Eng. &Tech.Journal, Vol.33,Part (A), No.9, 2015

Effect of Powder Concentration in PMEDM on Machining Performance for Different Die steel Types

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Received on:28/6/2015 & Accepted on:8/10/2015

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 machining performance of different types of die steel (AISID3, AISID6, H13) with round copper electrode(20 mm diameter) on machining performance. Experiments have been designed using Taguchi method. Taguchi L27 orthogonal array has been selected for five factors 3 levels design. The machining performance has evaluated in terms of metal removal rate (MRR). It is found that manganese powder concentration mixed in dielectric fluid significantly affect the machining performance, maximum (MRR) is obtained at a high peak current (12 A), pulse on (200µs), and (4g/L) concentration of manganese powder, the optimum MRR is 17. 56mm^3/min with percent of error about 5.61% compared with the Experimental value.

Keywords: EDM, PMEDM, MRR, Taguchi Method, ANOVA

تاثير تركيز المسحوق في عملية التشغيل بالتفريغ الكهربائي باستخدام مسحوق عالق بالسائل العازل على اداء التشغيل لانواع مختلفة من فولاذ القوالب

الخلاصة

عملية القطع بالشرارة الكهربائية من عمليات القطع غير التقليدية المستخدمة في تصنيع الاجزاء معقدة الاشكال باستخدام معادن ذات صلادة عالية وخاصة صناعة قوالب السباكة المعدنية، المعدات الطبية، واجزاء الطائرات. عملية القطع بالشرارة الكهربائية باستخدام مسحوق معدني ظهرت باعتبارها واحد من اهم الطرق المستخدمة لتحسين قدرات عميلة القطع بالشرارة الكهربائية .الهدف من البحث هو دراسة تاثير تركيز المسحوق المعدني و متغيرات العملية الكهربائية مثل التيار وزمن مكوث النبضة وقد استخدم ثلاثة انواع من المساحيق المعدنية وهي المنغنيز والالمنيوم ومزيج بين المنغنيز والالمنيوم بنسبة (75/25)% وحسب النسب الوزنية لتشغيل ثلاثة انواع من فولاذ القوالب وهي (AISID3,AISID6, H13)باستخدام قطب تشغيل دائري مصنوع من النحاس النقي(قطر 20 ملم) على معدل اداء القطع .تم اجراء مجموعة من التجارب تم تصميمها باستخدام طريقة تاكوجي,

https://doi.org/10.30684/etj.2015.116235
2412-0758/University of Technology-Iraq, Baghdad, Iraq

حيث تم اختيار 27 تجربة لخمس عوامل بثلاثة مستويات.اداء القطع تم تقيمه من خلال مصطلح معدل ازالة المعدن (MRR). وقد وجد من خلال النتائج ان تركيز مسحوق المنغنيز العالق بالسائل له تاثير كبير على اداء القطع حيث لوحظ بان اعلى معدل ازالة للمعدن تمت باستخدام تيار 12 امبير وزمن مكوث نبضة مقداره 200 مايكروثانية وتركيز مسحوق المنغنيز مقداره 4 غم/لتر، تم الحصول على الازالة المثلى بحدود التجارب ومقدارها 17.56 ملم^3/دقيقة بنسبة خطا مقدارها 5,61% من القيمة التجريبية.

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.[1,2].

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 [3].

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 [4,5]. 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).

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 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 [8].

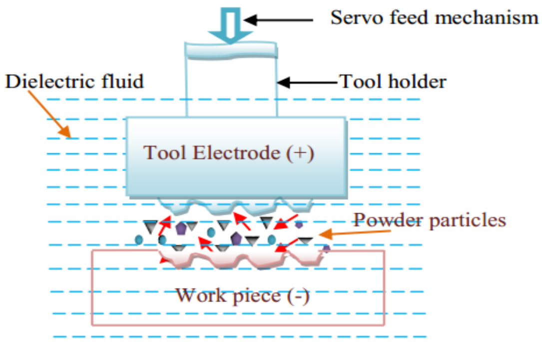

Figure (1) the principle of PMEDM [5]

Literature Review

Zhao et al. (2002) [5] 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)[6]studied (PMEDM) 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) [7] have studied the effect of (Al) powders added in the dielectric within the limit of (0.1 and 0.25) g/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 work piece has been improved up to 60% as compared to that EDM under pure dielectric with high surface roughness Ra of 0.434µm.

Kansal et al(2006)[8]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.

Kansal et al.(2007)[9] 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)[10]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 (7g/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)[11] 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)[12] 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)[13]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).

Experimental requirements

Workpiece materials:-

Three types of workpiece material have chosen for research works that AISI

D3, H13,
and AISI D6. The dimension of work piece 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 70 ×70 ×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	Elements	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

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	Property	Copper
1	Thermal conductivity	391.1 w/m. k
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 100 C$^{\circ}$

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

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	Property	Aluminum(Al)	Manganese(Man)
1	Thermal conductivity(W/mK)	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

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).

Figure(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 work piece weight	kg	500
Outside dimensions	mm	1200×1350×2250
Weight	kg	1000
For dielectric tank		D323

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 work piece, powder type and concentration, peak current and pulse of time. The effect of process parameters on material removal rate is analyzed by using statistical software MINITAB 16.The design variables can be summarized as follows:

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 five parameters each one 3-level factors.

Table (6) Factors interested and their levels

	Levels		
Parameters	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

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

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 work pieces on top and bottom faces to a good level of surface finish with the help of surface grinder.
5. The initial mass of the workpiece is measured with the help of Electronic weighing balance.
6. 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.
7. The parameters of the experiment are set according to the experimental setting finally; switch 'ON' the machine.
8. The workpiece is taken out and measures the mass once again on electronic weighing balance after machining operation.
9. 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.
10. The Material Removal Rate (MRR) is calculated by:
11.

$$MRR = \frac{W_i - W_f}{t \times \rho} \quad \ldots(1)$$

Where W_i = initial weight before machining

W_f = final weight after machining

t = machining time = 30 min

ρ= is the density of die steel

Results and Analysis

Analysis of variance – MRR

The results have analyzed using ANOVA for identifying the significant factors affecting the performance measures. The Analysis of Variance (ANOVA) for the mean MRR at 95% confidence interval has given in Table (8). The variation data for each factor were F-tested to find significance of each .The principle of the F-test is that the larger the F value for a particular change in that process parameter. ANOVA Table(8) shows that current (F value 145.15) parameter, the greater the effect on the performance characteristic due to the current , powder concentration (F value12.01), powder type (F value 9.22), workpiece (F value 3.57) are the factors that significantly affect the MRR. All others factors, namely, pulse on time has found to be insignificant. Table (9) shows the ranks of various factors in the terms of their relative significance. Current has the highest rank, signifying highest contribution to MRR and workpiece has the lowest rank and was observed to be insignificant in affecting MRR. Main effect plot for the mean MRR is shown in the Fig (3) which shows the variation of MRR with the input parameters. As it can be seen MRR increases with increase in current from 4A to 12A. MRR increases with manganese powder and powder concentration. Higher current means higher spark energy. Higher spark energy causes more material removal from the surface. Hence, MRR increases with increase in current. When pulse on time is high, it means sparking occurs for longer time. So material removal takes place for longer time and thus MRR increases with increase in pulse on time. When powder is added into the insulating dielectric, it becomes conductive and hence improvement in sparking occurs which causes more material removal from the surface. Thus, MRR increases with increase in powder concentration. The MRR is high with addition of manganese powder in dielectric fluid as compared to aluminum and mixture of aluminum and manganese powder.

Table (8) ANOVA for MRR

Source	DF	SS	Variance	F- Test	SS"	P	C%
Workpiece	2	12.763	6.381	3.57	8.7214	0.052	1.354
Powder	2	32.971	16.485	9.22	28.9294	0.002	4.49
Concentration	2	42.955	21.477	12.01	42.955	0.001	6.67
Current	2	519.294	259.647	145.15	515.252	0.000	79.96.
Pulse on	2	7.756	3.878	2.17	-	0.147	-
Residual Error	16	28.621	1.789				
Total	26	644.358					100
E Pooled	18	36.375	2.0208				7.526
SS=Sum of Squares, DOF=degree of freedom, C=Contribution, p=p value							

Table (9) Response for Means of MRR

Level	Workpiece	Powder	Concentration	Current	Pulse on
1	7.269	7.336	6.403	3.860	7.418
2	8.324	9.736	8.887	6.474	8.580
3	8.933	7.453	9.236	14.191	8.528
Delta	1.664	2.401	2.833	10.331	1.162
Rank	4	3	2	1	5

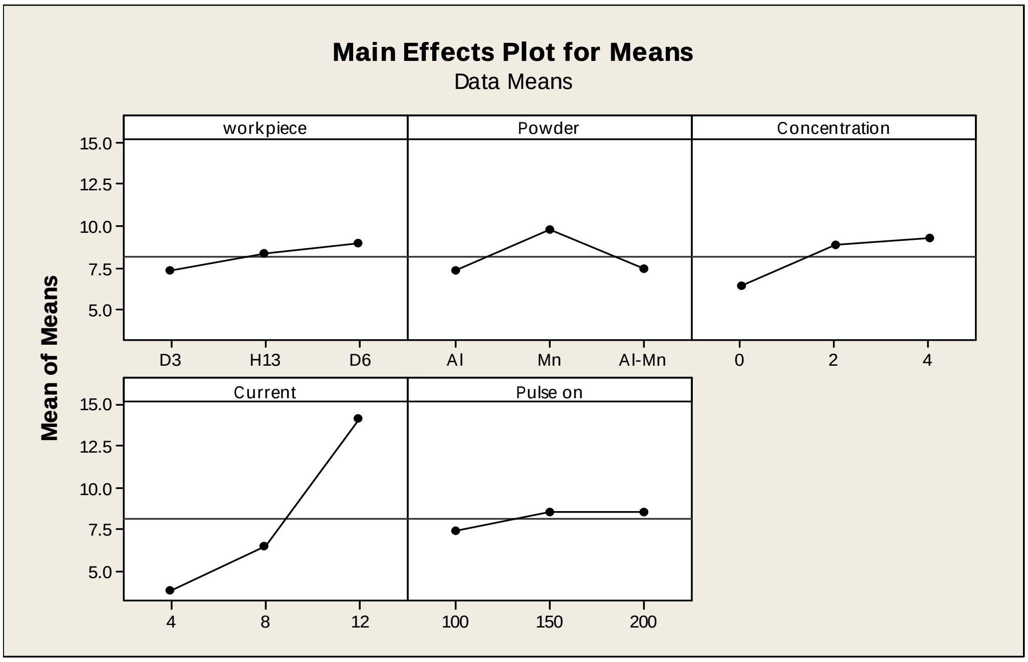

Figure (3) Main effects plot of mean for MRR

Results of S/N ratio – MRR

The S/N ratio is an indication of the amount of variation present in the process. The S/N ratios have been calculated to identify the major contributing factors that cause variation in MRR. MRR is a “Higher the better” type response and it is given by a logarithmic function based on the mean square deviation:

$(S/N)_{HB}$=-10log $(MSD)_{HB}$ … (2)

where MSD_{HB}=-$\frac{1}{r}\sum_{j=1}^{r}\left(\frac{1}{y_i^2}\right)$ … (3)

Table 10 shows the ranks of various for S/N ratio in terms of their relative significance. Current has the highest rank, signifying the highest contribution to MRR and pulse on has the lowest rank and was observed to be insignificant in affecting MRR.

Table (10) ANOVA of S/N for MRR larger is better

Level	Workpiece	Powder	Concentration	Current	Pulse on
1	14.742	13.161	12.522	9.335	14.959
2	16.518	18.802	17.192	16.121	16.238
3	17.071	16.368	18.617	22.875	17.133
Delta	2.329	5.641	6.096	13.539	2.174
Rank	4	3	2	1	5

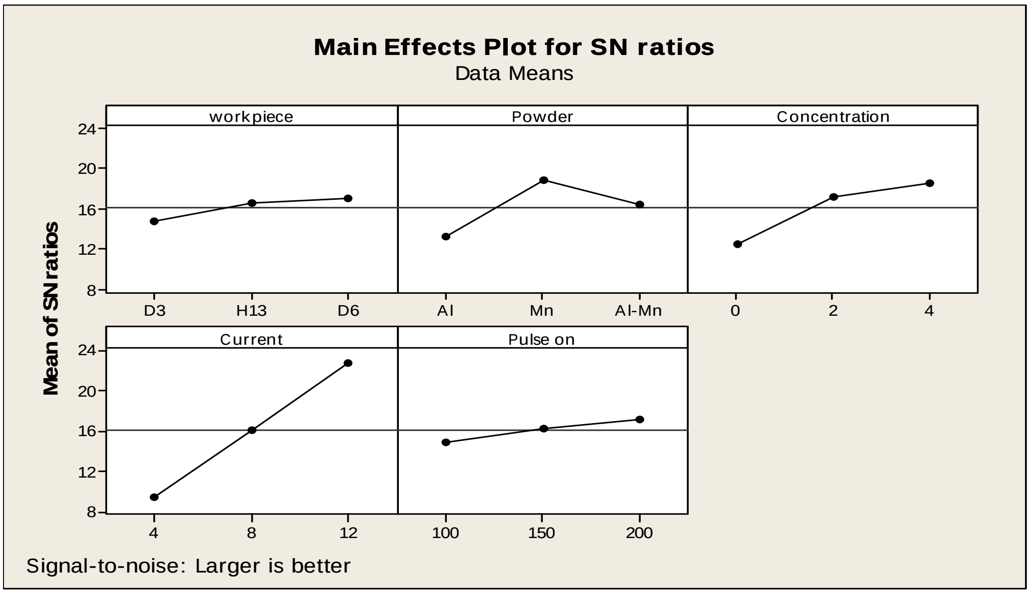

Figure (4) Main Effects Plot for S/N ratios

Optimal Design

In this experimental analysis, the main effect plot in Fig (3) is used to estimate the mean MRR with optimal design conditions. Highest MRR is achieved when manganese powder, powder concentration (4g/l), pulse on time (200 µs) and current (12A) was selected in the experimental trial.

Estimating the mean

MRR is a "Higher 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 MRR is given by:

$$\textbf{Mean MRR (optimum)} = m_{A3}+m_{B2}+m_{C3}+m_{D3}-(3\times m) \quad \ldots (4)$$

$$=8.933+9.736+9.236+14.191-(3\times8.18) =17.56\ mm^3/min$$

Optimum mean (MRR) $= 17.56\ mm^3/min$

Where:-

m = the overall mean, $\mathbf{m_{A2}}$ =optimum level of workpiece, $\mathbf{m_{B2}}$ =optimum level of powder, $\mathbf{m_{C2}}$**=** optimum level of concentration, $\mathbf{m_{D3}}$ =optimum level of current, $\mathbf{m_{E3}}$ =optimum level of pulse on.

6.5. Confirmation Experiments for Output Factors

The confirmation experiments are performed to validate the above analysis conclusions. The results of experimental confirmation using optimal parameters are shown in Table 11.

Table (11): Results of confirmation experiments

Response	Optimal condition	Predicted	Experiment	% Error
MRR	A3 B2 C3 D3 E3	**17.56mm^3/min**	**18.64 mm^3/min**	**5.79**

CONCLUSIONS

1. The addition of manganese powder mixed dielectric resulted in high MRR when compared with aluminum powder and mixed powder aluminum and manganese.
2. The significant factors for MRR are peak current, powder concentration and powder types.
3. The parameter pulse on time has no significant on material removal rate.
4. Maximum MRR have obtained at a high peak current of 12 A Pulse on of 200 µs, and4/L concentration of manganese powder.
5. The optimum treatment condition with the experiments determined on the basis of prescribed combination of factor levels is (17.56 mm^3/min) with error about 5.61% comparing with the Experimental value.
6. Current has the highest rank, signifying highest contribution to MRR and work piece has the lowest rank.

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