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Performance Evaluation of Composite Powder Metallurgy Electrode on P20+Ni Steel Using Electric Discharge Machining

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Abstract— In this work, an attempt has been made to study the performance of electrode prepared with Tungsten (W), Copper (Cu), and Silicon (Si) powder using powder metallurgy process on P20+Ni steel using Electric Discharge Machining (EDM). The work has been performed with negative polarity (electrode negative and work as positive) and EDM oil as a dielectric fluid. To measure the performance of P/M electrode experiments planned and performed as per Taguchi L9 orthogonal array. The effects of input process parameters such as Compaction pressure, Peak current, and Pulse on time have been investigated to identify their effects on Material removal rate (MRR) and Surface roughness (SR). It was observed that there was the significant role of P/M electrode on the performance of Electrical Discharge Machining using controlled input parameters.

Keywords— Electric Discharge Machining (EDM), Powder Metallurgy (P/M), Material removal rate (MRR), Surface Roughness (SR), Taguchi Methods

I. INTRODUCTION

Electrical Discharge Machining (EDM) is one of the important and successful thermo-electrical advanced machining process widely used in dies, molds, aerospace, automotive industry, and surgical components. In EDM shape of the electrode is a replica of shape to be produced on the workpiece. It has been widely used to produce very complex shapes as well as machining of very hard and brittle electrically conductive material without contact between tool and work.

EDM is work on the principle of conversion of electrical energy in thermal energy in which material is removed through the series of sparks between the electrode and the workpiece in presence of dielectric fluid. There are no mechanical stresses chatter and vibration problems during machining due to no direct contact between the tool and workpiece.

EDM electrode is one of the important elements in the process and it is mainly produced from material like copper, brass, graphite, chromium, tungsten, steel, copper-tungsten and copper chromium alloys. Researchers have been found that to produce complex shape EDM electrode using conventional methods consumes lots of time and cost, hence striving effort required to find alternate methods to produce EDM electrode with the goal to achieving less cost and less processing time.

Powder metallurgy process for EDM electrode fabrication is found important alternate methods with advantages of more economical and very fast production of complex shapes. A large number of the electrode can be produced with a single die. Thermal, electrical, physical and mechanical properties can be controlled during electrode processing by controlling process parameters like particle size, compaction load, sintering temperature etc. Therefore, PM turns out to be a viable alternative to produce EDM electrode. The electrodes produce by powder metallurgy process from fine powders like graphite, tungsten, silicon, nickel, chromium, manganese, etc have been used to modify work piece surfaces in recent years to improve wear and corrosion resistance.

Samuel and Philip (1996), tried to carry out an experiment for comparative analysis of EDMed machined surface machining by using conventional electrode and electrode produce with P/M Process. They conclude that P/M electrodes produce from electrolytic copper compact at 500 MPa with sintering temperature 850 ♂C are technologically feasible in EDM. P/M electrodes are observed to be more sensitive to pulse current and pulse duration than conventional solid electrodes [13]. Shunmugan and Philip (1999), used compact electrodes to enhance improvements in abrasive wear produce from tungsten carbide powder containing 40% WC and 60% Fe. They conclude that with WC-coated HSS tools during machining 20% to 50% reductions in cutting forces as well as 25% to 60% improvement in abrasive wear resistance. Simao et.al (2002), used powder metallurgy (P/M) green compact and sintered electrodes of TiC/WC/Co for the surface modification/alloying and combined electrical discharge texturing (EDT) of Sendzimir rolls, used for the production of the stainless steel strip. They observed as the compacting pressure and sintering temperature for P/M tool preparation increased, the physical, electrical, microstructural, thermal and mechanical properties of the electrode change leading to higher Texturing performance.

II. EXPERIMENTATION

A. *P/M Tool electrode preparation*

Electrode used for machining was prepared from mixtures of fine and pure metallic powders of Copper, Tungsten and Silicon (particle size less than 325 mesh) at 75, 23 and 2 % of weight respectively. Electrode assembly consists of two parts, a P/M compacted pellet which actually works as an electrode and a tool extension part for accurately holding P/M pellet in EDM system. Tool extension part again divides into two parts, one of them pellet fixture prepared from aluminum and another electrolytic copper rod for an extension. For preparing tool electrode copper, tungsten and silicon powder mixed uniformly using ceramic mortar and pestle. Powders mixture was pressed at compaction pressure 75, 125 and 175 kg/cm^2 on a hydraulic press using compaction die design and prepared from steel. Tool electrode and extension parts are showing in figure 1.

Fig. 1 P/M Tool electrode and Tool clamping extension

B. Experimental planning

To optimize the EDM parameters significantly affects the performance of EDM, Design of experiments (DOE) based on Taguchi techniques was considered. Taguchi method helps to find the effects of individual parameters by just performing small no. of experiments.

The Analysis of variance (ANOVA) based on Signal to noise (S/N) ratio was employed to find out optimum levels of parameters using Minitab 16 software. The process parameters like compaction pressure, peak current, and pulse on time were varied to know the influence in EDM. Some of the parameters like Gap voltage = 50 V, Duty factors = 50 %, Flushing pressure = 0.75 kg/cm^2, Polarity = - ve to electrode were kept constant during experiments. Levels consider for variable performance are shown in Table 1.

TABLE I
SELECTED INPUT PARAMETERS AND THEIR LEVELS

Symbol	**Parameters**	**Unit**	**Levels**		
			L1	**L2**	**L3**
A	Compaction pressure	(kg/cm^2)	75	125	175
B	Peak Current	(Ampere)	4	8	12
C	Pulse on time	(µs)	30	65	100

To obtain maximum MRR and minimum Surface roughness (SR) are desired. Therefore smaller- the – better surface roughness and larger – the – better MRR criteria were selected for calculating S/N ratio using Minitab 16.

C. Experimental procedure

The experiments were performed on an EDM machine model M22 of Maruti machine tools with straight polarity. P20+Ni steel specimen size 25 x 25 x 10 mm thick was used as a work material. EDM oil Pecific 300 as a dielectric fluid. Cylindrical P/M electrode made with Cu 75 %, W 23 %, and Silicon 2 % were used to carry out experimentation.

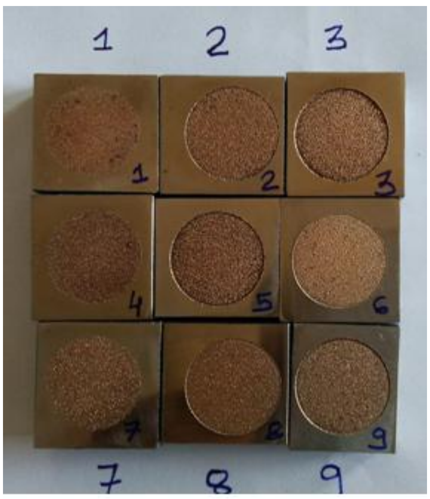

Fig. 2 EDMed workpiece of P20+Ni using P/M electrode

To obtain MRR workpiece was weighted before and after performing experiments on precision digital balance with accuracy 1 mg. The surface roughness was measured using portable surface roughness tester model ITI surf test. Total three sets of 9 experiments were performed as per L9 orthogonal array and the average value of each output parameters was analyzed using Minitab 16 software. The material removal rate was calculated using the following equations.

$$\text{MRR} = \frac{\text{The weight of w/p before exp.} - \text{The weight of w/p after exp.}}{\text{Time of Experiment}} \quad \textbf{gm/min}$$

III. RESULTS AND DISCUSSIONS

The results of Material Removal Rate (MRR) and Surface Roughness (SR) are represented in Table 2 as per Taguchi L9 orthogonal array.

TABLE II
DESIGN OF EXPERIMENT MATRIX AND MACHINING CHARACTERISTICS

Exp. No	Input process parameters						Responses			
	Cp		Ip		Ton		MRR (g/min)	S/N Ratio (dB)	SR µm	S/N Ratio (dB)
	Actual	Coded	Actual	Coded	Actual	Coded				
1	75	1	4	1	30	1	0.0009	-60.9151	5.43	-14.6960
2	75	1	8	2	65	2	0.0079	-42.0475	6.71	-16.5345
3	75	1	12	3	100	3	0.0280	-31.0568	8.80	-18.8897
4	125	2	4	1	65	2	0.0028	-51.0568	6.15	-15.7775
5	125	2	8	2	100	3	0.0159	-35.9721	7.12	-17.0496
6	125	2	12	3	30	1	0.0065	-43.7417	7.71	-17.7411
7	175	3	4	1	100	3	0.0044	-47.1309	6.78	-16.6246
8	175	3	8	2	30	1	0.0058	-44.7314	6.41	-16.1372
9	175	3	12	3	65	2	0.0192	-34.3340	8.28	-18.3606

A. Analysis of Material Removal Rate (MRR)

In order to enhance the effectiveness of various parameters for obtaining desired output (MRR), ANOVA was performed using S/N ratio. S/N ratio objective for MRR is "larger the better". S/N ratio for MRR was calculated using the following eqation.

$$S/N = -10\log_{10} \left[\frac{1}{n} \sum \frac{1}{y2}\right]$$

Where n is a number of results in a row, here in our case n = 1, and y = value of ith experiment in a row. ANOVA results for MRR represented in table lll.

TABLE III
ANOVA USING S/N RATIO DATA FOR MRR

Factor	DOF	SS	V	F	P	% of contribution
Compaction pressure	2	10.30	5.15	1.57	0.389	1.53
Peak Current	2	444.89	222.44	67.93	0.015	66.13
Pulse on time	2	211.02	105.51	32.22	0.030	31.37
Error	2	6.55	3.27			
Total	8	672.75				
S = 1.80958 R-Sq = 99.03% R-Sq(adj) = 96.11%						

The results of ANOVA reflect that the compaction pressure, peak current and pulse on time affect the performance. MRR response table for S/N ratio (Larger the better) is shown in table IV.

TABLE IV
MRR RESPONSE TABLE FOR S/N RATIO (LARGER IS BETTER)

Level	Compaction pressure	Peak current	Pulse on time
1	-44.67	-53.03	-49.80
2	-43.59	-40.92	-42.48
3	-42.07	-36.38	-38.05
Delta	2.61	16.66	11.74
Rank	3	1	2

From Table IV it is clear that peak current is the most significant factors for MRR and then after the pulse on time. Tool compaction pressure has very fewer effects on MRR. The main effect plot for S/N ratio, to find effects of various parameters on MRR are also shown in figure 3.

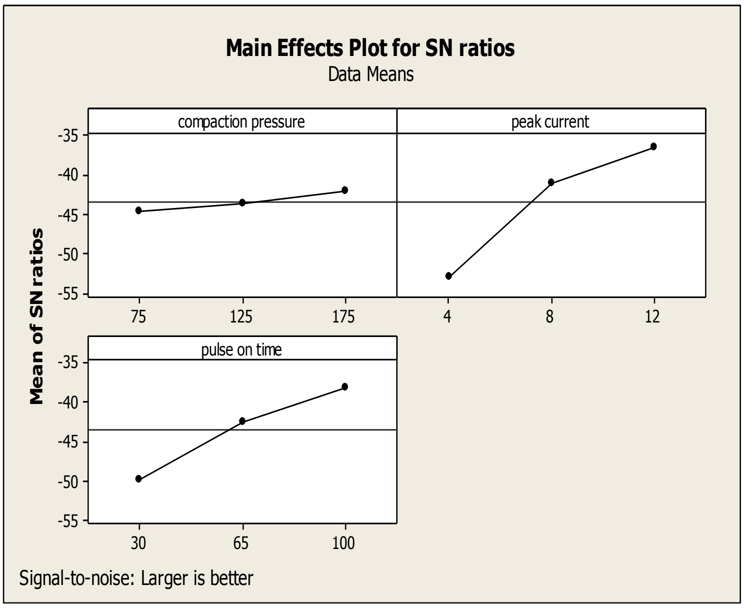

Fig. 3 Main effect plot of parameters for MRR

The optimum combinations of parameters for higher MRR are found when a tool electrode prepare with 175 kg/cm^2, 12 A peak current and 100 µs pulse on time.

B. Analysis of Surface Roughness (SR)

In order to enhance the effectiveness of various parameters for obtaining desired out put (SR), ANOVA was performed using S/N ratio. S/N ratio objective for SR is "Smaller the better". S/N ratio for SR was calculated using the following equation.

$$S/N = -10 \log_{10} [\frac{1}{n}\sum y^2]$$

Where n is a number of results in a row, here in our case n = 1, and y = value of ith experiment in a row. ANOVA results for surface roughness represented in table V.

TABLE V
ANOVA USING S/N RATIO DATA FOR MRR

Factor	DOF	SS	V	F	P	% of contribution
Compaction pressure	2	0.1680	0.0840	1.34	0.427	1.22
Peak Current	2	10.7732	5.3866	86.04	0.011	78.51
Pulse on time	2	2.6552	1.3276	21.21	0.045	19.35
Error	2	0.1252	0.0626			
Total	8	13.7216				
S = 0.250207 R-Sq = 99.09% R-Sq(adj) = 96.35%						

The results of ANOVA reflect that the compaction pressure, peak current and pulse on time affect the performance. SR response table for S/N ratio (Smaller the better) is shown in table VI.

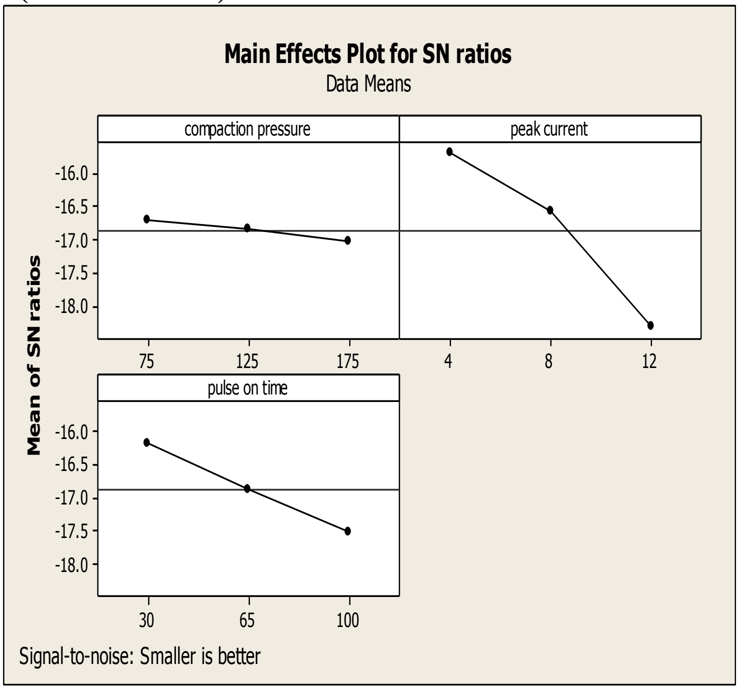

Fig. 4 Main effect plot of parameters for SR

TABLE VI
SR RESPONSE TABLE FOR S/N RATIO (SMALLER IS BETTER)

Level	Compaction pressure	Peak current	Pulse on time
1	-16.71	-15.70	-16.19
2	-16.86	-16.57	-16.89
3	-17.04	-18.33	-17.52
Delta	0.33	2.63	1.33
Rank	3	1	2

From Table VI it is clear that peak current is the most significant factors for SR and then after the pulse on time. Tool compaction pressure has very fewer effects on SR. Main effect plot for S/N ratio, to find effects of various parameters on SR also shown in figure 4.

The optimum combinations of parameters for smaller SR are found when a tool electrode prepare with 75 kg/cm^2, 4 A peak current and 30 μs pulse on time.

IV. CONCLUSIONS

The Taguchi techniques utilized for selection of most significant factors and their levels on specific output measures. Selection of proper operating values from the above data enabled preferred workpiece characteristics can be achieved. During machining of P20+Ni, it is found that compaction pressure, peak current, and pulse on time has a significant effect on both the output parameters.

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