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Research Article

Effect of Powder Concentration in PMEDM on Surface Roughness for Different Die steel Types

Maan Aabid Tawfiq[†*] **and Azzam Sabah Hameed**[†]

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Abstract

Electric discharge machining(EDM) is one of the nonconventional machining process which has been used in manufacturing complex shapes on hard material that are difficult to cut by conventional processes, especially, die casting, parts of aircraft, medical equipment, automobile industries. Powder mixed electric discharge machining (PMEDM), has emerged as one of the advanced techniques in the direction of the enhancement of the capabilities of EDM. The objective of the present research is to study the influence of process parameters such as peak current, pulse on time, manganese, aluminum, and aluminum-manganese mixing powder concentration on surface roughness of different types of die steel (AISID3, AISID6, H13) with round copper electrode(20 mm diameter) on Surface roughness. Experiments have been designed using Taguchi method. Taguchi L27 orthogonal array has been selected for five factor 3 levels design. The surface integrity has evaluated in terms of surface roughness (SR). It is found that manganese powder concentration mixed in dielectric fluid significantly affect the surface roughness, minimum (SR) is obtained at a low peak current (4 A), pulse on (150µs), and (4g/L) concentration of manganese powder, the optimum SR is 0.981µm.

Keywords: *EDM, PMEDM, SR, Taguchi method, ANOVA*

1. Introduction

Machining processes produce finished products with a high degree of accuracy and surface quality. Conventional machining utilizes cutting tools that must be harder than the workpiece material Scientifically highly advanced industries like automotive, aerospace, defense, micro-electronics, nuclear power, steam turbine, metallic molds and dies requires materials of high strength high temperature resistant alloys like stainless steels, titanium alloys, carbides, super alloys, haste alloys, dies steel etc.(Hassan El-Hoffy, 2005;Pradhan, Mohan Kumar, 2010).

These materials are difficult to machine by traditional machining processes. These also need development of improved cutting tool material so that the productivity is not hampered. The use of difficult-to-cut materials encouraged efforts that led to the introduction of the nonconventional machining processes that are well established in modern manufacturing industries (Jain, 2004).

One of these processes is electric discharge machining (EDM), this process is based on removing material from a part by means of a series of repeated electric discharge between tool called the electrode and the workpiece in the presence of a dielectric fluid. The material is removed with the erosive effect of the electric discharge from tool to workpiece; However, EDM suffers from few limitations such as low machining efficiency and poor surface finish. To overcome these limitations, a number of efforts have been made to develop such EDM systems that have capability of high material removal rate (MRR), high accuracy and precision without making any major alterations in its basic principle (Mahendra G.Rathi, 2014). From these efforts the use of electrode rotating, electrode orbiting - planetary motion to tool, workpiece applications of ultrasonic vibrations, and powder mixed electric discharge machining (PMEDM).

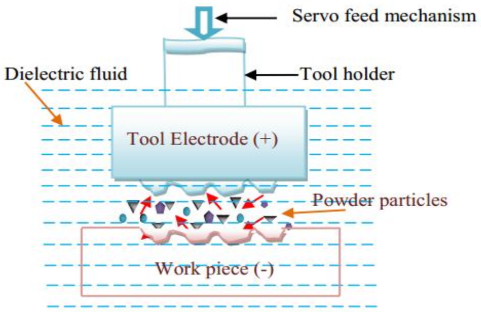

Fig (1) Principle of PMEDM

One of the innovations of the reinforcement and abilities of EDM process is the (PMEDM). In this process, an appropriate material in fine powder is

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*Corresponding author **Dr. Maan Aabid Tawfiq is working as Assistant Professor and Azzam Sabah Hameed is a PhD Student** rightly mixed into the dielectric fluid. The additive powder improves the breakdown properties of the dielectric fluid. The isolating strength of the breakdown properties for the dielectric fluid is decreased, and as a result, the spark gap distance between the tool and workpiece increased. The flushing of debris uniform" is made by expanding spark gap distance. This results in more stable process, thereby improving material removal rate. Fig 1 shows the principles of PMEDM (H.K. Kansal *et al*., 2006).

2. Literature Review

Zhao *et al*. (2002) have studied the effect of powder mixed EDM (PMEDM) in rough machining. They concluded that the machining efficiency becomes lower and the surface roughness becomes smaller in this method in comparison with traditional EDM, because of much loss of discharge energy in the discharge gaps and reduction of the ejecting force on the melted material .

Ho and Newman(2003) studied (PMEDM) has different mythology than conventional, which can improve the surface roughness, However , little research work has been carried out to study the PMEDM in rough machining, experimental research of PMEDM in rough machining has been conducted. The results show that PMEDM clearly improves the machining efficiency and at the same time, surface roughness by selecting proper discharge parameters from the study it is concluded that

- PMEDM make discharge brake down, enlarge discharge gaps and passages and lastly forms evenly distributed, large, and shallow or the area of 64 $cm^{2,}$ high- reflective surface was generated.
- The result for surface roughness is also same as the machining efficiency .Because of much of less discharge energy in discharge gaps and reduction of ejecting force on the melted material, the surface roughness becomes smaller in PMEDM than that of conventional EDM.

Kun *et al*. (2005) have studied the effect of Al powders added in the dielectric within the limit of (0.1 and 0.25g/L) respectively. They concluded that the optimal surface roughness (Ra) value of 0.172μm is achieved under the following parameters positive polarity, discharge current 0.3 A, pulse duration time 1.5μs, open circuit potential 140 V, gap voltage 90 V and dielectric concentration 0.25 g/L. The surface roughness status of the workpiece has been improved up to 60% as compared to that EDM under pure dielectric with high surface roughness Ra of 0.434μm.

H.K. Kansal *et al*(2006) made an investigation into the optimization of the EDM process when silicon powder is suspended onto dielectric fluid of EDM ,the predicted optimal values for material removal rate (MRR), surface roughness(SR), and tool wear ratio(TWR) obtained for PMEDM are 1.22 mm^3/min, 0.51 μm and 0.005 mm^3/min respectively.

H.K. Kansal *et al*. (2007) have studied the effect of silicon (PMEDM) on machining rate of AISI D2 Die steel. Six process parameters, namely peak current (3, 6, 10 A), pulse on time (50, 100, 150 μs), pulse off time (15, 20, 25 μs), concentration of powder(0, 2, 4 g/L), gain(0.83, 0.84and0.85 mm/s)and nozzle flushing (yes, no)have been considered. The optimum levels of various process parameters obtained in this work are peak current= 10 A, powder concentration =4 g/L, Pulse on time =100 μs, Pulse off time =15 μs, Gain=1 mm/s and the maximum material removal rate is 8.55 mm^3/min.

Sukhpal S.*et al*(2010)have studied the impact of different concentration of TiO_2 into the dielectric fluid of EDM on H11die steel to modify the surface characteristics, material removal rate , and hardness. They concluded that

- MRR increases with increase of TiO_2 powder concentration up to a certain limit (7gm/L) further increase lead to decrease MRR.
- TiO_2 powder reduces the surface roughness.
- The micro hardness increases with increase powder concentration.
- A certain amount of powder migrated results in surface modification.

Kuldeep Ojha *et al*.(2010) have studied a material removal rate(MRR) and tool wear rate (TWR)on the chromium powder mixed electrical discharge machining (PMEDM) of EN -8 steel .Response surface mythology (RSM)had been used to plan and analyze and they concluded that:

- Current, powder concentration and electrode diameter are significant factors affecting both MRR and TWR.
- The influence of duty cycle is insignificant on MRR.
- Maximum MRR has observed for a tool diameter of 12 mm. MRR shows decreasing trend both below and above 12 mm tool diameter range.

Devdatt R. Vhatkar, *et al* (2013) have reported the potential of silicon powder as additive, in enhancing machining capabilities of PMEDM on EN31 was realized by, peak current(3, 12, 21, 30)A, Pulse on time(20, 35, 55, 75) μs, Pulse off time(2, 5, 8, 11) μs, Gap voltage(40, 60, 80 ,100) V, Concentration(0, 2, 4, 6) g/l, of fine silicon powder added into the dielectric fluid, was chosen as input process variables, to study performance with respect to" MRR & SR, and they concluded that :

- PMEDM has important impact on the material removal rate and surface roughness.
- The additive silicon powders in the dielectric result in material removal rate have been increased largely and the surface roughness is reduced.

Nimo Singh Khundrakpam, *et al* (2014) have studied The effects of various tool electrode diameter and flushing pressure of (PMEDM) have been investigated to reveal their impact on (MRR) of EN-8 steel by mixing Zinc (Zn) powder to kerosene dielectric and concluded that:-

- The significant factors for MRR are power concentration, Peak current and Interaction of both.
- The parameters, pulse off time and tool electrode diameter have no significant on the material removal rate
- Maximum MRR (>14mm^3/min) is occurred at a nearby value of peak current (190 A) and powder concentration (4 g/l)

3. Experimental requirements

3.1. Workpiece materials

Three types of workpiece material have chosen for research works that AISI D3, H13, and AISI D6. The dimension of workpiece selected for and AISI D3 steel was 65 mm diameter and 10 mm thickness. The dimensions of workpiece selected for Hot Die Steel (H13) was 90×50×10 mm and for AISI D6 is 50 ×50 ×10 mm. The chemical composition of workpiece is shown in Table (1) in tested using an Optical Emission Spectrometer DV-6.

Table (1): Chemical composition of workpiece materials

No	Element	AISI D3 steel	H13	AISI D6 steel
1	C	2.10	0.465	2.48
2	Si	0.145	1.05	0.264
3	M n	0.292	0.312	0.328
4	P	0.020	0.038	0.035
5	S	0.007	0.015	0.049
6	Cr	12.1	4.50	12.4
7	Mo	0.001	1.16	0.118
8	Ni	0.119	0.258	0.243
9	Cu	0.021	0.185	0.123
10	V	----	0.862	0.012
11	W	----	0.005	0.764
12	Fe	balance	balance	balance

3.2. Tool material

The Thermo physical properties of copper electrode are summarized as follows in Table 2:

Table (2); Thermo-physical properties of electrolytic copper

No	Properties	Copper
1	Thermal conductivity	391.1 W/m k at100C°
2	Density	8.94×10^3 kg/m^3
3	Modulus of Elasticity	117 Gpa
4	Melting point	1356 K
5	Latent heat of fusion	134 J/g
6	Thermal expansion	16.9×10^{-6}/K at 100C°

3.3. Dielectric Fluid

Table (3): Physical properties of dielectric fluid

Dielectric constant	Electrical conductivity	Density	Dynamic viscosity
1.8	1.6×10^{-14}s/m	730 kg/m^3	0.94 m Pas

3.4. Micro size powder

Aluminum, manganese, mixture powder (aluminum (75%), manganese (25%)) dielectric powder are added to the dielectric fluid, the thermos- physical properties are listed in Table 4.

Table (4): Thermo-physical properties of metal powder

No	Type of powder	Aluminum (Al)	Manganese (Man)
1	Thermal conductivity(W/ m K)	2.38	1.59
2	Density(g/cm^3)	2.70	7.20
3	Electrical resistivity(Ω-cm)	2.45	185.0
5	Melting point(C^0)	660	1244

3.5. Machine

The experiments have been conducted on (EDM) model **CM 323+50N (CHMBER EDM)** available at University of Technology. A pictorial view of the machine is shown in Fig (2) and important technical data of the machine has summarized in Table (5).

Fig (2): EDM machine used for the experimentation

Table (5): Machine specification

Machine body	**CM 323C+50N**
Table size(W×D) mm	500×350
Work tank size mm	820×500×300
Table travel (X,Y) mm	300×200
Ram travel(Z1) mm	300
Distance from ram platen to work table mm	250-550
Max electrode weight kg	60
Max workpiece weight kg	500
Outside dimensions mm	1200×1350×2250
Weight kg	1000
For dielectric tank	D323

4. Experimental Design

The aim of this research work is to study the effect of powder mixed - dielectric combination upon MRR, by changing the various input machining process parameters, For conducting the experiment, it has been decided to follow the Taguchi design of experiments and a suitable orthogonal array L27 is to be selected after taken into concern the below design variable. The orthogonal array was selected for five variables namely workpiece, powder type and concentration, peak current and pulse of time. The effect of process parameters on SR is analyzed by using statistical software MINITAB 16.The design variables can be summarized as follows:

4.1. Process Parameters and their Levels

The list of factors studied with their levels is given in the Table (6).In the present experiment setup; there are six 3-level factors.

Table (6): Factors interested and their levels

Parameters	**Levels**		
Level	**1**	**2**	**3**
Workpiece	AISI D3	H13	AISI D6
Peak Current	4	8	12
Pulse on time	100	150	200
concentration	0	2	4
Powder	Al	Mn	Al-Mn

4.2. Fixed process parameters

The ranges of the parameters have varied for the experimental work. The input parameters, which have kept constant during the experimentation, are given in the Table 7.

Table (7): Constant input parameters

No	**Machining parameters**	**Fixed value**
1	Open circuit value	135 ±5
2	Polarity	straight
3	Machining time	30 min
4	Type of dielectric	kerosene
5	Pulse off	75μs

5. Experimental Procedure

The electric discharge machine is of die sinking type, with servo-head and straight polarity is used to conduct the experiments. The following steps have been followed during the experimentation work:

1. Place the separately manufactured mild steel container (machining tank) in the actual working tank of EDM machine and clamp firmly to the T-slots.
2. Attach the Motor-stirrer assembly to the machining tank at desired location, which is running at a speed of 1000 rpm.
3. The copper tool electrode (20 diameter) is fixed in the servo feed tool holder of EDM machine and check its alignment vertically and horizontally by the dial indicator.
4. Ground the workpieces on top and bottom faces to a good level of surface finish with the help of surface grinder.
5. Clamp the work material on the bench vise, which is placed in the machining tank and check its alignment with the help of the dial indicator and fill the machining tank with 12 liters of dielectric fluid.
6. The parameters of the experiment are set according to the experimental setting finally; switch 'ON' the machine.
7. The same experiment was repeated with different type and parameters for different levels depend on experimental design of fine metal powders in dielectric on various types of work materials.
8. Surface roughness measurement was carried out using a portable stylus type Profilo-meter for measuring (SR).

6. Results and Analysis

6.1. Analysis of variance – SR

ANOVA has been used to analyze the results for identifying the significant factors affecting the performance measures. (ANOVA) for the mean surface roughness at "95% confidence interval is given in Table 8. The factors such as powder concentration (F value 5.53), current (F value 15.68), powder types (F value 7.66) were found to be significant in surface roughness. Table3 shows the ranks of various factors

Table (8): ANOVA for SR

Source	DF	Seq SS	MS	F	SS"	P	C%
Workpiece	2	1.1242	0.5621	1.21		0.323	3.12
Powder	2	7.0922	3.5461	7.66	6.1642	0.005	17.114
Concentration	2	5.1259	2.5629	5.53	4.1979	0.015	11.655
Current	2	14.5170	7.2585	15.68	13.589	0.000	37.73
Pulse on	2	0.7511	0.3756	0.81		0.462	2.085
Residual Error	16	7.4089	0.4631				
Total	26	36.0193					100
E Pooled	20	9.2842	0.464				28.296

Table (9): Response for means of SR

Level	Workpiece	Powder	Concentration	Current	Pulse on
1	2.768	3.700	3.627	2.043	3.034
2	3.254	2.449	2.579	3.311	2.845
3	3.111	2.985	2.928	3.779	3.254
Delta	0.486	1.251	1.048	1.736	0.408
Rank	4	2	3	1	5

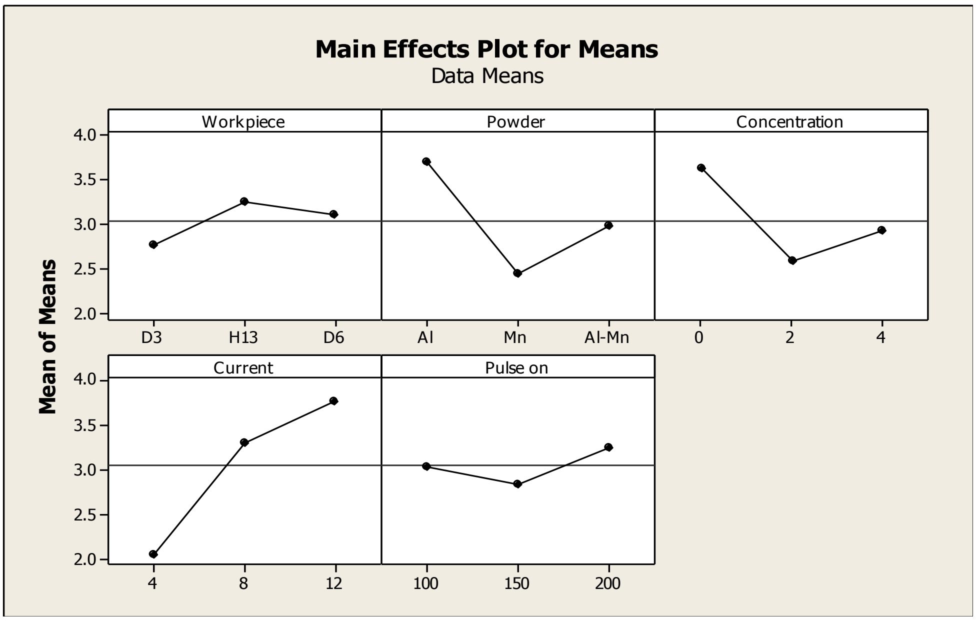

Fig (4): Main effects plot for mean SR

In terms of their relative significance. Current has the highest rank, signifying the highest contribution to surface roughness and pulse on has the lowest rank and was observed to be insignificant in affecting surface roughness. Main effect plot are shown in Fig 4. As the powder concentration increases, surface roughness decreases. When no powder is added into the dielectric fluid then sparking strikes the surface with an impulsive force which creates rough surface but when powder is added into the dielectric fluid, the impulsive force is dispersed among the powder and thus strike the surface with less impulsive force. Hence, smooth surface is created. High pulse on time means spark energy is available for longer time. When high input is current and pulse on time increases, surface roughness is increased. High current means more heat input and high pulse on time means spark energy is available for longer time. When high input is available for longer time then high spark energy creates rough surface.

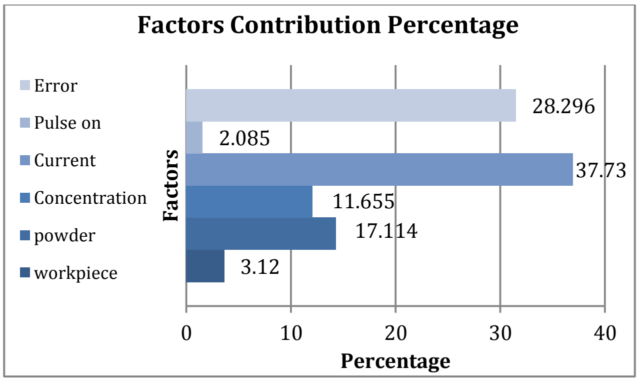

Fig (3): Percentage contribution of factors of SR

Table (10) Response table for signal to noise ratios(S/N) larger is better

Level	Workpiece	Powder	Concentration	Current	Pulse on
1	-8.009	-11.075	-11.007	-5.651	-8.864
2	-9.797	-6.985	-7.624	-10.197	-8.385
3	-9.067	-8.813	-8.241	-11.026	-9.624
Delta	1.788	4.090	3.383	5.375	1.238
Rank	4	2	3	1	5

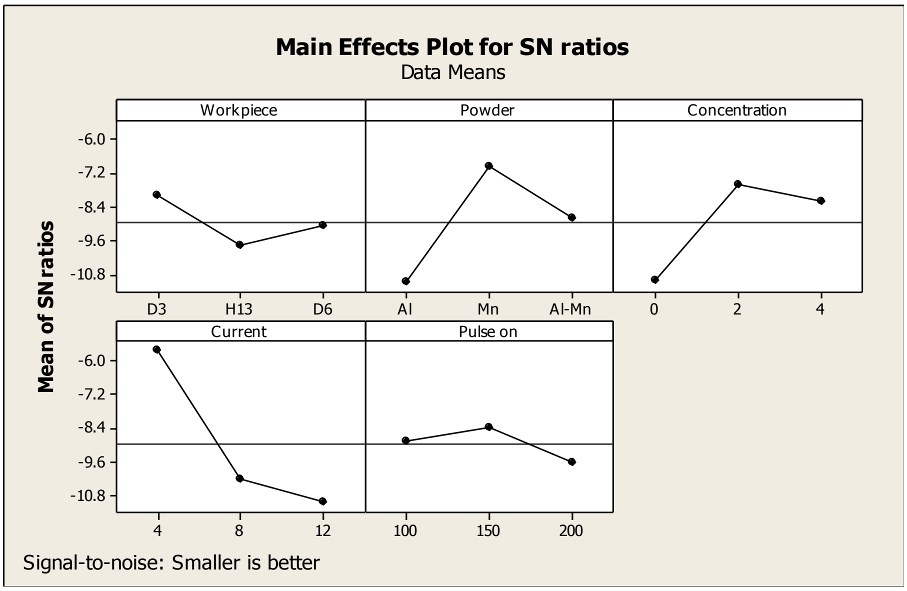

Fig (5): Main Effects Plot for S/N ratios

Table (11): Significant factors for SR

Factors	Affecting mean		Affecting variation(s/n ratio)	
	Contribution	Best level	Contribution	Best level
Workpiece	insignificant	Level 1-D3	insignificant	Level 1-D3
Powder	significant	Level 2-Mn	significant	Level 2-Mn
Powder concentration	significant	Level 2-2	significant	Level 2-2
Current	significant	Level 1-4	significant	Level 1-4
Pulse on	insignificant	Level 3-150	insignificant	Level 3-150

Fig 3 has shown the percentage of participation factors, where the highest participation for current with 36.936%, and lowest participation with 2.085% for pulse on time and the percentage for others factors are 17.114%, 112.655, 3.12% of powder, concentration, workpiece respectively.

6.2. Optimal Design

In this experimental analysis, the main effect plot in Fig (4) is used to estimate the mean SR with optimal design conditions. The lowest SR was achieved when manganese powder, powder concentration 2g/l, pulse on time 150 µs and current 4A was selected in the experiment trial in S/N ratio highest.

6.3. Estimating the mean

SR is a "lower the better" type response. In this experimental analysis, different experimental trials have been chosen to obtain satisfactory results. After conducting the experiments the optimum treatment condition within the experiments determined on the basis of prescribed combination of factor levels is determined to one of those in the experiment.

Mean value of SR is given by:

$$\textbf{Optimum mean (SR)} = \mathbf{m_{B2}+m_{C2}+m_{D1}-(2\times m)} \quad (5.1)$$
$$\mathbf{=2.4489+2.5789+2.043-(2\times 3.045)}$$
$$\mathbf{SR=0.981\mu m}$$

where:-

(m) the overall mean levels, (m_{A1})optimum level of workpiece, (m_{B2})optimum level of powder, (m_{C2})optimum level of concentration, (m_{D1}) optimum level of current, (m_{E1})optimum level of Pulse on time.

Table (12) Results of confirmation experiments

Response	Optimal condition	Predicted	Experiment	% Error
SR	A1 B2 C2 D1E2	**0.981μm**	**1.03 μm**	**4.76**

6.4 Confidence Interval around the Estimated Mean

The confidence interval signifies the maximum and minimum value between which the true average fall at some stated percentage of confidence. The estimate of the mean μ is only a point estimate based on the averages of results obtained from the experiment.

Statistically it specifies that there is 50% chance of the true averages being greater than μ and a 50% chance of the true average being less than μ.

$CI = \sqrt[2]{\frac{F_{\alpha,v_1,v_2}V_e}{n_{off}}}$ Where F_{α,v_1,v_2}=F ratio

α= risk (0.05)
Confidence = 1-α
v_1= dof for mean which is always =1
v_2= dof for error =V_e

n_{off}= Number of tests under that condition using the participating factors

$$n_{off} = \frac{N}{1+dof_{B_2,D_3}} = \frac{27}{1+2+2+2} = 3.859$$

Where N = number of trials in the experiment

$$CI = \sqrt[2]{\frac{F_{\alpha,v_1,v_2}V_e}{n_{off}}} = \sqrt[2]{\frac{4.3512 \times 0.464}{3.859}}$$

$$CI = \pm 0.723$$

Thus the confidence interval around the estimated mean of MRR is given by $\mathbf{SR = 0.981} \pm 0.723$μm
The predicted optimal range is
0.258μm < SR< 1.704 μm

6.5. Confirmation Experiments for Output Factors

The final step of the Taguchi method is the confirmation experiments conducted for examining the quality characteristics. The model used in the confirmation tests is defined with the total effect generated by the control factors. The confirmation experiments are performed to validate the above analysis conclusions.

Conclusions

1. The addition of manganese powder mixed dielectric resulted in low SR when compared with aluminum powder and mixed powder aluminum and manganese.
2. The significant factors for SR are peak current, powder concentration and powder types.
3. The parameters pulse on time and workpiece have no significant on material removal rate.
4. Minimum SR has obtained at a high peak current of 4 A Ton of 150 μs, and2/L concentration of manganese powder.
5. The optimum treatment condition with the experiments determined based on prescribed combination of factor levels is 0.981 μm, with percentage of Error 4.76% from Experimental value.
6. Current has the highest rank, signifying highest contribution to SR and workpiece has the lowest rank.

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