Theoretical and Experimental Investigation of the Effect of the Punch Angle on the Backward Extrusion Process

Ethar Mohammed Mahdi
Technical Institute - Baghdad , Mechanical Department

Abstract

The variation of punch angle on the flow metal for the backward extrusion is investigated theoretically and experimentally. Punches with different semi-cone angles varying from 30, 60, 70, 90 ° have been used to study its effect on the pressure required to extrude indirectly for lead. The findings of this experimental study show agreement in trends with the theoretical predictions. From this study it can be concluded that by a little change in the backward reduction in cross- sectional area different types or modes of extrusion process may be obtained and the streamline profile of the punch surface have an important effect in homogeneity of the material flow in the backward direction i.e. that the working pressure decreased when increasing the punch angles, the fact that the redundant strains will be decreased and there will be less restriction on the material flow also due to the complex deformation situation during the backward extrusion and availability of more than one type of velocity field through the process duration, finite element analysis via ANSYS software may be the superior for application.

Keywords: Extrusion , backward extrusion, metal forming , finite element method, ANSYS

الخلاصة

تم دراسة تغيير زاوية المخرم على جريان المعدن خلال عملية البثق العكسي حيث تمت الدراسة نظريا وعمليا . وقد استخدمت زوايا مختلفة للمخرم هي 30 و 60 و 70 و 90 درجة لدراسة تأثيرها على الضغط اللازم للبثقالغير مباشر لمادة الرصاص . تشير نتائج هذه الدراسة إلى تطابق بين النتائج التجريبية مع التنبؤات النظرية . يمكن أن نستنتج من هذه الدراسة بان تغيير قليل في مساحة انخفاض مقطع البثق العكسي يؤدي الى أنواع مختلفة من اطوار البثق وان انسيابية شكل المخرم له تاثير كبير على جريان المعدن بما معناه ان القوة تقل عند زيادة زاوية المخرم. والحقيقة أنه سيتم خفض الانفعالات الزائدة عن الحاجة وسيكون هناك قيود أقل على تدفق المعدن بسبب الحالة المعقدة للتشوه التي تحصل في عملية البثق العكسي. ان طريقة العناصر المحددة باستخدام برنامج ANSYS تعتبر من افضل الطرق لتحليل عملية البثق.

Symbols

h	land of the punch
m	friction factor
P	indirect extrusion pressure
R	extrusion ratio (R_o/R_f)
R_o/R_f	outside and inside radius of billet respectively
β	semi- cone punch angle
σ_o	effective flow stress
H	height of the friction land on billet outside surface
T	height of the billet

1- Introduction

In the process of extrusion, a billet is placed in an enclosed chamber. The chamber has an opening through which the material escapes or extrudes as the volume of the chamber is reduced by pushing a ram. The extruded material has a uniform cross section identical with that of the opening. Piercing extrusion of a cap is presented, with the gap between ram and chamber serving as the opening. An early analytical study of the process was undertaken by Siebel, 1934. Avitzur, 1968 studied the analysis of extrusion process through a chamber by using kinematically admissible velocity field. Kudo's , 1960 found that: at the beginning of stroke, higher extrusion stress is caused by using longer billets an direct extrusion. Many investigators (Kudo,1960; Rowe, 1977; Thomsen and Kobayashi,1964) found empirical relations for estimating the indirect extrusion pressure. In general extrusion is used to produce cylindrical bars, rods, hollow tubes with different and irregular sections. Applied force direction and the product flow direction is same in the direct extrusion process while it is opposite in indirect and piercing extrusion processes. In this investigation a theoretical and numerical analysis for piercing extrusion has been done. Effect of various punch angles (30° to 90°), extrusion ratios and punch speeds on pressure required to extrude piercing extrusion has been studied for lead.

2- Theoretical Consideration

The importance of analysis of the extrusion process lies in the determination of the extrusion pressure, flow pattern and stress state, since these provide the necessary design specifications and data for the press, dies, punches, die set-up etc. Since the extrusion pressure, flow pattern and stress state are influenced by various parameters, such as reduction of area, die shape, tribological characteristics and material properties, etc., it is almost impossible to find a mathematically exact solution to predict the real phenomenon. Avitzur, 1968 studied the analysis of extrusion process through a chamber by using kinematically admissible velocity field to obtain an upper-bound solution for the extrusion stress, and assumed a spherical velocity field for the early stages of the direct and indirect extrusion, and a radial velocity field at the end of stroke. These results were compared with Kudo's results and found that: at the beginning of stroke, higher extrusion stress is caused by using longer billets an direct extrusion, while unaffected by billet length in indirect extrusion, and at the end of stroke, extrusion stress increases with extrusion ratio and friction.

Theoretical studies for estimating the pressure required for indirect extrusion under cold conditions were reported by Avitzur ,1968 as given in equation(1) and by Kudo,1960 as given in equation (2) .

$$\frac{P}{\sqrt{3}\sigma_o} = 2\,f(\beta)\ln\left(\frac{R_o}{R_f}\right) + \frac{2}{\sqrt{3}}\left[\left(\frac{\beta}{\sin^2\beta} - \cot\beta\right) + \cot\beta\ln\left(\frac{R_o}{R_f}\right) + m\left(\left(1-\frac{R_f}{R_o}\right)\cot\beta + \frac{h}{R_f}\right)\right] \quad \ldots\ldots (1)$$

$$\frac{P}{\sigma_o} = \frac{2}{1-(R_o/R_f)^3} In\left(\frac{R}{R_o - R_f}\right) + \frac{1}{\sqrt{3}}\left[\frac{1}{3}\frac{(R_o/R_f)^3 - 1}{T/R_f}\left[1 + \frac{4(R_o/R_f)(T/R_f)^2}{\left[(R_o/R_f)^2 - 1\right]^2}\right]\right] + m\left[\frac{1}{3}\frac{(R_o/R_f)^3 + 1}{T/R_f} + \frac{2(R_o/R_f)}{1-(R_f/R_o)^2}\left(\frac{H}{R_f} + \frac{Ro}{R_f}\frac{h}{R_f}\right)\right]$$

……………………………………….. (2)

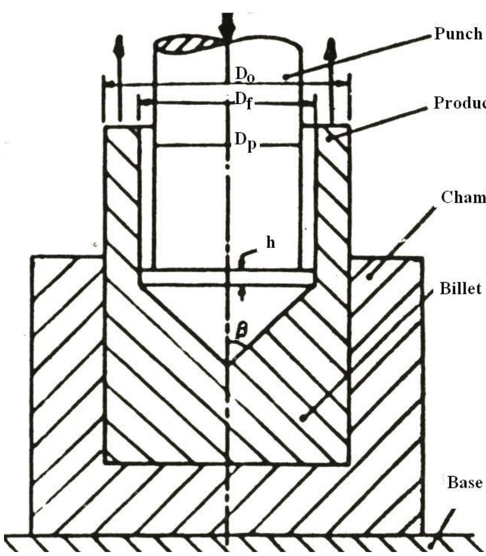
Where:

$$f(\beta)=\frac{1}{\sin^2\beta}\left[1-\cos\beta\sqrt{1-\frac{11}{12}\sin^2\beta}+\frac{1}{\sqrt{11*12}}\ln\frac{1+\sqrt{\frac{11}{12}}}{\sqrt{\frac{11}{12}}\cos\beta+\sqrt{1-\frac{11}{12}\sin^2\beta}}\right]$$

………………………………………………….. (3)

Equation(1) assumes that there is an angle β for metal flow as shown in Figure 1, for indirect extrusion process. In equation(2) a flat end punch is assumed to be used (as shown in Figure 2.).

Many investigators found empirical relations for estimating the indirect extrusion pressure for a wide range of reductions, by assuming no or very little effect of angle β and using a flat punch. Factors affecting the flow of metal in the backward extrusion process and the effect of ram nose was also reported by few workers (Bhattacharyya et al., 1982; Avitzur et al., 1972).



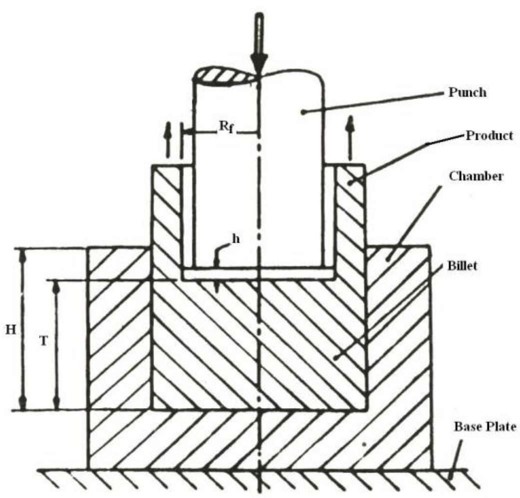


Figure 1: Indirect extrusion using punch semi- cone angle β (Kun et al., 2007)

Figure 2: Indirect extrusion using a of flat heat punch(Kun et al., 2007)

3- Experimental Consideration and Results

3-1 Chemical composition of the metal

The modeling material, which is used in this study, is (99.99%) commercially pure lead. The chemical compositions of this material are listed in Table 1.

Table 1: Chemical Composition of the Model Material .

Sb%	As%	Bi%	Cd%	Cu%	Fe%	Mn%
0.002	0.0005	0.005	0.0005	0.003	0.001	0.0005
Ni%	**Se%**	**Ag%**	**Te%**	**Sn%**	**Zn%**	
0.001	0.0005	0.002	0.0005	0.001	0.002	

3-2 Experimental Device

The apparatus shown in Figure 3, has been designed to stand an inside force of 40 tons. Pressure is applied using a hydraulic press machine.

Figure 3: Experimental rig

In the present study, the friction factor (m) was found experimentally by ring compression test method (depend on calculation was explained in Kudo, 1960 and Rowe, 1977), which is widely used in determining the value of friction factor for various forming processes. Figure 4, shows the results on the calibration chart for ring test, the value of (m) is found as 0.34 by interpolation.

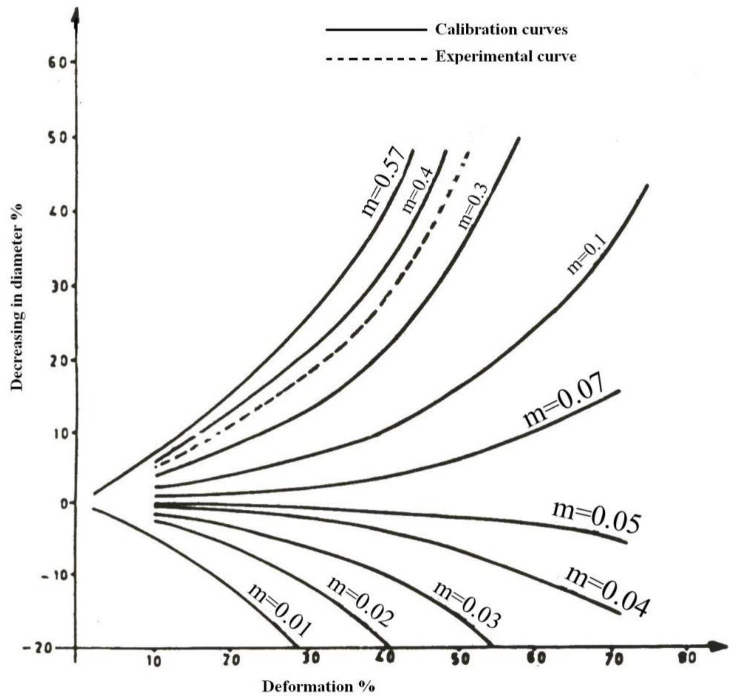


Figure 4: Experimental curve for friction factor evaluation using the calibration chart for the ring test (Kudo, 1960 and Rowe, 1977)

3-3 Method of Printing the Square Grids

The study of metal flow in metal forming processes requires a grid printing on the meridian plane or separation surface between the two, split parts of the testing billets. The grid may be as parallel lines or square grid lines or circular grid based on the specified metal forming process and its requirements for the parameters, which will be studied. There are many techniques or methods for printing the grid lines. As shown in the Figure 5, the grid may be applied by the following simple and available methods:

1- By using a special tool as shown in Figure 5-a, which look like a cylindrical milling cutter provided with threads that acts as cutting edges for scribing the billet meridian surface. This method should be carried out on a horizontal milling machine provided with a universal vice, which is capable to rotate about its axis.

2- By using a vertical or universal-milling machine with assistance of a special tool made of HSS and has a nose angle of (42°). The operation of grid printing is carried out by scratching parallel lines in one direction or square grids with depth of scratching (0.2mm). Figure 5-b, shows the grid printing on universal milling machine.

3- The selected and proposed method which had been used in printing of the square grids (5 mm x 5 mm) on the meridian plane of pure lead billets as shown in Figure6, prepared for this study, is based on pressing or hand hammering by using the tool shown in Figure 5-c. This tool was fabricated for this purpose and it can be applied with the assistance of a plastic head hammer. This method is more accurate than the first one where it gives a similar pitch of the grid lines and more time saving.

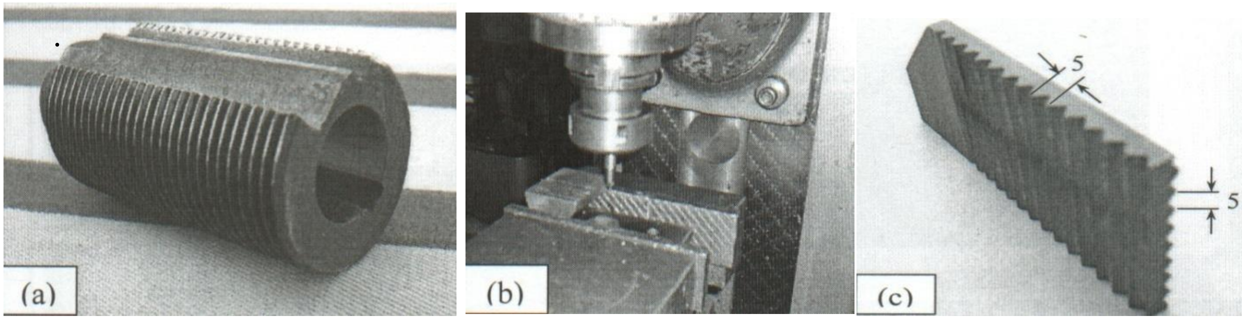


Figure 5: Various method, which may be used to print the square grids on the meridian plane of the testing billets. (a) by using a cylindrical tool on horizontal milling m/c. (b) By using (42°) nose angle cutting tool of HSS on vertical milling m/c. (c) By using a double side threaded tool for multiline printing.

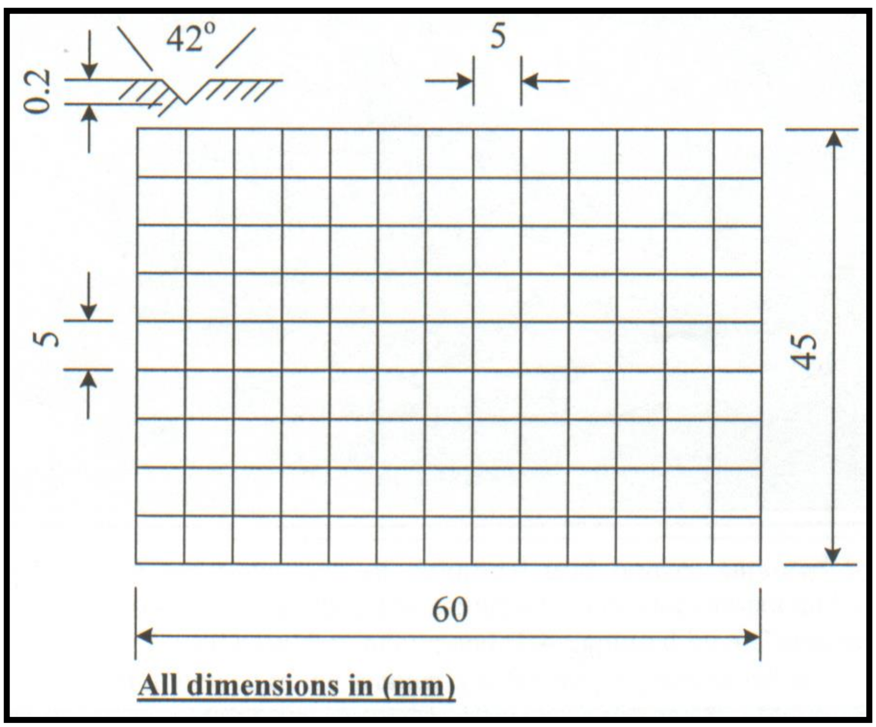


Figure 6: square grid dimensions printed on the meridian plane of the billets for viscoplasticity technique.

3-4 Effect of the Punch Angle on the Metal Flow Pattern

Figure 7, presents photos of the metal flow pattern captured by using a digital camera and optical scanner for the conical shape of the punch on flow mode or deformation pattern when the punch head angle β are 30, 60 , 70 and 90°. There are different modes of flow produced from the opposed flow direction on the backward direction, there is a central flow mode, which it was proposed for theoretical analysis of the backward extrusion of internally shaped tubes from round billets. Also this photo described the effect of pass geometry on the formation of dead metal zone at the corners between the die bottom and container walls when a flat-faced punch is used. It is clear that with the flat faced punch profile the slope of the deformed grid lines increases more than those for the conical converging punch profile. The probability of formation the shear band increases when using the flat-faced punch.

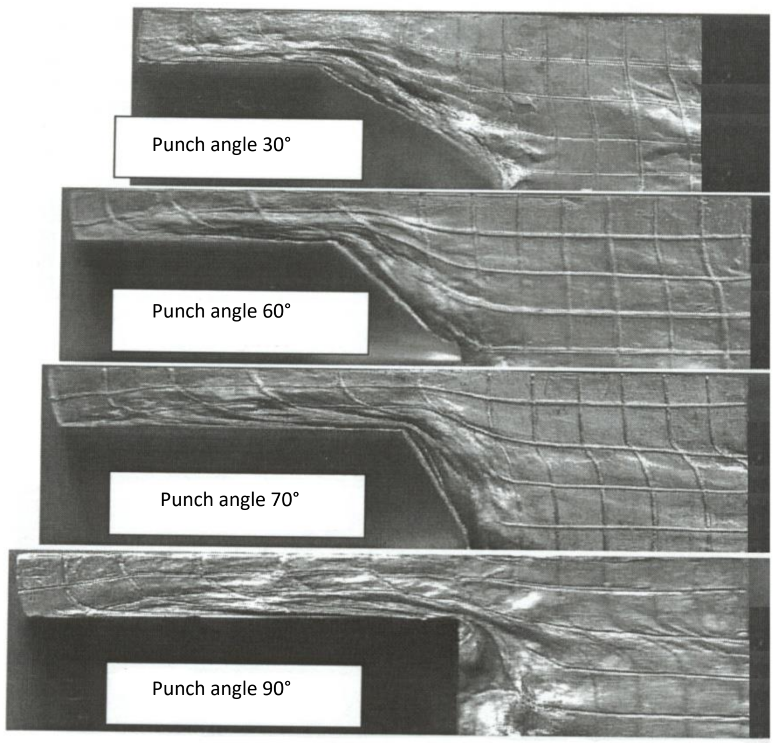


Figure 7: Photographs of flow pattern for 30, 60, 70, 90 ° punch profile

4- ANSYS Model

The ultimate purpose of a finite element analysis is to re-create mathematically the behavior of an actual engineering system. In other words, the analysis must be an accurate mathematical model of a physical prototype. In the broadest sense, the model comprises all the nodes, elements, material properties, real constants, boundary conditions and the other features that used to represent the physical system (Kun Chen et al., 2011). In ANSYS5.4 terminology, the term model generation usually takes on the narrower meaning of generating the nodes and elements that represent the special volume and connectivity of the actual system. Thus, model generation in this study will mean the process of defining the geometric configuration of the model's nodes and elements. The program offers the following approaches to model generation:

a) Creating a solid model , b) Using direct generation and c) Importing a model created in a computer-aided design CAD system. The method used in this research to generate a model is solid model. In solid modeling some one can be described the boundaries of the model, establish controls over the size and desired shape elements automatically, i.e. drawing the two dimensional specimen model and meshing using meshtool. Solid modeling is usually more powerful and versatile than other modeling, and is commonly the preferred method for generation models. The two Dimension model of specimen is done by plotting and meshing two dimension axisymmetric plane with elements , the billet element is visco106 and the contact condition is used via elements contac171 for deformable body and target169 for rigid body (Kun Chen et al., 2011). In this study ANSYS software is used to analyze and study the backward extrusion process and stresses distribution in the billet with different angle of the punch. The model generated for nonlinear materials and non linear geometry in addition to contact case between the die and billet and the punch and the billet, also it is nonlinear process (Saeed Moveni ,1999 ; ANSYS Structural Manual,1999). A complete APDL program is done to determine the stresses distributions and to show the process of backward extrusion. Four types of elements are used as shown in Figure 8.

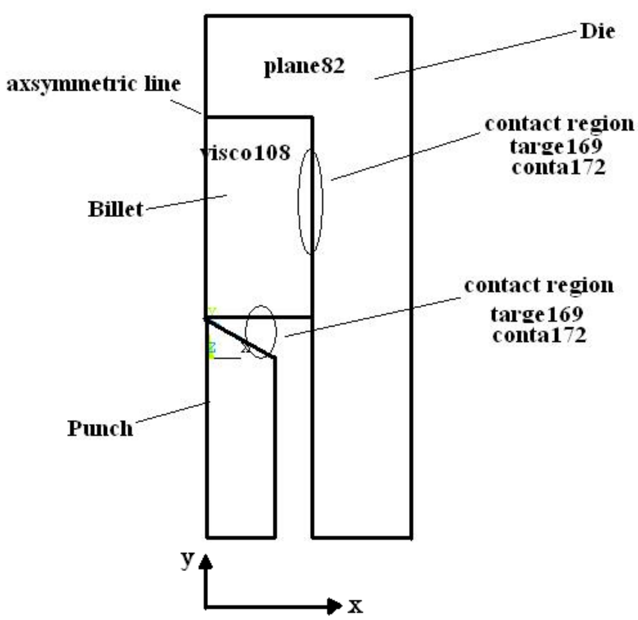


Figure 8: Extrusion process model

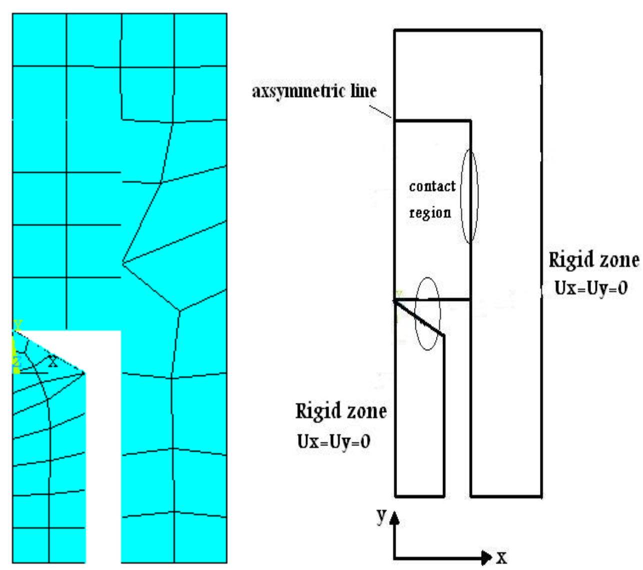
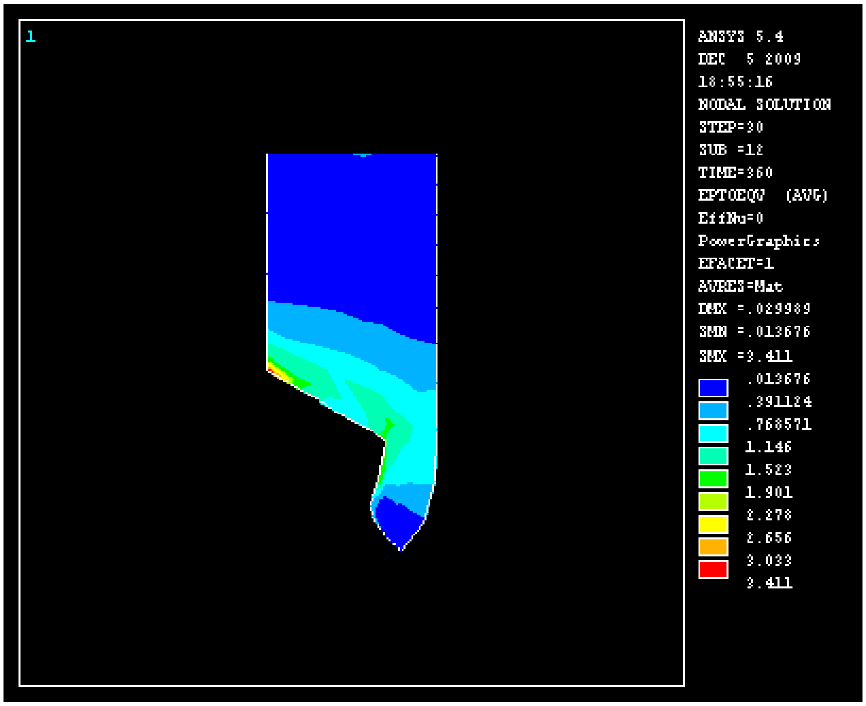


Figure 9: Mesh the model and boundary condition

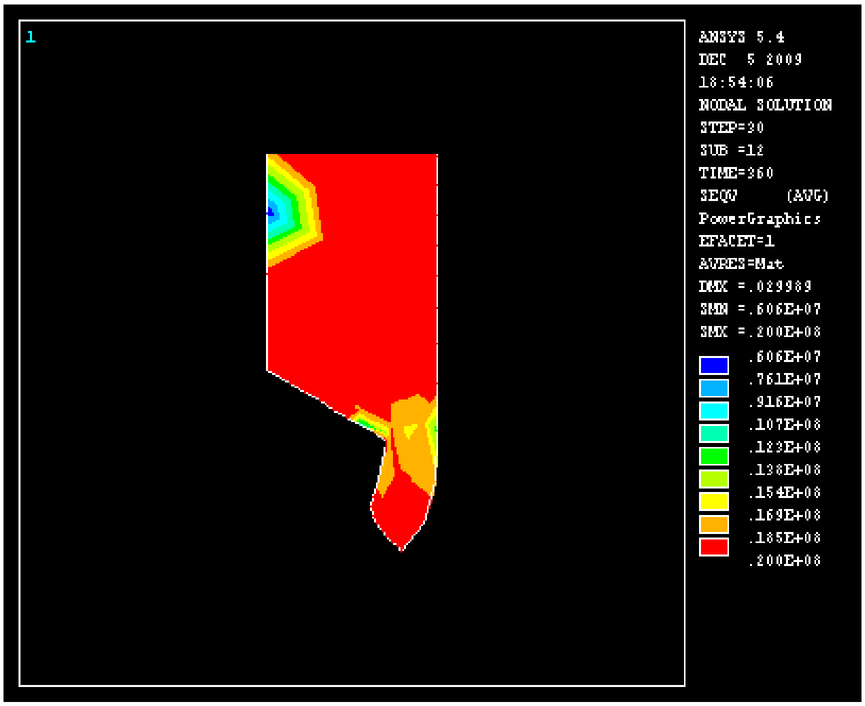
Due to symmetry, half of the billet is modeled. The element type visco108 is used for the billet and take into consideration the contact region which is meshed with element type target169 has been used for rigid portion and contac172 for deformed portion. Figure 9, shows the meshed model.

4-1 Distribution of Stresses in Extrusion Process

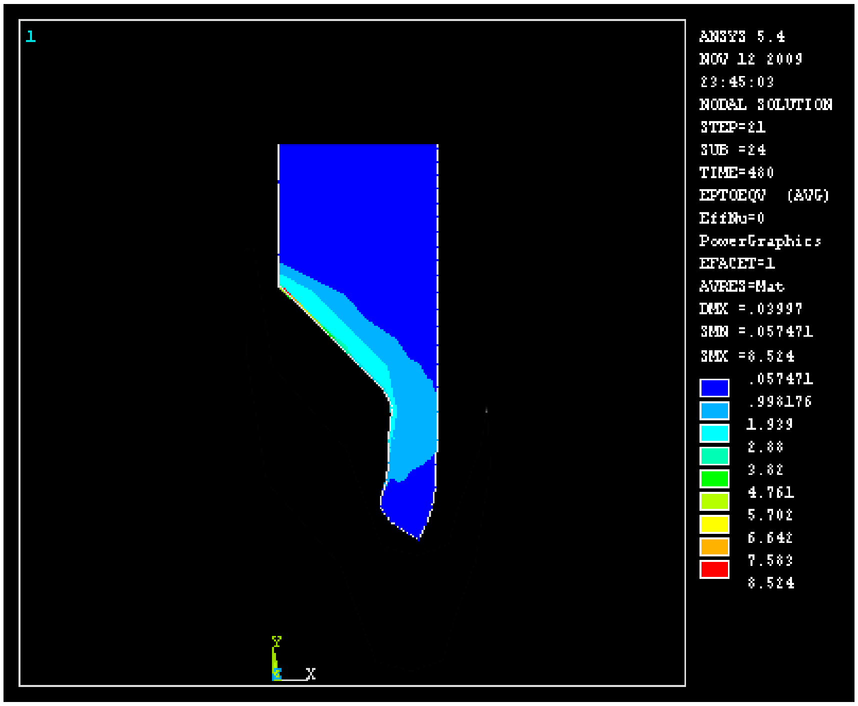
Figure 10, shows the stress and strain distributions at different punch profile follows the movement of billet inside the die. The speed of the particles in the internal area of the specimen would be greater than the adjacent areas, till reaching the surface of die, because the substance is pushed in the field due to constant volume and obstruction the die’s wall to the movement of the particles near the surface this is same as the speed of particle in the middle due to friction, and after a distance towards x-axis, In the outlet of the die, it is noticed that the metal's speed at the axisymmetric axis is seem to be constant but the speed of particle that is near the die surface, begins to increase, therefore, the metal speed would be at the end of area from the die, equal in all directions due to the constant of the vertical and horizontal components . The following figures represent the stress distributions (Von-Mises stress) and strain distribution in the billet according to ANSYS program at 30, 60, 70, 90 ° punch profile.



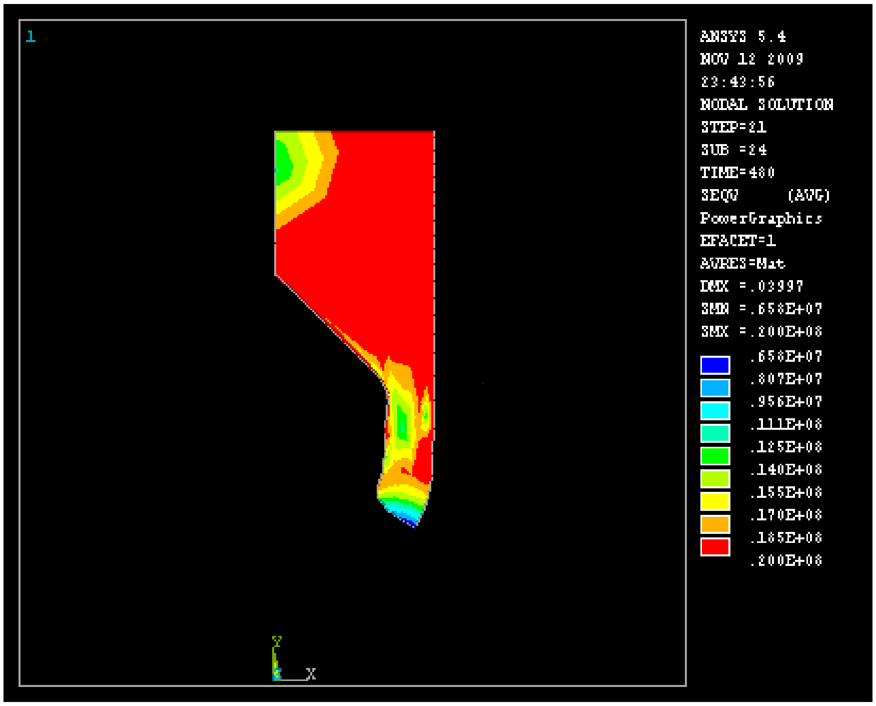
Strain distribution ($\beta = 30$ °)



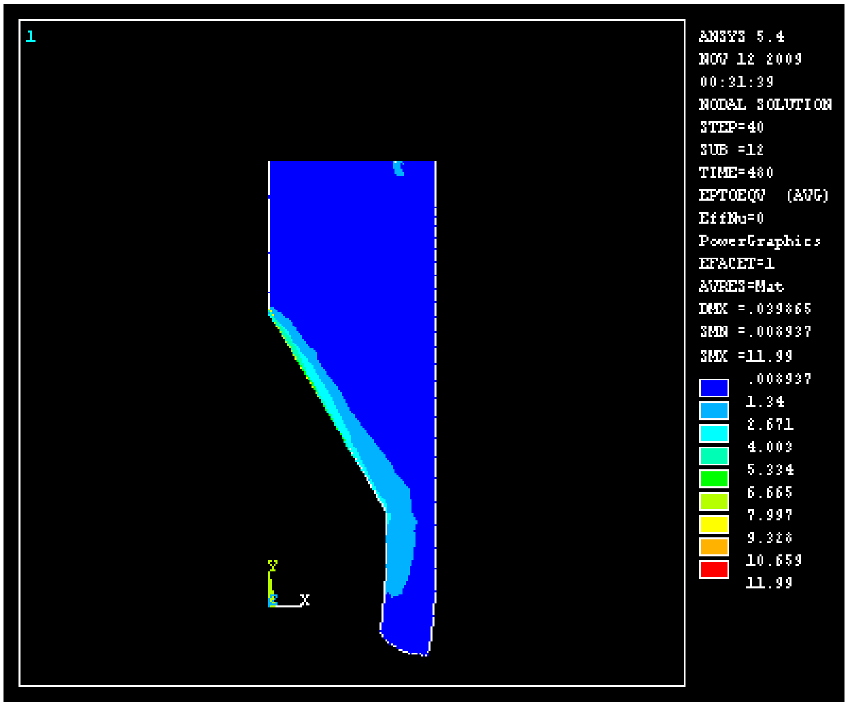
Stress distribution ($\beta = 30$ °)



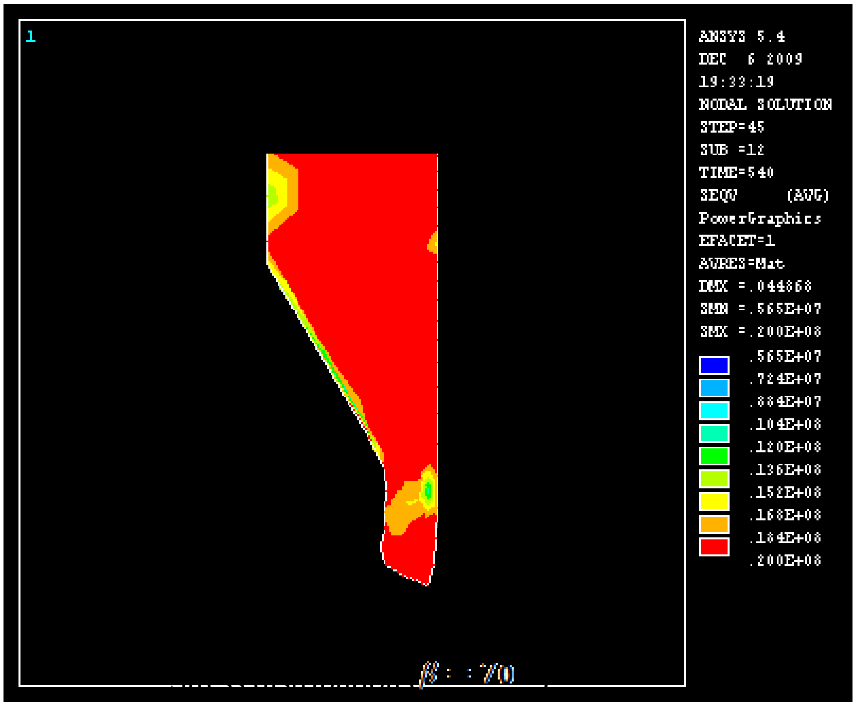
Strain distribution ($\beta = 60^\circ$)



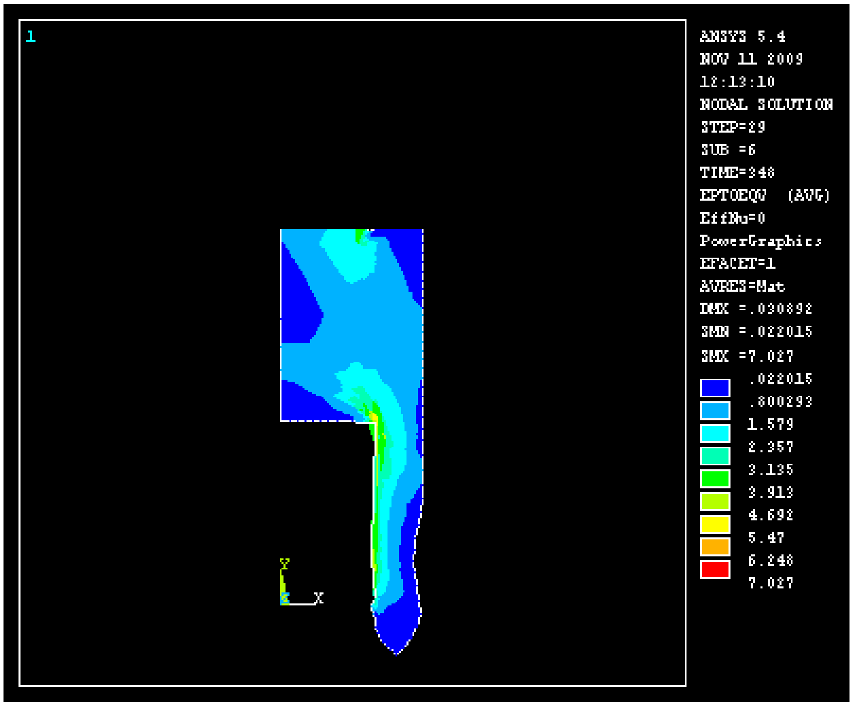
Stress distribution ($\beta = 60^\circ$)



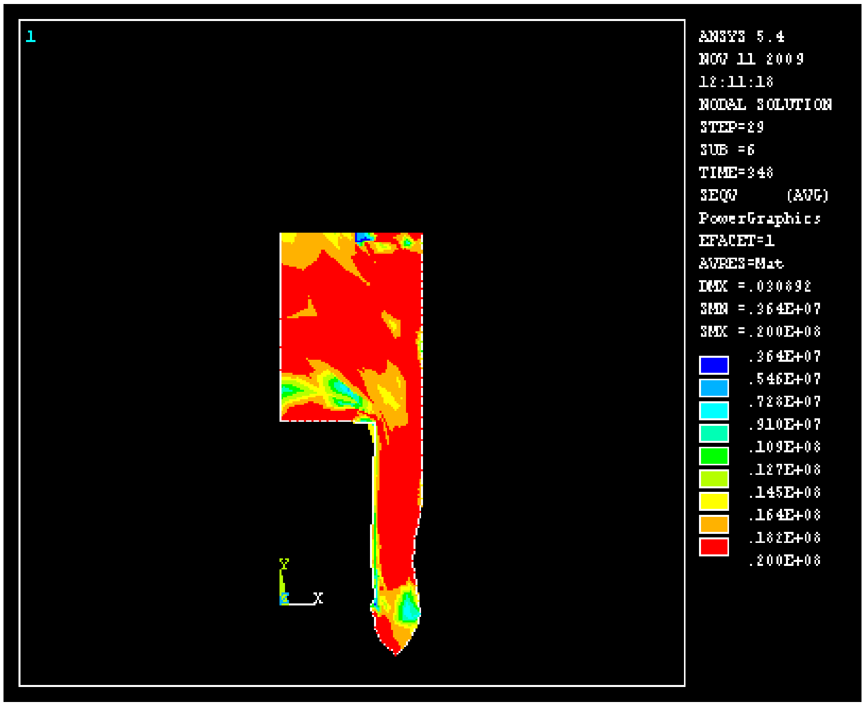
Strain distribution ($\beta = 70°$)



Stress distribution ($\beta = 70°$)



Strain distribution ($\beta = 90$ °)



Stress distribution ($\beta = 90$ °)

Figure 10: Stress and strain distribution in the billet

5- Discussion

Extrusion is a very complicated process, for the workpiece distorted greatly, there are geometrical nonlinear in the relation of displacement and strain and material nonlinear in the material constructive relationship. On the other hand, the punch geometrical shapes are often very complicated, so the contacting state are changed constantly, friction also can hardly be described, at the same time, there are coupling of hot and force between workpiece and dies, and there are many effected technology parameters. Also of this, it can hardly be gained accuracy solutions in the extrusion forming.

Figure 11, shows a comparison between theoretical and experimental results. The cause of this comparison between measured and theoretical pressure (equation (1)), for the same punch angle and percentage reduction in area is attributed mainly to the pressure used to overcome friction between cylinder and billet. Theoretical (equation (1)) and experimental results are in agreement (with discrepancy about 18%) . Theoretical results from equation(2) depend on punch angle β of 90° and they are nearer to the experimental results with same punch angle. Also it can be seen that there is little effect of punch angle β on the extrusion force required by using a flat end punch and a deviation between theoretical and experimental results, the cause of this deviation between measured and theoretical pressure (equation (1)), for the same punch angle is attributed mainly to the pressure used to overcome friction between cylinder and billet, besides some friction between punch and cover.

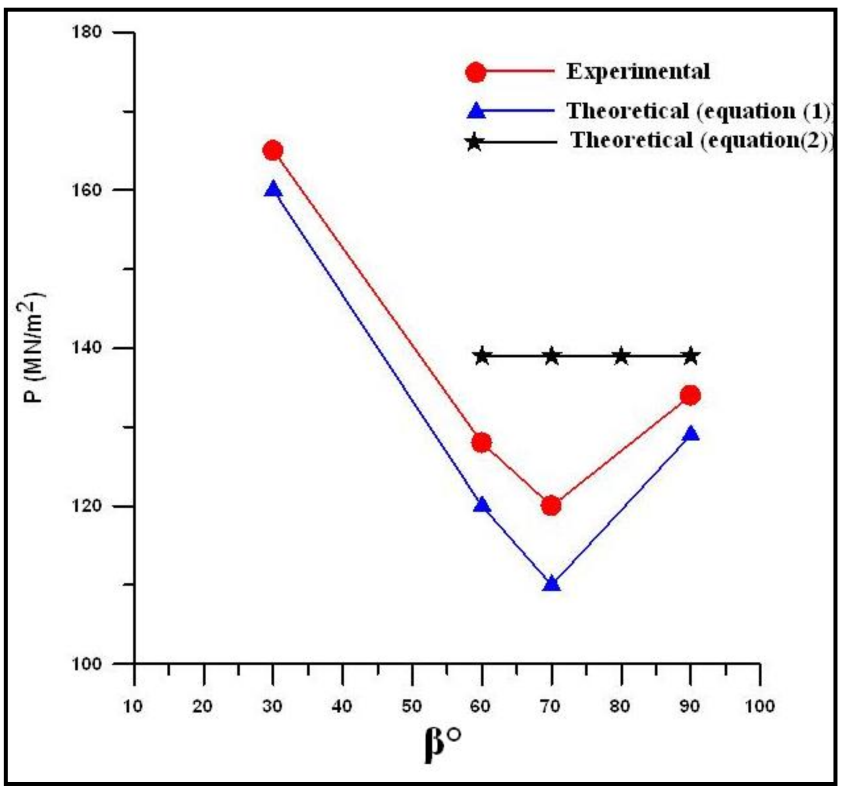


Figure 11: Experimental and theoretical relations between extrusion pressure (P) and semi- cone punch angle (β)

6- Conclusions

From the present investigation the following conclusions are drawn:

1- The trend of the findings of the investigation (Figure 4) shows an agreement to some extent with the existing theoretical results.
2- As extrusion ration increases, the working pressure also increases for all punch angles.
3- By a little change in the backward reduction in cross- sectional area different types or modes of extrusion process may be obtained.
4- The streamline profile of the punch surface have an important effect in homogeneity of the material flow in the backward direction, the fact that the redundant strains will be decreased and there will be less restriction on the material flow.
5- Because of the complex deformation situation during the backward extrusion and availability of more than one type of velocity field through the process duration, finite element analysis via ANSYS software may be the superior for application.
6- There is a good agreement and similarity in behavior between the results of the experimental tests and theoretical analysis, the discrepancy 18%.

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