EFFECT OF SIDE FORCE DURING DIE CUTTING PROCESS

Ahmed J. Hasan — M.Sc. Mechanical Engineering — Technical College/Baghdad
Rahman A. Hussain — M.Sc. Mechanical Engineering — Technical College/Baghdad
Abdulwahab A. Daud — M.Sc. Mechanical Engineering — Technical College/Baghdad

ABSTRACT

In this research the forces exerted on both blank and punch in chipping process are studied. These forces are analyzed initially from pressing force exerted by punch on blank in sheet metal cutting, which is selected according to many factors such as (process type, blank material specifications and dimensions and type of fixtures that means pressure pad if any). This research resulted in an equation used for computing the theoretical value of side force created through the pressing process which may push the end of the punch horizontally. Two sets of practical work include cutting a variable thickness steel 37 plate and (3 mm) thickness punch by using end cutting die. The punch has broken in the 1st set with plate thickness (8) mm due to the side force which is found approximately equal to (0.1718%) of total pressure load. In the 2nd the results show that the (3 mm) punch is broken by the side force equals approximately to (0.2 %) of total pressure load with plate thickness equals to (7.75 mm).

KEY WORDS: Side Force, Clearance, Blanking, Cutting Speed, Impact Phenomenon.

تأثير القوة الجانبية أثناء عملية القطع بالقوالب

أحمد جاسم حسن — **ماجستير هندسة** ميكانيكية — **الكلية التقنية بغداد**
رحمن علي حسين — **ماجستير هندسة** ميكانيكية — **الكلية التقنية بغداد**
عبد الوهاب أحمد داوود — **ماجستير هندسة** ميكانيكية — **الكلية التقنية بغداد**

الخلاصة

تم في هذا البحث دراسة مجمل القوى المتولدة أثناء عملية القطع عند تصميم القوالب حيث تم تحليل تلـك القوى الكلية المسلطة من قبل المكبس والتي يتم تحديدها من خلال نوع الكبس ونـوع الخامـة مواصـفاتها وأبعادها وطريقة التثبيت من حيث توفر وسادة الضغط من عدمه، أثناء عملية الكبس، وتم تحديـد معادلـة خاصة تحسب من خلالها مقدار القوى الجانبية المؤثرة والناتجة أثناء عملية الكبس والتي تدفع بالمكبس أفقيـآ بإتجاه عمودي على محور القطع . وقد تم التوصل من خلال هذه المعادلة الى تحديد قيمة نظريـة لحـساب مقدار القوة الجانبية الحاصلة . وتضمن الجانب العملي إجراء عدد من التجارب لقطع صفائح من الـصلب st.37 وبأسماك مختلفة للتوصل الى السمك الحرج المؤدي الى إنهيار الـشوكة بتـأثير القـوة الجانبيـة ، وأظهرت نتائج التجارب الخاصة بتغير سمك الصفيحة أن السمك الحرج (8) ملم أدى الى كسر الشوكة عنـد قوة جانبية تمثل (0.1718) % من القوة اللازمة لقطع هذا السمك . أما تجارب المرحلة الثانية فقد أظهرت

النتائج أن القوة الجانبية المسببة لكسر الشوكة كانت تساوي (0.2) % من القوة اللازمة للقطع عند سـمك صفيحة مقداره (7.75 mm.).

NOMENCLATURE

A Cross section area of shearing zone.
L Cutting length.
p_1, p_2 Pressing forces.
Q, R Side forces.
s Plate thickness.
z Clearance between punch and die.
γ Shear angle.
μ Coefficient of friction.
σ_α Pressing stress in x- direction.
σ_β Pressing stress in y- direction.
σ_γ Pressing stress in γ- direction.
σ_{shear} Shear stress.
σ_{ult} Ultimate stress.
τ_γ Shear stress in γ- direction.

INTRODUCTION

During the past century, mechanized and automated industries have created wealth by mass – production of industrial and consumer goods at affordable prices. The product diversity has drastically increased and product life cycles decreased, while competitive forces have forced companies to carry the lowest possible levels of raw material, work in progress and finished goods stock. This places high demands on manufacturing organizations in terms of flexibility, process quality and cost minimization. (**Slomp, andKlingenberg, 2004**).Blanking is an industrial process widely used in automotive, electronics and several other industrial applications. It consists in separating a part from a sheet by means of a high localized shear deformation due to the action of punch. The pioneering work of (**Johnson and Slator, 1967**) shows that the phenomena involved in the blanking operation have been well known for a long time. The authors are given the interesting schematic representation of punch force versus punch penetration diagram where the phases associated with the different phenomena are well identified. They clearly show that the maximum punch force is strongly related to the plastic flow and that it does not depend on the initiation and the propagation of a fracture. Despite its widespread use, the design of the metal blanking is often based on trial and error tests, that is a time consuming procedure. Over the last few decades (**Rachik, Roelandt and Maillard, 2002**) several researches have been devoted to the modeling of the blanking process. The earlier work of (**Atkins, 1980**) and (**Zhou and Wierzbicki, 1996**) concerned the development of some analytical models. These simple models can be used to estimate the punch force but they are not able to investigate all the phenomena involved. Moreover, they are limited to plain strain problems.

Punching and blanking are probably as old as any sheet metal forming operation which is said to date back to at least (250) BC. However, the operation is still not fully understood or captured by any comprehensive process model, although significant progress was made through experimental modeling [2,7] analytical modeling [6,15] and numerical (Finite Elements) modeling [3,10-13].

This research analyses the different factors affecting cutting forces with deep focus upon the side forces which have a considerable effect in blanking operation especially in large size and high speed die, this forces and related side effects do an important and sensitive work in die design.

The cutting in blanking process basically occurs by rapid falling stage vertically on die cutting edges by shearing action. It passes through three sequenced stages elastic, plastic and failure. These three stages represent the cutting theory (**Ramanorisky, 1971**). In blanking process the punch is partially inserted in the blank material making a ring around the bunch with a certain thickness, and from the other side a similar material ring inserted inside the die orifice. In this process the punch passes along three depths, the 1st one is burnished area, the 2nd is the fractured depth, and 3rd is the micro – crack depth and then separation occurs and form the out shape of work piece as shown in **Fig. 1 and Fig. 2 (b)**, and according to this process a torsional moment for a material around the bunch resulted by various and parallel forces acting on the material. All these forces and resulted tensile and compression stresses are normally radial stresses directed to the center, cause the micro-fractures in separation area.

When the punch speed increased the time required for 1st and 2nd stages are reduced and this allows the 3rd stage rapidly starts and impact occurs.

The high speeds of punch do not leave enough time for elastic region to occur and this in fact the reason of using the eccentric press in cold cutting to ensure impact cutting with low torsion moment. In cutting dies with blank holder especially with low thickness sheet material this holder prevents torsional moment or partially removed which allows for smooth and accurate cutting with no scales (the scales may occur when no holder is used as in low thickness materials cutting such as paper, leather, aluminum, copper, etc.). (**Wilson 1964**).

ADVANTAGES OF IMPACT CUTTING :(**Ramanorisky 1971**).

1 – Reduce of torsion moments in free ends of sheet.
2 – Reduce of elastic and plastic times.
3 – The operation is usually produces smooth, accurate and scale less cutting, especially with soft and low thickness materials.
4 – Increase tool life by reducing pressing time.
5 – Ensure that the separation line lies on a clearance line.
6 – Prevents the double cutting or additional fracture which reduces up normal loads.

Cutting force is the force required to separate molecular by micro – fracture along the cutting – separation line by overcoming the torsional moment caused by bunch pressing on blank and reaction forces exerted by die edges on blank. Pressing load distributes along the circumstance line shaped by punch and die end leads to activate a circular torsion moment due to cutting force. Therefore, the balanced effect of this moment will cause a vacuum torsion and as a result a tension stresses act on the external two sides and a compression stresses act on the opposite internal two sides**.**

The two pressing loads in opposite directions on the material make two forces (P_1P_2) equivalent and opposite in direction as shown in **Fig. 3**.the torsional moment causes blank to bend at outside edges of punch due to opposite pressing caused by die edges, the figure also shows the pressing projection of the forces (Q, R). With the friction forces (μQ, μR) which are non – similar acting upon blank surfaces in cutting areas.

In blanking the cutting theory can be analyzed by considering **Fig.3**:

The torsional moment M is:

$$M = P_1 a$$

, where P_1 is the pressing force.

$$a = z(1.5 \text{ t0 } 2)$$

, where z is the clearance between punch and die (**Ramanorisky 1971**).

A tangential force (Side force) is perpendicular to the direction of force P represents material resistance. To show the approach of shearing in blanking process, see **Fig. 4**. the area (abcd) fixed from one side loaded by tangential stress on the opposite side. The displacement of (ba) to (b_1a) makes an angle of cutting (γ). If (bb_1) displaced along (bc) without any shifting means no changing in clearance (h). With continues loading a similar torsional fractures along this stage occur under punch and die cutting edges. The combination of the torsional moments directed along separation line increased rapidly through cut areas. The velocity of punch induced through the blank material during the 1st and 2nd stages are slow but it is rapidly increased with the beginning of 3rd stage, the punch continues moving till the product is separated.

SIDE FORCE IN CHIPPING PROCESS:

Side forces in die cutting process such as blanking is usually small and has less effect on punch because this effect can be easily controlled by attaching a safety part in die design as a support like a pressure pad, these attachments shall balance these forces and make this effect low see **Figure 5**, therefore, the problem of side force appears serious in chipping process because this force may cause punch breaking and this problem pushes the researchers to find an efficient tool to keep the chipping punch works safely by adding a support parts attached against the punch to balance the side forces . The value of this force depends upon the work piece material, its thickness and punch dimension. So it is important to select the punch thickness accurately in order to withstand the side forces.

THEORY CONSIDERATIONS:

Assume that the material shearing resistance in case of constant strength through cutting process

$\sigma_{shear} = \frac{P_{max}}{ls}$ Kg/mm^2 where s is plate thickness

l is cutting length

The shearing resistance force is already resulted from relative force of complete part side surface which is not similar to that case in **Fig. 5**, that means the total force or maximum force increases according to increase in cutting part surface area at the moment of starting touch the (surface or breadth). The pressing depth is different for each metal and depends upon die clearance and, cutting speed so it is difficult to select its value.

To analyze the forces show in **Fig. 6**:

Suppose $\sigma_\alpha > \sigma_\beta$

And angle (γ) be measured from larger stress towards the vertical direction of area.

$\sum F = 0$ in σ_γ direction:

$$\sigma_\gamma\, da - (\sigma_\alpha\, dA\, cos\gamma) cos\gamma + (\tau dA cos\gamma) sin\gamma + (\tau dA\, sin\gamma) cos\gamma - (\sigma_\beta\, dA\, sin\gamma) sin\gamma = 0$$

$\sum F = 0$ in τ_γ direction:

$$\tau_\gamma\, da - (\sigma_\alpha\, dA\, cos\gamma) sin\gamma - (\tau dA cos\gamma) cos\gamma + (\tau dA\, sin\gamma) sin\gamma + (\sigma_\beta\, dA\, sin\gamma) cos\gamma = 0$$

By simplicity:

$$\sigma_\gamma = \sigma_\alpha \, Cos^2\gamma + \sigma_\beta \, Sin^2\gamma - \tau \, Sin2\gamma \quad (1)$$

$$\tau_\gamma = 0.5\,(\sigma_\alpha - \sigma_\beta)\, Sin\, 2\gamma + \tau\, Cos\, 2\gamma \quad (2)$$

σ_γ Changed in case γ changed as punch moving down. To get main areas, that means areas affected by great vertical stress let either

$\frac{d\sigma_\gamma}{d\gamma} = 0$, or $\tau_\gamma = 0$ (That is because main areas have no tangential stresses).

To get γ_o in both cases :

$0.5\ (\sigma_\alpha - \sigma_\beta)\sin 2\gamma_o + \tau \cos 2\gamma_o = 0$

$$\tan 2\gamma_o = \frac{2\gamma}{(\sigma_\beta - \sigma_\alpha)} \tag{3}$$

To obtain the maximum vertical stresses or main stresses substitute equation (3) in equation (1) and simplify:

$\text{Sin } 2\gamma_o = \pm\frac{\tan 2\gamma_o}{\sqrt{1+\tan^2\gamma_o}}$

$\cos 2\gamma_o = \pm\frac{1}{\sqrt{1+\tan^2\gamma_o}}$

$\sin^2\gamma_o = 0.5\ (1 - \cos^2\gamma_o\ )$

$\cos^2\gamma_o = 0.5\ (1 + \cos 2\ \gamma_o\ )$

$$\sigma_{\substack{max \\ min}} = 0.5\ (\sigma_\alpha + \sigma_\beta) \pm 0.5\sqrt{(\sigma_\alpha - \sigma_\beta)^2 + 4\tau^2} \tag{4}$$

If one of vertical stresses equal to zero, then equation (4) will be:

$$\sigma_{\substack{max \\ min}} = 0.5\ \sigma \pm 0.5\sqrt{\sigma^2 + 4\tau^2} \tag{5}$$

By similar method, when $\frac{d\tau_\gamma}{d\gamma} = 0$

$$\tau_{\substack{max \\ min}} = \pm 0.5\sqrt{\sigma^2 + 4\tau^2} \tag{6}$$

The shearing force and cutting resistance is varied continuously with pressing stroke because it depends upon loading material and mechanical properties, (tensile resistance proportional directly with the shearing resistance) (**Ramanorisky, 1971**).

EXPERIMENTAL WORK:

Since the side force is an important factor that causes punch failure so this factor is studied experimentally. Experiments are achieved on two stages by using a hydraulic press as in **Figure 7**

Stage 1:
A 37 steel plate with variable thickness are chipped by a punch of (H.S.S) (A turning cutting tool) with (3 mm) thickness and (20) mm width as shown in **Table 1**. And

Stage 2:
Variable plate thicknesses (7.6, 7.65, 7.7 and 7.75 mm) are chipped with the same punch dimension. The clearance of chipping die is kept constant for all the experiments.

THE CALCULATIONS AND RESULTS:

The calculation of H.S.S. failure force for both punch and plate are as follow:

$$F_{cutting} = A \ \sigma_{ult}$$

Where A is the cross section area of shearing zone.

The results of the forces for different plate thicknesses are listed in **Tables 1 and 2. Figure 8** represents the broken punch.

DISCUSSION AND CONCLUSION:

In blanking work the pressing load is selected according to all factors that affecting the process such as blank material properties, thickness, punch material properties, dimensions, die clearance, and the impact velocity. These factors may raise the total force exerted by the punch to achieve the cutting process.

The results obtained from the experiments show that the side force is increased proportionally with sheet thickness as shown in **Table 1 and 2**. In 1^{st} stage experiments punch is failed with (8) mm and the calculated cutting force required is equaled to (51200 N) which is less than the punch failure force of (60000 N). The difference between two forces represents the effect of side force which is equal to (8800 N), and this value equals (0.1719) % of the plate total cutting force. The 2^{nd} stage experiments include selection of thicknesses those near the failure thickness in 1^{st} stage as listed in **Table 2**. The results show that the punch failure occurred with (7.75 mm) and the calculated cutting force was equaled to (49600 N), and the difference between the two forces represents the effect of side force and the percentage value related to this force is equal to (0.2)of the total cutting force.

As a conclusion, this research shows that the side force in cutting by dies is a considerable factor due to its effect on punch durability especially in side cutting (chipping) process.

REFERENCES:

[1]A. G. Atkins:" On Cropping and Related Processes ", International Journal of Mechanical Sciences, 22, pp. 215-231, 1980.

[2]C. M. Choy, R. Balender:" Experimental Analysis of Parameters Influencing Sheared – edge Profiles", Proceeding of 4th. International Conference on Sheet Metal, University of Twente, The Netherlands, Vol. 11, pp. 101-110, 1996.

[3]D. C. Ko, B. M. Kim:" Development of an analytical Scheme to Predict the need for Tool Regrinding in Shearing Processes", International Journal of Machine Tools and Manufacture, Vol. 40, pp. 1329-1349, 2000.

[4]F. W. Wilson,"Die design handbook", SME, McGraw – Hill, 1964.

[5]J. Slomp, W. Klingenberg, "A proposal to Use Artificial Neural Networks for Process Control of Punching/Blanking operations," Flexible Automation and intelligent Manufacturing, FAIM, Canada, 2004.

[6]J. Ramaekers, J. Kals, "Strain, Stresses and Forces in Blanking", Proc. IMC Conference Galway, pp.126-138, 1986.

[7]K. Lange, " Handbook of Metal Forming," McGraw – Hill, New York, 1985.

[8]M. Rachik, J. M. Roelandt, A. Maillard, "Some Phenomenological and Computational Aspects of Sheet Metal Blanking Simulation," Journal of materials processing technology, 128, 2002.

[9]Q. Zhou, T. Wierzbicki, "A tension Zone Model of Blanking and Tearing of Ductile Metal Plates," International Journal of Mechanical Sciences, 38, (3), 303-324, 1996.

[10]R. Hambli:" Prediction of Burr Height Formation in Blanking Processes Using Neural Network", Int. Journal of mechanical sciences, Vol. 44, pp. 2089-2102, 2002.

[11]R. Hambli:" Blanking Tool Wear Modeling Using the Finite Elements Method", International Journal of Machine Tools and Manufacture, Vol. 41, No. 12, pp. 1815-1829, 2001.

[12]V. P. Ramanorisky:" Cold pressing dies handbook", Machines construction, 5th Edition, Leningrad, 1971.

[13]W. Johnson, R. Slater," Survey of Slow and Fast Blanking of Metals at Ambient Temperatures", Proceeding of the International Conference Manufacturing Technology, CIRP – ASTM, 1967.

[14]W. Klingenberg, U. P. Singh:" Finite Elements Simulation of the Punching / Blanking Process Using In-process Characterization of Mild Steel", Journal of materials processing technology, Vol. 134, No. 3, pp. 296-302, 2003.

[15]W. Klingenberg:" Numerical Modeling of the Punching/ Blanking Process Using In-process Characterization of Steel", DPhil. Dissertation, University of Ulster, 2000.

Table 1 Results of variable plate thickness.

Plate thickness mm	cutting force Ncalculated	Side force (N)
6	38400	21600
6.5	41600	18400
7	44880	15120
7.5	48000	12000
8	51200 failed	8800

Table 2 Results near the critical plate thickness.

Sheet thickness (mm)	Cutting force N	Side force (N)
7.6	48640	11360
7.65	48960	11040
7.7	49280	10720
7.75	49500 failed	10500

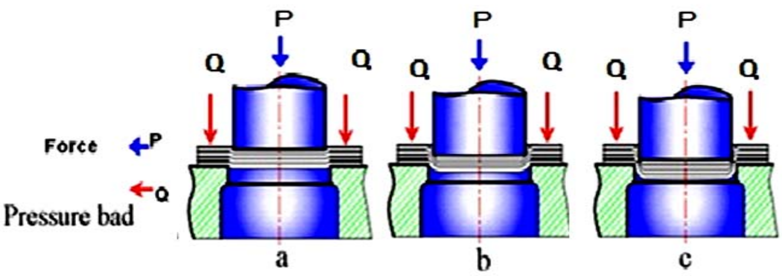
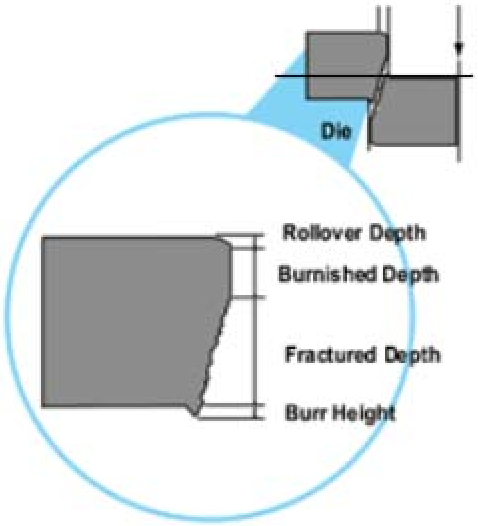
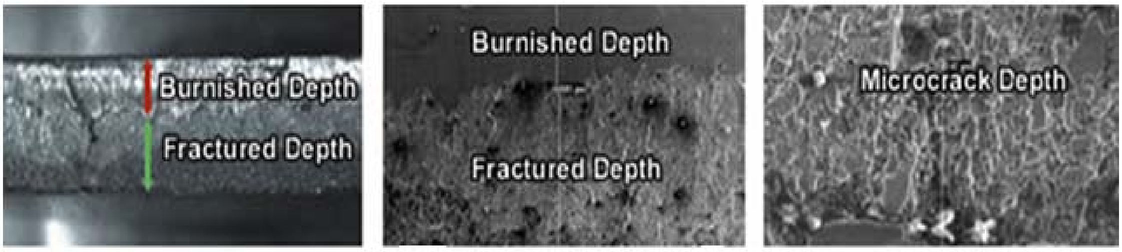


Figure 1 The three stages of blanking process.



(a)



(b)

Figure 2 Cross – section profile of the sheared edge of an aluminum blank at a magnification of 25x, 45x, and 450x, shows burnishing, burrs, micro cracks, and other edge conditions.

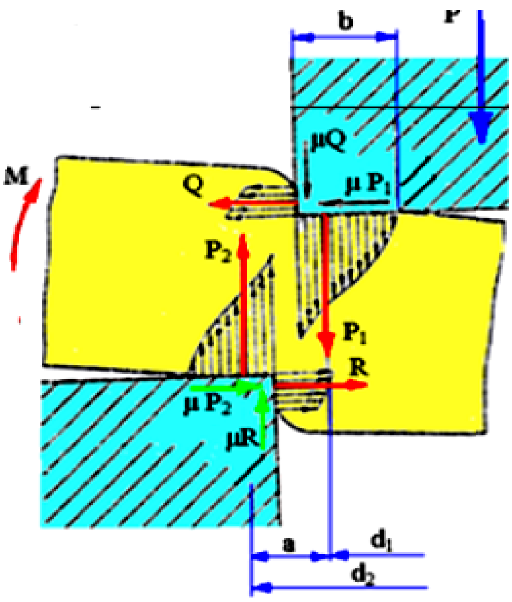


Figure 3 Cutting forces projections during end blanking process (Ramanorisky, 1971).

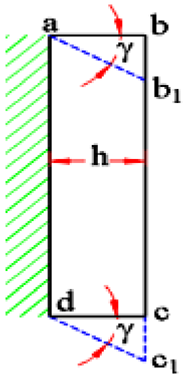


Figure 4 The relationship between the displacement and shearing angle (γ).

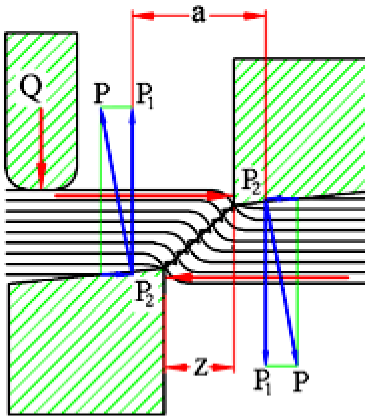


Figure 5 Forces in blanking process.

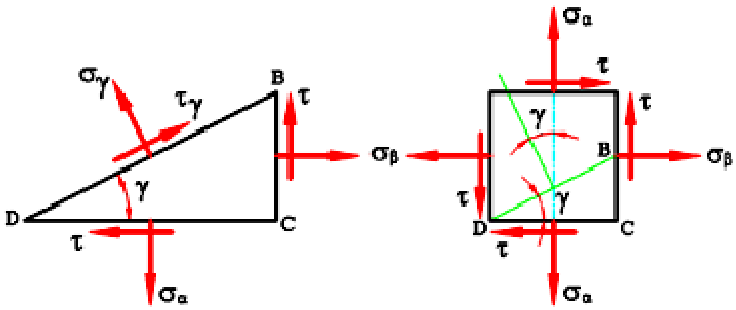


Figure 6 The free body diagram in shearing zone.

Figure 7 Represents the pressing equipment.

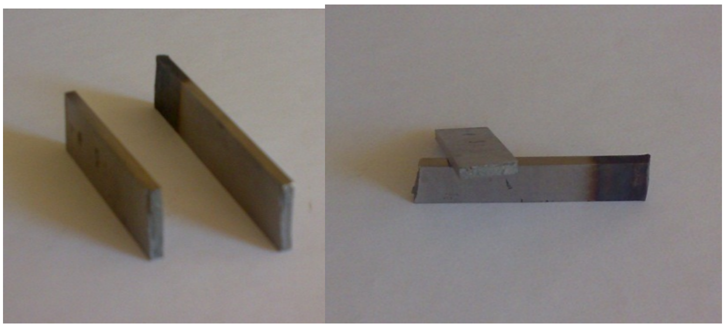


Figure 8 Represents the broken punch