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Performance Evaluation of Powder Metallurgy Processed Cu-Ti Electrodes in EDM of a AISI P20 Steel

Karambir Singh[1], Paramjit Singh[2], Gaurav Tejpal[3]

[1]*Department of Mechanical Engineering, ACET, Amritsar, Email:* karambirksn@yahoo.co.in
[2]*Department of Mechanical Engineering, ACET, Amritsar, Email:* er_pannu266@yahoo.com
[3]*Department of Mechanical Engineering, ACET, Amritsar, Email:* gaurav_tejpal@acetedu.in

Abstract— Conventional copper electrode is mostly used in electrical discharge machining process. But in the recent years powder metallurgy processed electrodes is used in few studies during EDM to enhance its performance characteristics. In this research work, an attempt has been made to evaluate the performance of powder metallurgy processed copper-titanium electrodes in comparison with conventional copper electrode in EDM process. Two powder metallurgy processed electrodes (90%Cu + 10% Ti) and (80%Cu + 20% Ti) and one conventional electrolytic copper rod tool electrode are used during EDM of AISI P20 steel and experimental results are presented in terms of material removal rate and tool wear rate. L_{18} orthogonal array of Taguchi methodology is employed to design experimental runs. Analysis of variance tables are used to summarize to results and to identify the percentage contribution of EDM variables affecting the performance characteristics. Experimental results are presented to demonstrate the effect of variables.

Keywords- electrical discharge machining (EDM); powder metallurgy; material removal rate (MRR); tool wear rate (TWR); Taguchi method

I. INTRODUCTION

Electrical Discharge Machining is one of the widely accepted non-conventional machining processes by tool and die manufacturing industry. This process is purely based on thermal energy produced by the electrical sparks between electrical conductive tool and work-piece material. This process is used in machining of intrinsic geometrical shapes and hard to cut materials. In this process there is no direct contact between tool and work-piece, thus eliminating mechanical stresses and vibrations during the machining process. Since material removal is associated with electrical sparks and not due the direct mechanical action, the material removal is not restricted by the work-piece hardness. The main factor which influences the machining is electrical conductivity of the material. Now days some conductive ceramics are also machined by this process. In 1770, it was Joseph Priestly, an English scientist, who discovered the erosive effect of electric discharges [1]. It was the first time in 1943, when N. I. Lazarenko and B. R. Lazarenko [2] used the electrical discharges in controlled manner for machining purpose, which is now being referred to as non-conventional machining process. The recent development in material science leads to new materials such as super alloys, ceramics composites, carbides, mould steels, etc. Modern manufacturing industry faces challenges, while machining of these materials, which are difficult to cut by conventional methods. EDM process is able to machine hard materials, and efficiently produces the complex geometrical shapes with higher degree of dimensional accuracy. Since the inception of EDM process, the process itself becomes very advance. Many researchers used different techniques for the better implementation of this process. In EDM process the major cost and time is associated with electrode fabrication. Electrode fabrication may account for over 50% of the total machining cost [3]. The common material used for EDM electrodes are copper, brass, tungsten, chromium, copper tungsten and copper chromium alloys [4, 5, 6]. Conventional methods of electrode fabrication require long processing time along with material wastage, if a complex shape is required [7, 8]. Most of the researchers used conventional electrodes, but fabrication of complex geometrical shaped electrode at lower cost is big challenge to the researchers and manufacturing industry. The one alternative to this challenge is using powder metallurgy electrodes instead of electrodes fabricated by conventional methods. Powder metallurgy electrodes are more economic to fabricate, as the same die and punch can be used to manufacture a large number of tool electrodes in one go. Also properties of different materials can be combined or enhanced by this technique. Using powder metallurgy electrodes is a feasible technique to get the desired material properties in the EDM process. Gangadhar et al. [9] accounts for surface deposition of tungsten carbide on the work-piece by using the powder metallurgy tool electrode having 40% WC and 60% Fe. Soni and Chakraverti [10] reported change in re-solidified layer due to migration of elements from tool electrode to the work-piece, thus resulting in surface alloying. Wang et al. [11] observed a hard ceramic layer on the work-piece by using Ti powder green compact tool electrode. Beri et al. [12] compared the performance characteristics of conventional copper electrode (Cu) with powder metallurgy electrode of copper tungsten (CuW) having 30%Cu and 70%W on AISI D2 work-piece in kerosene dielectric. It was concluded from the experiments that CuW electrode is better for higher surface finish, Cu electrode gives high MRR.

Form the above literature it is clear that, powder metallurgy compact electrodes have significant role in the EDM process. Powder metallurgy electrodes contribute in surface modification along with material removal during the process. This creates a need of research in this area of electro discharge machining. Cu-Ti powder metallurgy electrodes having different ratios of Cu and Ti along with conventionally processed electrolytic copper tool electrode was used to compare and optimize the process parameters in the EDM process.

II. EXPERIMENTAL STRATEGY AND MATERIAL

A. Second Equipment used

A number of experimental runs were performed on OSCARMAX S645 CNC EDM machine. Working tank dimensions of machine are length: 1500mm, width: 940mm and height: 520 mm and work table dimension are length: 1000mm and width: 600mm. Dielectric fluid capacity of integrated machining tank of machine was 1200 liter. Adair Dutt AD3000 weight balance was used to measure initial and final weight of work-piece and tool electrode before and after each experimental run. Standard EDM oil was used as the dielectric fluid and the integrated side injection flushing system of machine tool for dielectric fluid was used. To ensure adequate flushing of the debris from the gap zone, jet flushing system composed of two nozzles was employed near to place of cut.

B. Work-piece and tool electrode

One electrolytic copper solid rod diameter 9.5 mm is used as tool electrode. Important physical and mechanical properties of electrolytic copper are melting point 1,360 K, density 8.94 g/cm^3, thermal conductivity 226W/m.K, electrical resistivity 17.1nΩm. Two powder metallurgy processed electrodes in which the weight percentage of copper and titanium is varied are also used as tool electrodes. One electrode composed 90% of copper and 10% of titanium by weight and other electrode composed 80% of copper and 20% of titanium by weight. AISI P20 tool steel is used as work-piece material. Work-piece specimen was cut as a square block of 40mm × 40mm × 15 mm.

Important physical and mechanical properties of AISI P20 steel are hardness 48HRC, liquids temperature 2600 °F, density 7.85 g/cm^3, elastic modulus 207 GPa, yield tensile strength 827-862 MPa, compressive strength 862 MPa, thermal conductivity 41.5 W/m.K.

C. Response characteristics

In the present study, machining performance is evaluated by the material removal rate and tool wear rate. MRR is the work material weight loss under a period of machining time in minutes (T), i.e.

$$\text{MRR (g/min)} = \frac{\text{Workpiece weight loss}}{\text{Machining time}}$$

TWR is the tool electrode weight loss under a period of machining time in minutes (T), i.e.

$$\text{TWR (g/min)} = \frac{\text{Tool electrode weight loss}}{\text{Machining time}}$$

Basically, higher the material removal rate and lower the tool wear rate satisfy the desirability of overall improvement in productivity of machining process. Therefore, the TWR is the lower-the-better output response characteristic and MRR is higher-the-better output response characteristic.

D. Design of experiments (DOE)

Classical experimental design methods are not favorable to use in case the number of input machining variables is more. A large number of experiments are required to be performed as the number of input machining variables increases. Taguchi methodology makes the use of special set orthogonal arrays with only limited number of experimental runs to investigate entire variable space. Experimental results are converted to a signal-to-noise (S/N) ratio to observe the deviation of the output response characteristics from the desired values. To select an appropriate orthogonal array in Taguchi method, first step is to calculate the total degrees of freedom (DF) which depend upon the number of total input machining variables and their levels. Basically, degrees of freedom represent the number of combinations between input machining variables required to be made to determine which level is better and how much better it is as far as the output response characteristic under investigation is considered. For example, a two-level input machining variable counts for one DF. Interactions between input machining variables are sometimes important to investigate in certain cases. The DF of an interaction between two input machining variables is given by the product of the DF for the two variables. In the present research work, the interaction between the input machining variables is neglected. Therefore, the total DF is 9 owing to one two-level variable and four three-level variables selected in the present case. As per guidelines of Taguchi methodology, another necessary condition is that the DF of orthogonal array selected must be more than that of total DF of input machining variables.

In the present work, five important EDM input variables i.e. tool electrode polarity, peak current, pulse on time, gap voltage, and electrode type are selected to measure output performance measures. Out of these, four input variables are varied at three levels and polarity is varied at two levels i.e. positive and negative. Table 1 shows the values of five variables, their symbols used and their selected range.

Table 1. Design scheme of input machining variables

Symbol	Control Variable	Level 1	Level 2	Level 3
A	Polarity	+ve	-ve	
B	Peak current (amp)	6	9	12
C	Pulse on time (μs)	120	150	200
D	Gap voltage (volt)	40	60	80
E	Electrode Type	Cu	Cu_{90}-Ti_{10}	Cu_{80}-Ti_{20}

E. Orthogonal array (OA)

L_{18} orthogonal array was selected to make the combinations of machining variables. L_{18} orthogonal array is selected as it has 17 DF which is more than total 9 DF of machining variables. This orthogonal array has 5 columns and 18 rows and it handled one two-level input machining variable and four three-level variables. Each machining variable is assigned to a column and total eighteen machining variable combinations are made.

F. Signal to noise (S/N) ratio

Taguchi methodology defines a loss function to determine the deviation between the experimentally calculated value and the desired value of output response measure. The lower-the-better, the higher-the-better, and the nominal-the-better are three categories of the output response characteristics in the analysis of the signal-to-noise ratio. The loss function L_{ij} of the lower-the-better output response characteristic can be expressed as:

$$L_{ij} = \frac{1}{n}\sum_{k=1}^{n} y_{ijk}^{2} \qquad \text{……… eq. (1)}$$

Where L_{ij} is the loss function of the i^{th} output response characteristic in the j^{th} experiment, n is the number of tests, and y_{ijk} is the experimentally calculated value of i^{th} output response characteristic in the j^{th} experiment at the k^{th} test. The loss function of the higher-the-better output response characteristic can be expressed as:

$$L_{ij} = \frac{1}{n}\sum_{k=1}^{n} \frac{1}{y_{ijk}^{2}} \qquad \text{………. eq. (2)}$$

The loss function is converted into an S/N ratio which is used to find the deviation of the output response characteristic from the desired value. The S/N ratio for the i^{th} output response characteristic in the j^{th} experiment can be expressed as

$$\mathrm{S/N\ Ratio} = -10\ \mathrm{Log}\ (L_{ij}) \qquad \text{……….. eq. (3)}$$

Regardless of the category of the output response characteristic, a larger S/N ratio corresponds to better response characteristic. Therefore, the optimal level of the input machining variables is the level with the highest S/N ratio.

To obtain optimal machining performance and to optimize overall productivity, the maximum material removal rate and minimum tool wear rate are necessary conditions. Therefore, the higher-the-better material removal rate (eq. 2) and lower-the-better tool wear rate (eq. 1) are selected for analysis.

G. Analysis of variance (ANOVA)

Statistical analysis of variance is performed to identify the significance of input machining variables and their percentage contribution on the output response characteristic. Response tables are drawn to depict the 'delta' values for various input machining variables and to rank them with respect to their contribution towards response characteristic.

III. RESULTS AND DISCUSSION

Total eighteen experimental runs were conducted and the values of material removal rate and tool wear rate along with the design matrix are listed in table 2.

Table 2. Design layout: L_{18} orthogonal array (actual variable values) and experimental results

Exp. Run	Actual Variable Values					Response Value	
	(A)	(B)	(C)	(D)	(E)	MRR (g/min)	TWR (g/min)
1	positive	6	120	40	Cu	0.07303	0.00197

2	positive	6	150	60	Cu_{90}-Ti_{10}	0.06718	0.00695
3	positive	6	200	80	Cu_{80}-Ti_{20}	0.03448	0.00138
4	positive	9	120	40	Cu_{90}-Ti_{10}	0.11200	0.00400
5	positive	9	150	60	Cu_{80}-Ti_{20}	0.07642	0.01132
6	positive	9	200	80	Cu	0.09041	0.00205
7	positive	12	120	60	Cu	0.15224	0.00448
8	positive	12	150	80	Cu_{90}-Ti_{10}	0.15385	0.00513
9	positive	12	200	40	Cu_{80}-Ti_{20}	0.11250	0.01875
10	negative	6	120	80	Cu_{80}-Ti_{20}	0.00827	0.00354
11	negative	6	150	40	Cu	0.00685	0.00147
12	negative	6	200	60	Cu_{90}-Ti_{10}	0.01906	0.00454
13	negative	9	120	60	Cu_{80}-Ti_{20}	0.02447	0.01277
14	negative	9	150	80	Cu	0.00401	0.00057
15	negative	9	200	40	Cu_{90}-Ti_{10}	0.03086	0.00800
16	negative	12	120	80	Cu_{90}-Ti_{10}	0.04395	0.01338
17	negative	12	150	40	Cu_{80}-Ti_{20}	0.03684	0.01754
18	negative	12	200	60	Cu	0.00516	0.00048

A. Effect of input variables on material removal rate

Table 3 lists the ANOVA results, where the contribution of each input machining variables was calculated. It is observed statistically that the tool electrode polarity variation significantly affects the material removal rate with about 64% of the contribution ratio, and followed the peak current variable with 8.26% of the contribution ratio. The influence of each input machining variable on material removal rate is clearly presented in response graph called main effect plot (figure 1). In this S/N ratio graph, the slope of line which connects between the levels shows the power of influence of each input machining variable on material removal rate. This signal to noise ratio main effect plot shows the material removal rate increases with an increase in the peak current. This is attributed to the reason that the increasing peak current strengthens the pulsation energy so the work surface material is removed more easily by the high current density. Powder metallurgy processed electrode (Cu_{90}-Ti_{10}) erodes more work surface material as compare to its counterparts.

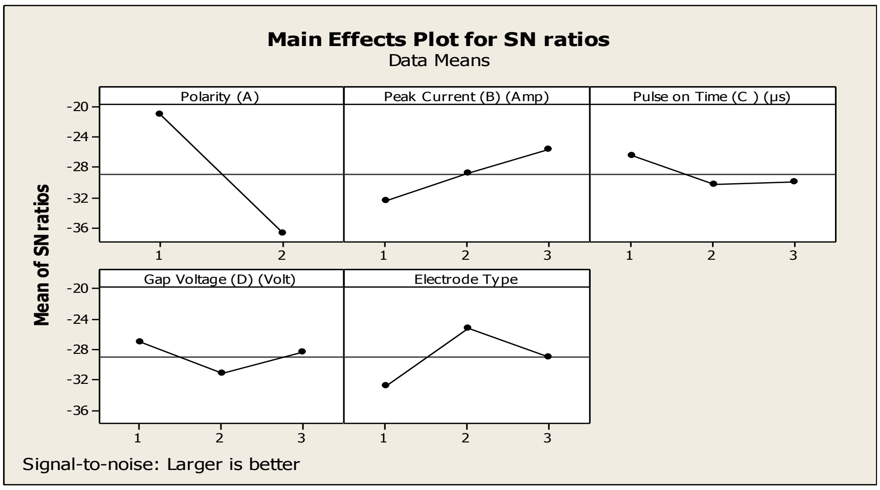

Figure 1. Main effects plot for MRR (S/N data)

For the performance characteristic of material removal rate, the $A_1B_3C_1D_1E_2$ machining variables setting including a positive electrode polarity, peak current of 12 amp, pulse on time of 120µs, gap voltage of 40V, powder metallurgy tool electrode containing 90% copper and 10% titanium can lead to optimal material removal rate.

Table 3. Analysis of variance results for MRR (S/N data)

Symbol	Source	DF	Seq SS	Adj SS	Adj MS	F ratio[#]	P	Contribution (%)
A	Polarity	1	1120.81	1121.53	1121.53	37.17	0.000	64.01
B	Peak Current	2	144.58	150.58	75.29	2.50	0.144	8.26
C	Pulse on Time	2	52.30	37.06	18.53	0.61	0.565	2.99
D	Gap Voltage	2	21.65	12.10	6.05	0.20	0.822	1.24
E	Electrode Type	2	170.33	170.33	85.17	2.82	0.118	9.73
	Residual Error	8	241.37	241.37	30.17			
	Total	17	1751.04					

[#] At least 95% confidence

Effect of each input machining variable (polarity, peak current, pulse on time, gap voltage and electrode type) on material removal rate is analyzed in signal to noise ratio response table. Response table for signal to noise ratio for material removal rate is given in table 4. This shows the signal to noise ratio values at each level of input variables and how it is changed when setting of each variable is changed from one level to another. The range of variation of signal to noise ratio for an input variable is calculated as the difference between signal to noise ratio values corresponding to lowest and highest level of that input variable. This range is presented as 'delta' in table 4. The higher the range the stronger is the effect of that variable. Highest 'delta' value for polarity variable ranks it as most influential input variable as far as material removal rate characteristic is concerned.

Table 4. Response table for MRR (S/N data)

Level	Polarity (A)	Peak Current (B)	Pulse on Time (C)	Gap Voltage (D)	Electrode Type (E)
1	- 21.03	- 32.46	- 26.52	- 26.88	- 32.82
2	- 36.81	- 28.77	- 30.33	- 31.12	- 25.08
3		- 25.53	- 29.91	- 28.29	- 28.85
Delta	15.78	6.94	3.81	4.24	7.74
Rank	1	3	5	4	2

B. Effect of input variables on tool wear rate

Table 5 lists the analysis of variance results, where the contribution of each input machining variables in affecting tool wear rate was calculated. Viewing the contribution of each parameter given in the table, it is found the electrode type dominates the performance characteristic and significantly affects the tool wear rate with about 45% of the contribution ratio followed by the gap voltage (12.72% of the contribution ratio). The influence of each input machining variable on tool wear rate is clearly presented in response graph called main effect plot (figure 2). In this signal to noise ratio data graph, the slope of line which connects between the levels shows the power of influence of each input machining variable on tool wear rate. The signal to noise ratio main effect plot shows that the conventional copper tool electrode wear at lower rate and the wear rate increase as the percentage of titanium increases in powder metallurgy processed electrodes. Tool electrode wear rate decreases upon decreasing the peak current. In other words, lower peak current is the key variable to obtain the lower tool electrode wear rate in the electrical discharge machining of AISI P20 steel.

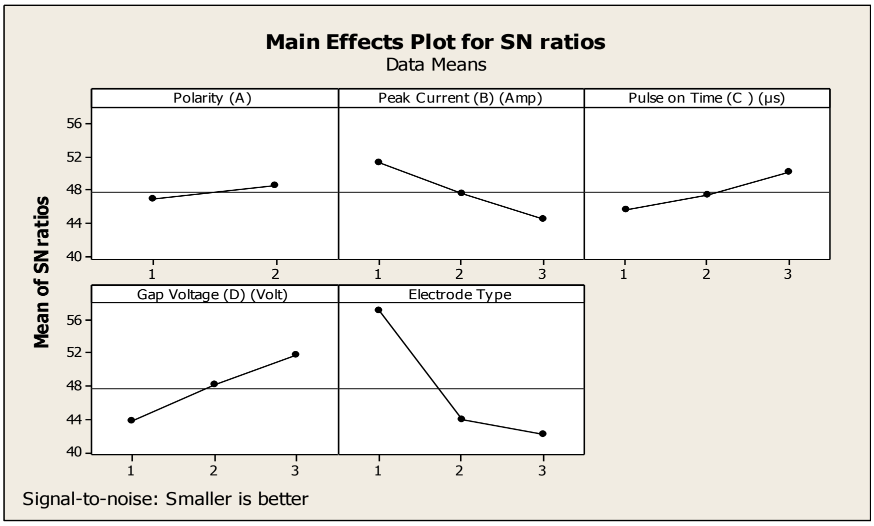

Figure 2. Main effects plot for TWR (S/N data)

Conventional electrolytic copper tool electrode wears less when compared with powder metallurgy processed electrodes. In addition the wear rate increases as the percentage of titanium increases by weigh in powder metallurgy electrodes. Figure 2 shows the $A_2B_1C_3D_3E_1$ variables including the including the negative electrode polarity, peak current of 6 amp, pulse on time of 200µs, gap voltage of 80 V, conventional electrolytic tool electrode, are optimal for the performance characteristic of the tool wear rate. Table 5 also shows the contribution of electrode polarity is smallest when compared with the contribution of other variables.

Table 5. Analysis of variance results for TWR (S/N data)

Symbol	Source	DF	Seq SS	Adj SS	Adj MS	F ratio[#]	P	Contribution (%)
A	Polarity	1	10.42	19.79	19.79	0.35	0.569	0.67
B	Peak Current	2	138.80	173.41	86.70	1.54	0.271	8.91
C	Pulse on Time	2	62.37	42.24	21.12	0.38	0.698	4.00
D	Gap Voltage	2	198.28	90.93	45.46	0.81	0.479	12.72
E	Electrode Type	2	699.07	699.07	349.53	6.22	0.023	44.86
	Residual Error	8	449.48	449.48	56.19			
	Total	17	1558.43					

[#] At least 95% confidence

Analysis of influence of each input machining variable (polarity, peak current, pulse on time, gap voltage and electrode type) on tool wear rate is performed with so called signal to noise ratio response table. Response table for S/N ratio for TWR is given in table 6. This shows the signal to noise ratio at each level of input variables and how it is changed when setting of each variable is changed from one level to another. Highest 'delta' value of electrode type variable ranks it as most influential input variable as far as tool wear rate characteristic is concerned.

Table 6. Response table for TWR (S/N data)

Level	Polarity (A)	Peak Current (B)	Pulse on Time (C)	Gap Voltage (D)	Electrode Type (E)
1	46.93	51.17	45.57	43.78	57.11
2	48.46	47.55	47.42	48.11	43.87
3		44.37	50.10	51.81	42.11
Delta	1.52	6.80	4.53	8.04	14.99
Rank	5	3	4	2	1

CONCLUSIONS

An experimental study into the effect of powder metallurgy electrodes along with other important input machining variables on electrical discharge machining of AISI P20 tool steel has been carried out. From the experimental investigations, it is evident that there is great influence of type of electrode used such as pure copper electrode and powder metallurgy electrode on electrical discharge machining performance measures such as material removal rate and tool wear rate during machining of AISI P20 steel. Taguchi method employed enabled the identification of significant input machining variables and their associated levels on specific output performance characteristics. Selection of appropriate operating values within experimental range enabled preferred work material characteristics to be achieved. In sinking electro discharge machining operation on AISI P20 steel it is found that tool electrode polarity has significant effect on material removal rate. Type of electrode used is significantly affecting the other performance characteristic i.e. tool wear rate. Optimum input machining variables setting within the experiment range for maximum material removal rate is $A_1B_3C_1D_1E_2$ and for minimum tool wear rate is $A_2B_1C_3D_3E_1$. Optimum input variable setting reveals that powder metallurgy Cu_{90}-Ti_{10} electrode erodes more material from work-piece surface but tool wear rate of conventional electrolytic copper is less. If the comparison is made for weight percentage of titanium in two powder metallurgy electrodes, Cu_{90}-Ti_{10} electrode erodes more work material at the cost of less itself erosion when compared with Cu_{80}-Ti_{10} electrode.

REFERENCES

[1] S. Kumar, R. Singh, T. P. Singh, and B.L. Sethi, "Surface modification by electrical discharge machining: A Review", Journal of Materials Processing Technology, vol. 209 (8), pp.3675-3687, 2009.

[2] Anonymous, History and development, in: The Techniques and Practice of Spark Erosion Machining, Sparcatron Limited, Gloucester, UK, 1965, p. 6.

[3] G. Semon, A practical guide to electro-discharge machining, 2nd ed., Geneva: Ateliers des harmilles, 1975.

[4] A. Arthur, P. M. Dickens, R. C. Cobb, " Using rapid prototyping to produce electrical discharge machining electrodes," Rapid Prototyping Journal, vol. 2 (1), pp. 4-12, 1996.

[5] S. Singh, S. Maheshwari, and P.C. Pandey, "Some Investigations into electric discharge machining of hardened tool steel using different electrode materials," Journal of Material Processing Technology, 149 (1-3), pp. 272-277, 2004.

[6] S. Singh, S. Maheshwar, A. Dey, and P. C. Pandey, "Experimental Investigations into Die- Sinking Electric Discharge Machining of Hardened AISI 6150 Tool Steel using different electrode Materials," Journal of Mechanical Engineering, vol. 56 (4). pp. 197-210, 2005.

[7] M. Bayramoglu and A.W. Duffill, "Manufacturing linear and circular contours using CNC EDM and fame type tools," International Journal of Machine Tool and Manufacture, vol. 35 (8). pp. 1125-1136, 1995.

[8] T. Ishida and Y. Takeuchi, "L-shaped curved hole creation by means of electrical discharge machining and an electrode curved motion generator," International Journal of Advance Manufacturing Technology, vol. 19 (4), pp. 260-265, 2002.

[9] A. Gangadhar, M.S. Shunmugam, and P. K. Philip, "Surface modification in electro discharge processing with a powder compact tool electrode," Wear, vol. 143 (1), pp. 45-55, 1991.

[10] J. S. Soni and G. Chakraverti, "Experimental investigation on migration of material during EDM of die steel (T215 Cr12)," Journal of Material Processing Technology, vol. 56 (1-4), pp. 439-451, 1996.

[11] Z. L. Wang, Y. Fang, P. N. Wu, W. S. Zhao, and K. Cheng, "Surface modification process by electrical discharge machining with a Ti powder green compact electrode," Journal of Material Processing Technology, vol. 129 (1-3), pp. 139-142, 2002.

[12] N. Beri, S. Meaheshwari, C. Sharma, and A. Kumar, "Performance evaluation of powder metallurgy electrode in electrical discharge machining of AISI D2 steel using taguchi method," International Journal of Mechanical, Industrial and Aerospace Engineering, vol. 2 (3), pp. 167-171, 2008.