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Research Article

Performance Study of Electrical Discharge Machining (EDM) Process in Burr Removal of Drilled Holes in D2 Steel

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Abstract

Deburring is a finishing process in which burrs and sharp edges are removed from metal, plastics and other work piece materials. This research paper is about deburring through Electric Discharge Machining process (EDM), which is useful for finishing materials with very high precision. This is one of the latest process, which are called as Advanced Finishing Processes. In this research, the drilling operation was done on the specimen material D2 to obtain burrs and comparative study was done with different parameters and different electrodes for deburring effectively through EDM. The variable parameters were discharge current, pulse time on and pulse time off and other parameters were remained constant. Material removal rate, tool wear rate and burr height were studied as output parameters to analyze the performance of the combination of the input parameters for burr removal. Grey relational analysis was used to find out the optimal levels of the parameters with copper and brass electrodes respectively. And obtained contour graphs shows the effect of input parameters on the output parameters.

Keywords: *EDM, D2, Burrs, Deburring, Material Removal Rate, Tool Wear Rate, GRA.*

1. Introduction

Metal is frequently machined using many processes in order to create pieces of specific shape and size. Like Drilling is a cutting process. It is the creation or enlarging of a hole in a solid material with a drill. These procedures often create ragged edges or protrusions (burrs). Removal of burrs (Deburring) is important for quality, aesthetics, functionality, and the smooth operation of working parts. It greatly improves the quality and functionality of metal and wood pieces, making it a necessary use of time and a cost effective process. A Burr is a raised edge or small pieces of material remaining attached to a work piece after a modification process. It is usually an unwanted piece of material, removed with a deburring tool in a process called 'deburring'. Burrs are most commonly created after machining operations, such as grinding, drilling, milling, engraving, or turning. The ISO 13715:2000 defines the edge of a work piece as burred if it has an overhang greater than zero. A comprehensive definition was proposed by Beier, according to it, a burr is a body created on a work piece surface during the manufacturing of a work piece, which extends over the intended and actual work piece surface and has a slight volume in comparison to the work piece, undesired, but to some extended, unavoidable (H.M. BEIER, 1999). Machining burrs typically form because of material being plastically deformed rather than cut towards the entrance or exit of a machined feature. Burrs are formed in most of the machining operations; they cannot be eliminated during the machining process, but can be minimized by controlling the process parameters, tool geometry, etc. (Young Hun Jeong, Byung Han Yoo, Dong–Woo Cho and Sang Jo Lee, 2009). According Aurich, a study carried out in the German automotive and machine tool industries showed that the deburring causes an increase of about 15% in work force and cycle times. In addition, a 2% share in the reject rate and a 4% share in machine breakdown times due to burrs. Averaging the presented distribution without any weight factors the share accounts of up to 9% of total manufacturing cost. An economic evaluation of the impact of burrs related Aurich has provided production cost too, the costs are estimated at up to 500 million Euro expense per year only in Germany (J.C. Aurich, 2006).

According to Gillespie (L.K. Gillespie, 1999), in drilling the burr formed at the entrance of the hole can be a result of tearing, a bending action followed by clean shearing, or lateral extrusion when chip forming and impacting of cutting edges. Kim and others (J. KIM., S. Min., and D. Dornfeld, 2001) describe drilling burrs as uniform burr with or without a drill cap, crown burr, or petal burr according to their shapes and formation mechanism. When drilling stainless steel, Stein (J. Stein, D.A. Dornfeld, 1997) revealed small or large uniform burrs as well as crown burrs, and when low alloyed

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steel drilling small or large uniform burrs, transient burrs and crown burrs were found. It was found that the constant ratio between burr height and undeformed chip thickness might be a fundamental property of work material for particular tool geometry (J. Stein, D.A. Dornfeld, 1997).

Burr shape is the most important because the burr size, and as a result, deburring cost is greatly dependent on it. Three different shapes of drilling burrs:

A. The uniform burr has relatively small and uniform burr height and thickness around the hole periphery.
B. The crown burr has a larger and irregular height distribution around the hole.
C. The transient burr is a type of burr formed in the transient stage between the uniform burr and the crown burr (Dornfeld, D.A., 2006).

Deburring is an essential secondary operation, which is mainly used for burr removal. Deburring is usually the last process during part production, therefore the loss of potential due to any failure in deburring process is very large (Dornfield, S. Min and J. Kim, 2001). Deburring includes both the removal of burrs and maintenance of the proper edge condition. Deburring of inaccessible, an area via conventional methods does not ensure burr removal and edge conditioning; deburring via non–conventional techniques provides a better solution (R. Balasubramaniam, J. Krishnan, N. Ramakrishnan, 1998). The limitations of traditional finishing led to the development of advanced finishing techniques like Abrasive Flow Machining, Magnetic Abrasive Finishing, and Ion Beam Machining, Electric Discharge Machining.

Electric discharge machining

It is a manufacturing process whereby a desired shape is obtained using electrical discharges (sparks). Material is removed from the work piece by a series of rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage. One of the electrodes is called the tool-electrode, or simply the 'tool' or 'electrode', while the other is called the work piece-electrode, or 'work piece'. In this process, the metal is removing from the work piece due to erosion case by rapidly recurring spark discharge taking place between the tool and work-piece. The electrode and the work piece must have electrical conductivity in order to generate the spark (N. M. Abbas, D. G. Solomon and F. Bahari, 2006). EDM is a non-conventional machining process but the technique of material erosion employed in EDM is still debatable (Tsai, K.M., Wang, P.J., 2001). The basic principal followed is the conversion of electrical energy into thermal energy through a series of discrete electrical discharges occurring between the electrode (tool) and work piece immersed in a dielectric fluid (Kalpajian, S., Schmid, S.R., 2003).

Input Process Parameters of EDM	***Output Parameters or Responses***
• Discharge current	• Material removal rate
• Pulse time on	• Tool wear rate
• Pulse time off	• Burr Height

Surendra S. Kurane, Uday A. Dabade investigated that the quality of the burr removed with Brass electrode is better as compared with Aluminum and Copper electrodes. Secondly, it observed that the Aluminum electrodes wear is more irrespective of process parameters due to lower electrical conductivity than other electrodes. Finally, it is concluded that the Brass electrodes gives better results in terms of quality, material removal rate, and electrode wear than Aluminum and Copper electrodes (Kurane Surendra S., Dabade Uday A., 2011).

Optimization technique

It is a mathematical results and numerical methods for finding and identifying the best candidate from a collection of alternatives without having to explicitly enumerate and evaluate all possible alternatives.

2. Details of the Experiment

To obtain the burrs and to see the burr formation, each work piece was drilled by HSS cutting tool in the wet cutting conditions. Further, EDM Operations were performed to measure material removal rate and tool wear rate on each work piece, In order to study the effect of three different parameters (current supply, pulse time on, & pulse time off with different electrodes) on the burr removal of the specimens.

2.1 Details of the Specimen Materials selected for the proposed Research work

D2 were selected as the specimen materials for the research work. The material composition of specimen material D2 is shown in Table no. 1 and physical and mechanical properties are shown in Table no. 2 respectively.

Fig1. Raw specimen material – D2 Steel

Table1. Material Composition of D2 steel specimen

Component	Wt. %
C	1.50%
Si	0.60%
Cr	12.00%
Mo	0.80%
V	0.90%
S	0.03%
Mn	0.6%
Co	1.0%
Cu	0.25%
Ni	0.30%

Table2. Mechanical properties of D2 steel specimen

Physical Properties	**Metric**
Density	7.7 x 1000 kg/m^3
Melting point	1421°C
Mechanical Properties	
Hardness, Knoop	769
Hardness, Rockwell C	62
Hardness, Vickers	748
Izod impact unnotched	77.0 J
Poisson's ratio	0.27-0.30
Elastic modulus	190-210 GPa

Typical applications for D2 tool steel are blanking, forming, and trim dies, gages, slitting cutters, wear parts, lamination dies, thread rolling dies, drawing dies, rotary cutting dies, knurls, bending dies, gages, shear blades, burnishing tools, rolls, machine parts, master parts, injection screw and tip components, seaming rolls, extrusion dies, tire shredders, scrap choppers, etc.. D2 tool steels are used for long run tooling applications, where wear resistance is important, such as blanking or forming dies and thread rolling dies.

2.2 Cutting tools used

Brass: Brass is the generic term for a range of copper-zinc alloys with differing combinations of properties, including strength, machinability, ductility, wear-resistance, hardness, colour, antimicrobial, electrical, and thermal conductivity, corrosion resistance. Brass has higher malleability than bronze or zinc. The relatively low melting point of brass (900 to 940 °C, 1652 to 1724 °F, depending on composition) and its flow characteristics make it a relatively easy material to cast.

Copper

Copper has properties, such as its high electrical conductivity, tensile strength, ductility, creep (deformation) resistance, corrosion resistance, low thermal expansion, high thermal conductivity, solder ability, and ease of installation. Copper is a chemical element with symbol Cu and atomic number 29. It is a ductile metal with very high thermal and electrical conductivity. Pure copper is soft and malleable. A freshly exposed surface has a reddish-orange color.

2.3 Grey relational analysis

Deng proposed it in 1989 as cited in is widely used for measuring the degree of relationship between sequences by grey relational grade. Several researchers to Optimize control parameters having multi-responses through grey relational grade apply grey relational analysis. Deng (Deng, J.L., 1989) had proposed Grey relational analysis in the Grey theory that was already proved to be a simple and accurate method for multiple attributes decision problems (Hsu T.H., 1997), (Chang, Y.C., 1996), (Tzeng, G.H. and Tsaur, S.H., 1994), (Luo, M. and Kuhnell, B.T., 1993), especially for those problems with very unique characteristic (Chiang, K.S., 1997), (Wu, H.H., 1998). This analytical model magnifies and clarifies the Grey relation among all factors. It also provides data to support quantification and comparison analysis (Sih, K.C., 1997). In other words, the Grey relational analysis is a method to analyze the relational grade for discrete sequences. This is unlike the traditional statistics analysis handling the relation between variables. The use of grey relational analysis to optimize the burr removal operations includes the following steps:

1. To identify the performance characteristics and process parameters to be evaluated.
2. To determine the number of levels for the process parameters.
3. To select the appropriate orthogonal array and assign the process parameters to the orthogonal array.
4. To conduct the experiments based on the arrangement of the orthogonal array.
5. To perform the grey relational generating and calculate the grey relational coefficient.
6. To calculate the grey relational grade by averaging the grey relational coefficient.
7. To analyses the experimental results using the grey Relational grade.
8. To select the optimal levels of machining parameters.

2.3.1 Data Pre-Processing

In grey relational analysis, the data pre-processing is the first step performed to normalize the random grey data with different measurement units to transform them to dimensionless parameters. Thus, data pre-processing converts the original sequences to a set of comparable sequences. Different methods are employed to pre-process grey data depending upon the quality characteristics of the original data. The original reference sequence and pre -processed data (comparability sequence) are represented by $X_0^{(0)}$ and $X_i^{(0)}$, and i =1,2,….,m; k =1,2,.....,n respectively, Where m is the number of experiments and n is the total number of observations of data. Depending upon the quality characteristics, the three main categories for normalizing the original sequence:

If the original sequence data has quality characteristic as 'larger-the-better' then the original data is pre-processed as 'Larger-the-best'

$$x_i\,(k) = \frac{x_i^{(0)}\,(k) - \min\, x_i^{(0)}(k)}{\max x_i^{(0)}(k) - \min\, x_i^{(0)}(k)} \quad (1)$$

If the original data has the quality characteristic as 'smaller the better', then original data is pre-processed as 'Smaller-the best'

$$x_i^*(k) = \frac{\max\, x_i^{(0)}(k) - x_i^{(0)}(k)}{\max\, x_i^{(0)}(k) - \min x_i^{(0)}(k)} \quad (2)$$

However, if the original data has a target optimum value (OV) then quality characteristic is 'nominal-the-better' and the original data is pre-processed as 'nominal-the-better'

$$x_i^*(k) = 1 - \frac{|x_i^{(0)}(k) - OV|}{\max\{\max x_i^{(0)}(k) - OV, OV - \min x_i^{(0)}(k)\}} \quad (3)$$

In addition, the original sequence is normalized by a simple method in which all the values of the sequence are divided by the first value of the sequence.

$$x_i^*(k) = \frac{x_i^{(0)}(k)}{x_i^{(0)}(1)} \quad (4)$$

Where max $X_i^{(0)}$ (k) and min $X_i^{(0)}$ (k) are the maximum and minimum values respectively of the original sequence $X_i^{(0)}$ (k).Comparable sequence $X_i^*(k)$ is the normalized sequence of original data.

2.3.2 Grey Relation Grade

Next step is the calculation of deviation sequence, $\Delta O_i\,(k)$ from the reference sequence of pre-processes data $x_i^*(k)$ and the comparability sequence $x_i^*(k)$.The grey relational coefficient is calculated from the deviation sequence using the following relation:

$$\gamma(x_0^*(k),\ x_i^*(k)) = \frac{\Delta \min + \xi\Delta\max}{\Delta\, oi(k) + \xi\Delta\max}\ 0 < \gamma(x_0^*(k), x_i^*(k)) \leq 1 \quad (5)$$

Where $\Delta O_i\ (k)$ is the deviation sequence of the reference sequence $X_0{}^*(k)$ and comparability sequence $X_i{}^*\,(k)$.

$$\Delta 0i(k) = |x_0^*(k) - x_i^*(k)| \quad (6)$$

$$\Delta\max = \max_{\forall j \in i}\max_{\forall k} |x_0^*(k) - x_i^*(k)| \quad (7)$$

$$\Delta\min = \min_{\forall j \in i}\min_{\forall k} |x_0^*(k) - x_i^*(k)| \quad (8)$$

ξ is the distinguishing coefficient $\xi \in [0, 1]$. The distinguishing coefficient (ξ) value is chosen to be 0.5. A grey relational grade is the weighted average of the grey relational coefficient and is defined as follows:

$$\gamma(x_0^*, x_i^*) = \sum_{k=1}^{n} \beta k y(x_0^*(k), x_i^*(k)), \sum_{k=1}^{n} \beta k = 1 \quad (9)$$

The grey relational grade ($x_0{}^*$, $x_i{}^*$) represents the degree of correlation between the reference and comparability sequences. If two sequences are identical, then grey relational grade value equals unity. The grey relational grade implies that the degree of influence related between the comparability sequence and the reference sequence. In case, if a particular comparability sequence has more influence on the reference sequence than the other ones, the grey relational grade for comparability and reference sequence will exceed that for the other grey relational grades. Hence, grey relational grade is an accurate measurement of the absolute difference in data between sequences and can be applied to appropriate the correlation between sequences.

2.4 Methodology

For the proposed work, the following Methodology was adopted:

1. To prepare the specimen
2. To prepare the electrode tools
3. To perform Drilling operation on the specimen
4. To investigate the following:
   - Burrs height measurement
   - Weight measurement
5. To perform EDM operation to remove burrs with define parameters
6. To investigate the following after EDM process:
   - Burrs height measurement
   - Weight measurement
7. To analyse tool Electrode weight
8. To find optimal results through Grey relational analysis based calculation

D2 specimen was cut in desired dimensions by chain drilling operation because of its high strength and hardness. The desired dimensions of specimen work piece are shown in table no. 3. The brass and the copper electrode rods also were cut into small pieces as per required dimensions as shown in table no. 4.

Table3. Dimensions of specimen

Specimen Material D2 Steel	
Length	40±0.5
Breath	25±0.5
Height	30±0.5

Table4. Dimensions of electrodes

	Brass	Copper
Diameter	5±0.5	5±0.5
Length	30±0.5	30±0.5

Then drilling operations were performed on each work pieces to see the burrs formation. As the result of drilling operation variety of burrs were formed as shown in figure no. 2 & 3. As per requirement two holes were drilled on each work piece and burr height were measured with digital Vernier callipers. Then Average burr heights, weight of the specimen were calculated for calculation purpose. Later EDM machining were done on each work piece according to L4 array as shown in table no. 5 with three factors and two levels of each factors as shown in table no. 6.

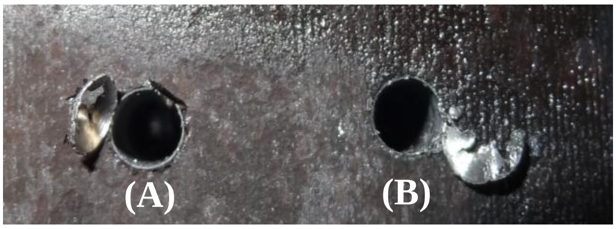

Fig 2. Burrs formed in D2 (A) Uniform Burr with cap (B) Uniform Burr with chips

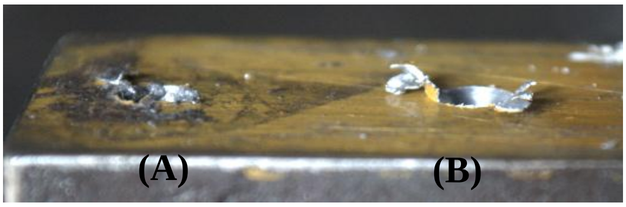

Fig3. Burrs formed in D2 (A) Non-Uniform Burr (B) Transient Burr

Table5. Standard L4 Orthogonal Array

Experiment No.	Factor A	Factor B	Factor C
1.	1	1	1
2.	1	2	2
3.	2	1	2
4.	2	2	1

Table6. Experimental factors and their levels for EDM Operation on 'D2'

Sym.	Cutting parameter	Unit	Lev. 1	Lev. 2
A	Discharge Current (DC)	Amp.	15	20
B	Pulse Time on (P Ton)	µ sec.	10	11
C	Pulse Time off (P Toff)	µ sec.	8	9

The experimental setup of EDM machine is shown in figure no. 4.

Fig4. Experimental Setup of EDM

3. Results and discussion

The factors were varied at two levels for burr removal machining operations in EDM process. Analysis of the results was carried out analytically as well as graphically. All the statistical calculations and plots were generated by MINITAB 17 software.

There were four optimal combinations of the parameters at which experimental processes were performed and the corresponding Material Removal Rate (MRR) and Tool Wear Rate (TWR) were found out by the following formulas:

$$\text{MRR} = \left[\frac{\{E2-E1\}}{\rho * t}\right] * 1000 \quad \text{mm}^3/\text{ sec.} \qquad (10)$$

Where E1 = weight of material before EDM in gm.
E2 = weight of material after EDM in gm.
ρ = density of the material in gm/cm^3
T = machining time in seconds

$$\text{TWR} = \left[\frac{\{E2-E1\}}{\rho * t}\right] * 1000 \quad \text{mm}^3/\text{ sec} \qquad (11)$$

Where E1 = weight of material before EDM in gm.
E2 = weight of material after EDM in gm.
ρ = density of the material in gm/cm^3
T = machining time in seconds

3.1 With Copper Electrode

Table7 presents the experimental result and effect of three input control parameters (discharge current, pulse time on and pulse time off) on D2 specimen with copper electrode in terms of three output parameters (material removal rate, tool wear rate and burr height). Table8 represent data pre-processing results for EDM operation on specimen with copper electrode. For MRR largest is best (eqation1) and for TWR and BH smallest is best (eqation2) is used. Here it was not possible to calculate the Material removal rate at macro level due to the less material removal from the specimen material. So only Tool Wear Rate and change in Burr Height were examined. Table9 represents the Deviation Sequence for EDM Operation for out parameters. The deviation sequences ΔOi, ΔOi max (k) and ΔOi min (k) were calculated.

The deviation sequences ΔO_1 (1) were calculated as:

ΔOi (k) =|x_0* (k) - x_i* (k) | = |1.0000– 0.000| = 1.0000.

Table7. Results of Experimental Trial Runs for EDM on 'D2' with Copper Electrode

Run No.	D C (Amp)	P Ton (μ sec)	P Toff (μ sec)	TWR (mm^3/sec)	BH (mm)
1	15	10	8	0.00755	0.025
2	15	11	9	0.00755	0.015
3	20	10	9	0.00755	0.025
4	20	11	8	0.00755	0.055

Table8. Data Pre-processing result for EDM Operation on 'D2' with Copper Electrode

Run No.	TWR (mm^3/sec)	BH (mm)
1.	1.00	0.95
2.	1.00	1.0
3.	1.00	0.0
4.	1.00	0.82

Table9. Deviation Sequence for EDM Operation on 'D2' with Copper Electrode

Run No.	TWR (mm^3/sec)	BH (mm)
1.	0.00	0.05
2.	0.00	0.0
3.	0.00	1.0
4.	0.00	0.18

In table10 grey relational grades are shown, the Grey relational grades shows the level of correlation between the reference and the comparability sequences, the larger Grey relational grade means the comparability sequence exhibiting a stronger correlation with the reference sequence. So here, combination 2 tells the optimal combination of parameters. The response table was used to calculate the average Grey relational grades for each factor level, as listed in Table11. Based on this study, a combination of the levels that provide the largest average response can be selected. Here from table11 the optimal levels A1, B2, and C1 were found.

Table10. Calculated Grey Relational Coefficients and Grey Relational Grade for EDM Operation on 'D2' with Copper Electrode

Run No.	Grey Relational Coefficient for		Grey Relational Grade
	TWR	BH	
1	1.00	0.9090	0.9545
2	1.00	1.0000	1.0000
3	1.00	0.3333	0.6665
4	1.00	0.7352	0.8676

Table11. Response Table for Grey Relational Grade for EDM Operation on 'D2' with Copper Electrode

	Factors		
Levels	D C	P T on	P T off
1.	0.9772	0.8105	0.9110
2.	0.7670	0.9338	0.8332

From minitab17 software graphs were obtained for each output, parameters (figure 5). Contour graphs are surface graphs plotted in 2D space. Viewing a contour graph is the same as viewing a 3D surface graph from a vantage point perpendicular to the XZ plane. In contour graphs, different colors or levels of gray scale, labeled contour lines, or both distinguish ranges of Z values.

Fig. 5 (A), (B) depicts that maximum Burr Removal (maximum change in burr height) (BH) was found when the discharge current values were kept between 18-19 Amp. and pulse time on values between 10.2-10.4 μ sec. with all the chosen level of pulse time off.

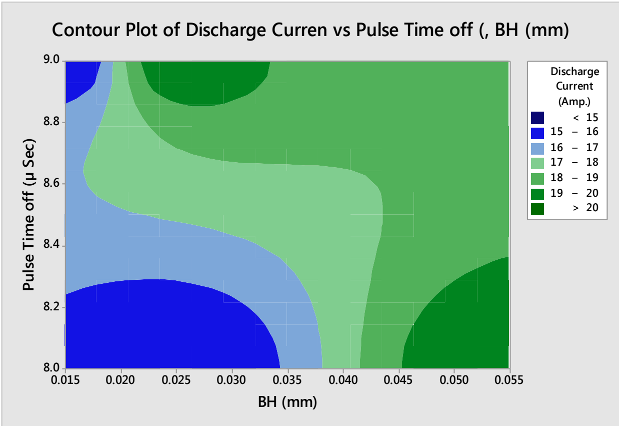

Fig 5 (A). Contour plot for D2 specimen showing the Effect on BH with respect to Pulse time off and Discharge Current when machined with Copper electrode

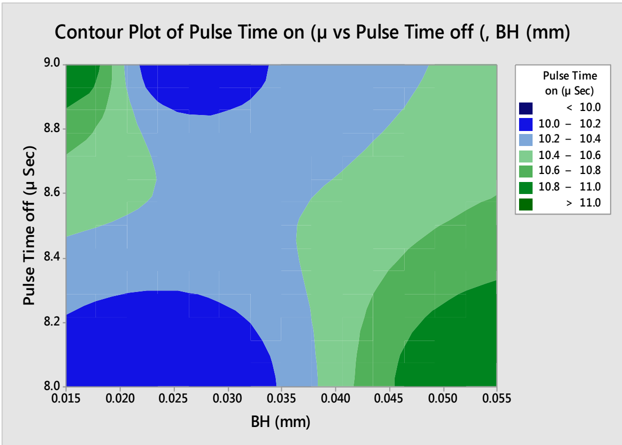

Fig 5 (B). Contour plot for D2 specimen showing the Effect on BH with respect to Pulse time on and pulse time off when machined with Copper electrode

Because tool wear rate was same for all the experiments with copper electrode so it was not possible to plot contour graph for TWR.

3.2 With Brass electrode

With brass electrode, all calculations were done as it was done with copper electrode. Here, Table12 presents the experimental result and effect of three input control parameters on D2 specimen with brass electrode in terms of output parameters. Table13 represent data pre-processing results for EDM operation on specimen. Table14 represents the Deviation Sequence for EDM Operation for out parameters.

Table12. Results of Experimental Trial Runs for EDM on 'D2' with Brass electrode

Run No.	D C (Amp)	P Ton (μ sec)	P Toff (μ sec)	TWR (mm³/sec)	BH (mm)
1	15	10	8	0.31189	0.045
2	15	11	9	0.07797	0.06
3	20	10	9	0.31189	0.035
4	20	11	8	0.15594	0.6

Table13. Data Pre-processing result for EDM Operation on 'D2' with Brass Electrode

Run No.	TWR (mm³/sec)	BH (mm)
1.	0.0000	0.98
2.	1.0000	0.95
3.	0.0000	1.0
4.	0.4221	0.0

Table14. Deviation Sequence for EDM Operation on 'D2' with Brass Electrode

Run No.	TWR (mm³/sec)	BH (mm)
1.	1.0000	0.02
2.	0.0000	0.05
3.	1.0000	0.0
4.	0.5779	1.0

Here in table15, by the grey relational grade the optimal combination of machining was found no. 2. Here from response table 16 the optimal levels A1, B2, and C2 were found.

Table15. Calculated Grey Relational Coefficients and Grey Relational Grade for EDM Operation on 'D2' with Brass Electrode

Run No.	Grey Relational Coefficient for		Grey Relational Grade
	TWR	BH	
1	0.3333	0.9615	0.6474
2	1.0000	0.9090	0.9545
3	0.3333	1.0000	0.6665
4	0.4640	0.3333	0.3986

Table16. Response Table for Grey Relational Grade for EDM Operation on 'D2' with brass electrode

	Factors		
Levels	D C	P T on	P T off
1.	0.8009	0.6569	0.5230
2.	0.5325	0.67655	0.8105

Here also in contour plot shows the effect on output parameters with different level of input parameters.

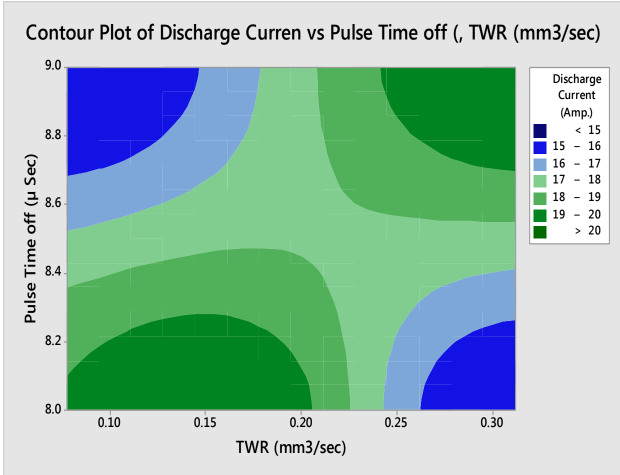

Fig 6 (A). Contour plot for D2 specimen showing the Effect on TWR with respect to Pulse time off and Discharge Current when machined with Brass electrode

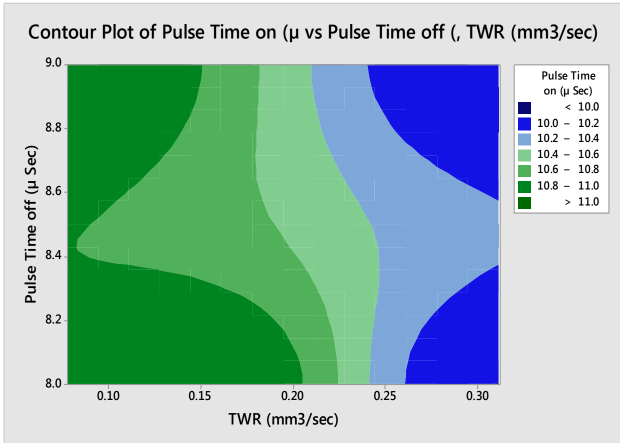

Fig 6 (A). Contour plot for D2 specimen showing the Effect on TWR with respect to Pulse time off and Pulse time on when machined with Brass electrode

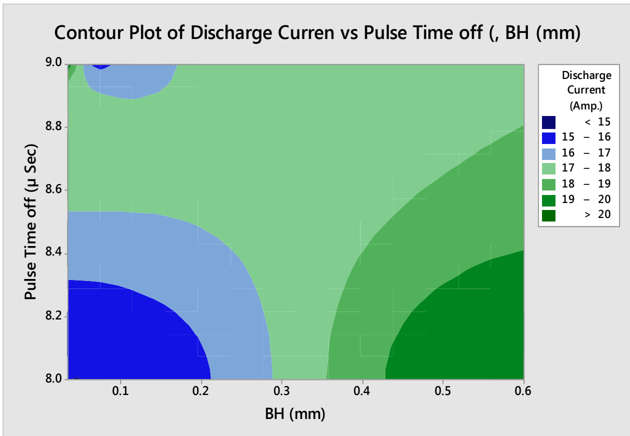

Fig 7 (A). Contour plot for D2 specimen showing the Effect on BH with respect to Pulse time off and Discharge Current when machined with Brass electrode

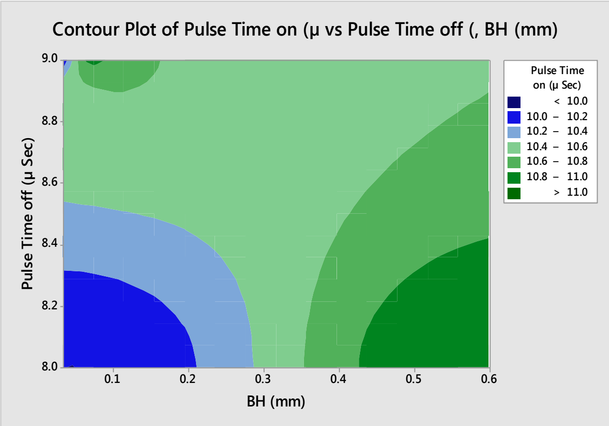

Fig 7 (B). Contour plot for D2 specimen showing the Effect on BH with respect to Pulse time off and Pulse time on when machined with Brass electrode

Fig. 6 (A), (B) depicts that minimum tool wear rate (TWR) was found when the discharge current values were kept between 17-18 Amp and pulse time on values are greater than 11 μ sec. with all the chosen level of pulse time off. Similarly, Fig. 7 (A), (B) depicts that maximum change in burr height (BH) was found when the discharge current values were kept between 17-18 Amp and pulse time on values between 10.4-10.6 μ sec. with all the chosen level of pulse time off.

Conclusion

In the present research work, drilling operations were performed on specimen material D2 to investigate the formation of burr and their removal to the maximum extent as per the recommendations of latest research works. The research work consisted of removal of burrs (deburring) though EDM unconventional machining method. Optimum combinations were obtained for machining parameters such as discharge current, pulse time on and pulse time off for change in burr height (BH), tool wear rate (TWR), material removal rate (MRR) through Grey Relational Analysis.

Following were the conclusions:

- While machining with copper electrodes, the Optimal parameters for deburring on D2 specimen material, consisted of minimum value of discharge current, maximum value of pulse time on and minimum value of pulse time off.
- While machining with brass electrodes, the Optimal parameters for deburring on D2 specimen material, consisted of minimum value of discharge current, maximum value of pulse time on and maximum value of pulse time off.

Various contour plots indicated the effect of the input control process parameters on material removal rate and tool wear rate.

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