacement (mm) is shown in Figure (2). It is observed that the maximum amount of process load occurred after 60% of the punch displacement. In the other words, the 40 percent of final steps of the process has been performed under average load of 37kN.

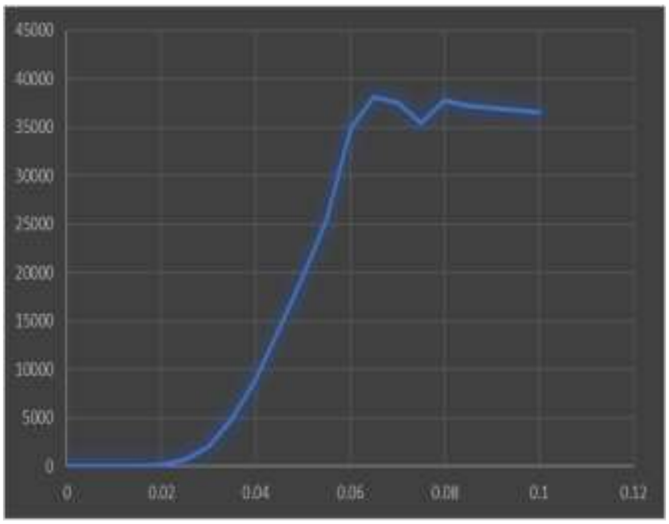


Figure 2. The diagram of process load versus punch displacement during the backward extrusion

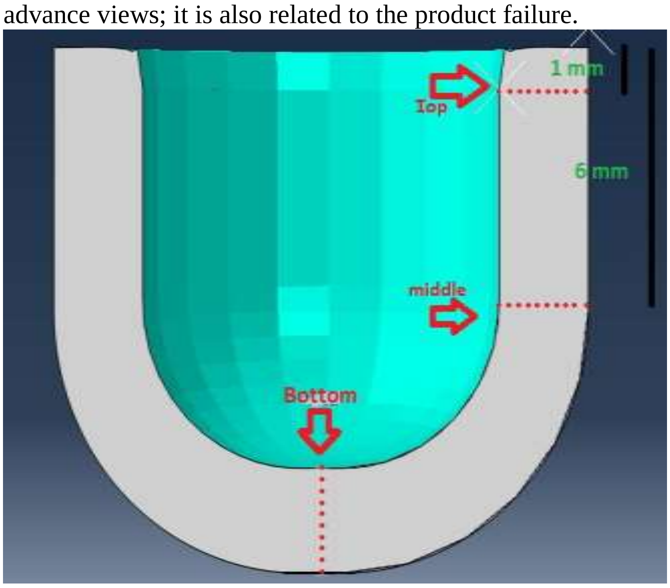
After the element sensitivity test and the selection of 2000 element as a reliable element, we will now examine the effects of friction on the force process as well as strain changes in the direction of thickness. For this purpose, we use 4 distinct values for the coefficient of friction in four analyzes with the same test conditions. The selected numbers for the coefficient of friction are 0, 0.05, 0.1, 0.15.

At this stage, each coefficient of friction is examined separately and the percentage of force increase in terms of increase in friction is according to the table below. The table below shows the extreme importance of friction in the inverse extrusion debate.

Table 3.The percentage increase in friction according to the coefficient of friction

Friction Coefficient	Maximum Force
0	31474
0.05	38155
0.1	51700.5
0.15	73038.7

The results confirmed that by increasing the value of friction coefficient, the maximum process load has been increased. It is obvious that the maximum process load at the friction value of 0.15 is more than two times while the friction coefficient hypothetically has been considered as zero. It shows that finding the suitable value of friction, while the process load is logical, is the best way for producing the products. Increasing the value of friction has harmful effects on the die life and the required energy for the process while in advance views; it is also related to the product failure.



Friction coefficient 0

The following figures show how the stress distribution under hypothetical conditions without friction. The results show that the deformed billet has a maximum stress in almost all parts, which distributes the stress in almost all tests. It is the same and this is while after the complete deformation of the stress distribution is variable and according to the picture, all the prices at the end of the mold have maximum stress and in the upper half of the mold we gradually see a decrease in stress.

Stress changes are also very important after stress. The strain distribution in the deforming billet is quite clear, which is increasing in the parts that are in contact with the punch, and the inner wall of the billet that is in contact with the punch has a part where we see the maximum strain and it is expanding. Towards the middle of the billet. Also, after the extrusion operation, it is observed in the billet that it is completely shaped, that as expected, the maximum strain is slightly extended towards the middle of the billet and also more part of the billet wall is in contact with the punch.

Finally, the strain changes in the direction of thickness in the three end, middle and edge of the billet are examined and the result is as follows. The strain changes applied in the direction of thickness in all sections were nonlinear and parabolic.

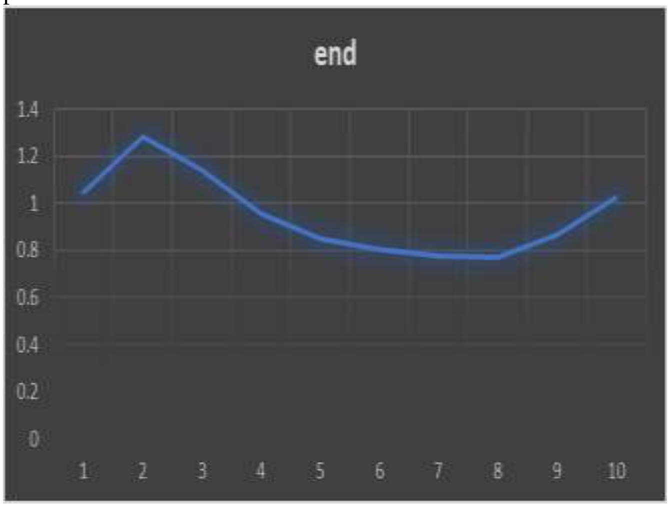


Figure 3. Strain changes along the thickness in the end part of the deformed billet with a friction coefficient of 0

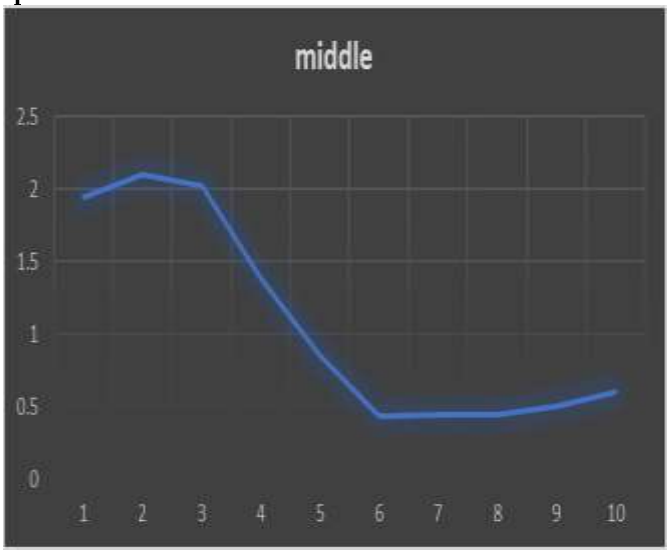


Figure 4. Strain changes along the thickness in the middle part of the deformed billet with a friction coefficient of 0

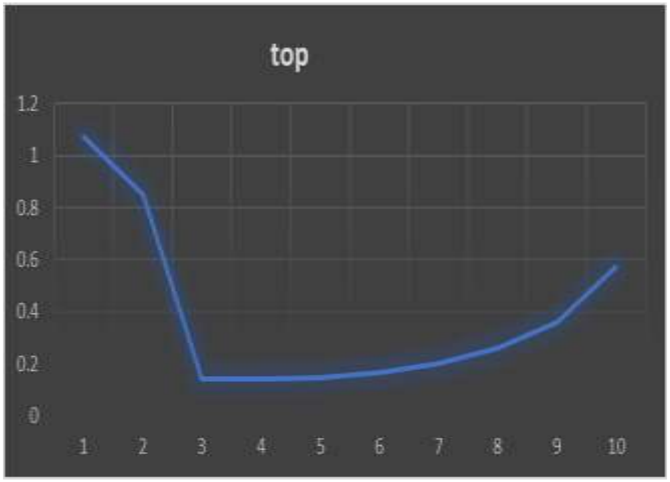


Figure 5. Strain changes along the thickness in the initial part of the deformed billet with a friction coefficient of 0

Friction coefficient 0.05

This coefficient of friction is actually the coefficient of friction used in the mesh sensitivity test section and the coefficient of friction which is the ideal condition and the corresponding stress and strain distribution explanations are given in the section sensitivity test of the element, but the strain distribution diagram is in line. Its thickness is as follows.

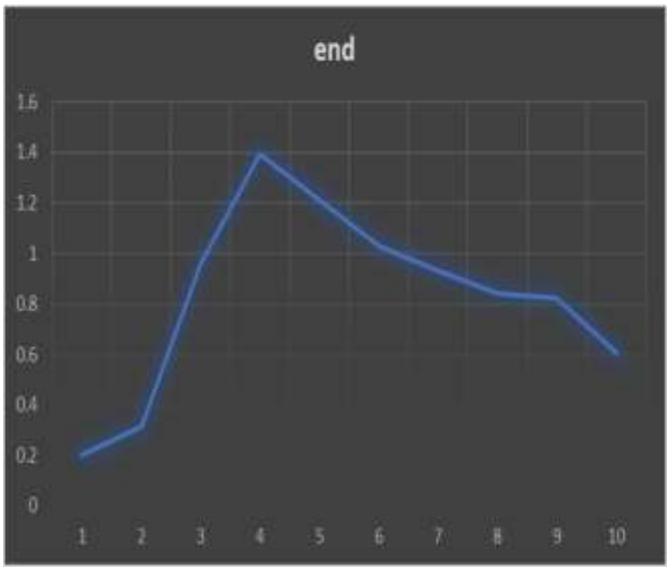


Figure 6. rain changes along the thickness in the end part of the deformed billet with a friction factor of 0.05

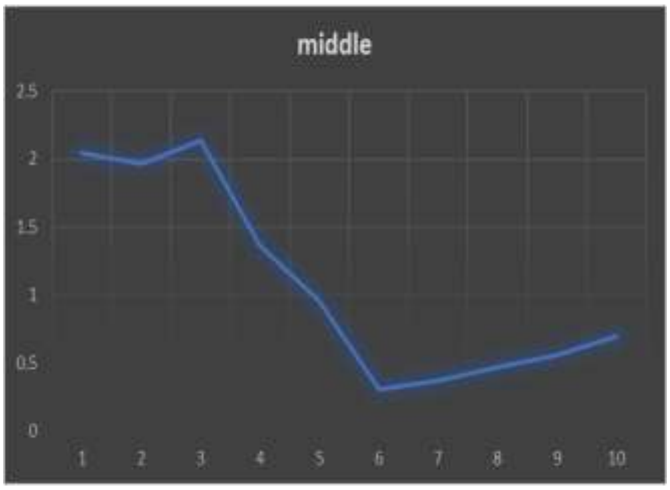


Figure 7.Strain changes along the thickness in the middle part of the deformed billet with a friction coefficient of 0.5

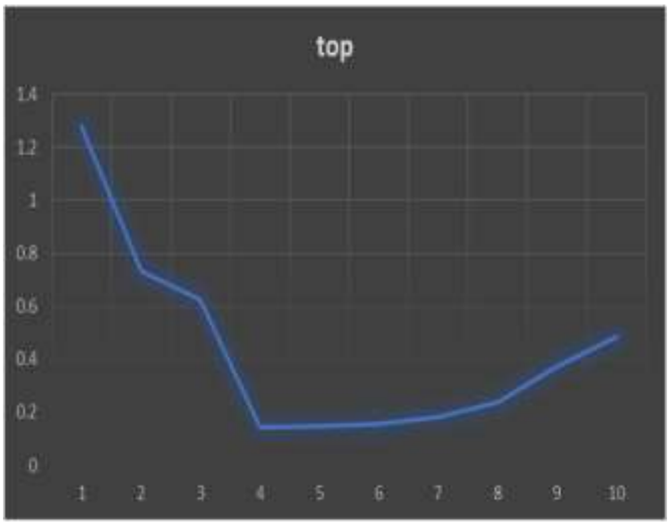


Figure 8. Strain changes along the thickness in the initial part of the deformed billet with a friction coefficient of 0.5

Friction coefficient 0.1

The following figures show how the stress distribution under hypothetical conditions with a friction of 0.1 shows that the deforming billet has a maximum stress in almost all parts. And according to the picture, all the end parts of the mold and also the middle and part of the beginning have the maximum stress and only a small part of it does not include the maximum stress.

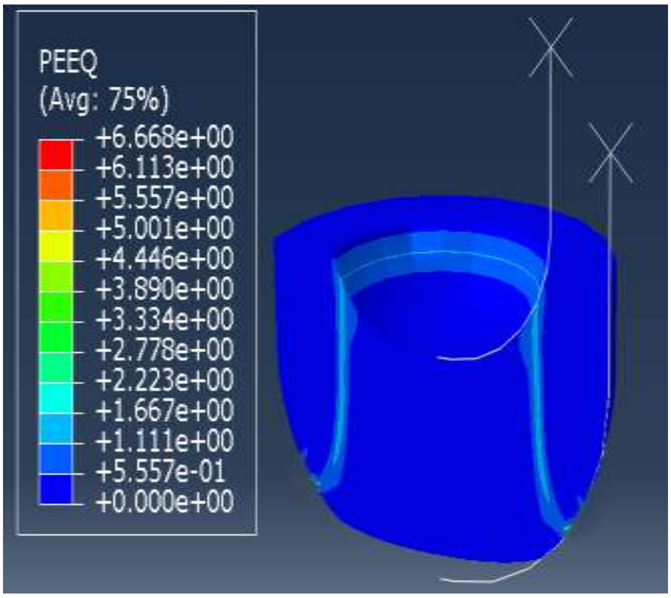


Figure 9. Strain distribution on the deforming billet with a friction coefficient of 0.1

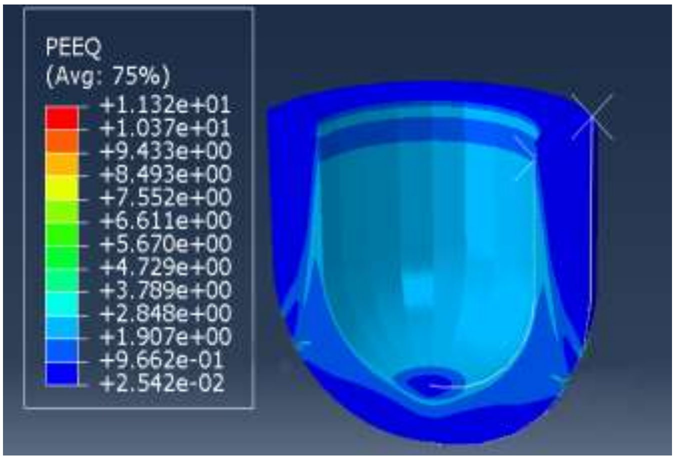


Figure 10. Strain distribution on the deformed billet with a friction coefficient of 0.1

The test result in relation to the distribution of strain with a coefficient of friction of 0.1 is equal to the following images, which shows that the distribution of strain is very different from the previous two tests and almost no maximum strain is seen in the figure.

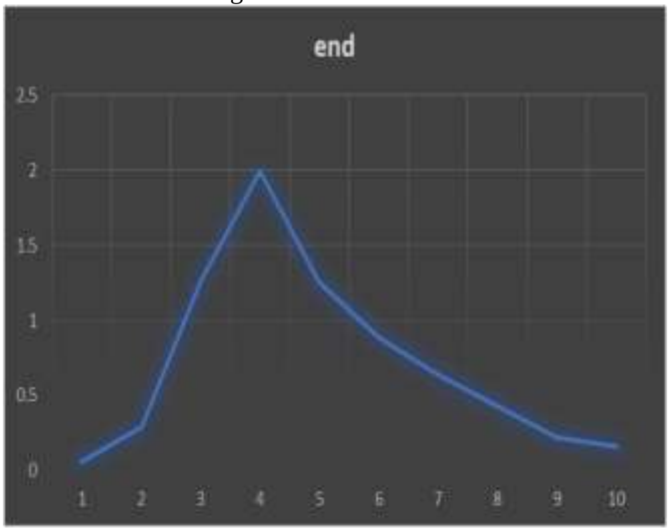


Figure 11. Strain changes along the thickness in the end part of the deformed billet with a friction coefficient of 0.1

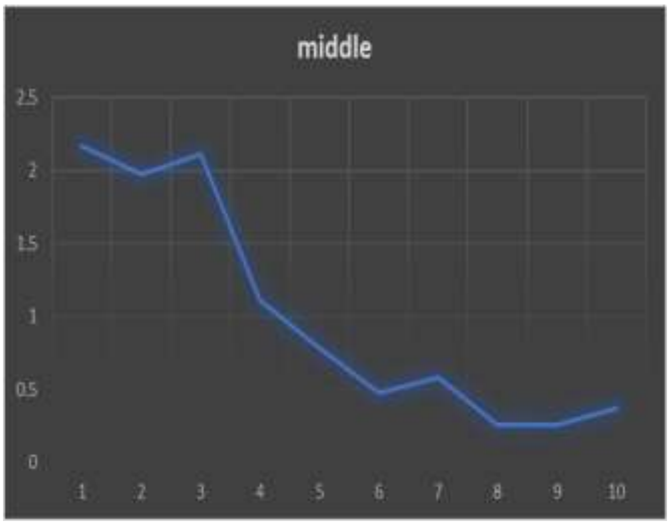


Figure 12. Strain changes along the thickness in the middle part of the deformed billet with a friction coefficient of 0.1

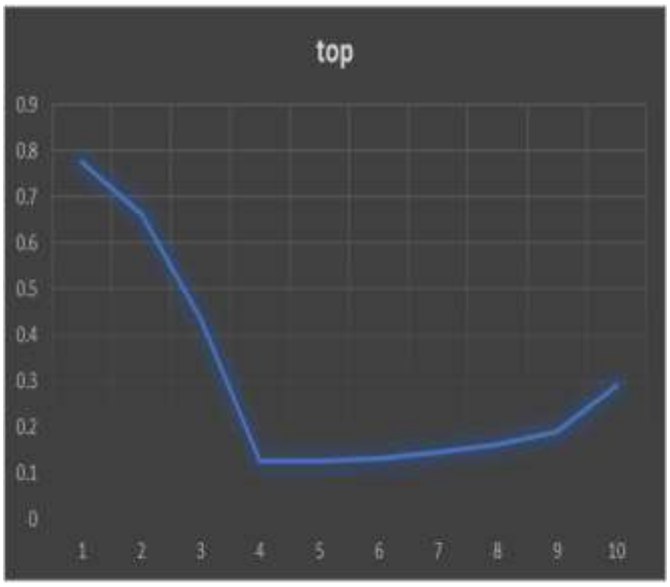


Figure 13. Strain changes along the thickness in the initial part of the deformed billet with a friction coefficient of 0.1

In this part, the graph of strain change in the direction of thickness can be seen, which according to the previous two tests, the graphs are still parabolic.

Friction coefficient 0.15

The last test was performed with a friction of 0.15 and this friction is the most snake friction in this project and the maximum observed stress is equal to 73038.7 N, which is the highest force observed between the tests performed.

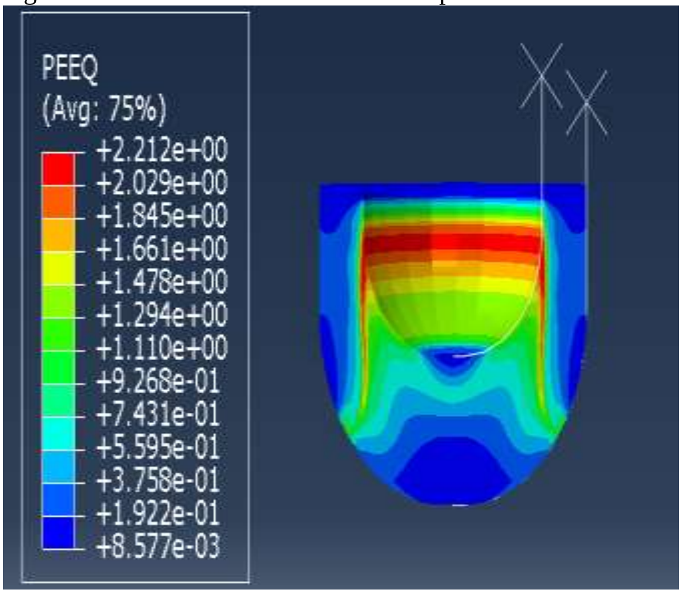


Figure 14. Strain distribution on the deforming billet with a friction coefficient of 0.15

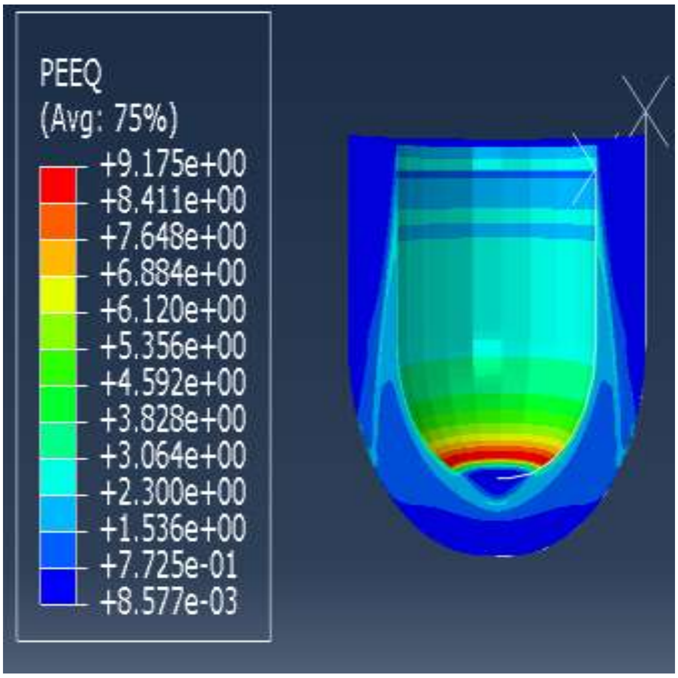


Figure 15. Strain distribution on the deformed billet with a friction coefficient of 0.15

Also, in this section, according to the previous sections, we will examine the strain entered in the middle of the extrusion test and also at the end of the test. It is in the middle, but after completing the strain test, the maximum is only in the wall, but at the end of the wall, which is not observed in previous tests.

Finally, the graphs of strain changes in the direction of thickness are examined. As can be seen, despite the difference in how the strain is distributed, the graphs of strain changes have been in the direction of parabolic thickness.

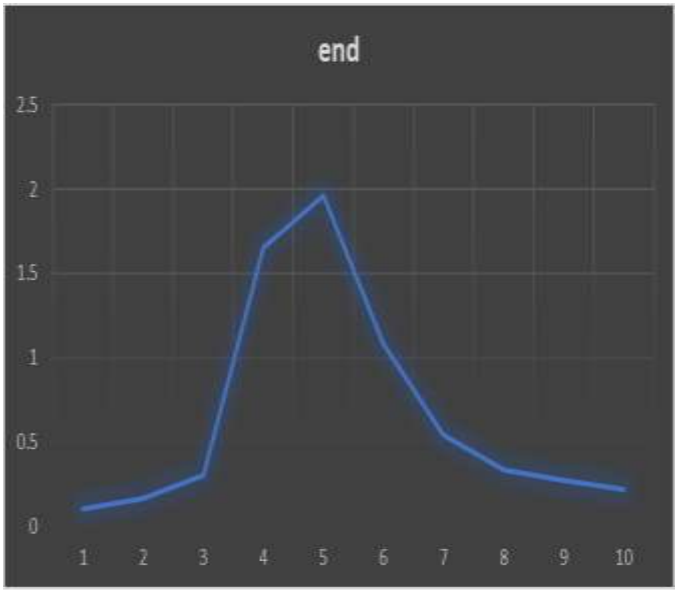


Figure 16. Strain changes along the thickness in the end part of the deformed billet with a friction coefficient of 0.15

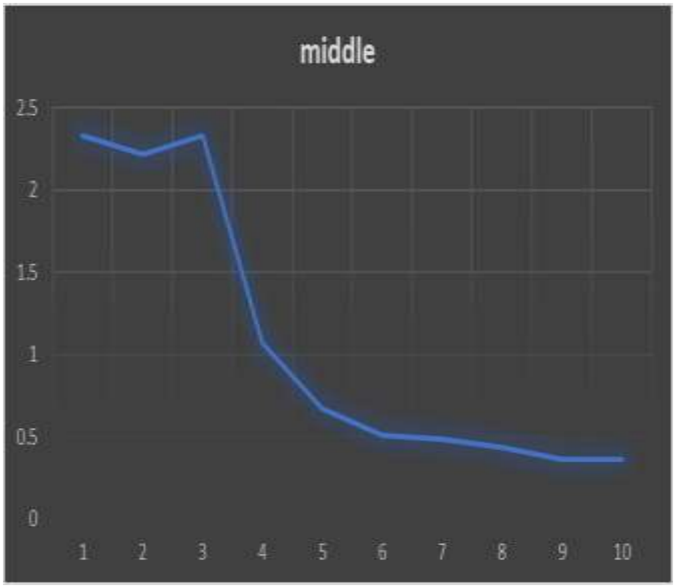


Figure 17. Strain changes along the thickness in the middle part of the deformed billet with a friction coefficient of 0.15

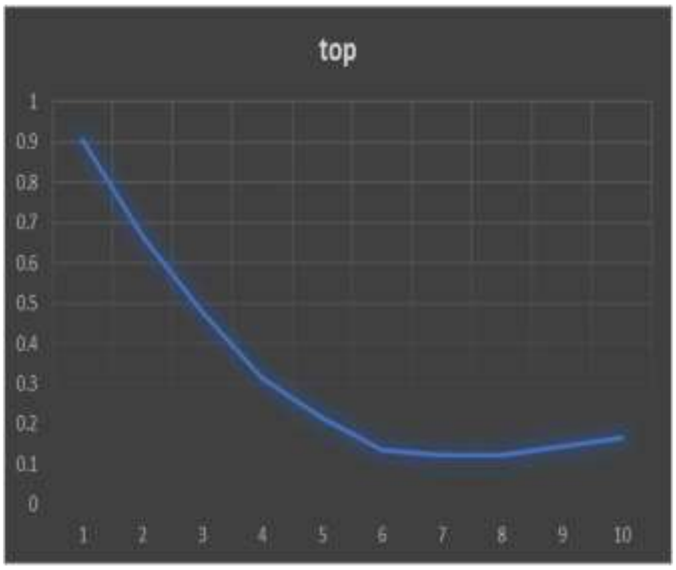


Figure 18. Strain changes in the direction of thickness in the initial part of the deformed billet with coefficient of friction 0.15

Conclusion

After the sensitivity test of the element, the relative error value of the extrusion force changes was reported to be about 0.25%. And this error is very insignificant and does not show the accuracy of the analysis. It was observed that in this process, the amount of plastic strain applied to the deforming part has reached above 2, which indicates that in this process, suitable mechanical properties can be expected from the manufactured part. It should be noted that in this process, the maximum amount of extrusion force occurred after 60% of the punch displacement. The result of friction sensitivity test also shows the great importance of lubrication in the reverse extrusion process, because in addition to the fact that the reverse extrusion process is a very sensitive process to friction, 7075 aluminum alloy is a special and very strong alloy, which increases the applied strain. By reducing the friction parameter, it is possible to help reduce the strain and make extrusion easier. Lubricating fluid must have special properties to have the best performance in the extrusion process. Among the important parameters in choosing the right lubricant are the viscosity and thickness of the lubricant. As the thickness of the lubricant increases, the contact between the billet and the mold wall decreases, the work of the friction force decreases, and finally the pressure required to deform decreases. On the other hand, lubrication leads to better smoothness of the final surface of the production part. Viscosity is another factor in choosing a lubricant. As the viscosity increases, the deformation conditions worsen, leading to cracks in the billet and the final material. Therefore, lubrication as well as the type of lubricant is very important.

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