The Effect of Area Reduction of Forward Die on the Combined Forward- Backward Extrusion Process

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Abstract

The effect of reduction area for flat and conical dies in forward-backward extrusion process was investigated experimentally using flat punches with three reduction areas (0.305,0.444,0.605), 0.444 with cone angles (60°,90°,120°) and polygonal punches (hexagonal and square).Three reduction areas of dies (0.395, 0.555, 0.691) are used. The results show that the extrusion load is effected with reduction area of flat dies more than conical dies when using cone and flat punches while the reduction area of conical dies affected with square punch more than hexagonal punch and this result was inversed with flat dies. The relative extrusion pressure P/$\overline{Y}$ increases when the reduction area of conical and flat dies increases too for all punches, but this result contrasts with the square punch at conical dies.The less value of max. stress was found with cone punch of prism angle 120° among cone punches for conical dies except the die of reduction area (0.555) and the cone punch of 90° prism angle gave less max. stress with all flat dies. Flat punch of reduction area (0.444) among the flat punches gave less value of max. stress with all conical dies and flat die of reduction area (0.691).

Key wards: Extrusion, Die

Notation

C.D 2 Conical die with exit diameter 25 mm
C.D 30 Conical die with exit diameter 30 mm
C.D 35 Conical die with exit diameter 35 mm
C.P 120 Cone punch with prism angle 120^0
C.P 60 Cone punch with prism angle 60^0
C.P 90 Cone punch with prism angle 90^0
F.D 25 Flat die with exit diameter 25 mm
F.D 30 Flat die with exit diameter 30 mm
F.D 35 Flat die with exit diameter 35 mm
F.P 25 Flat punch with head diameter 25 mm
F.P 30 Flat punch with head diameter 30 mm
F.P 35 Flat punch with head diameter 35 mm
H.P Hexagonal punch
S.P Square punch
σ_y Yield stress

Introduction

In the metal forming processes such as extrusion where the billet is deformed plastically between tools to obtain a final desired configuration, several parameters affect the value of extrusion power and quality of product. Die profile, reduction area and friction condition are the main parameters that influence this forming operation [1].

Recently many researchers have studied the design of dies and metal flow in the forward extrusion and backward extrusion processes using analytical or numerical methods. On the other hand the study in the combined forward-backward extrusion process is still less than other extrusion processes to predict the metal flow presentation and load requirements as a relative pressure , which should be taken into consideration in order to design the extrusion process and to control the material properties of products effectively.This method of extrusion can be used in production some mechanical parts such as an automotive spark plug and automotive socket[1]. Kudo [2] applied the upper-bound method to analyze the backward-forward combined extrusion of axi-symmetric shapes. Aide [3] and his coworkers studed this process by using a graphical upper bound method. Avitzur [4] used an analytical upper bound approach to solve the solve the combined extrusion process. Scherniber [5] applied combined physical and numerical simulation for study of material flow in this process. Guo and his coworkers [6] analyzed hot backward-forward extrusion process by visco-plastic FEM. Kawable [7] proposed numerical analysis for predicting dimensional accuracy under thermal influence during repeated forward-backward cold extrusion. Chitkara and Butt [8] applied a numerical solution to analyze the process of rod and tube combined extrusion. Moshksar and et al. [9] propose a simple kinematically admissible velocity field for the backward-forward combined extrusion of polygonal cup-bar shape components. Math and Grizelj [10] analyzed the process of simultaneous forward-backward extrusion of the body of automatic valve for central low pressure heating installations using finite element simulation to predict both the magnitude and the distribution of the stresses. Ok, et al [11] investigated the influences of tool geometry and process condition on balanced material flow in a combined forward and backward can extrusion process using FEM

In this work the effect of reduction area of forward die in combined forward(rod)-backward(can) extrusion process has been investigated experimentally using flat and conical dies with different punches.Also the distribution of stresses was investigated by the FEM.

Experimental procedure

1- Forward dies : Two groups of forward dies were used in this work ; the first consisted of three flat faced dies with reduction areas (R_f = 0.395, 0.555 and 0.691) with the die land length (L_D = 10mm). The second group consisted of three conical dies designed with constant converging angle ($2\alpha=60^o$) and have the same reduction in area similar to the first group.

2- Backward punches : The punches used in this paper consist of three groups. The first group includes flat head circular of sizes (25,30,35)mm with different reductions in area (R_b= 0.309,0.444,0.605) respectively.

The second group consists of three plugs with different head angles (2θ = 60^o,90^o,120^o) and constant diameter (30mm) with area reduction of (R_b=0.444). The nose of plugs was blended to reduce the stress concentration. The third group of punches includes two regular polygonal heads (hexagonal and square) with the same reduction area (R_b =0.444). The land of punch head is 10mm [12].

Both dies and punches are made of the same material DIN (C80W2).

All surfaces of dies and punches were ground and polished to get the same surface roughness for each test.

3- Material of the Billets

Pure aluminum of 1061.1 used in the electrical industry is employed as a billet. The chemical composition of this material is illustrated in Table

Table (1) Chemical composition of the martial

Element	Si	Cu	Mn	Mg	Zn	Cr	pb	Fe	AL
%	0.13	0.04	0.01	0.006	0.01	0.01	0.001	0.31	99.483

The round billet of 45mm in diameter and 60mm in length is used. The billet prepared by machining on the lathe from a cast bar.

4- Mechanical properties

Table (2) includes the mechanical properties for the material which were obtained from tensile test and hardness test. The equation of fitting true stress – true strain curve of this test is given by :

$$\sigma_y = 104.306\ \epsilon^{0.23} \quad \text{(Mpa)}$$

This equation is used in determine the mean yield stress ($\bar{Y}$) according to the strain in this study through the following equation [13] :

$$\bar{Y} = \frac{1}{\epsilon_2 - \epsilon_1} \int_{\epsilon_1}^{\epsilon_2} \sigma_y \, d\epsilon$$

Where ϵ_1 and ϵ_2 are the strain before and after deformation respectively for each forward and backward sides.

Table (2) Mechanical properties of the material

Ultimate stress (σu)(Mpa)	Yield stress (σy) (Mpa)	Hardness (HB)
63.7	43.3	25

5- The Compression Machine

TORSEE 's universal testing machine type (RAT-100) with capacity 100 ton is used to perform the combined forward- backward extrusion tests with constant stroke 30mm.Fig. (1) shows sample of the extruded specimens.

Fig. (1) Sample of extruded specimens

Results and discussion

1- Load versus displacement:

In the cone punches the load increases with advanced punch forward, beginning at low values and rises gradually. The reason refers to punch penetration easily and also the gradually increasing of metal area during deformation. In the flat punches the extrusion load is relatively more than its value in cone punches because the metal quantity during pressure and deformation in these punches is large and the load increases as punch advances toward the forward die.For both flat and cone punches , the conical converged dies have reduction area 0.395 , 0.555 , 0.691, the load behavior is in the continual rising until reaching the max. value at the end of stroke for all punches except the cone punch(angle 120) where the load is decreasing before the stroke end in all those dies except the die of reduction area 0.555 as shown in the Fig(2)

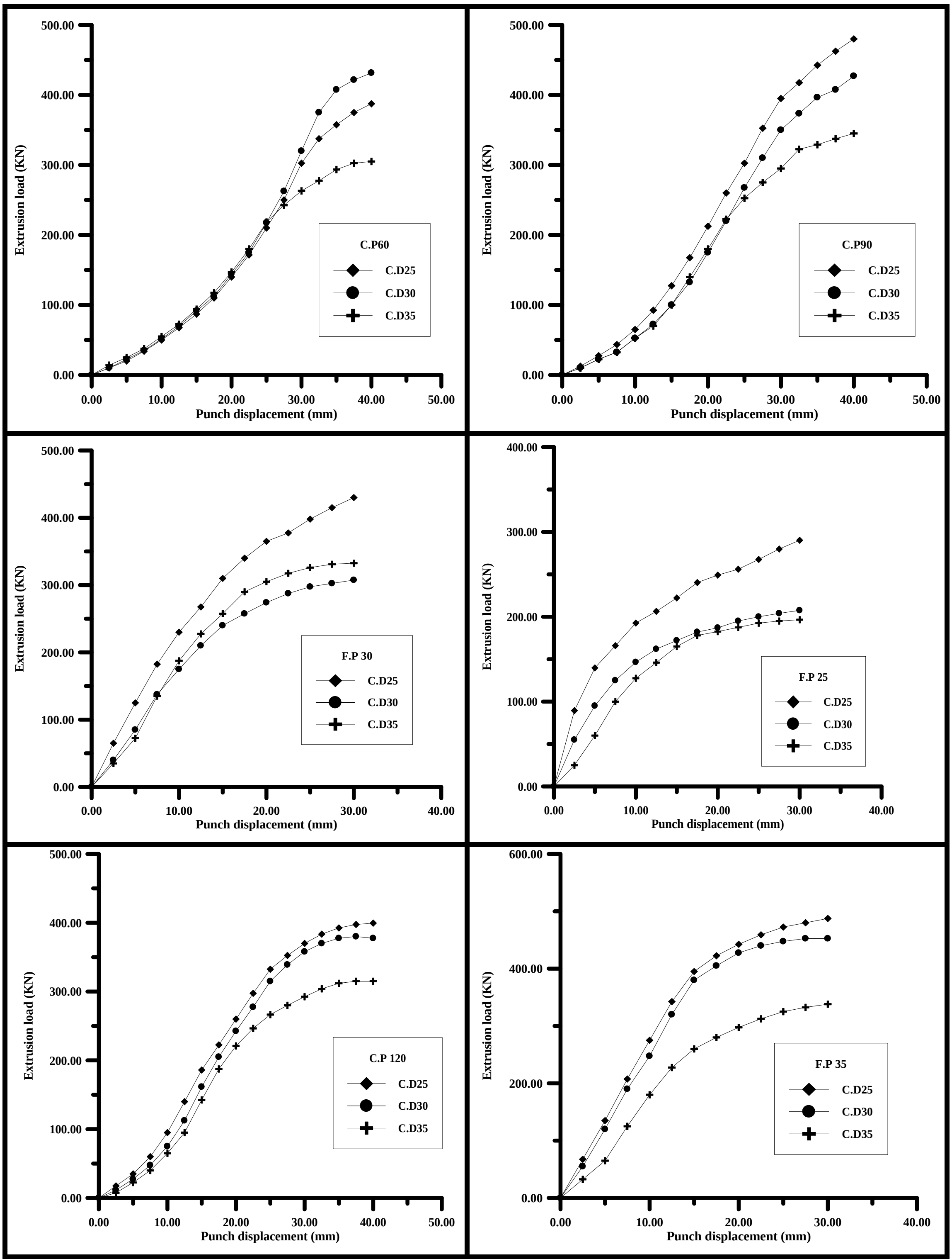


Fig. (2) Extrusion load-punch displacement relationship for conical dieswith cone and flat punches

In the flat dies of the reduction area (0.395 , 0.555 , 0.691), also the load is lowered after it reaches a maximum value before the stroke end except the F.D25 where , the load is continuing to rise to the end of stroke with the punches C.P90,F.P30 and F.P35 as shown in Fig. (3) . The reason for continual rising load is to the metal flow restriction forward and dead zone formation . The decrease in load in the stage near to the end stroke occurs because of the steady state of metal flow after reaching the maximum value of that load, which in this case the shear component of extrusion power decreases to the minimum value and the friction component remains active as a redundant work.

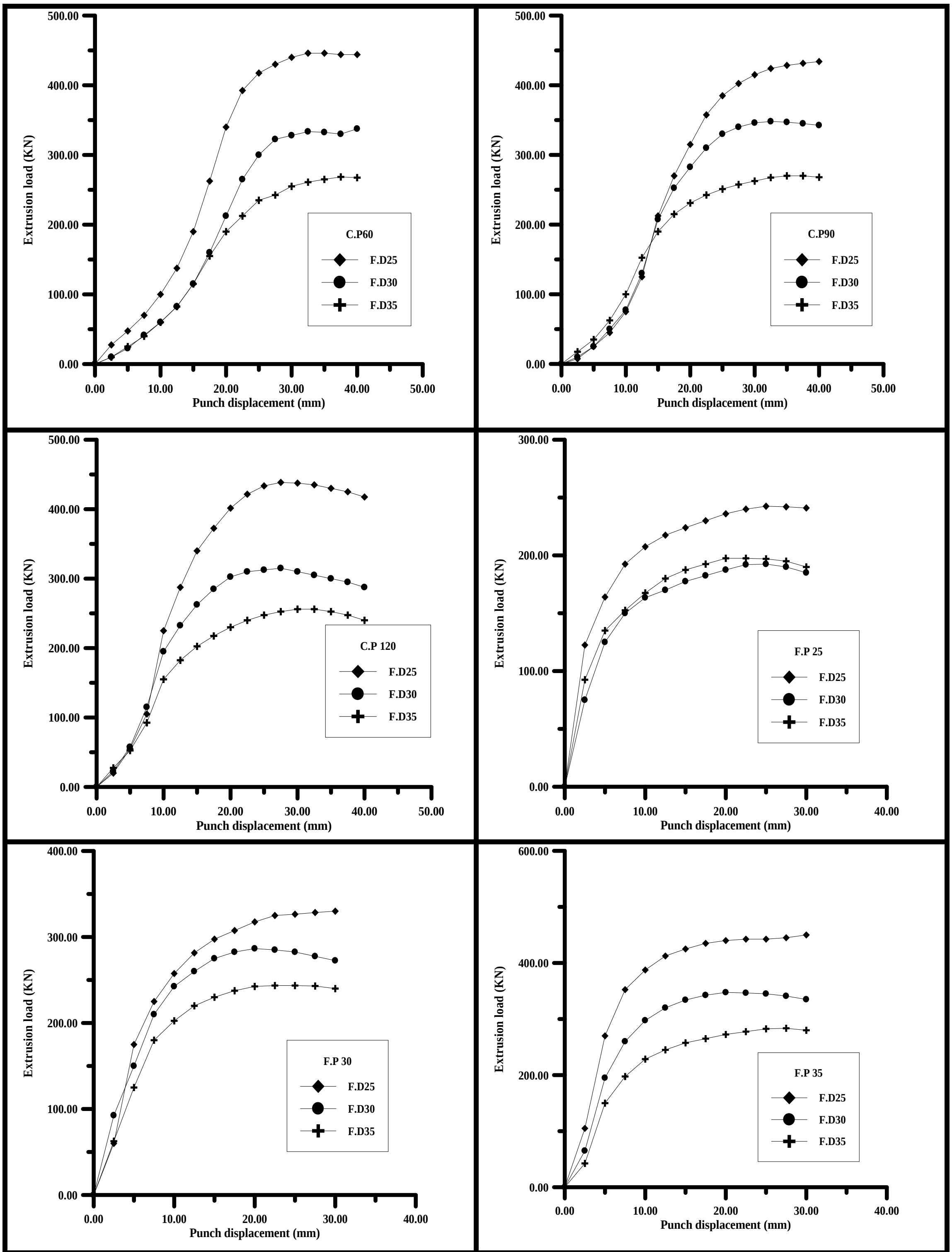


Fig. (3) Extrusion load-punch displacement relationship for flat dies with cone and flat punches.

For the conical converged and flat dies , the lower extrusion load appears with reduction area (0.395) of those dies which means that when the reduction area of die decreases the maximum extrusion load decreases too in those dies in the same stroke.

In the conical converged dies , the lower load appears in the die (reduction area 0.395) for the punches (F.P25 and F.P35) but for punch (F.P30) the lower load appears in the (C.D30) . For the flat dies the lower load appears in the (F.D35) for the punches (F.P30 and F.P35), while the lower load with punch (F.P25) appears at (F.D30) . The reason for decrease in the maximum load value with conical converged and flat dies is due to reduction area 0.395 which belongs to the large quantity of metal flow forward which reduces the restriction of compression metal and less formation of dead zone caused by shearing

It has been observed that the lower load occurs at flat punch and conical converged die when the diameter of punch equals the exit diameter of the die (35 , 30mm) and the reason for this be might due to the velocity of metal flow at steady state which is approximately the same as punch velocity[9].The effect of reduction area of conical dies on the extrusion load for hexagonal and square punches is shown in Fig. (4) and Fig.(5) respectively. It can be seen that the extrusion load with hexagonal punch has the same behavior and its values are close to each other for three dies from the beginning of the stroke until approximately (20mm), and after this point the load increases in conical die of reduction area 0.691 more than in conical dies of reduction areas 0.555 and 0.395 respectively , which means that the load is increased a bit when the reduction area of die increases because the increasing of surface area leads to higher friction.

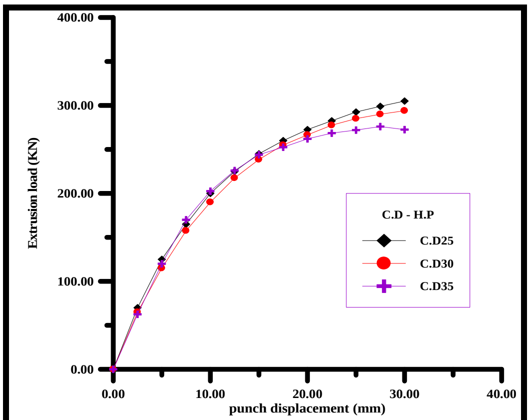


Fig.(4) Load-displacement for conical dies with hexagonal punch.

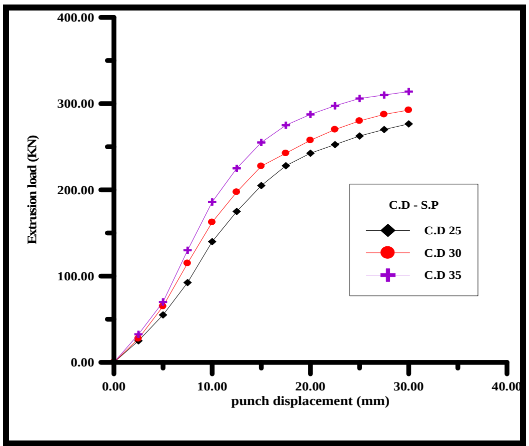


Fig.(5) Load-displacement for conical dies with square punch.

In the square punch which has the same reduction area the extrusion load is increased when the reduction area of die decreases from the beginning of the stroke.This is due to the friction condition which increases when the number of polygonal sides decreases [9] , as the friction strongly affects the force in the backward extrusion [14] , so the effect of friction at forward die decreases and the shear component of extrusion power increases when the reduction area of conical die decreases .

When flat dies are used, the reduction area of the die is more effective on the extrusion load with the hexagonal punch. Fig. (6) shows that the extrusion load at flat die of reduction area 0.395 is less than its value with flat die of reduction areas 0.691 and 0.555 , while the load at reduction area 0.555 is higher than reduction area 0.691. The load is decreased after reaching the maximum value because of steady state of metal flow.

In the square punch the reduction area of die hasn't got large effect on the extrusion load , but when the load reaches the maximum value and the steady state occurs, the load is decreased with simple difference in values where in flat die of reduction area 0.691 is larger than flat die of reduction areas (0.395) and (0.555) as shown in Fig. (7).

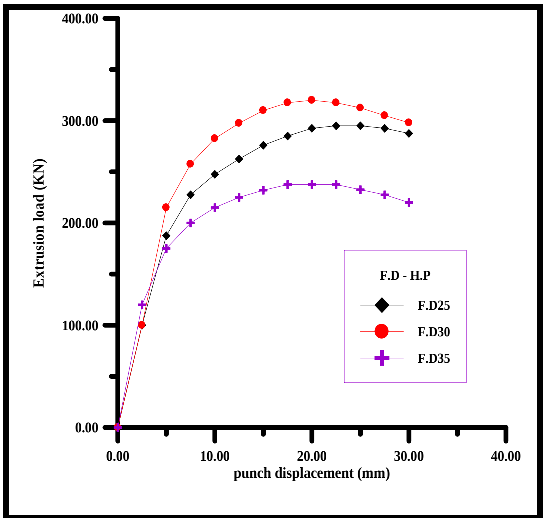


Fig.(6) Load-displacement for flat dies with hexagonal punch

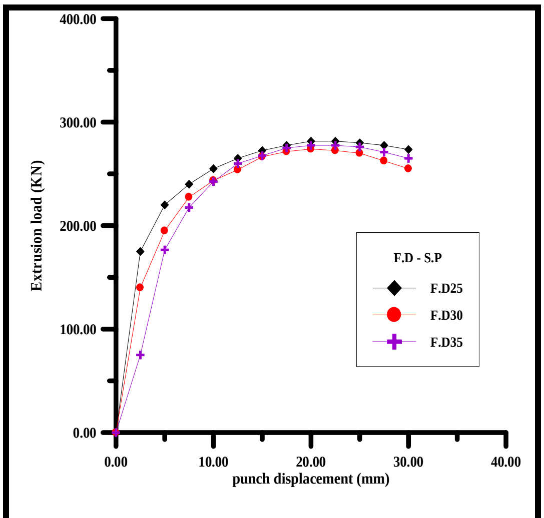
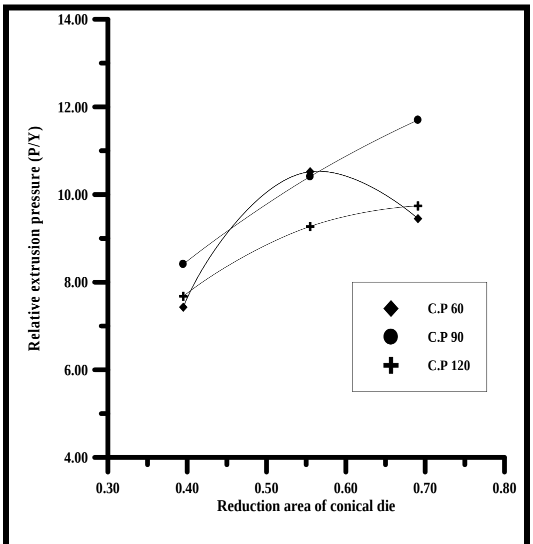


Fig.(7) Load-displacement for conical dies with square punch

The comparison between the square and hexagonal punches (of the same reduction in area) shows that the reduction area of flat die is more effective on the value of extrusion load with hexagonal punch than square punch. This is attributed to the effect of punch head geometry on the shear strain with the flat die , because the shear component of the extrusion power is increased with flat dies and it is also increased when the corners are increased in the geometry of head punch. The shear component of power causes the rise in the value of load with the flat dies compared with the conical dies at the beginning of the process with the square punch especially when the reduction in area of flat die increases.

2-Relative extrusion pressure P/$\bar{Y}$

Fig(8) shows the effect of reduction area of forward conical dies which have the same angle (α =30^{o}) on the value of relative extrusion pressure with cone punches. It has been found that the reduction area (0.395) has less value of (P/$\bar{Y}$) than other reduction areas with all cone punches. Also, it is noticed that the value of (P/ $\bar{Y}$) decreases when the reduction area decreases with (C.P90 & C.120) which doesn't work with (C.P60). This difference is caused by the length of cone head increase with the small angle which leads to punch penetration effect and friction condition that determine the metal flow at the same stroke. The effect of flat punches on those dies is explained in Fig.(9). Also, the less value of (P/$\bar{Y}$) appears with (C.D35) for (F.P25 & F.P35) which means that the (P/$\bar{Y}$) decreases when the reduction area of conical die decreases too at those punches. On the other hand in the (F.P30) the less value of (P/$\bar{Y}$) appears with (C.D30).The main reason for (P/$\bar{Y}$) decrease when the reduction area of conical die decreases is the increasing of friction component of extrusion power when the reduction area of die increases in conical dies.



Fi.(8) Relationship between reduction area of conical dies and extrusion pressure with cone punches

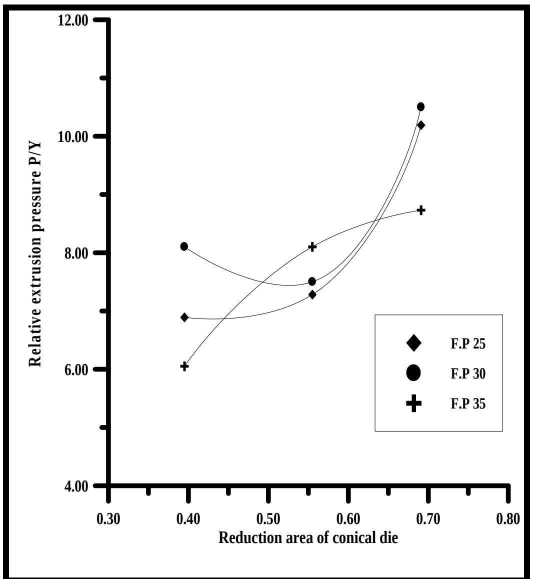


Fig.(9) Relationship between reduction area of conical dies and extrusion pressure with flat punches

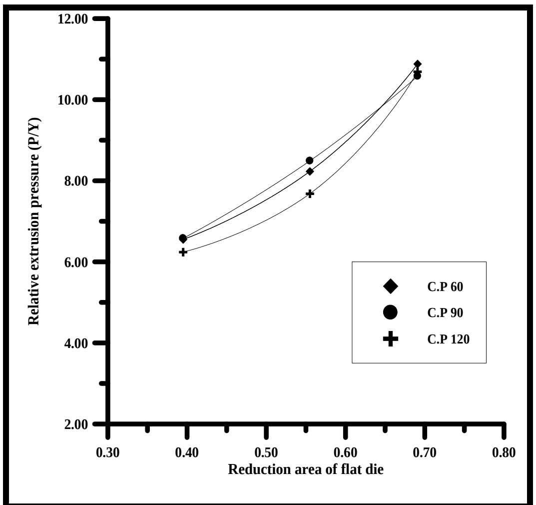


Fig.(10) Relationship between reduction area of flat dies and extrusion pressure with cone punches

Fig. (10) and Fig.(11) show the effect of reduction area of flat die on the relative extrusion pressure with cone and flat punches. It is clear that the reduction area (0.395) has a lower value of (P/$\bar{Y}$) in all cone punches, (F.P30 and F.P35) while with (F.P25) a less value of (P/$\bar{Y}$) is found with reduction area (0.555). Also it is noticed that the value of (P/$\bar{Y}$) is decreased when the reduction area of flat dies decreases in all punches except the (F.P25) one. The values of (P/$\bar{Y}$) of (F.D30 & F.D35) were close to each other. The restriction to metal flow is decreased when the reduction area of flat die decreases, so the value of relative extrusion pressure decreases too.

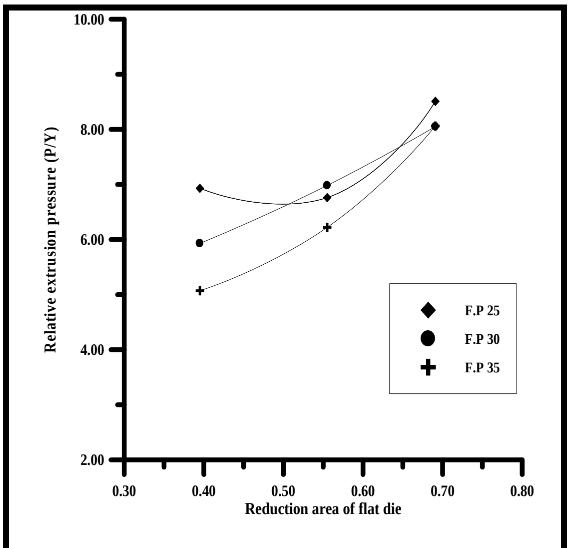


Fig.(11) Relationship between reduction area of flat dies and extrusion pressure with flat punches

The variation of reduction area of conical die has clear effect with polygonal punches. Fig.(12) shows that the relative extrusion pressure is decreased when the reduction area of die is decreased too with the hexagonal punch. While this effect is inversed at square punch as shown in Fig. (13). The reasons belong to the friction and shear strain which discussed in details previously. It is obvious that the value of (P/$\bar{Y}$) in the conical die of reduction area (0.555) is approximately similar for both punches. The effect of reduction area in the flat dies on the value of relative extrusion pressure is different from conical dies. The less value with hexagonal punch is appeared in flat die of reduction area 0.395 but with square punch appeared in flat die of reduction area (0.555).

It is noticed that the variation in values of relative pressure with square punch is less according to the reduction area of flat die as shown in Fig.(14) and Fig.(15).

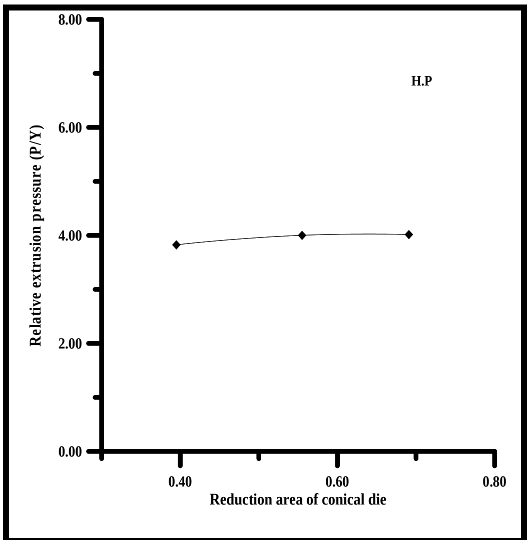


Fig. (12) Relative extrusion pressure of conical dies for hexagonal punch

The empirical equations obtained from the linear curve fitting of the relationship between (In 1/1-R_f) and relative extrusion pressure (P/$\bar{Y}$) for flat and conical dies are shown in table (3).

Generally those results agree with what the authors [9 , 12] have found.

Table (3) Empirical equations obtained from the linear curve fitting of the relationship between (ln 1/1-R_f) and relative extrusion pressure (P/$\bar{Y}$) for flat dies

C.P 60	$\frac{P}{\bar{Y}} = 2.1363 + 3.1417 \ln \frac{1}{1-R_f}$
C.P 90	$\frac{P}{\bar{Y}} = 2.3727 + 2.8607 \ln \frac{1}{1-R_f}$
C.P 120	$\frac{P}{\bar{Y}} = 1.8382 + 3.2686 \ln \frac{1}{1 \quad R_f}$
F.P 25	$\frac{P}{\bar{Y}} = 3.595 + 0.8902 \ln \frac{1}{1-R_f}$
F.P 30	$\frac{P}{\bar{Y}} = 2.7415 + 1.3777 \ln \frac{1}{1-R_f}$
F.P 35	$\frac{P}{\bar{Y}} = 1.6419 + 2.0874 \ln \frac{1}{1-R_f}$
H.P	$\frac{P}{\bar{Y}} = 2.8331 + 0.979 \ln \frac{1}{1-R_f}$
S.P	$\frac{P}{\bar{Y}} = 3.7325 - 0.1632 \ln \frac{1}{1-R_f}$

Effective stress distribution:

To investigate the distribution of stresses in this process with flat and cone punches (2D-axisymmtric) a commercially available finite element program code called (ANSYS 5.4) is used to perform the numerical simulation of the combined forward-backward extrusion process. In this study material properties are adopted as non-linear, isotropic and constant temperature (room temperature). As with element types and real constant, each set of material properties can be specified by using the commands (MP) and (TB). The command (TB) includes option (BISO) which characterizes the material behavior and means bilinear isotropic hardening.

The properties of the material are shown below which obtained from experimental tests concerning (Et , σ_y) and (E , ρ , ν) from table [1] .

Tangent modulus (Et) =16.67 Gpa

Yield stress (σ_y) =43.3 Mpa

Modulus of elasticity (E) = 70 Gpa

Density (ρ) =2700 Kg/m^3

Poisson's ration (ν) =0.3

Shear friction factor (m) = 0.12

The velocity which adopted in the simulation is the same value used experimentally in the extrusion tests as follows .

Velocity = 3mm/min

From Fig. (16) it can be noticed that the stress distribution and those values in the backward side are more than the forward side because of strong distortion of the metal particularly at high reduction area of flat punch at backward side .

Also , the distribution of stresses and those values are more at the forward side with flat dies than with conical dies because high shear strain occurs with those dies .

The effect of mesh in the simulation of this process is very important in those results . The procedure of meshing is carried out similarly for all models that adopt a fine mesh in the contact surfaces exposed to the high distortion and course mesh in the remain regions . So the various stress distributions refer to the effect of die type and shape of punch .

The effect of reduction area of conical dies on the magnitude of maximum stress with cone and flat punches is shown in Fig.(17) and Fig.(18) respectively.

The less value of maximum stress according to the reduction area of conical die was found at (0.555) with (C.P 60) and at (0.395) with both (C.P 90 and C.P120).

It is noticed that the difference between the less values of max. stress and other values with (C.P 60) is large . Also this case can be observed with (C.P 120) and this is due to the friction condition and metal flow quantity. The values of max. stress of reduction areas (0.555 and 0.395) with (C.P 90) and (0.555 and 0.691) with (C.P 120) are close to each other .

The less values of max. stress for reduction area (0.395) are close to each other for (C.P 90 and C.P 120) because of the decreasing friction condition in those cases which leads to the decrease in the compression stresses.

The effect of reduction area of conical die with flat punches refers to obtaining a less value of max. stress when the exit diameter of die is equal to the diameter of punch at (F.P 30 and F.P 35) but the less value of max. stress with (F.P 25) occurs at reduction area (0.555) .

It is observed that the max. stress decreases linearly when the reduction area of conical die decreases too with (F.P 35) because the surface area of cone decreases when the reduction area decreases too which leads to the decrease in the friction , in addition to the decrease in the shear strain . But with (F.P 30 and F.P 25) there is a difference in the behavior of metal flow on backward side which is affected by the reduction area and gives high value of max. stress with less reduction area (0.395) .

The results of flat punches indicate that the best values of max. stress according to the reduction area of conical dies were found with the(F.P30) and are increased at (F.P35) more than at (F.P25) with reduction area (0.691 & 0.555) , but this result contrasts with reduction area (o.395) . It is concluded that the backward reduction area of flat punch is more effective than reduction area of conical die in determination of the maximum stress.

The effect of reduction area of flat die with cone and flat punches is illustrated in Fig.(19) and Fig.(20) respectively. The (C.P90) gives the less value of max. stress than the (C.P60 and C.P120) for all reduction areas of flat die.

For (C.P 90) and (C.P 120) , it is noticed that the max. stress decreases linearly when the reduction area of flat die decreases too. The less value of max. stress is observed at reduction area (0.395) for both (C.P 90 and C.P 120) . While with the (C.P 60) , it is noticed at reduction area (0.555). This result is due to the high shear strain that occurs with high reduction area of flat die and dead metal zone formation, and this factor is affected by the decrease in prism angle of punch as the metal flow is more affected too.

For flat punches the max. stress increases when the backward reduction area increases too at forward reduction area (0.555).The less value of max. stress is observed at reduction area of flat die (0.395) with (F.P 25 & F.P 35) , while with (F.P 30) it occurs at reduction area (0.691)

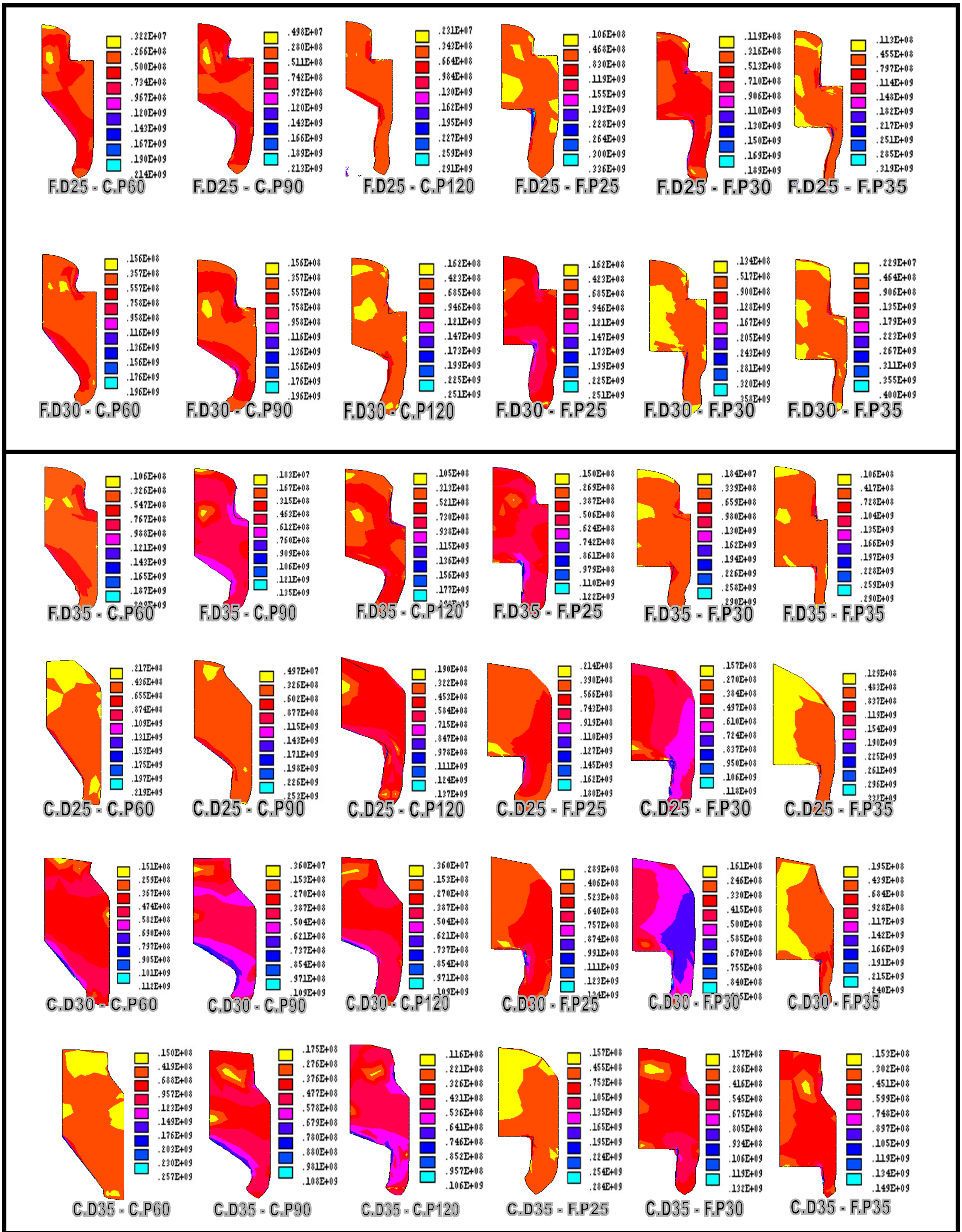


Fig.(16) Effective stress distribution

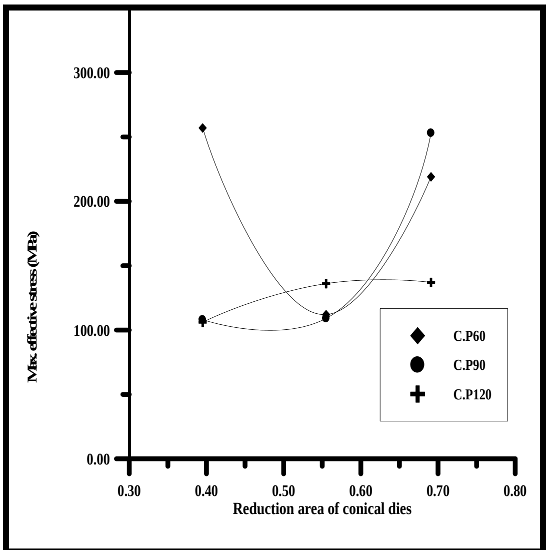


Fig.(17) The effect of reduction area of conical dies on max. effective stress with cone punches

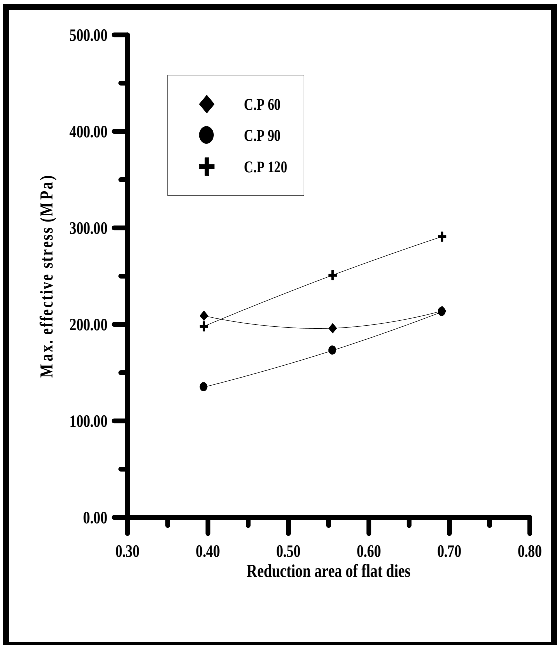


Fig.(19) The effect of reduction area. of flat dies on max. effective stress with cone punches

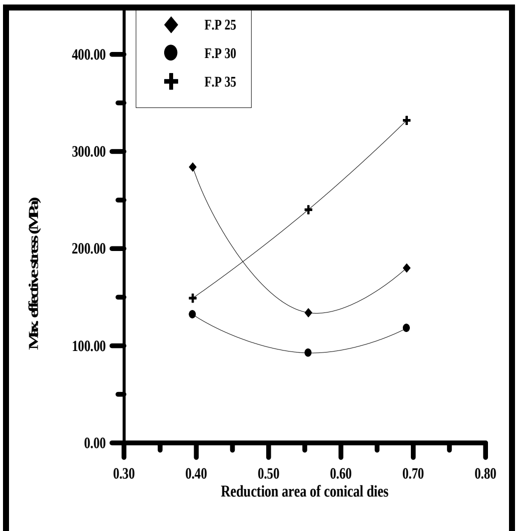


Fig.(18) The effect of reduction area of conical dies on max. effective stress with flat punches.

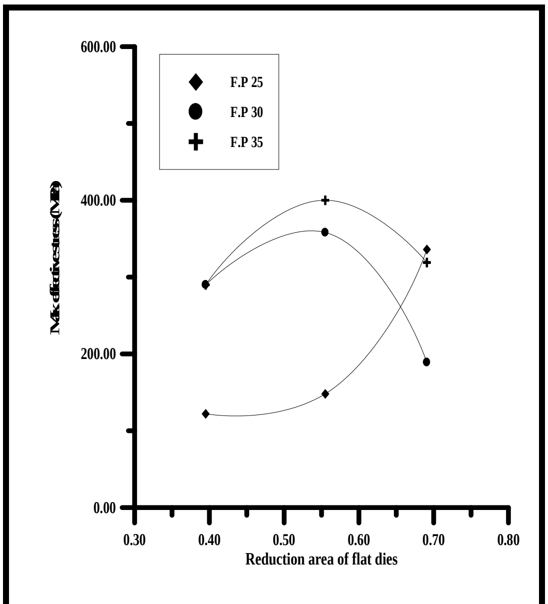


Fig. (20) The effect of reduction area of flat dies on max. effective stress with flat punches.

Conclusions

In the combined forward-backward extrusion process, the extrusion load is affected with reduction area of flat dies more than conical dies when using cone and flat punches. The effect of reduction area of conical dies when using square punch is more than hexagonal punch while this result was inversed with flat dies. The relative extrusion pressure P/ $\bar{Y}$ increases when the reduction area of conical and flat dies increases too for all punches, but this result contrasts with the square punch at conical dies. The less value of max. Stress is obtained at C.D35 and C.D30 with C.P120 among cone punches and F.P30 among flat punches respectively, and at F.D35 with both C.P90 among cone punches and F.P25 among flat punches respectively.

C.P120 among cone punches gives a less value of max. stress of conical dies except C.D30 because the values of max. Stress are increased with mean ratio 64.5% at other cone punches. C.P90 gives that result of all flat dies because in other cone punches the value is increased with mean ratio 45.5%. F.P30 among flat punches gives a less value of max. stress with all conical dies and F.D25.

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تأثير التخفيض في مساحة القطع للقوالب الأمامية (*Forward*) في عملية البثق المركب (*Forward- Backward*)

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الخلاصة

تم دراسة تاثير التخفيض في مساحة المقطع للقوالب المسطحة والمخروطية في عملية البثق المركب عمليا باستخدام مكابس مسطحة بنسب تخفيض في مساحة المقطع (0.305,0.444,0.605)ومكابس مخروطية بثلاث زوايا (60^o,90^o,120^o) ذات نسبة تخفيض ثابتة (0.444) ومكابس مضلعة الشكل (سداسي ، مربع) ذات نسبة تخفيض في مساحة المقطع متساوية (0.444).تم استخدام ثلاثة نسب تخفيض في مساحة المقطع للقوالب هى

(0.395, 0.555, 0.691) .النتائج اظهرت ان حمل البثق يتأثر بنسبة تخفيض المساحة للقوالب المسطحة اكثر من القوالب المخروطية عند استعمال المكابس المخروطية والمسطحة بينما يتأثر حمل البثق بنسبة تخفيض القوالب المخروطية مع المكبس المربع الشكل اكثر من المكبس السداسي الشكل ، بينما تنعكس هذه النتيجة مع القوالب المسطحة . ان ضغط البثق النسبي ($P/\bar{Y}$) يزداد عندما تزداد نسبة التخفيض في مساحة المقطع للقوالب المخروطية الشكل والمسطحة مع كافة المكابس الا ان هذه النتيجة مختلفة في المكبس المربع مع القوالب المخروطية . ان ضغط البثق النسبي يتغير مع نسبة تخفيض المساحة للقوالب المسطحة مع المكابس المضلعة.