

An Overview of Clearance Optimization in Sheet Metal Blanking Process

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Abstract: This document prescribes a model investigation the effect of potential parameters influencing the blanking process and their interaction. The blanking process optimization carried out by using Design of Experiment (DOE), Finite Element Method (FEM) with ANSYS Package, Simulation with ABAQUS-Explicit software, Blank soft Software and Neural Network Simulation in order to achieve the intended model objectives.

Keywords: Blanking Process, DOE, FEM, Optimum Clearance and Simulation.

I. INTRODUCTION

There are thousands of products manufactured with sheet metal parts. The first step in forming such a part involves cutting of the sheet into appropriate shapes by means of the physical process of shearing. A contoured part is cut between a punch and die in a press. Recent international market demands are that mechanical parts should be produced to net-shape or near net-shape with improved mechanical properties, a smooth surface finish, good dimensional accuracy and material savings, depending on service conditions. In practice, manufacturing engineers are faced with the problem of determining the proper design of dies to cut metal sheets without causing any surface or internal defects at a lower manufacturing cost, depending on the material, the part geometry, and the process.

1.1 The Blanking Process

Blanking is a manufacturing operation as old as the technology itself. Its applications range from components of very light to heavy appliances and machineries [1]. Blanking is defined as the cutting of a work piece between two die components to a predetermined contour [2]. During blanking, the part is subjected to complex solicitations such as deformation, hardening and crack initiation and propagation. The theoretical modeling of such processes is very difficult due to the complexity in describing the different stages of the whole shearing process starting with the elastic stage and ending with the total separation of the sheet metal [3].

The behavior of the blank material during the blanking process can be divided into five stages. During the start of the process, the sheet is pushed into the die and the blank material is deformed, first elastically. The process continues and the yield strength of the blank material is reached, first at the outer fibers and later at all the fibers in the zone between the punch and the die. Normally, the material underneath the punch is subjected to thinning. The plastic deformation causes rounding of the edge of the blank. During this stage, or possibly as early as during the plastic deformation stage, damage initiation followed by the nucleation and growth of cracks takes places. In most of the conventional blanking situations, ductile fracture occurs after shear deformation. This causes rough, dimpled rupture morphology on the fractured surface of the product. Finally, the work due to friction is dissipated when forcing (pushing) the slug through the die hole [4].

II. Literature Review

The process of identifying process influencing parameters of blanking process includes an exhaustive literature review of the factors that have been suggested by various authors. Literature review was performed by collecting articles from various journals, and various popular research related sites viz. Science Direct, IEEE, Emerald, Springer Link and various free articles from internet. Literature from journal papers and conference studied for various press tool works parameters optimization are reviewed.

S. K. Maiti, A. A. Ambekar, U. P. Singh, P.P. Date, K. Narasimhan, [1], they evaluate the influence of tool clearance, friction, sheet thickness, punch/die size and blanking layout on the sheet deformation for thin M. S. sheet. The punch load variation with tool travel and stress distribution in the sheet has been obtained. The results indicate that a reduction in the tool clearance increases the blanking load. The blanking load increases with an increase in the coefficient of friction. These observations are very similar to the case of blanking of component of large size. Further, these effects are very similar in the case of both single and double blanking. An inter blanking site distance of about twice the sheet thickness is good to reduce the thinning of sheet at the intermediate regions between the two blanking sites.

Ridha Hambli [3], presents industrial software called BLANKSOFT dedicated to sheet metal blanking processes optimization. The code allows for the prediction of the geometry of the sheared profile, the mechanical state of the sheared zone, the burr height, the force–penetration curve, and the wear evolution of the punch versus the number of the blanking cycles. The approach is based on an original theoretical investigation formulated from plasticity theories. This program is designed by considering several factors, such as material and geometry of product as well as the wear state of the tool. The numerical results obtained by the proposed programs were compared with experimental ones to verify the validity of the proposed software.

R. Hambli [5], presents an experimental investigation into the blanking process was carried out using tools with four different wear states (wear radius 0.01, 0.06, 0.012, 0.2 mm) and four different clearances (5%, 10%, 15%, 20%). The aim was to study the effects of the interaction between the clearance, the wear state of the tool and the sheet metal thickness on the evolution of the blanking force and the geometry of the sheared profile. He used designed of experiment method for

model and analysis the relationships that describe process variations. This investigation shows that, in order to minimize the blanking force, the clearance should be set at 10%, however, to minimize the fracture angle and the fracture depth, it is preferable to set the clearance at 5%. When the clearance is set at 10%, the process is slightly more robust to tool wear, as far as the blanking force response is concerned. Whether clearance should be set at 5% or 10% ultimately depends on the priorities of the practitioners.

F. Faura, A. Garcia, M. Estrems [6], they proposed a methodology to obtain optimum punch-die clearance values for a given sheet material and thickness to be blanked, using the finite-element technique. To determine the optimum clearance, the diagonal angle and the angle of the direction of crack propagation for different clearances were calculated. The influence of clearance on diagonal angle and angle of the direction of crack propagation, from which it is seen that as the clearance increases, diagonal angle increases proportionally while angle of the direction of crack propagation remains nearly constant. At the point of intersection, the direction of crack propagation coincides with the diagonal line, and so the cracks emanating from the punch and die meet, resulting in a cleanly blanked surface. Hence, this value of clearance is taken as the optimum clearance. The optimum clearance for the values of the parameters used in this work is between 11 and 12%. It is observed that punch penetration increases as the c/t ratio increases.

R. Hambli, S. Richir, P. Crubleau, B. Taravel [7] elaborates blanking process and structures of the blanked surfaces are influenced by both the tooling (clearance and tool geometry) and properties of the work piece material (blank thickness, mechanical properties, microstructure, etc.). Therefore, for a given material, the clearance and tool geometry are the most important parameters. They use simulation of an ax symmetric blanking operation with ABAQUS- explicit software for a given sheet material. A damage model of the Lemaitre type is used in order to describe crack initiation and propagation into the sheet. They use four materials for testing with four different elongation (30%, 47%, 58%, and 65%). They show that the optimum clearance decreases as the material elongation increases. The results of the proposed experimental investigation show that there is no universal optimal clearance value. Whether clearance should be set at 5% or 10% ultimately depends on the priorities of the practitioners.

Emad Al-Momani, Ibrahim Rawabdeh [8], Represents a model investigates the effect of potential parameters influencing the blanking process and their interactions. Finite Element Method (FEM) and Design of Experiments (DOE) approach are used in order to achieve the intended model objectives. They use Design of Experiments (DOE) technique by selecting the experimental levels for each selected factor, i.e. the clearance to be in five levels (5, 10, 15, 20, 25) % of the sheet metal thickness, blank holder force to be in two levels (0, 3000N) and sheet metal thickness to be in four levels (0.5, 0.6, 0.7, 0.8)mm. Perform a factorial experimental design in order to take high-level interactions. Develop a Finite Element Model (FEM) that represents the existing process in order to evaluate the quality of the inputs. Compare the two techniques (FEM and DOE) and analyze the results to get the proposed optimal set of parameters. Simulations are conducted on commercial FEM software package ABAQUS/Explicit. in their article , they show that, in order to minimize the burrs height, the clearance should be set at about 5 % with almost no blank holder force.

Ridha Hambli [9], describes a methodology using the finite element method and neural network simulation in order to predict the optimum punch–die clearance during sheet metal blanking processes. A damage model is used in order to describe crack initiation and propagation into the sheet. The proposed approach combines predictive finite element and neural network modeling of the leading blanking parameters.

Gang Fang*, Pan Zeng, Lulian Lou [10], in this paper, the punch–die clearance values for a given sheet material and thickness are optimized, using the finite element technique and Cockcroft and Latham fracture criterion. In the study, the shearing mechanism was studied by simulating the blanking operation of an aluminum alloy 2024. The results of the present paper agree with the previous experimental results.

III. FUNDAMENTALS OF THE THEORETICAL MODEL

The errors on blanks are influenced by material, the tool shape, process variations and the machine. The form errors represented in “Fig. (1)” are connected to the geometry of the sheared edge such as the roll-over depth, the fracture depth, the smooth-sheared depth, the burr formation and the fracture angle.

Various experimental studies [17–23] showed that the mechanical and geometrical aspect of the sheared edge during the blanking operation for a given material are affected by some parameters like the blanking clearance, the wear state of the tool and the thickness of the sheet.

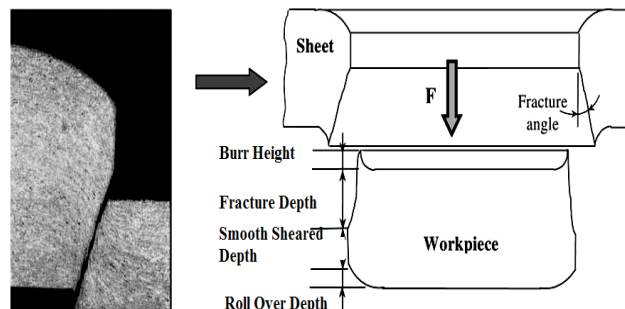


Figure. (1). Geometry of the sheared work piece

3.1. Deformation and rupture mechanism

During sheet metal shearing operation, the part is subjected to complex solicitations such as deformation, hardening and crack initiation and propagation. The theoretical modeling of such processes is very difficult due to the complexity of describing the different stages of the whole shearing process starting from the elastic stage and ending to the total separation of the sheet metal” Fig (2)”.

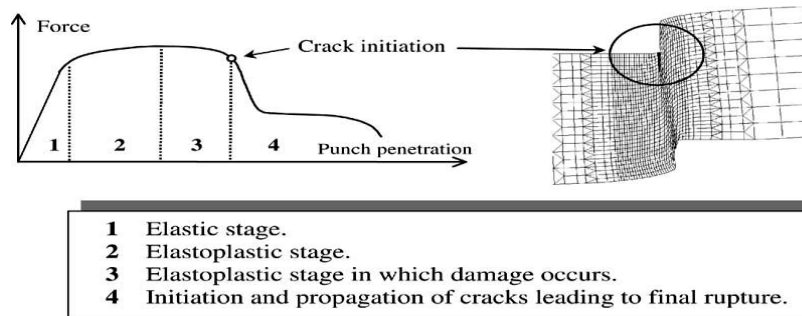


Figure. (2). Different stage of the blanking process.

Accurate knowledge of the failure process is essential for the selection of a suitable damage model. In the case of sheet blanking by shearing processes, numerous authors have studied the different physical mechanisms leading to the final rupture, and proposed their own models.

In their investigation dealing with a planar blanking process, Stegeman et al. [12] used a CCD camera records in order to quantify the displacement of material points at the sheared surface “Fig.(3)”. One can observe the grid deformation in the

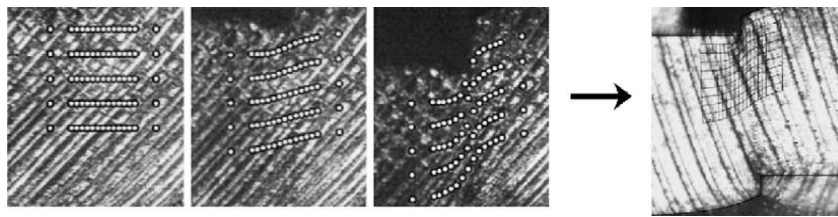


Figure. (3). Grid deformation of material points during blanking process.

Clearance zone of the tool. Recently, an analytical study and experimental tests [20, 21] showed that the physical mechanisms leading to the complete failure of the sheet material can be described as follows.

First, due to the penetration of the punch into the sheet, cracks initiate at the cutting edges ‘A’ and ‘B’ of the tools “Fig.(4)”. Secondly, the cracks propagate when and where Rice & Tracey fracture criterion value exceeds a critical value, and thus progressively cut the material fibers one after the other.

The aforementioned rupture mechanism has been applied with success in a previous work [11] to numerically simulate the whole blanking process until the final separation of the sheet. In this investigation, the mechanism model based on the material cutting fibers has been applied to describe the deformation mechanism of the sheet metal during the shearing process. The main idea is to update incrementally the deformation mechanism in the clearance zone of the part for a given punch penetration increment. The equilibrium state of the part is then described using the concept of the continuum mechanics theory.

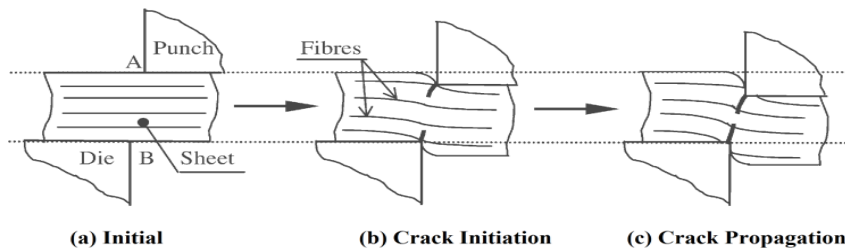


Figure. (4). Rupture of the sheet.

A set of formulae taking into account the material characteristics of the sheet, the geometry of the operation and the wear state of the tool has been developed allowing for the prediction of the characteristic zone heights of the blanked part such the heights of the burr the roll-over, the sheared and the fractured zones. The punch penetration curve can also be plotted which allows for the computation of the maximum blanking force and the blanking energy. The equivalent plastic strain and equivalent stress of the sheared zone can be also predicted which permits the computation of the hardening state of the sheared zone.

IV. OPTIMUM CLEARANCE

Various experimental studies [15,16,22,23,24,25,26] showed that the mechanical and geometrical aspect of the sheared edge during the blanking operation for a given material are affected by some parameters such as the blanking clearance, the wear state of the tool, and the thickness of the sheet. In blanking processes, the clearance is expressed in percentage of the sheet thickness and is defined by:

$$c = \frac{100(D_m - D_p)}{2t} \%$$

Where D_m , D_p and t are the die diameter, the punch diameter and the sheet thickness, respectively.

In the case of blanking processes, one seeks to generate cracks at the sharp edges of the punch and the die, then, through the choice of the parameters of cutting, attempt to make this crack propagate as soon as possible to obtain total rupture.

In this investigation, it is assumed that the clearance is optimum when the direction of crack propagation coincides with the line joining the points of crack initiation (A and B of "Fig.(5)" in the punch and die, giving cleanly blanked surfaces without secondary crack formation "Fig.(5)". In this case, the total separation of the sheet is obtained for a lower value of punch penetration. If the cracks generated by the punch and die (A and B of "Fig.(5b)") do not coincide, the formation of secondary cracks exists.

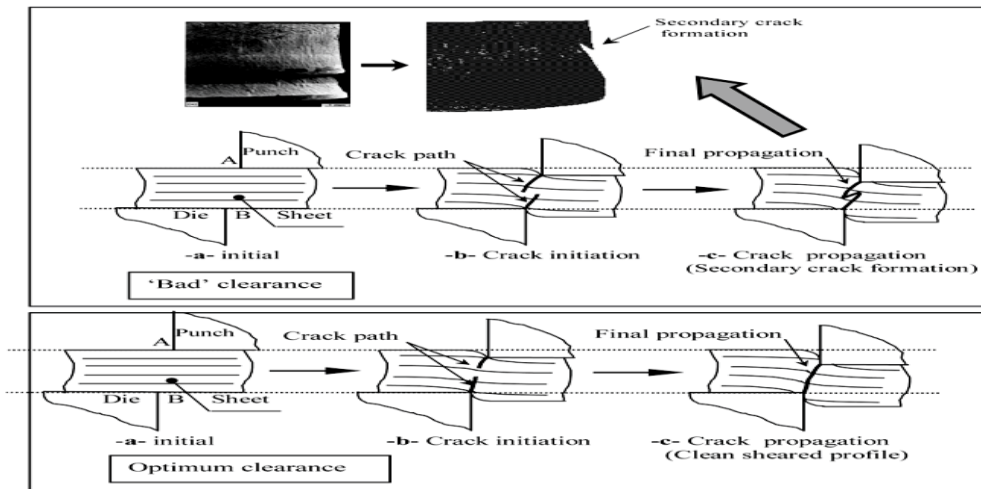


Figure. (5). Secondary crack formation during blanking process.

In order to obtain the optimum clearance value, the angle (θ) of the line joining the points of crack initiation in the punch and die (diagonal angle) and the angle (β) of the direction of crack propagation must coincide "Fig.(6)". This can be expressed by:

$$\theta = \beta$$

The diagonal angle can be expressed by:

$$\theta = \text{Arc tan}(c / t - u_p)$$

Where u_p is the punch penetration corresponding to the first crack initiation within the sheet.

4.1. Optimum Clearance Algorithm

The optimum clearance value can be obtained by performing a series of numerical analyses in order to pursue a minimum cost function between the angle of the line joining the points of crack initiation in the punch and die θ_d (diagonal angle) and the angle of the direction of crack propagation (DCP) β "Figure (6)".

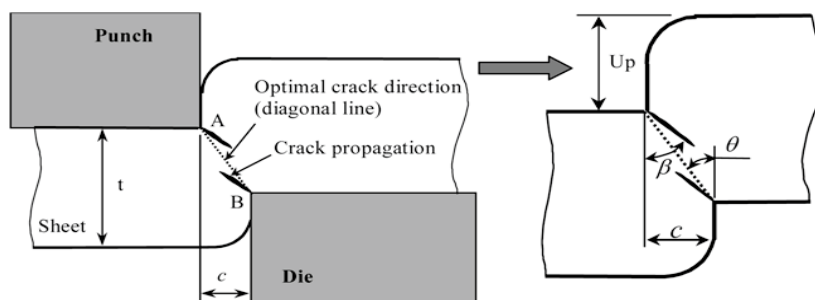


Figure. (6) Crack propagation angle and diagonal angle.

During the optimization process a multi-variable objective function was chosen in the following form:

$$\Phi = \beta^n - \theta_d^n$$

β^n is the direction of crack propagation angle at increment and θ_d^n is the diagonal angle at increment n .

The optimum clearance value can be obtained by performing a series of numerical analyses in order to pursue a minimum cost function between the angles θ_d and β .

The global criteria of convergence are such that the numerical results must satisfy the following conditions:

$$\frac{\text{Abs}(\beta^n - \theta_d^n)}{\theta_d^n} \leq Tol$$

Tol. Is tolerance convergence value given by the user?

Different simulations using different values of tolerance parameter showed that the final results are not sensitive to the selection of *Tol*.

In this investigation, *Tol.* is taken equal to 10E-05.

The iterative finite element program including the algorithm of the clearance optimization is schematically represented by the following flow chart of "Figure (7)".

Incremental displacements are applied to the punch. At each increment, a fracture test is applied to each finite element of the mesh. When the damage reaches its critical value at fracture D_c , the programs compute the angles β^n and θ_d^n .

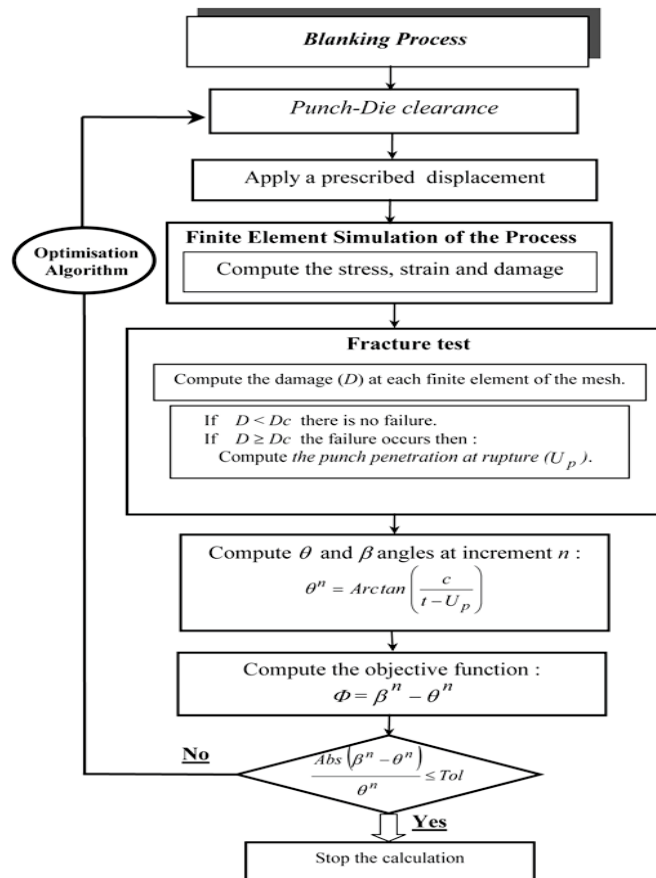


Figure. (7). Flow chart of calculation.

V. FINITE ELEMENT METHOD (FEM) AND DESIGN OF EXPERIMENTS (DOE)

Numerical methods provide a general tool to analyze arbitrary geometries and loading conditions. Among the numerical methods, Finite Element Analysis (FEA) has been extensively used with success; however, this kind of analysis requires the generation of a large set of data in order to obtain reasonably accurate results and consumes large investment in engineering time and computer resources [27]. FEM is a good choice for the analysis of sheet metal processes since it helps in eliminating the need for time-consuming experiments to optimize the process parameters [1]. The FEM simulations are increasingly used for investigating and optimizing the blanking processes. Many time-consuming experiments can be replaced by computer simulations. Therefore, highly accurate results of sheet metal forming may be obtained by using the FEM simulation [28]. The finite element method gives an approximate solution with an accuracy that depends mainly on the type of element and the fineness of the finite element mesh.

In the manufacturing area, Design of Experiments (DOE) is found to be an efficient statistical technique that can be used for various experimental investigations. The design of experiments is one of the powerful tools used to investigate deeply hidden causes of process variation [29]. It is a systematic, rigorous approach to engineering problem solving that applies principles and techniques at the data collection stage to ensure the generation of valid, defensible, and supportable conclusions. In the blanking process, experimental design is considered a powerful approach for product and process

development, and for improving the yield and stability of an ongoing process. Hambli *et al.*, [30] found that the design of experiments technique is an efficient and cost-effective way to model and analyze the relationships that describe process variations.

The sheet metal industry is highly interested in knowing if two identical products manufactured of two different materials, can be blanked with a reasonable quality without the need to build two separate setups. This will increase the efficiency of the production processes and reduce the level of wasted materials, time, cost, and effort involved in the production stages. In addition, the industry needs a suitable model to overcome the long cycle time in developing a particular blanking process. This can be achieved by combining the Finite Element Method and Design of Experiments techniques aiming at identifying opportunities to increase efficiency and productivity as well as eliminating waste and reducing production cost associated with the blanking process. The main objective of this paper is to construct a finite element model to predict the shape of the cut side of a blanked product, and to investigate the effect of potential parameters influencing the blanking process and their interactions using the design of experiments approach in order to choose the process leading parameters in an optimal way.

VI. SIMULATION OF THE PROCESS

6.1. FEM package

The FEM program used to simulate the blanking process is ANSYS v. 5.1 [31], which is capable of solving the non-linearity's of material behavior, large deformations, and contact between surfaces of different bodies.

For the simulation described here, which is merely to determine the stress and strain of each node during the process, the use of specific codes devoted to simulating metal forming processes is not necessary.

6.2. Model geometry

The following assumptions are made for the purposes of the present analysis:

- The process is simplified to a two-dimensional situation, under plane-strain conditions, since in a normal blanking operation the punch-die clearance is usually very small in relation to the blank diameter.
- The process is considered quasi-static, and hence the effects of strain rate are neglected.
- The sheet material is considered as a plastic object while the punch and die are defined as rigid bodies. Table I: summaries the geometric values used in the simulations.

The tool wear geometry has been simulated by rounding off of the cutting edge (P-D radius). The friction contact between sheet and tool follows Coulomb's law:

$$T_f = \mu s_n$$

Where T_f is friction shear stress, s_n is normal stress at interface, and μ is the friction coefficient.

“Fig. (8)”. Shows the finite element model. The increasing deformation in the simulation shows that the regions beyond a distance t from the shear zone undergo very much smaller deformation than that in the clearance zone. Moreover, the strains at the punch-die cutting edges reach the crack initiation value well before any significant deformation can take place in the region beyond t . Thus, the blanking operation is modeled by two rigid blocks, which are separated by a distance c and which move in opposite directions.

Parameter	Value	Dimension
Shearing gap	$c = (D-d)/2$	M
Clearance	$Cl = [(D-d)/2t] \times 100$	%
P-D radius	$r = 10^{-4}$	M
Friction coefficient	$\mu = 0.05$	

Table I: Geometric parameter settings

D and d are punch and die diameters;
 t is thickness.

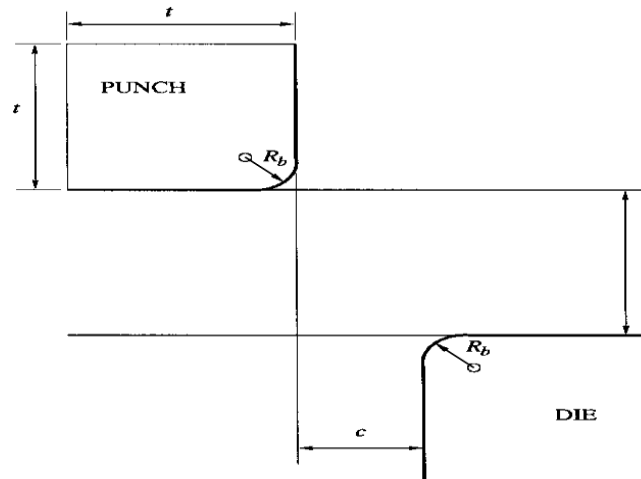


Figure. (8). Simulation model.

In the blanking operation, deformation is concentrated along the very narrow shear band. The width of the shear band is a few microns. Thus, the number of elements used is critical for every simulation since a large number of elements increases the accuracy of the result, but also substantially increases the calculation time. Therefore, a very dense mesh was defined in the shearing band and relatively large elements for the remainder. It should also be mentioned that the CPU-time for one simulation was about 10 h on an IBM RISC 6000 work station.

VII. CASE STUDY

Design of Experiment Based Analysis for Sheet Metal Blanking Processes Optimization

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7.1 Material model

In the present investigation, the optimum clearance was studied by simulating blanking of an AISI 304 sheet with the specifications as in Table:2.

It is assumed that the material is isotropic and that its yielding point follows the von Mises yield criterion. A bilinear representation of the stress–strain curve is used to model the behavior of the material, which is defined by two slopes: the elastic and the plastic slope.

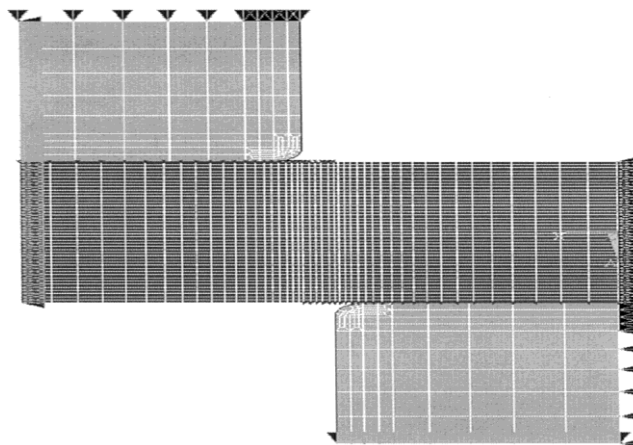


Figure. (9). Mesh in the shearing zone.

7.2 Ductile fracture criterion (crack initiation criterion)

Many experimental studies have been conducted to establish ductile fracture criteria in order to calculate the formability limits of different materials. Among the various fracture criteria proposed, it has been found that the criterion suggested by Cockcroft and Latham [10] predicts the most reasonable fracture strain in metal forming operations. This criterion states that fracture takes place when the following relation is satisfied:

$$\int_0^{\varepsilon-f} \left(\frac{\sigma^*}{\bar{\sigma}} \right) d\bar{\varepsilon} = C$$

Where σ^* is the maximum principal tensile stress, ε^f the fracture strain, and C the material constant. The effective stress and effective strain are represented by $\bar{\sigma}$ and $\bar{\varepsilon}$, respectively. In the shearing operation, deformation is concentrated along the shear band the stress ratio ($\sigma^*/\bar{\sigma}$) is not expected to change along the shear band.

Parameter	Value	Dimension
Thickness	$t=10^{-3}$	M
Yield Stress	$\sigma_y= 2.45 \cdot 10^8$	Pa
Elastic modules	$E= 1.225 \cdot 10^{11}$	Pa
Tangent plastic slope	$E_t= 1.586 \cdot 10^9$	Pa

Table II: Material specifications

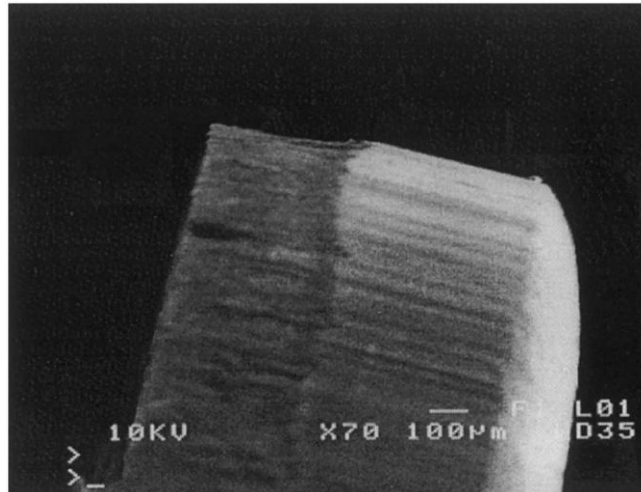


Figure. (10). Electron microscopic observation on sheared blank (11% Clearance, 8 mm punch diameter).

Therefore, Cockcroft and Latham’s criterion may be approximated by $\varepsilon^f = C^*$ at the shear band [7]. Consequently, it may be assumed that fracture takes place at a given effective strain. (During the blanking operation it is observed that when the punch penetrates the sheet, the metal lying between the edges of the punch and the die (shearing gap) deforms severely, and finally cracks are initiated. Crack initiation is a local phenomenon and in this methodology it is postulated that a crack is initiated at the point of the sheet whose effective strain first reaches the fracture strain of the work material. In the present investigation, the material constant, C^* was obtained by measuring experimentally the punch penetration (Δ) that causes a crack to begin, and computing numerically the maximum effective deformation for the punch penetration value determined.

According to the studies with worn tools presented in [1, 2], the crack does not emanate from the cutting edge but from the free surface. We considered that a crack starts in the punch-die flank at or just before the beginning of the radius of the cutting edges. The following values were obtained: $\Delta=7.5 \cdot 10^{-4}$ m in the experimental “Fig. (10)”, and $\varepsilon^f = 3.88$ in the numerical Simulation.

7.3 Optimum clearance

In this investigation it is assumed that clearance is optimum when the direction of crack propagation coincides with the line joining the points of crack initiation in the punch and die (diagonal line), giving cleanly blanked surfaces. To determine the optimum clearance, the diagonal angle (θ) and the angle of the direction of crack propagation (φ) for different clearances were

Cl (%)	Δ (%)	φ ($^{\circ}$)	θ ($^{\circ}$)
5	64	14.38	5.10
8	69.3	15.34	8.97
11	75	14.49	13.74
14	81.5	14.12	19.18
17	88.5	14.57	28.35

Table III: Punch penetration, diagonal angle and direction of crack Propagation for different clearances Calculated. It is postulated that cracks propagate perpendicularly to the maximum principal tensile stress [8].

In order to obtain the diagonal angle it is also assumed that the crack is initiated at or just before the radius of the cutting edges. The process to determine the optimum clearance can be observed in the flow chart represented in “Fig. (11)”. Successive displacements are imposed on the punch until any node (i) fulfils the crack initiation criterion The values of the effective strains, principal stress directions and punch penetration at crack initiation were obtained from the output of each computer run. When the crack is initiated, the angle made by the diagonal with the y-axis was also calculated.

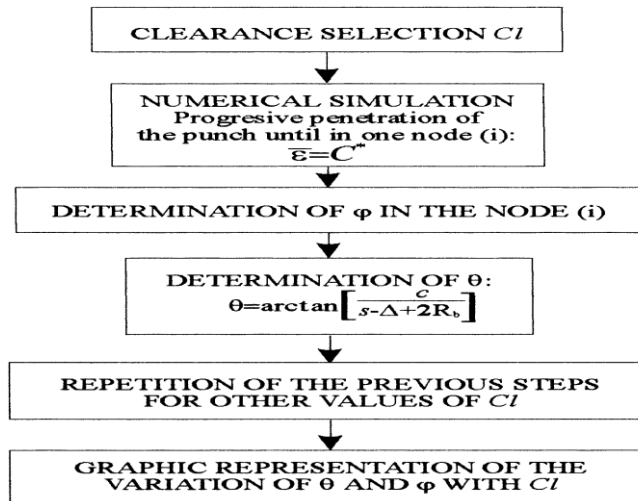


Figure. (11). Flow chart to applied to determining the optimum clearance.

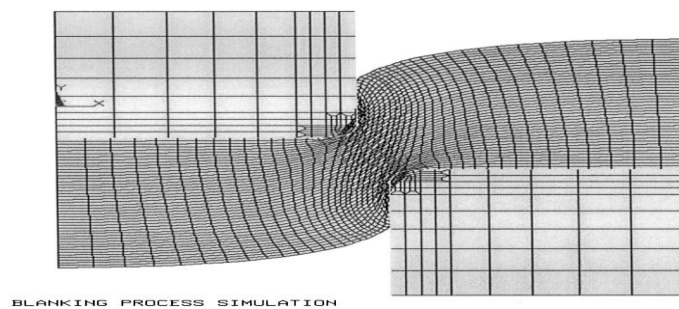


Figure. (12). Simulated part edge (Cl=11%, Δ=75%).

“Fig. (12)” shows the final edge of a simulation carried out with an 11% punch-die clearance and 75% punch penetration (percentages refer to the thickness of the sheet).

7.4 Analysis of the results

The values of the angles θ and φ were calculated for different clearances using the results of the finite-element analysis. These results are tabulated in Table 3, in which the punch penetration values (Δ as % of the thickness of the work material) at crack initiation are also shown. “Fig. (13)” illustrates the influence of Cl on θ and φ , from which it is seen that as the clearance increases, angle θ increases proportionally while angle φ remains nearly constant: the plots thus intersect.

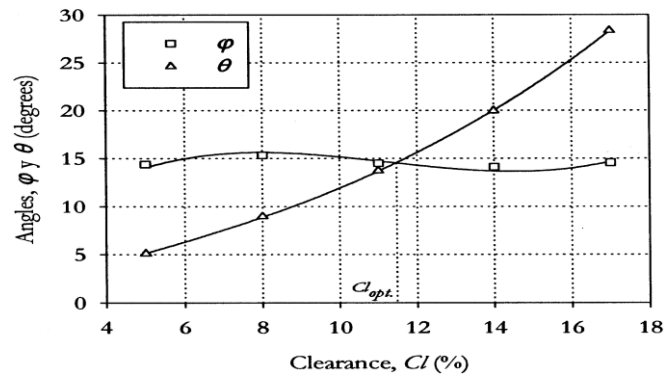


Figure. (13). Variation of the diagonal angle and the direction of crack Propagation with the clearance.

At the point of intersection, the direction of crack propagation coincides with the diagonal line, and so the cracks emanating from the punch and die meet, resulting in a cleanly blanked surface. Hence, this value of CI is taken as the optimum clearance.

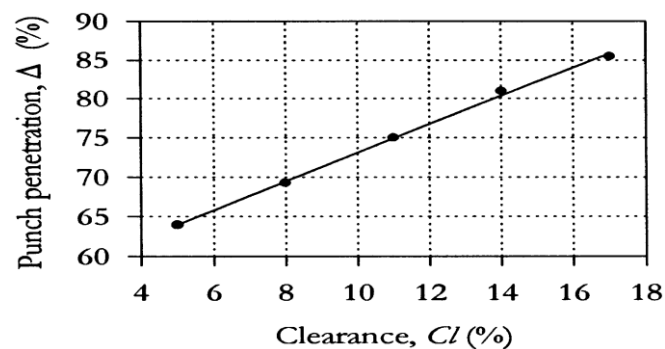


Figure. (14). Correlation between punch penetrations at crack initiation with Clearance.

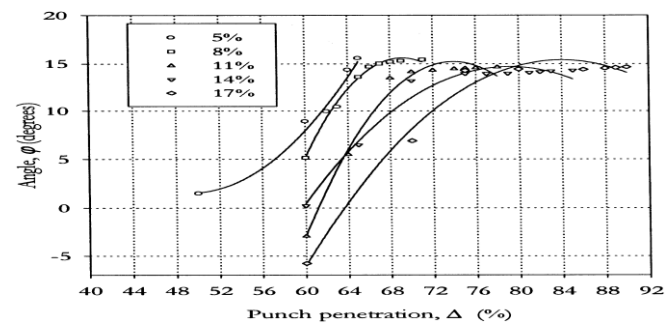


Figure. (15). Variation of angle of the direction perpendicular to the maximum principal tensile stress in node i , with punch penetration.

The optimum clearance for the values of the parameters used in this work is between 11 and 12%, which is in agreement with previous experimental results and theoretical work [11, 12]. “Fig.(14)” illustrates the influence of clearance on punch penetration at crack initiation, the results being similar to those of previous investigations [13]. It is observed that punch penetration increases as the c/t ratio increases. Consequently, with larger clearance, the severity of deformation decreases, i.e. the material can deform more easily, so that greater punch penetration is necessary before cracks are initiated. “Fig.(15)” shows variations in the angle of the direction perpendicular to the maximum principal tensile stress in node i with increasing punch penetration values, for different clearances. This figure shows how this angle reaches feasible values (in terms of material fracture) for a range of punch penetration values similar to those observed experimentally at crack initiation.

7.5 Conclusions

The methodology proposed makes it possible to predict optimum clearance using a general purpose FEM code for a given sheet material and thickness to be blanked. In the absence of such an analytical method, a large number of experiments would be required and their results would have to be analyzed carefully, for the optimum clearance to be calculated. The hypothesis proposed in the present work regarding the point of crack initiation in the punch and die, which is used to determine the values of C^* and diagonal angle, closely reflects previous experimental results concerning optimum clearance.

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VIII. CONCLUSION

The experimental investigation of the sheet metal blanking process makes it possible to study the effects of process parameters such as the material type, the punch-die clearance, the thickness of the sheet and their interactions on the geometry of the sheared edge especially the burrs height. Various methods are used in order to obtain a better understanding of the blanking manufacturing response.

The investigation shows that, the blanking load increases with a reduction in the tool clearance in the case of both single and double blanking. It is observed that the diagonal angle (θ) increases linearly according to the clearance, the crack propagation angle (β) evolves nearly constant. One clear trend is that optimum clearance decreases as the material elongation increases.

There is no universal optimal clearance value in order to minimize the blanking force, the clearance should be set at 10% and however, to minimize the fracture angle, the fracture depth and the burrs height; it is preferable to set the clearance at 5%. When the clearance is set at 10%, the process is slightly more robust to tool wear, as far as the blanking force response is concerned. Whether clearance should be set at 5% or 10% ultimately depends on the priorities of the practitioners.

As a conclusion drawn from the proposed investigation, it is possible to optimize the sheet metal blanking process by a proper selection of the clearance.

IX. FUTURE WORK

Further investigation is needed to explore more parameters and operating conditions to develop a general model for more material types by using the combination of various techniques. A combination of techniques can be used in order to achieve a higher level of verification and to reduce the cost of the necessary experimental effort.

It is recommended to experimentally perform the blanking process that combines the optimal set of parameters and monitor its output quality.

X. NOMENCLATURE

Cl or c = Punch-Die Clearance
t = Sheet Thickness
D_m or D = Die Diameter
D_p or d = Punch Diameter
 θ = Diagonal Angle
B or ϕ = Direction of Crack Propagation Angle
Up = Punch Penetration
Tol = Tolerance Convergence Value
Tf = Friction Shear Stress,
Sn = Normal Stress at Interface
m = Friction Coefficient.
r = Punch-Die Radius
 μ = Friction Coefficient

Σ^* = the Maximum Principal Tensile Stress,
 $E-f$ = Fracture Strain
 C = Material Constant.
 σ^- = Effective Stress
 ε^- = Effective Strain
 Σ_y = Yield Stress
 E = Elastic Modules
 E_T = Tangent Plastic Slope
 Δ = Punch Penetration

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