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Optimization of Sheet Metal Blanking Process Parameters Using Taguchi Method and Grey Relational Analysis

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Abstract:

The main objective is to present the development of a model to predict the shape of the cut side. The model investigates the effect of potential parameters influencing the blanking process there interactions. This helped in choosing the 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 blanking to find out the variations in three performance characteristic such as burr height, accuracy & circularity value for blanking of medium carbon steel. Based on experiments are conducted on L-9 orthogonal array, analysis has been carried on by using Grey Relational Analysis, a Taguchi method. Response tables & graphs were used to find optimal level of parameters in blanking process. The obtained results show that the Taguchi Grey Relational Analysis is being effective technique to optimize the parameters for Blanking Process.

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***Keywords**: Blanking; GRA; Taguchi method, Orthogonal Array;*

I. INTRODUCTION

A blanking operation consists in cutting a sheet by subjecting it to shear stresses. The shearing process develops between a punch and a die and leads to the total rupture of the sheet. Blanking process is widely used in the manufacturing of small components such as electronic and electrical connectors for automotive or telecommunication industries. In these high productivity industries the components are obtained using high stroke rates.Various experimental studies carried out to find out which parameters influence more. The optimal parameter choice is crucial: to avoid additional operations such as removal of burrs to improve the geometrical quality of the sheared edge, to increase the fatigue life of the parts in service and to increase the fatigue life of the tool [1]. 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 [1].

II. EXPERIMENTATION

This experimentation was conducted using the Machines and Equipment's listed in Table 1 on press machine as shown in figure At Indo-German Tool Room, P-31, MIDC Chikalthana, Aurangabad-431006 (M. S.). A blanking die having Ø10 cut profile manufactured in same organization. After experimentation output variables / Parameters are measured at Mikronix Calibration Center, Plot 12, Cidco service industrial zone, opp. A. P. I. Ltd, Aurangabad-431210.

Sr. No.	Item	Specification
1	Video Mesuring Machine (VMM)	Model VMM 2515,Glass Table Sie-350 x 280, Metal Table Size-480 x 280mm X, Y Travel 250 x 150, Net Wt. 120kg, Z Axis Travel-150mm, Resolution X,Y,Z Scales:1um, Work Distance-108mm, X, Y Axis Accuracy-(3+L/200)um, Optical Magnification 0.7-4.5X, Digital Magnification 10-300X, Power AC 110V/60Hz;220v/50Hz, Software-Quick Mesuring 3.0
2	Fly Press Machine	Freme Height-48-60", work Height-15-20",Screw Diameter-3.5", Screw Lead-3 start, Maximum Wt.-800kg, Fly Wheel Mass-322lbs, Application-Two Operator Floor (Standing)Work
3	Press Tool/Blanking Die	L x W x H- 150x100x120, Blank Size-Ø10,Punch Length 75mm, Die Plate size-80x80x25, Tool Wt.8.61kg

Figure 1.1 VMM & Fly Press Machine

III. SHEET METAL BLANKING

Experimental observations [11] show that, in general, cutting takes place in three stages, i.e., contact engaging, penetration and fracture. Initially, the punch pushes the metal sheet into the die causing the blank to bend slightly, followed by a sliding of the sheet over the tools. Further punch penetration gives rise to a rounding of the edge of the blank (roll-over) and to shear plastic deformation. The large plastic deformation during this stage causes a burnished zone on the blank. Finally, when penetration is between 15% and 60% of the metal thickness, material separation onsets along a plane defined approximately by the punch and die corners, first usually at die edge [10]. At this stage, plastic deformation can cause a long fin (burr) at the blank upper edge.

In practical terms, the cutting operation is influenced by tooling (tool geometry and clearance), properties of the blank material (mechanical and thermal properties, blank thickness and microstructure) and contact/friction conditions (tool wear, sheet dislocation, use of lubricants and surface quality). The compound effect of the process parameters mentioned above and the physical phenomena involved will determine the final blank structure and quality of the blanked surface. Experimental studies have shown that the clearance between punch and die is one of the most important parameters in determining quality of the blanked surface. Small clearance values cause the cracks originating from the tool edges to miss each other producing a jagged edge midway in the blank thickness.

In this paper, GRA method is used to determine the blanking process parameters with optimal burr height. This is because the Taguchi method is a systematic application of design & analysis of experiments for the purpose of designing & improving the quality at the design stage. In recent years, the Taguchi based GRA method has become a powerful tool for improving productivity during research & development so that high quality products can be produced quickly and at low cost.

A. Assortment of Blanking Parameters & their levels:

Problem studied here consists of a blanking operation of Medium carbon steel sheet. Experiment is carried out on press machine. For these a simple blanking die is manufactured to obtained 10mm diameter blank. Different punches of appropriate diameters are used to obtained different clearances. The different parameters & their levels that are selected for experimentation are sheet metal thickness (0.25, 0.5, 0.6 mm), clearance (5%, 10%, 15%) & tool wear radius (0.01, 0.15, 0.30mm). The most of these ranges are selected in the light of the data available in the literature. The parameters & their levels are shown in Table 3.1.

In this work, for selecting appropriate orthogonal arrays, degree of freedom (Number of fair & independent comparisons needed for optimization of process parameters and is one less than the number of levels of parameters) of array is calculated.[4] There is six degree of freedom owing to three blanking input parameters. Accordingly, full factorial, 9 experiments were carried out to study the effect of input parameters. Each experiment was repeated five times in order to find out closest experimental results. The readings are taken of each blank at five different positions by rotating the blank & average of that is taken as the burr height reading of that blank. In all tests, burr height is calculated using video measuring machine (VMM) and the final results. Table: 2.3

Level	Sheet Thickness (mm)	Clearance (%)	Tool Wear Radius (mm)
	(A)	*(B)*	*(C)*
1	0.25	5	0.01
2	0.5	10	0.15
3	0.6	15	0.3

Table 2.1 Process parameters and their level

Run No.	L-9 Array (Half factorial)			Parameters		
				Thickness	Clearance	
	A	B	C	in MM	%	Redius
1	1	1	1	0.25	5	0.01
2	1	2	2	0.25	10	0.15
3	1	3	3	0.25	15	0.3
4	2	1	2	0.5	5	0.15
5	2	2	3	0.5	10	0.3
6	2	3	1	0.5	15	0.01
7	3	1	3	0.6	5	0.3
8	3	2	1	0.6	10	0.01
9	3	3	2	0.6	15	0.15

Table 2.2 Design Matrix of L-9 Orthogonal Array

IV. OPTIMIZATION USING GRA

Taguchi's method [13] is focused on the effective application of engineering strategies rather than advanced statistical techniques. The primary goals of Taguchi method are

- A reduction in the variation of a product design to improve quality and lower the loss imparted to society.
- A proper product or process implementation strategy, which can further reduce the level of variation

The steps involved in Taguchi's Grey Relational Analysis are:

- Optimization using GRA
  Step 1: Taguchi Method for S/N ratio
  Step 2: Normalization of S/N ratio
  Step 3: Determination of deviation sequences,
  Step 4: Calculation of grey relational coefficient (GRC)
  Step 5: Determination of grey relational grade (GRG)
  Step 6: Determination of optimum parameters
- Confirming Result

GREY RELATIONAL ANALYSIS

STEP 1: The transformation of S-N Ratio values from the original response values was the initial step. For that the equations of larger the better, smaller the better and nominal the best were used. Subsequent analysis was carried out on the basis of these S/N ratio values.

This is shown in Table 4.1

$$\text{Type 1: } S/N_{HB} = -10\log_{10}[(\frac{1}{n})(\Sigma\frac{1}{Y_{ij}^2})]$$

$$\text{Type 2: } S/N_{LB} = -10\log_{10}[\Sigma\frac{Y_{ij}^2}{n}]$$

$$\text{Type 3: } S/N_{NB} = 10\log_{10}[\frac{1}{S^2}]$$

Where Y_{ij} is the value of the response 'j' in the i^{th} experiment condition, with i=1, 2, 3,…n; j = 1,2…k and S^2 are the sample mean and variance

	RESPONSE VALUE			S/N RATIO		
Run No.	Average Burr Height in µ	Average Accuracy (Ø in mm)	Average Circularity (Ø in mm)	Average Burr Height(LB)	Average Accuracy(HB)	Average Circularity(HB)
1	0.013	10.036	0.048	-37.72	-20.03	-26.38
2	0.023	10.082	0.045	-32.77	-20.07	-26.94
3	0.034	10.014	0.08	-29.37	-20.01	-21.94
4	0.024	10.065	0.07	-32.40	-20.06	-23.10
5	0.038	10.045	0.038	-28.40	-20.04	-28.40
6	0.067	10.033	0.039	-23.48	-20.03	-28.18
7	0.049	10.01	0.008	-26.20	-20.01	-41.94
8	0.082	10.043	0.042	-21.72	-20.04	-27.54
9	0.106	10.064	0.053	-19.49	-20.06	-25.51

Table 4.1 Output Parameters and S/N Ratio

STEP 2: In the 2nd step of the grey relational analysis [14], pre-processing of the data was first performed for normalizing the raw data for analysis. This is shown in Table IV Yij is normalized as Zij (0 ≤ Zij ≤ 1) by the following formula to avoid the effect of adopting different units and to reduce the variability. The normalized output parameter corresponding to the larger-the-better criterion can be expressed as

$$Zij = \frac{y_{ij} - \min(y_{ij}, i = 1,2,\ldots n)}{\max(y_{ij}, i = 1,2,\ldots n) - \min(y_{ij}, i = 1,2\ldots n)}$$

Then for the output parameters, which follow the lower-the-better criterion can be expressed as

$$Zij = \frac{\max(y_{ij}, i = 1,2,...,n) - y_{ij}}{\max(y_{ij}, i = 1,2,...,n) - \min(y_{ij}, i = 1,2,...,n)}$$

	Parameters			NORMALISED S/N RATIO		
Run No.	Thickness in MM	Clearance %	Redius	Average Burr Height(LB)	Average Accuracy(HB)	Average Circularity(HB)
1	0.25	5	0.01	1.00	0.6	0.8
2	0.25	10	0.15	0.73	0.0	0.8
3	0.25	15	0.3	0.54	1.0	1.0
4	0.5	5	0.15	0.71	0.2	0.9
5	0.5	10	0.3	0.49	0.5	0.7
6	0.5	15	0.01	0.22	0.7	0.7
7	0.6	5	0.3	0.37	1.0	0.0
8	0.6	10	0.01	0.12	0.5	0.7
9	0.6	15	0.15	0.00	0.2	0.8

Table 4.2 Normalised S/N Ratio

STEP 3: The grey relational coefficient [15] is calculated to express the relationship between the ideal (best) and actual normalized experimental results. Before that the deviation sequence for the reference, comparability sequence, and grey relational coefficient were found out. These are given in Table 3.4 grey relational coefficient can be expressed as

$$\xi_i(k) = \frac{\Delta_{\min} + \zeta\Delta_{\max}}{\Delta_{0i}(k) + \zeta\Delta_{\max}}$$

Where,

Δ0i (k) is the deviation sequence of the reference sequence and comparability sequence.

$$\Delta_{0i}(k) = \|y_0(k) - y_i(k)\|$$

$$\Delta_{\min} = \min_{\forall j \in i} \min_{\forall k} \|y_0(k) - y_j(k)\|$$

$$\Delta_{\max} = \max_{\forall j \in i} \max_{\forall k} \|y_0(k) - y_j(k)\|$$

Denotes the sequence and yj (k) denotes the comparability sequence is distinguishing or identified coefficient. The value of ζ is the smaller and the distinguished ability is the larger. ζ = 0.5 is generally used.

	Parameters			DEVIATION SEQUENCE		
Run No.	Thickness in MM	Clearance %	Redius	Average Burr Height(LB)	Average Accuracy(HB)	Average Circularity(HB)
1	0.25	5	0.01	0.00	0.4	0.2
2	0.25	10	0.15	0.27	1.0	0.2
3	0.25	15	0.3	0.46	0.0	0.0
4	0.5	5	0.15	0.29	0.8	0.1
5	0.5	10	0.3	0.51	0.5	0.3
6	0.5	15	0.01	0.78	0.3	0.3
7	0.6	5	0.3	0.63	0.0	1.0
8	0.6	10	0.01	0.88	0.5	0.3
9	0.6	15	0.15	1.00	0.8	0.2

Table 4.3 Deviation sequences

STEP 4: The grey relational grade was determined by averaging the grey relational coefficient corresponding to each performance characteristic [12, 16]. It is given in the Table 3.4 the overall performance characteristic of the multiple response process depends on the calculated grey relational grade. The grey relational grade can be expressed as

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n}\xi_i(k)$$

Where, γ_i is the grey relational grade for the j^{th} experiment and k is the number of performance characteristic

Run No.	Parameters			GREY RELATIONAL COEFFICIENT			GREY RELATIONAL GRADE	RANK
	Thickness in MM	Clearance %	Redius	Average Burr Height(LB)	Average Accuracy(HB)	Average Circularity(HB)		
1	0.25	5	0.01	1.00	0.6	0.7	1.82	1
2	0.25	10	0.15	0.65	0.3	0.7	1.20	7
3	0.25	15	0.3	0.52	0.9	1.0	1.79	2
4	0.5	5	0.15	0.63	0.4	0.9	1.32	4
5	0.5	10	0.3	0.49	0.5	0.6	1.21	5
6	0.5	15	0.01	0.39	0.6	0.6	1.21	6
7	0.6	5	0.3	0.44	1.0	0.3	1.60	3
8	0.6	10	0.01	0.36	0.5	0.6	1.10	8
9	0.6	15	0.15	0.33	0.4	0.7	0.98	9

Table 4.4 Grey Relational Coefficient.

Step 5: Determination of the Optimal Factor and its Level Combination. The Fig. 3.1 shows the Grey relational grades [17] for Minimum Burr Height. Since the experimental design is orthogonal, it is possible to separate out the effect of each Blanking parameter on the grey relational grade at different levels. The mean of the grey relational grade for each level of the machining parameters is summarized and shown in Table 4.4

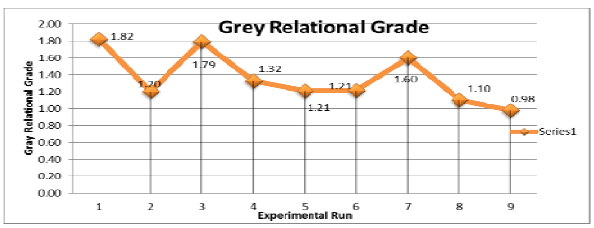
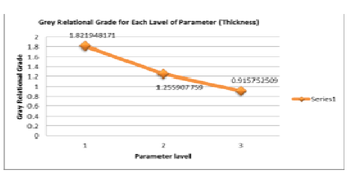


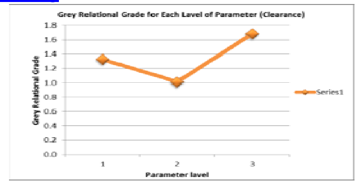
Fig.3.1 Grey Relational Grade for Minimum Burr Height (BH)

The larger the grey relational grade [12,19], the better is the multiple performance characteristics. However, the relative importance among the Blanking parameters for the multiple performance characteristics still needs to be known, so that the optimal combinations of the Blanking parameter levels can be determined more accurately. With the help of Fig.3.2 and Table 3.5, the optimal parameter combination was determined as A3 (Thickness 0.6mm), B3 (Clearance 15%) and C2 (Wear Radius 0.15mm).

Parameters	Lavel 1	Lavel 2	Lavel 3	Max-Min	Rank
Thickness	1.821948171	1.255907759	0.915752509	0.906195662	1
Clearance	1.3	1.013008601	1.682757026	0.669748425	2
Wear Redius	1.522308312	1.808629209	1.718671492	0.286320897	3

Table 4.5 Main effect of factors on Grey Relational Grade





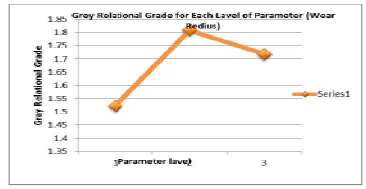


Fig: 3.2 Grey relational grades for each level of parameters

V. CONFIRMING RESULTS

The Confirmation for the optimal process parameters with its level was conducted to evaluate quality characteristics for Blanking of medium carbon steel sheet.[12] Table 12 shows highest grey relational grade, indicating the initial process parameters set of A1B1C1 for the best multiple performance characteristics among the nine experiments. Table 4.6 shows the comparison of the experimental results for the conditions (A1B1C1) with predicted result for optimal (A1B1C1) Blanking process parameters.
The predicted Values were obtained by

Predicted Response=Average of A1 + Average of B1 + Average of C1 – 2 x Mean of response (Yij)

The response value obtained from the experiment are Minimum Burr height = 0.013mm, Accuracy of Blank = 10.036mm, and Circularity of Blank = 0.048mm. The comparison is shows the good agreement between the predicted and experimental values.

	Optimal Process Parameters	
	Predicted	**Experimented**
Level	**A1B1C1**	**A1B1C1**
Burr Height	0.013	0.037
Accuracy of Blank	10.036	10.081
Circularity of Blank	0.048	0.033

Table 4.6 Confirmation Result

VI. CONCLUSION

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 the blank holder force and their interactions on the geometry of the sheared edge especially the burrs height. In general, clearance plays a key role in both product quality and the service life of dies. A good clearance design not only increases the quality of product manufactured, but also reduces product's burr. As a result, the wear of punches and dies can be greatly reduced and the life expectancy of punching dies increased. More punching times is positively related to bigger wear, while less punching times is related to smaller wear.

The quality of a product is the main factor for showing growth of a company. The quality of the product mainly depends upon the material and process parameters. Optimization technique plays a vital role to increase the quality of the product. To overcome the shortage of regression analysis and factor analysis, multi-attribute method, Grey relational analysis (GRA) has been proposed to solve the problem. The Grey Relational Analysis (GRA) associated with the Taguchi method represents a rather new approach to optimization. While only one outcome is optimized in the Taguchi method, multiple outcomes can be optimized in a Grey Relational Analysis. Grey relation analysis is an effective means of analysing the relationship between sequences with less data and can analyse many factors that can overcome the disadvantages of statistical method.

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