OPTIMIZATION OF PROCESS PARAMETERS IN ELECTROCHEMICAL DEBURRING OF DIE STEEL USING TAGUCHI METHOD

Manoj Singha[1], Soumyya Sarkar[1], Souren Mitra[1] & Arunanshu Shekhar Kuar[1]

[1]Jadavpur University, Production Engineering Department, 188, Raja Subodh Chandra Mullick Road, Jadavpur, Kolkata, West Bengal - 700032, India

Corresponding author: Manoj Singha, manoj.singha.ju@gmail.com

Abstract: In this paper, an experimental investigation into electrochemical deburring (ECD) of die steel is carried out. The Taguchi method is used to formulate the experimental plan to analyse the effect of each electrochemical deburring process parameters on change in burr height and to predict the optimal setting for each ECD process parameter. Taguchi's L_{16} orthogonal array design is chosen for the experiments. Maximization of change in burr height is selected as the required surface quality at lower machining time. The signal-to-noise ratio and the analysis of variance are used to find the optimum levels within the window of parameters selected and to identify the order of importance of the process parameters. Finally, a confirmation test is conducted, which verifies that optimal ECD parameters can be determined effectively so as improve the rate of change in burr height.

Key words: ECD; Taguchi method; Orthogonal array; Burr height; Optimization

1. INTRODUCTION

Deburring is a finishing method used in industrial setting and manufacturing environments. There is no standard procedure to remove burrs having different shape and dimensions. For removing burrs of different sizes, shapes and properties, a number of conventional processes are available. Conventional deburring processes necessitate time, labour and other associated costs. Electrochemical deburring has been found to offer a potential solution to these problems (Choi and Kim, 1998a; Jain, 2002; Sarkar et al., 2004). ECD is one of the most promising machining techniques in accuracy manufacturing and high quality machining. In ECD process any type of conducting materials can be used as the workpiece material apart from of its hardness. Due to electrochemical dissolution between tool and burr tip, the material removed from burr tip.

Many researchers have studied the ECD methods. Choi and Kim (1998b) explain the mechanism of ECD by using electroplated Cubic Boron Nitride (CBN) wheels that examined the deburring efficiency and the deburring performance through various electrolytic currents and other electrochemical conditions for an internal cross hole. Pramanik et al. (1982) has presented an investigation on the ECD process with graphite balls using turned aluminium specimens for three different electrolytes. Ghabrial and Ebeid (1981) pointed out that stationary machining is suitable for deburring, embossing, finishing of dies with intricate profiles for forging, pressure-casting and extrusion processes. Shome et al. (2008) presented an investigation on the ECD of stainless steel. Xu et al. (2010) developed a mathematical model that can predict the deburring time for different burr heights. Ning et al. (2011) analyzed pulse electrochemical deburring through a developed mathematical model.

However, it is necessary to find an optimal process condition capable of higher removal of burr.

Taguchi's philosophy for the robust design is an important and powerful tool for the purpose of designing and improving product quality (Phadke, 1989). The original Taguchi method is designed to optimize a single quality characteristic. Taguchi method has been successfully applied in different advanced manufacturing processes to optimize the control parameters (Amini et al., 2011; Acherjee et al., 2011).

In present research, experimental investigation on electrochemical deburring process of die steel is performed. Effort is also made to optimize the ECD process parameters with consideration of deburring characteristic like change in burr height using Taguchi method. Additional experiment has been carried out to verify predicted result at optimum level and an effective improvement is observed in selected deburring characteristics. In addition to that the effect of process parameters on deburring characteristics is also reported.

2. TAGUCHI METHOD

Taguchi (1991) method is a widely used approach for robust design, which utilizes an orthogonal array (OA) to obtain dependable information about the design parameter with minimum time and resources, and adopts signal-to-noise (S/N) ratio to interpret experimental data and optimize performance. Usually, there are three categories of quality characteristic in the analysis of the S/N ratio, i.e. the-higher-the-better, the-lower-the-better, and the-nominal-the-better (Ross, 1998). The S/N ratio for each level of process parameters is calculated based on the S/N analysis. Despite of the category of the quality characteristic, a greater S/N ratio corresponds to improved quality characteristics. Therefore, the optimal setting of the process parameters is the parameter combination, which has the greatest S/N ratio.

3. EXPERIMENTATION

3.1 Experimental set-up

To carry out experimental investigation, an ECD system having the provisions of controlled electrical power supply, electrolyte flow system and machining chamber was developed. The electrical circuitry of the ECD setup includes a DC power supply with electrical elements for sort-circuit prevention, spark detection and auto tripping operation of the ECD system. A sufficient flow of electrolyte into the gap between tool and the workpiece is necessary to carry away the heat and products of machining and to assist the machining process at required feed, producing satisfactory deburring results. The electrolyte flow system consists of a filter, pump, electrolyte storage tank, pressure gauge and flow measuring device, etc. Initially suction inlet valve and discharge outlet valve is open. For the large opening of the bypass outlet valve, the flow of electrolyte in the machining chamber must be reduced. The machining chamber is made of transparent perspex sheet. The perspex material has enough rigidity and also has good corrosion resistant properly against electrolytes generally used in ECD. Workpiece was fixed with machining chamber by the fixing arrangement. The fixture is used to hold the flat workpiece tightly and with a proper accuracy for better performance. Work holding device also connect the workpiece with the electric supply and a perspex sheet is used to prevent current flow through the machine body. A strap clamp, a square block and a stud with nut used as a work holding device. This strap clamp and stud are based on the lever principle to amplify the required clamping force. By tightening the stud, clamping force is transferred to the workpiece. Square block work as a fulcrum about which the lever acts while the clamping force is applied at the stud by tightening the bolt. Tool holding device is a tool post and a tool holder and they were adjusted by tightening the tool. The tool and workpiece material was copper and die-steel respectively. The composition of workpiece material given in Table 1.

Table 1. Composition of Die-steel

Composition	Symbol	Percentage
Carbon	C	0.35%
Manganese	Mn	0.4%
Silicon	Si	1.0%
Chromium	Cr	5.0%
Molybdenum	Mo	1.5%
Vanadium	V	1.0%

3.2 Experimental planning

The design of the experiments for exploring the influence of various predominant process parameters (e.g. deburring voltage, gap between tool and burr tip, electrolyte concentration and deburring time) on the machining characteristic (e.g. change in burr height) was modeled with respect to indigenously developed ECD set-up for observing the influence of the above process parameters on the machining rate and accuracy. The experimentation scheme based on Taguchi method was designed in such a way as to explore the influence of the various dominant machining parameters. The actual values of process parameters at various levels in this set of investigations are as shown in Table 2. The experimental plan chosen for studying the relationship between the controlling parameters and the various machining criteria, L_{16} orthogonal array and is shown in Table 3. According to Taguchi methodology, a large value of burr removal rate represents the better machining performance is called higher-the-better type problem.

For carrying out the experiments, a rectangular tip solid copper tool and triangular edge workpieces were used. $NaNO_3$ salt solution of varying concentration was chosen as the electrolyte, because of its good conductivity and non-passive characteristics. During the machining electrolyte supplied at constant flow rate for given time setting. After machining the change in burr height was measured by flat tip digital micrometer.

Table 2. Independent factor and their levels

Character	Control factors	Levels			
		1	2	3	4
V	Voltage (volts)	13	17	21	25
G	Gap between tool and burr tip (mm)	0.1	0.2	0.3	0.4
C	Concentration (gm/lit)	16	20	24	28
T	Time (min)	3	4	5	6

Table 3. Combination of input factors and the measured responses

Experiment No.	Control Factors				Response
	Voltage, V (volts)	Gap between tool and burr tip, G (mm)	Concentration, C (gm/lit)	Time, T (min)	Change in burr height (mm)
1	13	0.1	16	3	0.354
2	13	0.2	20	4	0.341
3	13	0.3	24	5	0.302
4	13	0.4	28	6	0.389
5	17	0.1	20	5	0.507
6	17	0.2	16	6	0.496
7	17	0.3	28	3	0.318
8	17	0.4	24	4	0.317
9	21	0.1	24	6	0.803
10	21	0.2	28	5	0.837
11	21	0.3	16	4	0.343
12	21	0.4	20	3	0.325
13	25	0.1	28	4	0.942
14	25	0.2	24	3	0.887
15	25	0.3	20	6	0.716
16	25	0.4	16	5	0.513

4. EXPERIMENTAL OBSERVATIONS

The goal of the study presented in this paper is to optimize the ECD parameters to get higher removal of burr. Thus, the observed values of change in burr height were set to maximum. That means the objective function, signal-to-noise ratio, is calculated based on the higher the better characteristic. This will be calculated as:

$$\eta_{HB} = -10\log_{10}[\frac{1}{n}\sum_{i=1}^{n}(1/y_i^2)]\text{ ; } i = 1,2,3\ldots n \qquad (1)$$

Table 4 shows the experimental results for signal-to-noise ratio.

Figure 1 shows the signal-to-noise ratio graph of four control factors on change in burr height. From Figure 1 it is observed that change in burr height has an increasing trend with increase of deburring voltage, electrolyte concentration and deburring time and the change in burr height has a decreasing trend with the increase of gap between tool and burr tip. Current density increased with increase of voltage and electrolyte concentration as a result burr removal rate increases. With decrease of gap between tool and burr tip, current density increased in the gap between tool and burr tip due to which removal rate of burr increased.

Table 4. Signal-to-noise ratio value for change in burr height

Experiment no.	S/N ratio (dB) value for change in burr height
1	-9.0199
2	-9.3449
3	-10.3999
4	-8.2010
5	-5.8998
6	-6.0904
7	-9.9515
8	-9.9788
9	-1.9057
10	-1.5455
11	-9.2941
12	-9.7623
13	-0.5190
14	-1.0415
15	-2.9017
16	-5.7977

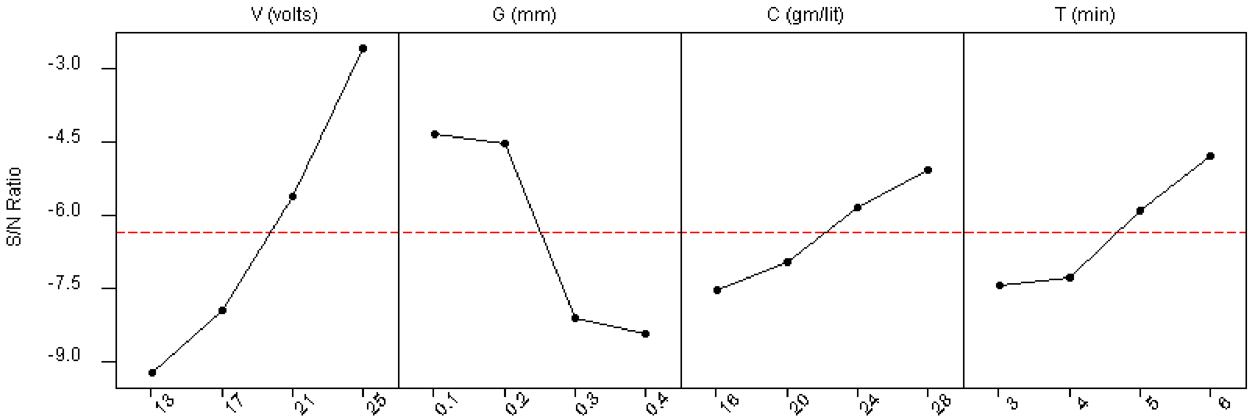

Fig. 1. signal-to-noise ratio graph for change in burr height

5. PARAMETRIC OPTIMIZATION OF ECD PROCESS

5.1 Optimal parameter setting of change in burr height

Since the experimental design is orthogonal, it is then possible to separate out the effect of each ECD process parameter at different levels. The mean S/N ratio for the gap between tool and burr tip at level 1, 2, 3 and 4 are calculated by averaging the S/N ratio for the experiment number 1to 4, 5 to 8, 9 to 12 and 13 to 16, respectively. Similarly, it is calculated for the respective levels for deburring voltage, electrolyte concentration and deburring time and is summarized in Table 5.

5.2 Analysis of variance

The purpose of the analysis of variance is to investigate which ECD parameters significantly affect the deburring quality characteristics. This is accomplished by separating the total variability of the response signal-to-noise ratios, which is measured by the sum of the squared deviations from the total mean of the response signal-to-noise ratio, into contributions by each of the process parameter and error. Statistically there is a tool called an *F*-test, named after R.A. Fisher (1925) to see which process parameters have a significant effect on the deburring quality characteristic. In performing the *F*-test, the mean of the squared deviations due to each of the process parameters must be calculated. The mean of the squared deviations is equal to the sum of the squared deviations divided by the number of degrees of freedom associated with the process parameter. Then the *F*-value for each process parameter is simply a ratio of the mean of the squared deviations to the mean of the squared error.

Usually, when the *F*-value is greater than 4 it means that a change in the process parameter has a significant effect on the deburring quality characteristics. Table 6 shows the results of analysis of variance, it can be found that deburring voltage has a higher significant effect and electrolyte concentration is near about significant effect on the defined deburring quality characteristics.

The same table shows the percentage contribution of each process parameter to the total variation indicating their degree of influence on the change in burr height.

The Figure 1 shows the optimal parametric combination where the optimal ECD parameter setting is to maintain voltage at level 4 (V=25volts), gap at level 1 (G=0.1mm), concentration at level 4 (C=28gm/lit) and time at level 4 (T=6 min) for maximizing the change in burr height.

Table 5. Response table for S/N ratio

ECD parameters	S/N ratios (dB)					
	Level 1	Level 2	Level 3	Level 4	Delta	Rank
V	-9.241	-7.980	-5.627	-2.565	6.676	1
G	-4.336	-4.506	-8.137	-8.435	4.099	2
C	-7.551	-6.977	-5.831	-5.054	2.496	4
T	-7.444	-7.284	-5.911	-4.775	2.669	3
Total mean value of S/N ratio (dB)= -6.353						

Table 6. Results of the ANOVA

Input Factor	Degrees of freedom	Sum of Squares	Mean Square	% of contribution	*F*-Value
Voltage	3	0.4211	0.1404	52.65	4.35
Gap between tool and burr tip	3	0.2387	0.0796	29.85	1.68
Concentration	3	0.0981	0.0327	12.67	
Time	3	0.0418	0.0139	5.23	
Error	3	0.0082	0.0027		
Total	15	0.8079			
S = 0.07524 R-Sq = 92.3% R-Sq(adj) = 89.5%					

Table 7. Results of confirmatory experiment

	Initial parameter setting	Optimal parameters	
		Prediction	Experiment
Level	$V_4 G_1 C_4 T_2$	$V_4 G_1 C_4 T_4$	$V_4 G_1 C_4 T_4$
Change in burr height (mm)	0.942		1.12
S/N ratio (dB)	-0.579	2.33	2.21
Improvement of S/N ratio = 2.789 dB			

5.3 Confirmation tests

After evaluating the optimal parameter settings, the final stage is to predict and verify the improvement of the deburring quality characteristics using optimal parameter setting. The predicted optimum signal-to-noise ratio can be calculated as:

$$\gamma_{opt} = \gamma_m + \sum_{i=1}^{o} (\bar{\gamma}_i - \gamma_m) \qquad (2)$$

where:

γ_m = Total mean of the signal-to-noise ratio

$\bar{\gamma}_i$ = mean signal-to-noise ratio at optimum level

o = number of ECD parameters that significantly affect the quality characteristics.

Confirmation experiment is performed by conducting a test with optimal setting of the ECD parameters and levels previously determined. Table 7 shows the comparison of the predicted and actual machining performance, using their respective optimal parameters. The improvement in signal-to-noise ratio at optimum level is found to be 2.789 dB. As shown in Table 7, the change in burr height increased from 0.942 to 1.12.

6. CONCLUSIONS

This paper has described an application of the Taguchi method to the optimization of change in burr height in the ECD process. It has been shown that the Taguchi method provides a systematic and efficient methodology for searching the ECD process parameters with an optimal burr removal rate. The optimal change in burr height has a higher-the-better quality characteristic for the deburring voltage and electrolyte concentration are the important ECD process parameters. Planned experiments and subsequent analyses are carried out to appraise the optimal parametric combination. The significant of the ECD parameters on deburring quality is evaluated quantitatively by ANOVA technique. According to ANOVA results, deburring time has the most dominant effect on the total variation. The confirmation experiments were conducted to verify the optimal ECD process parameters. It has been shown that change in burr height in the ECD process is greatly improved by using this approach.

7. REFERENCES

1. Choi, I-H., Kim, J-D., (1998a). *A study of the characteristics of the electrochemical deburring of a governor-shaft cross hole,* Journal of Materials Processing Technology, Vol. 75, pp.198–203.

2. Jain, V.K., (2002) *Advanced Machining Processes,* Allied Publishers, New Delhi.

3. Sarkar, S., Mitra, S., Bhattacharya, B., (2004). *Mathematical modeling for controlled electrochemical deburring (ECD),* Journal of Materials Processing Technology, Vol. 147, pp.241–246.

4. Choi, I-H., Kim, J-D., (1998b). *Electrochemical deburring system using electroplated CBN wheels,* Int. J. Mach. Tools Manufact., Vol. 38, pp.29–40.

5. Pramanik, D.K., Dasgupta, R.K., Basu, S.K., (1982) *'A study of electrochemical deburring using a moving electrode'*, Wear, Vol. 82, pp. 309-316.

6. Ghabrial, S.R., Ebeid, S.J., (1981). *Beneficial effect of air-electrolyte mixtures in stationery electrochemical machining,* Precision Engineering, Vol. 3, pp. 221-223.

7. Shome, D., Mitra, S., Sarkar, S., (2008). *Response surface methodology-based approach to electrochemical deburrring of SS304 stainless steel workpiece*, Int. J. Product Development, Vol. 6, No. 1, pp. 2-15.

8. Xu, W. J., Wang, W., Wang, X. Y., Pang, G. B., (2010). *Mathematical modeling of electrochemical deburring,* Advanced Materials Research, Vols. 126-128, pp. 545-550.

9. Ning, M., Wen, J. X., Wei, Z. F., Pang, G. B., (2011). *Modeling and experiment of pulse electrochemical deburring on inclined exit surface of exit hole,* Advanced Materials Research, Vols. 328-330, pp. 502-506.

10. Phadke, M.S., (1989). *Quality Engineering Using Robust Design*, Prentice-Hall, Englewood CL.

11. Amini, H., Soleymani, Yazdi M. R., Dehghan, G. H., (2011). *Optimization of process parameters in wire electrical discharge machining of TiB_2 nanocomposite ceramic*, Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 225(12), pp. 2220-2227.

12. Acherjee, B., Kuar, A. S., Mitra, S., Misra, D., (2011). *Selection of process parameters for optimizing the weld strength in laser transmission welding of acrylics*, Proc. IMechE Part B: Journal of Engineering Manufacture, SAGE Publications (UK), 2010, 224(B10), 1529–1536.

13. Taguchi, G., (1991). *Taguchi methods.* Research and development, Vol. 1. MI: American Suppliers Institute Press, Dearborn**.**

14. Ross, P.S., (1998). *Taguchi technique for quality engineering,* McGraw Hill, Newyork.

15. Fisher R.A., (1925). *Statistical methods for the research worker,* Oliver and Boyd, London.

Received: April 5, 2012 / Accepted: June 8, 2012 / Paper available online: June 10, 2012 © International Journal of Modern Manufacturing Technologies.