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Process Parameter Optimization of Copper Sheet Metal Blanking

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ABSTRACT:- Sheet metal blanking is one of the most widely used process in industry. Productivity and quality in sheet metal blanking is mainly expressed in terms of burr formation on blanked part. This paper discusses influence of process parameters of blanking such as thickness of copper sheet, punch-die clearance and punching tool wear radii on burr height formation on blanking product. For optimization of selected process parameters for burr minimization, Design of Experiment (DOE) is coupled with MATLAB Optimization toolbox and the function 'Particle swarm'.

Keywords:- burr formation, copper sheet material, Design of Experiment, MATLAB Optimization, Particle swarm (PSO), Sheet metal blanking.

I. INTRODUCTION

In sheet metal industry, thousands of products are manufactured by using various sheet materials for variety of applications. Sheet metal blanking is cheapest and most widely used process in industries, applications ranging from components of very light to heavy appliances and machineries. The design of blanking processes in industrial practice still follows time-consuming and expensive trial and-error iterations on experimentations. Various material coefficients and process factors affect the quality of the blanked part. The main objectives of the process design in metal blanking are to choose the leading process parameters in an optimal way to ensure high-quality parts. To have cost effective quality product Engineers and Researchers are often investigating the optimized process parameters. Finite element method is one of the good choice for the process parameters for optimization. This type of analysis can help to eliminate the requirements of time consuming experiments to optimize the process parameters. Despite the availability of a large number of commercial finite element packages, their applications to the blanking or punching processes are limited. The elements in the shearing region undergo very large plastic deformation and this makes it difficult to do accurate simulation of the shearing of sheet metal process. Having a good understanding of the fundamentals and science behind this high deformation shearing process can help to improve the blanked edge quality in various ways [1]

1.1 ERRORS ON SHEARED SURFACE OF BLANKED PRODUCT

The blanking process has some downside effects. These include:
Generating residual cracks along the blanked edges, hardening along the edge of the blanked part or work piece, secondary shear, curvature due to spring back effect, creating excess roll-over and burr if the clearance is excessive. The clearance, the tool wear state and the sheet thickness are the major factors that determine the shape and the quality of the work piece. Blanking has a large number of inputs. Each of these inputs has an associated variation that leads to variations in the final part [2, 3, 12, and 13]

II. LITERATURE SURVEY

Chan et al [4] In this study, a comprehensive review on sheet metal blanking burr formation and the responsible parameters are discussed. The paper also presents the current challenges facing by the manufacturer as well as researcher on burr problem and outlined some of the remedial measures to overcome this problem. In addition, the authors raised the problem on measurement of the burr as the size of the component become smaller and level of precision is higher.

Lahoti [5] In this paper, Design of Experiments (DOE) coupled with Artificial Neural Fuzzy Interface System (ANFIS) is used for optimization of the blanking process. In this experiment author studied the effect of the sheet thickness and punch stroke on shear zone and burr height of the blanked part. Maximum shear and minimum burr leads to the quality of blanked part. The investigation shows that sheet thickness is very important parameter in blanking operation. As the sheet thickness of the material increases shear zone increases and burr minimizes of the blanked part.

Dhoble et al [6] investigated model which helps to choose process leading parameters for two identical product manufactures from two different materials blanked with reasonable quality on the same Tool/Die. The main objective of this study is to find out optimal parameters such as sheet thickness, clearance & wear radius in relation with variations in three performance characteristic such as burr height, accuracy & circularity value for blanking of medium carbon steel. Experiments are conducted on L-9 orthogonal array, analysis has been carried on by using Grey Relational Analysis, a Taguchi method. The developed experimental investigations of the sheet metal blanking process helps to study the effects of process parameters such as punch die clearance, material type and blank holder force and their interaction on the geometry of sheared edge surface quality specially burr height. Author has presented new approach to optimization by associating Grey Relational Analysis (GRA) with the Taguchi method. Grey relation analysis is an effective mean of analyzing the relationship between sequences with less data and can analyze many factors that can overcome the disadvantages of statistical method.

Hilditch and Hodgson [7] found that, in general the burr height and rollover depth increased with increasing clearance for all examined materials. However, there were differences in the fracture surface profile shape, the burr shape and the mechanism of burr formation, between the two steels and the two light alloys. The major cause of these differences appeared to be the rate of crack propagation through the sheet material. Meanwhile, rollover is also affected by material's ductility and work hardening. Different burr formation mechanisms existed for the two classes of materials. Rapid crack propagation and part/scrap separation at a low punch penetration in both the aluminum and magnesium alloy samples resulted in a curved fracture profile and 'right-angle' shaped burr. From their research, they found that slow crack propagation after crack initiation in the steel samples and subsequent part/scrap separation at a significantly higher punch penetration, resulted in a straight fracture profile and a 'v' shaped burr.

Hambli [8] in this paper, an experimental investigation into the blanking process was carried out using tools with four different wear states and four different clearances. 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. The design of experiments method used in this paper provides a better understanding of the blanking manufacturing response. 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. The analysis of the tool wear influence 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, and it is considerably more robust (almost insensitive) to tool wear and sheet thickness as far as the fracture depth 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.

Al-Momania et al [9] integrates a Finite Element Method (FEM) and Design of Experiments (DOE) approaches to optimize the sheet metal blanking process. Finite Element Simulations are conducted on the commercial finite element software package ABAQUS/Explicit. The process parameters such as the material type, the punch-die clearance, the thickness of the sheet and the blank holder force and their interactions on the burrs height have been investigated. The results show that the higher the clearance the higher the burrs height and the lower the blank holder force the lower the burr height. The material type has effect but the thickness effect is insignificant. In order to minimize the burrs height, the clearance should be set at about 5% with almost no blank holder force. When blank holder force is set to zero, the process is slightly more robust to clearance changes than when a high blank holder force is used. However a small value in the order of about 2% of the blanking force is favorable since it can prevent the remaining skeleton from moving out of plane. 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.

Martin Grünbaum [10] have studied influence of high cutting speeds on the quality of blanked parts which investigates the effect of different parameters on the part edge quality of blanked parts. Experiments have been conducted using four different materials low carbon steel, high strength steel, aluminum and copper have been blanked with punch-die clearances between 4% and 24%, and different cutting speeds. In order to determine the reachable cutting speeds and to calculate the energy required for blanking, velocity-stroke curves were obtained. In addition, blanking simulations with DEFORM 2D have been performed. When evaluating the part edge quality of the blanked parts, all the different zones were taken into consideration (burr height, shear, rupture/penetration depth, and rollover). The results of the part quality investigations show that the positive influence of high cutting speeds on the quality of the part edge is more obvious for low carbon and high strength steels.

Subramonian et al [11] discussed the responsible factors affecting punch failure in blanking are contact pressure and temperature at the interface of the punch surface and sheet, tool material and coating, velocity and lubrication. As sliding contact between the work piece and tool, repeated impact loads or thermal shocks results in tool wear. Different types of tool failure such wear, chipping, cracking, galling and gross fracture are discussed in brief.

Rai et al. (12) found that the factors causing burr can be summarized into man (operator awareness, skill of operator), material (raw material grade and thickness), machine (alignment, clearance) and method (part handling). Besides that, the authors also explain how the selection of tool material will affect the tool life, part quality and tool sharpening frequency. A brief guideline about the correct die-punch alignment and tool assembly also had been included in this study.

Totre et al. (13) discussed impact of various parameters of blanking process such as clearance, tool wear, Sheet thickness, material, punch geometry on quality product with the aid of relevant sketches. Paper concludes that clearance, thickness & tool wear are important process parameters affecting geometry of sheared surface of blanked product.

III. METHODOLOGY

Literature review elaborates different analysis tools and experimental techniques to produce quality product in sheet metal blanking. Majority of research papers concludes that punch- die clearance, tool wear radii and material ductility as a dominant process parameters contributing quality in blanking product. Quality impact due to tool wear is one of the area where research is required. By considering observed research gap this paper discusses the effect of tool wear radii on burr formation on copper sheet material.

The methodology that is used to attain the research objectives is tracked through the following phases. Punch-die clearance, sheet thickness and tool wear radii are selected as important parameters that influence the blanking process as the interest domain. An appropriate working range for each potential parameter is selected by considering reviewed research papers. It is found that the working range of clearance fall within the range (0-25)% of the sheet metal thickness, range for metal thickness is 0.5-1.5 mm and tool wear radii within the range of 0.01 - 0.30 mm. Process parameters and their levels for experimentation is shown in Table 1.

Table 1 Levels of process parameters

Parameters	Levels of parameters		
	Level 1	Level 2	Level 3
Sheet Thickness (mm)	0.8	1.2	1.5
Clearance (%)	5	10	15
Tool wear radius (mm)	0.01	0.15	0.3

Design of Experiments (DOE) technique is adapted to select optimum level of these parameters to produce least burr on blanked part. MATLAB Optimization toolbox and the function ‘Particle swarm’ coupled with Design of Experiments (DOE) technique to optimize the selected process parameters to minimize burr formation on blanked part.

Experimentation is conducted on mechanical press of 10 Tonne capacity. Punches of appropriate diameters with wear radius are designed to achieve different clearances. The following readings are taken for Copper sheet material. Average Burr height readings are taken on each blank at five different positions by using precision digital height gauge having least count 0.001mm. for different clearances, thickness and tool wear radii. To ascertain the relative importance of each of these factors on burrs height, a set of experiments is based on a full factorial experimental design. To meet intended objectives, for analysis Minitab software 17 with L_{-27} array is used.

Table 2 Experimental data for Copper Sheet

Run No.	Sheet Thickness (mm)	Clearance (%)	Wear Radius (mm)	Burr Height 1	Burr Height 2	Burr Height 3	Burr Height 4	Burr Height 5	Mean Burr Height (mm)	SNRA1
1	0.8	5	0.01	0.0986	0.0608	0.0912	0.0684	0.0874	0.0836	21.55587
2	0.8	5	0.15	0.1672	0.2014	0.1976	0.2242	0.1786	0.1938	14.25292
3	0.8	5	0.3	0.4294	0.4522	0.3762	0.4028	0.3876	0.40964	7.751953
4	0.8	10	0.01	0.1596	0.1292	0.1444	0.1672	0.1349	0.14706	16.65011
5	0.8	10	0.15	0.3135	0.2926	0.2641	0.2774	0.2508	0.27968	11.06677
6	0.8	10	0.3	0.5662	0.532	0.5738	0.5472	0.5852	0.56088	5.022601
7	0.8	15	0.01	0.2204	0.1976	0.1729	0.2356	0.2128	0.20786	13.64458
8	0.8	15	0.15	0.4104	0.3762	0.4446	0.3952	0.3496	0.3952	8.063661
9	0.8	15	0.3	0.6802	0.6004	0.5928	0.6498	0.5966	0.62396	4.096865
10	1.2	5	0.01	0.0684	0.1292	0.1064	0.0836	0.1235	0.10222	19.80928
11	1.2	5	0.15	0.2052	0.2508	0.2166	0.2242	0.1824	0.21584	13.31736
12	1.2	5	0.3	0.4902	0.3914	0.4655	0.4522	0.4294	0.44574	7.018368
13	1.2	10	0.01	0.1824	0.1634	0.1558	0.2014	0.1748	0.17556	15.11149
14	1.2	10	0.15	0.3496	0.3078	0.3648	0.3401	0.3496	0.34238	9.309832
15	1.2	10	0.3	0.5814	0.5092	0.5472	0.5624	0.5301	0.54606	5.255193
16	1.2	15	0.01	0.2318	0.2774	0.3078	0.2584	0.2432	0.26372	11.57714
17	1.2	15	0.15	0.4655	0.5434	0.5548	0.5092	0.589	0.53238	5.475565
18	1.2	15	0.3	0.7866	0.9082	0.8284	0.9082	0.9272	0.87172	1.19246
19	1.5	5	0.01	0.0722	0.057	0.0532	0.0684	0.0532	0.0608	24.32193
20	1.5	5	0.15	0.1634	0.1862	0.1178	0.1368	0.1026	0.14136	16.99347
21	1.5	5	0.3	0.3838	0.3724	0.3572	0.38	0.3192	0.36252	8.813361
22	1.5	10	0.01	0.0912	0.0874	0.0988	0.1254	0.1064	0.10184	19.84163
23	1.5	10	0.15	0.4826	0.3876	0.475	0.4712	0.5054	0.46436	6.662904
24	1.5	10	0.3	0.6498	0.5434	0.6878	0.6612	0.6764	0.64372	3.82606
25	1.5	15	0.01	0.1482	0.1976	0.1748	0.1672	0.2052	0.1786	14.96237
26	1.5	15	0.15	0.418	0.3686	0.2736	0.3572	0.3819	0.35986	8.877328
27	1.5	15	0.3	0.5168	0.5662	0.6004	0.5548	0.6232	0.57228	4.847829

IV. RESULT AND DISCUSSION

4.1 Analysis of Variance (ANOVA). The obtained ANOVA results are shown in Table

Table 3: Analysis of Variance

Process Parameters	DF	Adj SS	AdjMS	F-Value	P-Value	% contribution
Sheet Thickness (mm)	2	0.02687	0.013435	4.00	0.062	2.53%
Clearance (% Thickness)	2	0.22469	0.112343	33.49	0.000	21.21%
Wear Radius (mm)	2	0.77162	0.385811	115.00	0.000	72.83%
Sheet Thickness (mm)*Clearance	4	0.04593	0.011483	3.42	0.065	2.17%
Sheet Thickness (mm)*Wear Radius (mm)	4	0.00516	0.001291	0.38	0.814	0.24%
Sheet Thickness (mm)*Wear Radius (mm)	4	0.02220	0.005550	1.65	0.252	1.03%
Error	8	0.02684	0.003355			
Total	26	1.12331				
Model Summary S=0.0579208, R-Sq = 97.61%, R-sq(adj)= 92.24%, R-sq (pred)= 72.79%						

The result of ANOVA table for burr height is presented in Table 3. Statistically, larger F – value indicates that the variation of the process parameter makes a big change on the performance. According to this analysis, the most effective parameter with respect to burr height is wear radius and then clearance. The P-values test the statistical significance of each of the factors. It is observed from the above ANOVA table, there are two P-values are less than 0.05, these two factors that is wear radius and clearance have a statistically significant effect on burr height at the 95.0% confidence level. From the percentage contribution of the blanking parameters on the burr height, wear radius was found to be first ranking factor affecting the burr height (72.83%), whereas clearance was found to be second ranking factor (21.21%). The percentage contribution of sheet thickness is much lower (2.53%). The P – value of interaction between thickness * clearance, thickness * wear, and clearance * wear are higher than 0.05. Hence the above interactions are not significantly affecting the burr height.

4.2 RESPONSE FOR MEANS

In Table 4, mean for each level is summarized and called the mean response table for burr height

Table 4 Response Table for Means burr Height

Level	Sheet thickness (mm)	Clearance (%)	Wear Radius (mm)
1	0.3224	0.2239	0.1468
2	0.3884	0.3624	0.3250
3	0.3206	0.4451	0.5596
Delta	0.0678	0.2211	0.4128
Rank	3	2	1

According to Table 4, for wear radius as the difference between level 1 and level 3 are much higher (delta=0.4128). Hence the slight increase of wear radius will increase the burr height significantly. Hence wear is most influencing parameter in blanking process. The difference between level 1 and level 3 for clearance is (delta=0.2211) for mean burr height. Hence clearance is second influencing parameter in blanking process. The third blanking parameter sheet thickness is not much influencing (Delta = 0.0678) according to the response table, hence ranked third.

4.3 MAIN EFFECT PLOTS

As burr minimization is intended objective, Fig. 4 shows that minimum burr height for sheet thickness is observed at level 3, for clearance at level 1 and for wear radius at level1. Similarly from Fig.5 strong signal / noise ratio are observed for sheet thickness at level 3, for clearance at level 1 and that for wear radius at level 1.Optimum set of parameter and levels are tabulated in Table 5

Table 5: Optimum working parameter

Levels	Thickness(mm) A	Clearance (%) B	Wear radius (mm) C
$A_3B_1C_1$	1.5	5	0.01

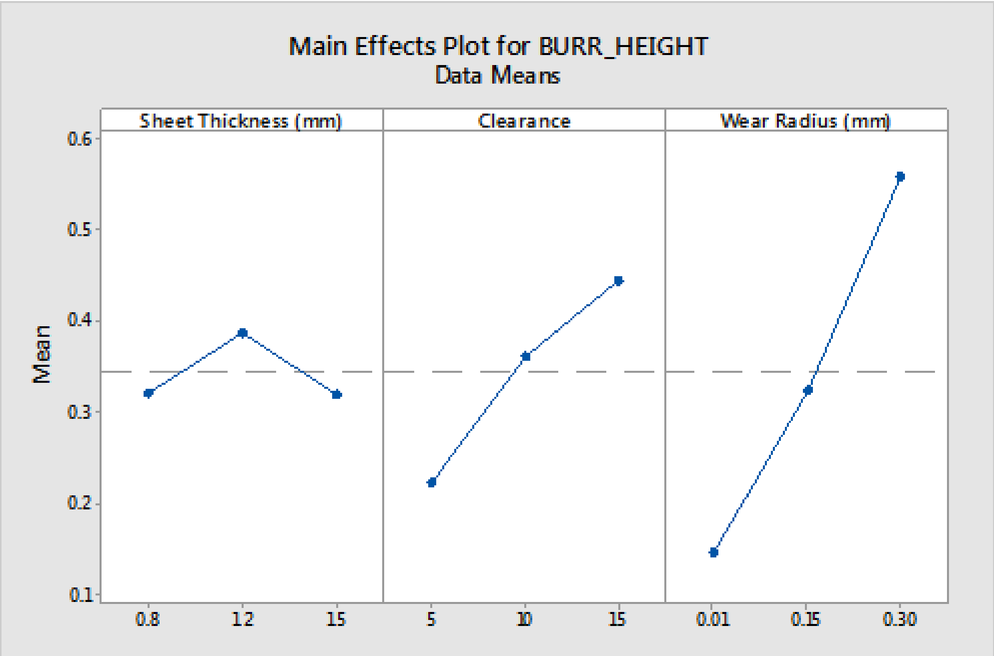

Figure 1: Main effect plot for Burr Height

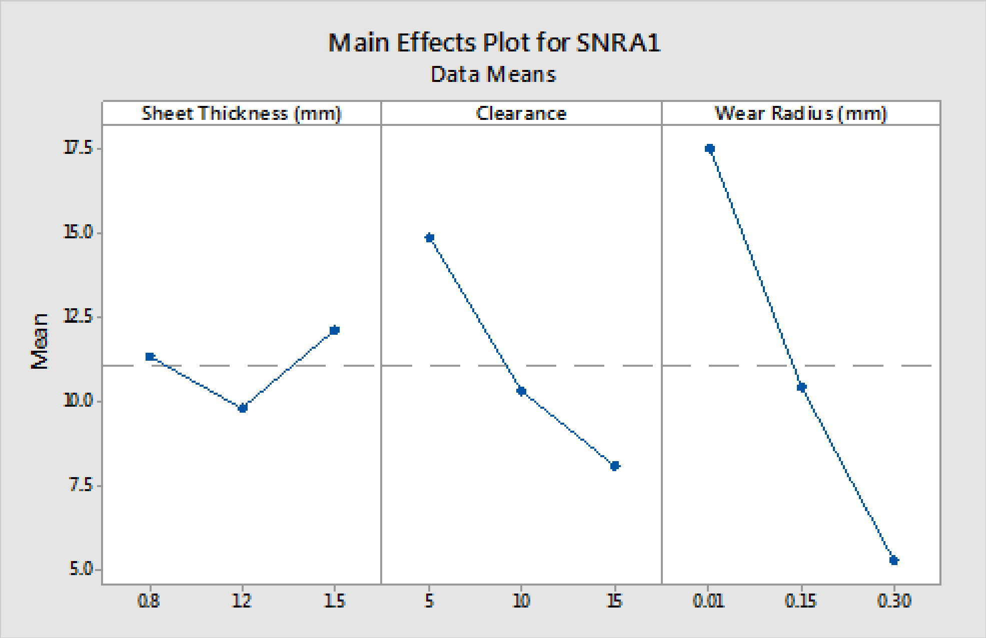

Figure 2: main effect plot for S/N ratio

4.4 PARTICLE SWARM OPTIMIZATION (PSO)

The objective function for burr height which must be minimized is shown in following equation. The constraints of the welding parameters are given below.

For burr height Minimize:

Burr Height = -0.707+1.282*x(1)+0.01429*x(2)+0.915*x(3)-0.559*x(1)*x(1) +0.510*x(2)*x(3)

Where x(1) is sheet thickness, x(2) is clearance, x(3) is Wear radius

Subject to constraint:

0.8≤x(1)(Sheet Thickness (mm) **)≤ 1.5**

5≤x(2)(Clearance**) ≤ 15**

0.01≤x(3)(Wear Radius (mm)**) ≤ 0.30**

MATLAB Optimization toolbox and the function 'Particleswarm' were used for this optimization problem. The input parameters to get minimize burr height its corresponding values are shown in Table 6.

Table 6. Results of optimization

Parameter	Sheet Thickness (mm)	Clearance	Wear Radius (mm)	Burr Height
Optimized value	1.41675	4.6547	0.0112	0.0644

V. CONCLUSION

- ANOVA and statistical analyses confirms that model is adequate to predict the response.
- PSO is used to optimize the combinations of input parameters to get minimize burr height.

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