"Clearance Optimization of Blanking Process"

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Abstract: Metal blanking is awidely used process in high volume production of sheet metal components. The Research work is carried out for investigating the effect of potential parameters, influencing the blanking process and their interactions. This helped in choosing the process leading parameters for two identical products manufactured from two different materials blanked with a reasonable quality on the same mold. The study has helped to evaluate the influence of tool clearance, sheet thickness and sheet material thus optimizing clearance which affects other process parameters. The designs of experiments (DOE) approach by Taguchi method is used in order to achieve the intended model objectives. Design of experiments are an efficient and cost effective way to model & analyze the relationships that describe process variations.This thesis deals with the issue of the accurate prediction of blanked edges and will therefore focus on the optimization of clearance. This research paper presents a method for optimum clearance prediction of sheet metal blanking processes by using "Design of Experiment".

Keywords: Blanking, optimization, clearance, Taguchi, Design of Experiments (DOE).

1. INTRODUCTION

During the past decade, two clear trends have been observed in the production of metal components i.e. time-to-market needs to be shortened &ongoing miniaturization which forces product dimensions to decrease.

Blanking is a metal fabricating process, during which a metal work-piece is removed from the primary metal strip or sheet when it is punched. The material that is removed is the new metal work-piece or blank.

The blanking process, is illustrated in figure 1.1

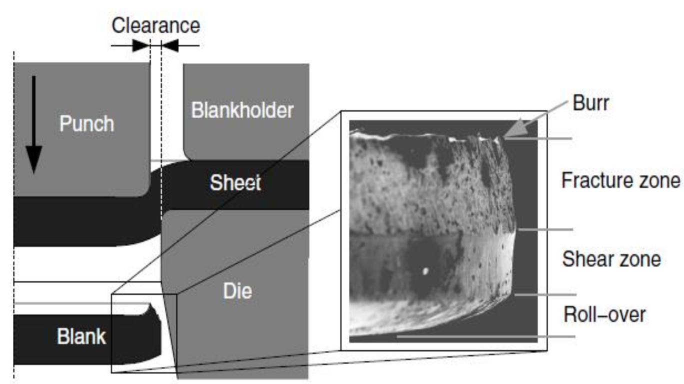


Figure 1.1: A schematic representation of the blanking process with an indication of the different zones determining the product shape[3]

International Journal of Scientific & Engineering Research, Volume 6, Issue 12, December-2015
ISSN 2229-5518

Their formation can be explained from three different stages of the blanking process shown in figure 1.2:

1. The bending stage.
2. The shearing stage.
3. The fracture stage.

The different zones determine the quality of the blanked edge.

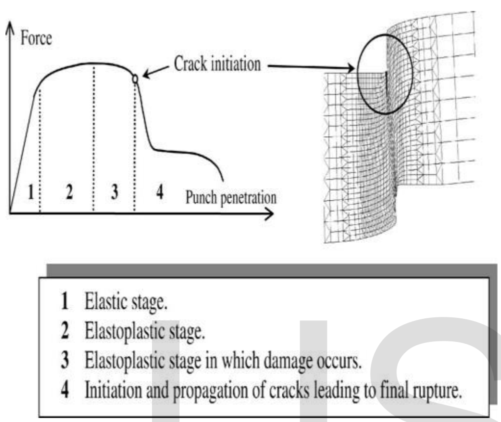


Fig.1.2. Different stage of the blanking process [2]

The first step in forming sheet metal parts 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.

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 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 blanking process forces a metal punch into a die that shears the part from the larger primary metal strip or sheet. A die cut edge normally has four attributes.

These include:

- Burnish
- Burr
- Fracture
- Roll-over

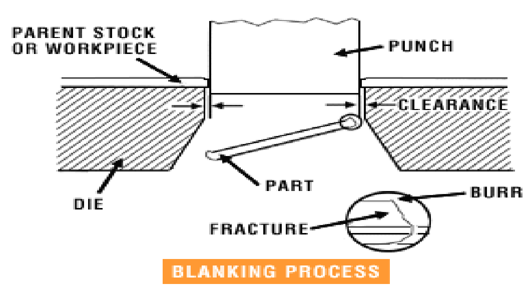


Figure no.1.3 Blanking Process [5]

2. 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.

R. Hambli [1] , 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 design of experiment method for modelling and analyzing the relationships that describe process variations. The interactions between controllable factors (clearance) and noise factors (wear and thickness) are useful in reducing the influence of the noise factors and thereby making the process more robust against variations in tool wear and sheet thickness. The process signatures indicate that the maximum shearing force, the fracture angle and the fractured surface depth are influenced by the material condition as well as the geometric characteristics of the tools and their configurations. This investigation shows that, in order to minimise the blanking force, the clearance should be set at 10%, however, to minimise 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.

F. Faura , A. Garcia , M. Estrems [2] , 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. In the present investigation, the shearing mechanism was studied by simulating the blanking operation of an AISI 304 sheet. Simulation used the FEM program ANSYS and also the Crockroft and Latham fracture criterion. In his 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 and the angle of the direction of crack propagation for different clearances were calculated. The influence of clearanceon 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 clearances 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 [3] elaborates blanking process and structure 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.). A damage model of the Lemaitre type is used in order to describe crack initiation and propagation into the sheet. Four materials are used 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; said by Emad Al-Momani, Ibrahim Rawabdeh [4].

Emad Al-Momani, Ibrahim Rawabdeh [4], 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. The combination of both techniques is proposed to result in a reduction of the necessary experimental cost. 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. Develop a Finite Element Model (FEM) that represents the existing process in order to evaluate the quality of the inputs. In their article, they showed that, in order to minimize the burrs height, the clearance should be set at about 5% with almost no blank holder force.

S. K. Maiti, A. A. Ambekar, U. P. Singh, P.P. Date, K. Narasimhan, [5], 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 at the tool sheet interfaces. 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. The blanking load increases with a reduction in the tool clearance in the case of both single and double blanking.

RidhaHambli [6], presents an 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. 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.

RidhaHambli, Fabrice Guerin [8], they develop a methodology to obtain the optimum punch–die clearance for a given sheet material by the simulation of the blanking process. A damage model of type Lemaitre 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. The blanking process and the structure of the blanked surface are influenced by both the tooling (clearance and the tool geometry) and the properties of the work piece material (blank thickness, mechanical properties, microstructure, etc.).They show that the optimum value of clearance decreases with increasing material ductility.
They have developed a methodology to obtain the optimum punch–die clearance for a given sheet material by the simulation of the blanking process. The proposed approach combined predictive finite element and neural network modeling of the leading blanking parameters.

Fang *et al.* [12] investigated the punch–die clearance values for a given sheet material and the thickness are optimized by using a finite element technique in which the shearing mechanism was studied by simulating the blanking operation. The clearance impact on the blanking processes has consumed a significant amount of research. This concern about the clearance factor is because the structure of the blanked surfaces is influenced by both the tooling (clearance and tool geometry) and the properties of the work piece material (blank thickness, mechanical properties, microstructure, etc.). The selection of the clearance influences the life of the die or punch, the blanking force, the unloading force and the dimensional precision.

Maiti*et al*. [5] analyzed the blanking of thin sheet of mild steel using an elastic plastic finite element analysis based on the incremental theory of plasticity. The study has helped to evaluate the influence of tool clearance, friction, sheet thickness, punch/die size, and blanking layout on the sheet deformation.

A review of the literature on the blanking process shows that while a large number of analytical techniques have been used to study the process, the amount of theoretical and practical work done is relatively insufficient and thus further investigation is still needed.

3 DATA COLLECTION AND EXPERIMENTATION

3.1 METHODOLOGY

Design of Experiments (DOE) provides the guidance in the selection of the proper combination of the process parameters at their specified levels, in such a way that costly dies will not be manufactured. The methodology that is followed to attain the research objectives is divided into the following work phases:

1. Classify the blanking parameters into controllable and uncountable. The identified controllable parameters are clearance, blank holder force, sheet metal thickness, and material type. While, the uncountable parameters are material properties inconsistency and conditions (shape, defects and internal stresses), friction and wear state of the tool, stroke rate or blanking speed, and punch-diealignment.

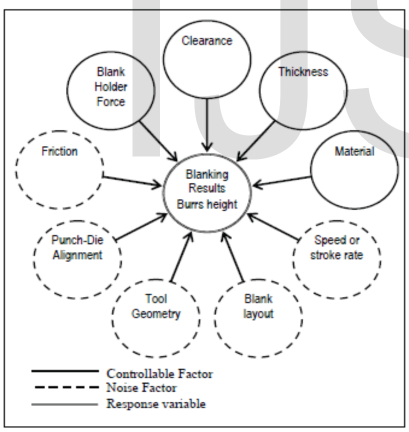


Figure no. 3.1.1 Summary of the blanking parameters situation in this research [1]

2. Choosing the controllable factors material, thickness, clearance that influences the blanking process as the interest domain.
3. Selecting an appropriate working range for each potential factor. It is found that the working range of clearance fall within the range (0-15)% of the sheet metal thickness, the working range of the thickness of their used material fall within the range (0.5-0.8) mm. and the two materials Mild Steel & Copper.
4. Preparing to use of Design of Experiments (DOE) technique by selecting the experimental levels for each selected factor, i.e. the clearance to be in three levels (5, 10, 15) % of the sheet metal thickness and sheet metal thickness to be in four levels (0.8, 1.2, 1.5,) mm.
5. Perform a factorial experimental design in order to take high-level interactions based on the findings of the previous steps.
6. Analyze the results to get the proposed optimal set of parameters.

3.2 OPTIMUM CLEARANCE

In blanking processes, the clearance is expressed in percentage of the sheet thickness and is defined by:

$$C=100\frac{Dm-Dp}{2t}\ (\%)$$

WhereD_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 order to obtain the optimum clearance value, the angle (Θ_d) 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. 3.2.1). This can be expressed by:

$\Theta_d = \beta$

The diagonal angle can be expressed by:

$\Theta_d = \text{Arc tan}\left(\frac{c}{t-U_p}\right)$

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

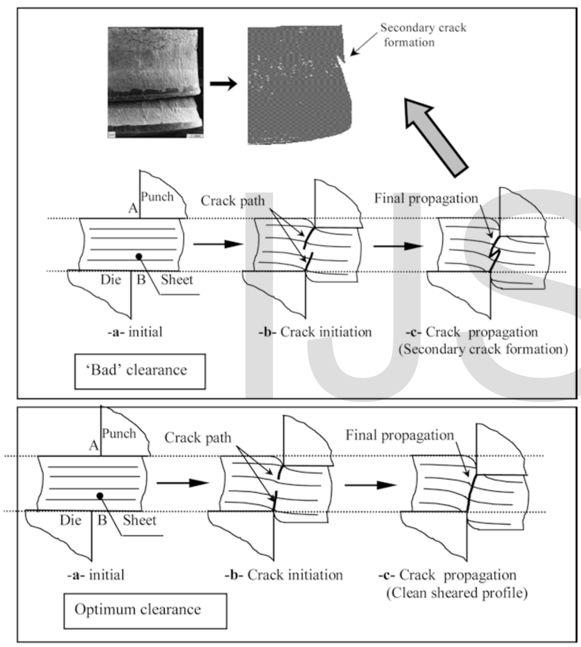


Fig. 3.2.1 Secondary crack formation during blanking process [4].

3.3 EXPERIMENTATION

Experimentation is the important step in the total analysis. Total 9 runs of experiments based on randomized OA were done for each material (i.e. for mild steel and copper). Sheet thickness and clearance are varied as per values for each level mentioned in Table-3.3.1

Material type	Process parameters	Level 1	Level 2	Level 3
Mild Steel	Thickness	0.8 mm	1.2 mm	1.5mm
	Clearance	5%	10%	15%
Copper	Thickness	0.8 mm	1.2 mm	1.5mm
	Clearance	5%	10%	15%

Table 3.3.1: Process Parameters and Their Levels

Observation table for Mild Steel

Exp no.	Thickness	Clearance	Sample1	Sample2	Sample3	Sample4	Sample5
1	1	1	0.078	0.052	0.072	0.058	0.05
2	1	2	0.1	0.123	0.124	0.13	0.128
3	1	3	0.15	0.147	0.135	0.166	0.158
4	2	1	0.032	0.024	0.031	0.031	0.037
5	2	2	0.042	0.036	0.044	0.056	0.047
6	2	3	0.138	0.16	0.162	0.174	0.174
7	3	1	0.056	0.054	0.05	0.038	0.05
8	3	2	0.04	0.056	0.05	0.038	0.05
9	3	3	0.157	0.142	0.176	0.168	0.174

Table 3.3.3 OA for Mild Steel

Observation table for Copper

Exp no.	Thickness	Clearance	Sample1	Sample2	Sample3	Sample4	Sample5
1	1	1	0.088	0.082	0.084	0.08	0.088
2	1	2	0.124	0.138	0.12	0.124	0.116
3	1	3	0.212	0.234	0.227	0.248	0.256
4	2	1	0.058	0.058	0.056	0.06	0.062
5	2	2	0.076	0.084	0.08	0.086	0.074
6	2	3	0.152	0.13	0.167	0.144	0.138
7	3	1	0.038	0.034	0.036	0.037	0.034
8	3	2	0.03	0.044	0.044	0.046	0.054
9	3	3	0.687	0.731	0.75	0.654	0.762

Table 3.3.4 OA for Copper

3.4 ANALYSIS OF MILD STEEL BY TAGUCHI METHOD

Thickness	Clearance	Sp.01	Sp.02	Sp.03	Sp.04	Sp.05	SNRA	MEAN
1	1	0.078	0.052	0.072	0.058	0.05	24.0152	0.062
1	2	0.1	0.123	0.124	0.13	0.128	18.3098	0.121
1	3	0.15	0.147	0.135	0.166	0.158	16.3882	0.1512
2	1	0.032	0.024	0.031	0.031	0.037	30.0957	0.031
2	2	0.042	0.036	0.044	0.056	0.047	26.8441	0.045
2	3	0.138	0.16	0.162	0.174	0.174	15.8024	0.1616
3	1	0.056	0.054	0.04	0.03	0.036	27.0562	0.0432
3	2	0.04	0.056	0.05	0.038	0.05	26.5053	0.0468
3	3	0.157	0.148	0.176	0.168	0.174	15.6534	0.1646

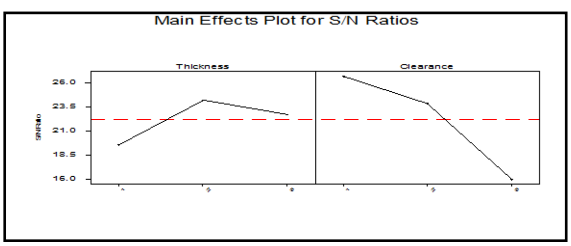
Table no.3.4.1 Response Table for Signal to Noise Ratio & Mean

3.4.1 Analysis by signal to noise ratio

Quality Characteristic: Burr Height of blanked componentQuality Characteristic Feature:Smaller-the- better

Level	Thickness	Clearance
1	19.5711	27.0557
2	24.2474	23.8864
3	23.0716	15.9480
Delta	4.6763	11.1077
Rank	2	1

Table no. 3.4.2 Response Table for Signal to Noise Ratios



Plot 3.4.2 Main effect plot for signal to noise ratio

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	217.17	108.59	14.56	0.005
Residual Error	6	44.76	7.46		
Total	8	261.94			

Table no. 3.4.3

Plot no. 3.4.2 shows the S/N ratio graph where the horizontal line is the value of the total mean of the S/N ratio. Basically, larger the S/N ratio, the better is the quality characteristics for the blank. As per the S/N ratio analysis from graph the levels of parameters to be set for getting optimum value of burr height are A_2B_1.

According to this, clearance was found to be the major factor affecting the burr height (21%). The percent contributions of sheet thickness is much lower, being (1.8 %). As we conduct full factorial experimentation & the optimum level condition A_2B_1 has already perform, hence there is no need of confirmation experiment.

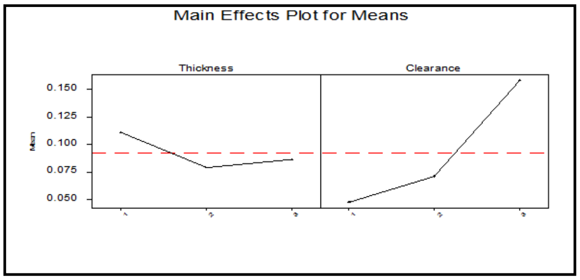
3.4.2 Analysis by means

Quality Characteristic: Burr Height of blanked component

Quality Characteristic Feature: Smaller-the-better

Level	Thickness	Clearance
1	17.3667	24.9959
2	21.0667	22.3626
3	19.6225	10.6973
Delta	3.6999	14.2984
Rank	2	1

Table no. 3.4.4Response Table for Means



Plot no 3.4.4 Main effect plots for means

Plot no. 3.4.4 shows the means plot where the horizontal line is the value of the total mean of the means. Basically, smaller the means, the better is the quality characteristics for the blank. As per the means analysis from graph the levels of parameters to be set for getting optimum value of burr height are A_2B_1.

3.5 ANALYSIS OF COPPER BY TAGUCHI METHOD:

Thickness	Clearance	Sp.01	Sp.02	Sp.03	Sp.04	Sp.05	SNRA	MEAN
1	1	0.088	0.082	0.084	0.08	0.088	21.4669	0.0844
1	2	0.124	0.138	0.12	0.124	0.116	18.0882	0.1244
1	3	0.212	0.234	0.227	0.248	0.256	12.5451	0.2354
2	1	0.058	0.058	0.056	0.06	0.062	24.6072	0.0588
2	2	0.076	0.084	0.08	0.086	0.074	21.9241	0.08
2	3	0.152	0.13	0.167	0.144	0.138	16.6686	0.1462
3	1	0.038	0.034	0.036	0.037	0.034	28.9137	0.0358
3	2	0.03	0.044	0.044	0.046	0.054	27.0757	0.0436

Table no. 3.5Response Table for Signal to Noise Ratio & Mean

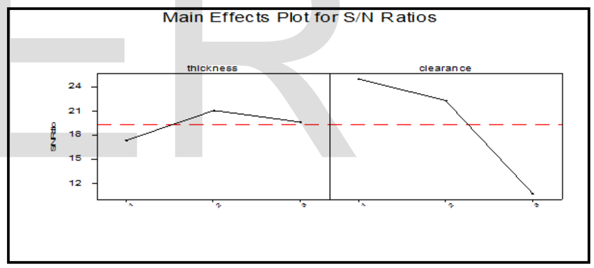
3.5.1 Analysis by signal to noise ratio

Level	Thickness	Clearance
1	0.1114	0.0454
2	0.0792	0.070933
3	0.08687	0.159133
Delta	0.0322	0.1113733
Rank	2	1

Table no.3.5.1

Quality Characteristic: Burr Height of blanked component.

Quality Characteristic Feature: Smaller-the-better.



Plot 3.5.1 Main effect plot for signal to noise ratio

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	314.31	157.15	4.67	0.06
Residual Error	6	201.99	33.67		
Total	8	516.3			

Table no.3.5.2Analysis of Variance

Plot no. 3.5.1 shows the S/N ratio graph where the horizontal line is the value of the total mean of the S/N ratio. Basically, larger the S/N ratio, the better is the quality characteristics for the blank. As per the S/N ratio analysis from graph the levels of parameters to be set for getting optimum value of burr height are A_2B_1.

According to this, clearance was found to be the major factor affecting the burr height (76.8%). A percent contribution of sheet thickness is much lower, being (8.9%). As we conduct full factorial experimentation & the optimum level condition A_2B_1 has already perform, hence there is no need of confirmation experiment.

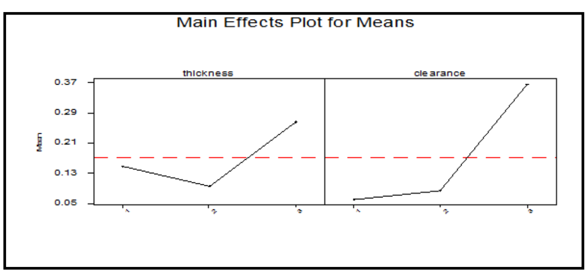
3.5.2 Analysis by means

Quality Characteristic: Burr Height of blanked component

Quality Characteristic Feature: Smaller-the-better

Level	Thickness	Clearance
1	0.148067	0.059667
2	0.095	0.082667
3	0.2654	0.366133
Delta	0.1704	0.306467
Rank	2	1

Table no. 3.5.3 Response Table for Means



Plot no 3.5.3 Main effect plot for means

Plot no. 3.5.3 shows the means plot where the horizontal line is the value of the total mean of the means. Basically, smaller the means, the better is the quality characteristics for the blank. As per the means analysis from graph the levels of parameters to be set for getting optimum value of burr height are A_2B_1.

4. RESULTS AND VALIDATION OF RESULTS

4.1 RESULTS:

Discussion of results obtained by signal to noise ratio

In Taguchi method, the term 'signal' represents the desirable effect (mean) for the output characteristic and the term 'noise' represents the undesirable effect (signal disturbance, S.D) for the output characteristic which influence the outcome due to external factors namely noise factors. The S/N ratio can be defined as:

S/N ratio, $\eta = -10 \log (MSD)$

where, MSD: mean-square deviation for the output characteristic.

Analysis of Variance (ANOVA Analysis)

For Mild Steel

The percent contributions of the blanking parameters on the burr height are shown in Table-6.3. According to this, clearance was found to be the major factor affecting the burr height (21%). The percent contributions of sheet thickness is much lower, being (1.8 %).

For Copper

The percent contributions of the blanking parameters on the burr height are shown in Table-6.11. According to this, clearance was found to be the major factor affecting the burr height (76.8%). A percent contribution of sheet thickness is much lower, being (8.9%).

4.2 VALIDATION OF RESULTS

By S. Maiti, A. Ambekar, U. Singh, P. Date, and K. Narasimhan, [5]

An intermediate range of tool clearance (about 10% of the sheet thickness) appears good from the point of view of requirement of load and sheet deformation.

By Emad Al-Momani, Ibrahim Rawabdeh [4]

The investigation shows that, in order to minimize the burrs height, the clearance should be set at about 5 % with almost no blank holder force.

From above two results of respective Author it clear that our results and prediction about optimum clearance is promising and thus VALID.

Representing shortly the work done by above Author [4] for validation purpose,

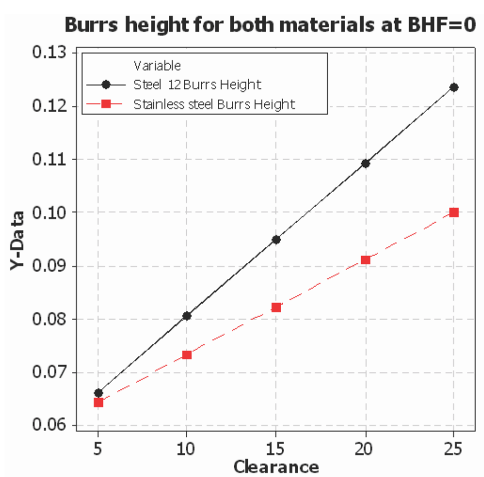
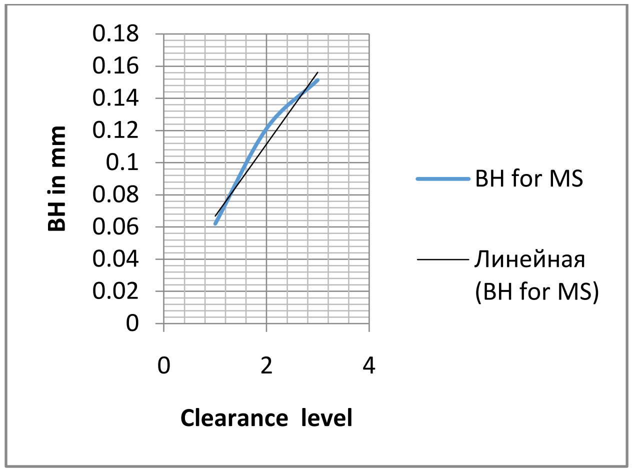
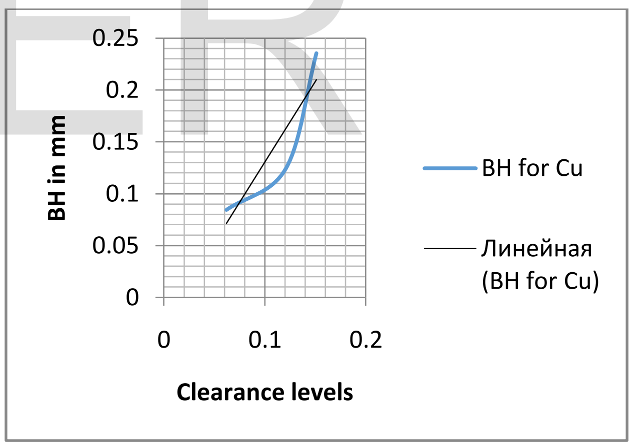


Figure 4 A plot for the burrs height of Steel 12 and Stainless steel 480 at no blank holder force and different clearances.



Plot no.4.1A plot for the burrs height of MS with different clearances.



Plot no. 4.2A plot for the burrs height of Cu with different clearances.

Comparing figure 4 with plot no. 4.1 and 4.2 we find that Burr Height increases with increase in Clearance hence we can say that for minimum Burr height the optimum clearance should lay about and at 5%. Thus it is clear that our results are promising and hence VALID.

5. Conclusions and Future Work

The developed 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. The Design of experiments (Taguchi Method) method is used in order to obtain a better understanding of the blanking manufacturing response. The process signatures indicate that the material types as well as the geometric characteristics of the tools and their configuration influence the burrs height of the sheared edge.

This investigation shows that, in order to minimize the burrs height, the clearance should be set at about 5 % with almost no blank holder force. The presented investigation of the blanking process makes it possible to predict optimum process parameters. It is possible to reduce the lead-time by using Taguchi Method as a Design of Experiment technique in the design process, where computer software can replace many time consuming experiments. This will make the design process faster and more reliable. From another point of view, it is possible to build quality into products from the early design phases by predicting the shape of the cut edge and the burs height of a blanked product. This will improve the final products quality and reduce burrs removal rework in addition to increasing the manufacturing process flexibility and reducing its cost through building one blanking setup for different materials. In conclusion, it can be stated that the Design of Experiments technique can be used in order to contribute towards the optimization of sheet metal blanking processes.

5.1 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 the Design of Experiment technique and Finite Element Method. A combination of both techniques can be used in order to achieve a higher level of verification and to reduce the cost of the necessary experimental effort. Design of experiments will aid in guiding the selection of the proper combination of the process parameters at their specified levels in such a way that costly dies will not be manufactured until the finite element method shows the best set of the process parameters.

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

Further investigation also explore parameters like blank holder force, wear state of tool, height of sheared edge, fracture depth which are influencing parameters on blanked workpiece. Also the punch force and punch velocity is strongly related with the plastic flow and Burr height.

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