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Experimental Study of PMEDM on EN 24 Steel with Tungsten Powder in Dielectric

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ABSTRACT: In this paper, an experimental study of the machining performance of PMEDM on EN 24 alloy steel in terms of Material Removal Rate has been carried out. A fine powder of tungsten has been suspended in the EDM oil dielectric as an additive. Four input parameters i.e. concentration of tungsten powder; peak current; pulse on time and duty cycle were selected as process variables to investigate PMEDM performance. Experiments have been designed using Taguchi method. Taguchi L9 orthogonal array has been selected for 4-factors 3-levels design. The most significant factors contributing towards MRR and TWR have been identified. The results clearly showed that addition of tungsten powder has increased the MRR. The optimum values of all the factors have been obtained for maximum machining efficiency.

I. INTRODUCTION

Electric discharge machining (EDM) is one of the most important modern machining methods. It is most commonly used for mould-making, tool and die industries, but is also becoming a common method of making prototype and production parts, especially in the aerospace, automobile and electronics industries in which production quantities are relatively low. This process is finding an increasing industrial application because of its ability to produce geometrically complex shapes and its ability to machine materials irrespective to their hardness and toughness. But low machining efficiency in terms of MRR has been found to be major limitation of conventional EDM. In order to improve the performance of EDM, a fine powder suspended in dielectric of EDM has been used by several investigators. This new method known as Powder Mixed Electric Discharge Machining (PMEDM) has emerged as a significant technique for increasing efficiency of the process. The mechanism of PMEDM is somewhat different from conventional EDM in the sense that a fine powder of some suitable material is mixed in dielectric fluid. The powder particles lead to a series of discharges in the gap as shown in figure 1. The electrically conductive powders widen the discharge gap by reducing the insulating strength of dielectric. With large inter-electrode gap, the electric density decreases and the process becomes more stable with less possibility of arcing (Zhao *et al.,* 2002).

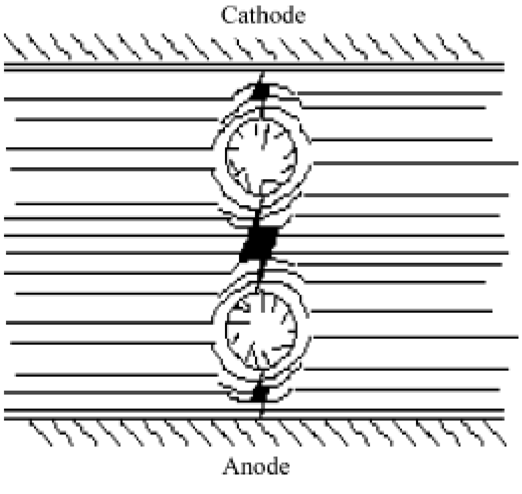


Fig. 1: Series of Discharges (Zhao *et al.,* 2002).

The series discharges at increased rate in plasma channel results in faster erosion of material and hence improves MRR.

II. LITERATURE REVIEW

Wong *et al.* (1998) studied the near-mirror-finish phenomenon in electrical discharge machining (EDM) by fine powder introduced into the dielectric fluid. Al powder at concentration of 2 g/l has been reported to give mirror finish in PMEDM for SKH-51 work pieces. Chow *et al.* (2000) carried out a study on micro-slit machining of titanium alloy with aluminum and SiC powder added in kerosene. It was proposed that SiC powder can produce a better material removal depth than Al powder added to the kerosene. Tzeng and Lee (2001) presented the effects of various powder characteristics on the efficiency of electro discharge machining on mould steel SKD-11 work pieces. It was reported that 70–80 nm powders produced the greatest MRR, followed by 10–15 µm, with 100 µm producing the lowest. For the TWR, the reverse trend was observed. Cr powder produced the greatest MRR, followed by Al, then SiC.

Zhao *et al.* (2002) performed experimental research on machining efficiency and surface roughness of PMEDM in rough machining with aluminum powder of 10µm granularity and 40 g/l of concentration. It was concluded that PMEDM can improve machining efficiency by selecting proper discharge parameters like peak current and pulse width.

Pecas and Henriques (2003) enumerated the influence of silicon powder-mixed dielectric on hardened AISI-H13 mould steel. The results indicated the positive influence of 2 g/l concentration of the silicon powder towards the reduction of the operating time required to achieve a specific surface quality. Kansal *et al.* (2007) studied the effect of silicon powder mixing into the dielectric fluid of EDM on machining characteristics of AISI D2 die steel. Peak current and concentration of powder were found to be most significant parameters for material removal. High MRR was achieved at high concentration of 4 g/l and large Peak current of 10 A. Chow et al. (2008) proposed the use of SiC powder of size 3 – 5 µm in water for micro-slit EDM machining of titanium alloy and indicated that the addition of SiC powder would enlarge the electrode and workpiece gap, and also extrude debris easily, therefore increasing the MRR. Kansal et al. (2008) presented the numerical simulation of PMEDM of AISI D2 die steel using finite element method. Kung et al. (2009) carried out a study on MRR and EWR on PMEDM of cobalt-bonded tungsten carbide and reported optimal MRR at the aluminum powder concentration of 17.5 g/l. It was enumerated that EWR value tends to decrease with the aluminum powder concentration down to a minimum value after which it tends to increase. Both MRR and EWR increase with an increase of the grain size, discharge current and pulse on time. Wu et al. (2009) reported a 40 – 80% improvement in MRR of SKD-61 mold steel by adding surfactant to the dielectric. Prihandana et al. (2011) showed that the nanographite powder with concentration of 2 g/l has a significant effect in reducing machining time up to 35%.

Ojha et al. (2011) experimentally investigated MRR and EWR in PMEDM process with Chromium powder suspended dielectric. It was concluded that MRR showed an increasing trend for increase in powder concentration. Sukhjeet et al. (2011) studied the effect of Al_2O_3 and TiC powder mixed dielectric on ASTM A681 D3 die steel and showed that MRR was increased to a great extent and TWR was reduced by using TiC powder. Jabbaripour et al. (2013) reported 54% enhancement of MRR with 2 µm size aluminum powder mixed dielectric in a defined setting of input parameters. Furutani et al. (2001), Uno et al. (2001), Kumar and Singh (2010), Hu et al. (2013), Syed and Kuppan (2013) and Bhattacharya et al. (2013) showed improvement in surface properties like micro hardness, wear and corrosion resistance using various powder additives in PMEDM.

Janmanee and Muttamara (2012) studied surface modification of tungsten carbide by electrical discharge coating (EDC) using a titanium powder suspended dielectric. Kumar and Batra (2012) investigated the surface modification by EDM method with tungsten powder mixed in the dielectric medium. Substantial transfer of tungsten and carbon to the workpiece surface and an improvement of more than 100% in micro-hardness were recorded.

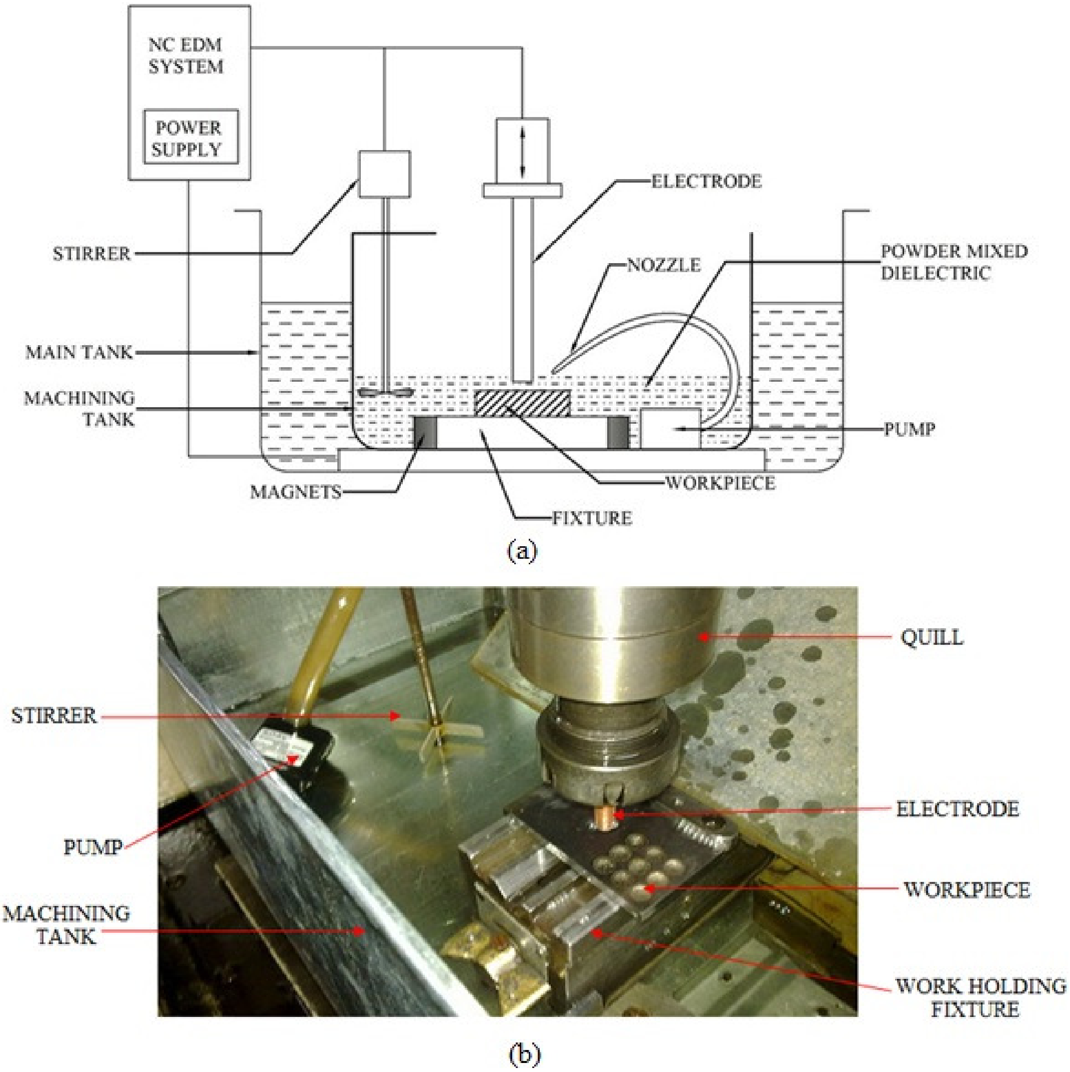
Literature review reveals that PMEDM has been found to be a suitable solution to overcome the limitation of low machining efficiency. It was observed that although a lot of work has been done in the field of PMEDM using various powders such as nickel, Silicon, Aluminum, Graphite etc., but Tungsten powder has not been explored in PMEDM for improving machining efficiency. In the present study, Tungsten (W) powder, having highest melting point and high conductivity, has been selected for PMEDM of EN 24 alloy steel. EN 24, also known as AISI 4340 steel, is a popular grade of through-hardening, heat treatable and low alloy steel. It exhibits good response to heat treatment and posses a good combination of strength, ductility, and toughness in quenched and tempered condition.

It finds wide applications in motor vehicle and machine tool industries for power transmission gears, pinions, shafts, spindles, aircraft landing gear. It is also used for manufacturing aircraft and heavy vehicle crank shafts, connecting rods, chain parts, clutches, propeller shafts, cam shafts, tappets etc. So, it is clear that investigation for improving machining efficiency of EN 24 will be a significant contribution to these industries.

III. EXPERIMENT

The experiments have been conducted on Electrical Discharge Machine model PS-35 of Electronica Machine Tools Ltd. (EMTL) India. Fig. 2 (a) shows the schematic diagram of PMEDM. The mixing of powder in whole dielectric of machine was undesirable. Therefore, a special tank of Galvanised iron sheet was fabricated and placed inside the main tank so that the tungsten powder does not enter into main dielectric sump which may otherwise clog the filtration system. A stirrer is attached to the tank to prevent the settling of the powder and to maintain uniform concentration of powder throughout the experimentation. The machining tank is also provided with a circulation pump for proper flushing. Magnets are placed inside the tank to separate the debris particles from tungsten powder. Fig. 2 (b) shows pictorial view of the setup.

EN 24 is selected as workpiece material and commercial copper as tool electrode. Tungsten powder has been chosen for mixing in dielectric of PMEDM.



(a)

(b)

Fig. 2: Experimental Setup (a) Schematic diagram (b) Pictorial view.

IV. EXPERIMENTAL DESIGN

Taguchi method is selected for planning and design of experiments. The Taguchi experimental design approach involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied. There are a number of input parameters in PMEDM process which can be varied. In the present study, four independent input process parameters namely concentration of Tungsten powder; peak current; pulse ON time and duty cycle have been selected. Material Removal Rate (MRR) is selected as response variable as it refers to the machining efficiency. MRR will be calculated by weight loss method.

The ranges of the parameters varied for the experimental work were selected on the basis of results of preliminary experiments. The levels of experiment parameters powder concentration (Conc.), peak current (Ip), pulse ON time (T_{ON}) and duty cycle (τ) are given in table 1 below.

$$\mathrm{MRR} = \frac{\text{Difference of weight of workpiece before and after machining}}{\text{Time of machining}}$$

Table 1: Machining parameters and their level.

S.No	Parameter	Symbol	Unit	Level		
				1	2	3
1	Powder Concentration	Conc.	g/l	0	2	4
2	Peak Current	Ip	Ampere	12	14	16
3	Pulse ON	T_{ON}	µs	50	100	150
4	Duty Cycle	τ	%	48	56	64

In Taguchi design, a four factor three level design is selected with a total of nine numbers of experiments to be conducted and hence the Orthogonal Array L9 has been chosen.

V. RESULTS AND DISCUSSION

For calculation of MRR, the specimen is weighed before and after each run using electronic balance having a resolution of 0.01gm. The weight difference gives the amount of material removed during machining, also the machining time is noted down for each run to calculate MRR. The data of experimentation is entered into MINITAB software and values of mean of MRR and Signal to Noise ratio have been calculated as shown in Table 2.

The figure 3 shows the variation of MRR with various input parameters. It is clear from the graph that MRR keeps on increasing with increase in powder concentration. The graph also represents the comparison of conventional EDM and PMEDM. The zero concentration shows the conventional EDM condition while 2 and 4 g/l concentration represents PMEDM. When dielectric is used without powder i.e. at zero concentration, MRR is low and at concentration of 2 and 4 g/l, MRR obtained is higher.

Table 2: Mean and S/N ratio for MRR.

S.No.	Powder concentration (g/l)	Peak current (A)	Pulse-ON time (µs)	Duty Cycle (%)	MRR for Trial 1	MRR for Trial 2	MRR for Trial 3	Mean of MRR (g/min)	Mean of S/N (dB)
1.	0	12	50	48	0.069	0.081	0.075	0.075	-22.54
2.	0	14	100	56	0.108	0.128	0.115	0.117	-18.69
3.	0	16	150	64	0.133	0.142	0.125	0.133	-17.53
4.	2	12	100	64	0.158	0.145	0.142	0.148	-16.60
5.	2	14	150	48	0.148	0.150	0.154	0.150	-16.44
6.	2	16	50	56	0.164	0.150	0.173	0.162	-15.83
7.	4	12	150	56	0.187	0.176	0.176	0.179	-14.92
8.	4	14	50	64	0.203	0.170	0.183	0.185	-14.70
9.	4	16	100	48	0.229	0.263	0.254	0.248	-12.13

This increasing trend is in conformance with the results of Ojha et al. (2011) and Kansal et al. (2007). This observation suggests that the addition of tungsten powder into the dielectric fluid of EDM results in greater erosion of the material. The reason for low MRR in conventional EDM is that loss of discharge energy in the discharge gap is much higher as dielectric strength is quite high. On the other hand, in PMEDM, the addition of highly conductive tungsten powder in dielectric decreases the dielectric strength of the discharge gap, resulting in optimum utilization of discharge energy and consequently increases the MRR. Fig. 3 (b) shows that MRR increases with increase in peak current. The reason may be that the discharge energy per pulse increases with increase in peak current and therefore, more material is eroded from the surface. The results obtained are in conformance with the findings of other researchers like Zhao *et al.* (2002) and Kansal *et al.* (2007).

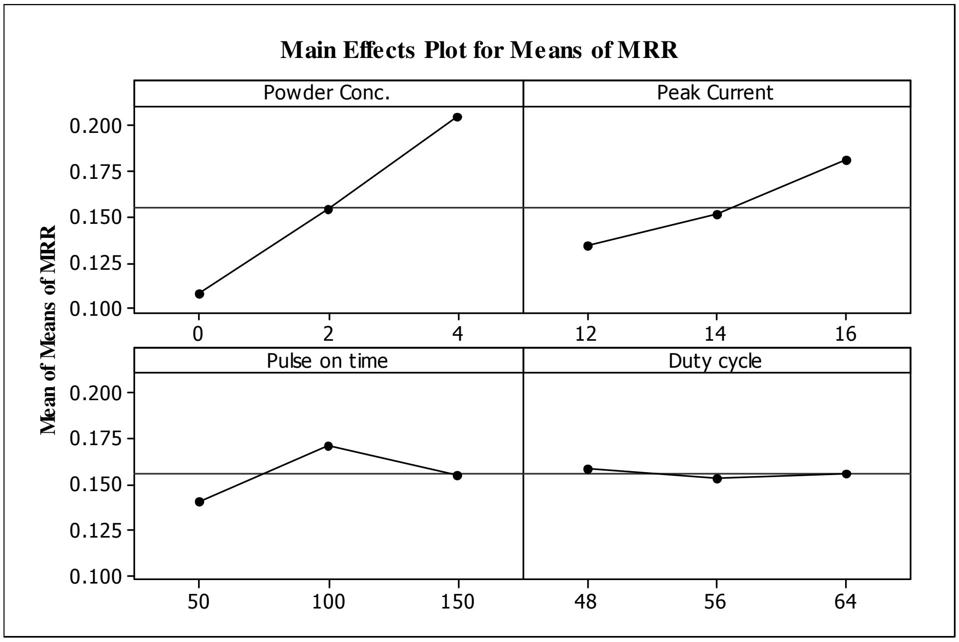


Fig. 3. Mean of means for MRR.

Fig. 3 (c) represents that MRR first increases and then decreases with increase in pulse-on time. This can be attributed to the fact that very short pulse duration imparts less energy which causes less vaporization on the workpiece surface resulting in low MRR, whereas longer pulse duration makes the machining process unstable due to the increased probability of short circuiting. The results are similar with the findings of Tzeng and Lee (2001). The maximum value of MRR is obtained at pulse ON time of 100 µs. The maximum MRR is obtained for 48% duty cycle. The effect of duty cycle on MRR is not so significant.

MRR is considered as ‘Larger is better’ quality characteristic as the objective is to maximize the machining efficiency by obtaining maximum Material Removal Rate. The graphs for signal to noise ratios (SNR or S/N) are plotted for various input parameters as shown in Fig. 4.

An increasing trend can be visualized in SNR of MRR with increase in powder concentration. The highest value of S/N ratio is obtained for a powder concentration of 4 g/l. The effect of concentration can be explained as in case of mean of MRR. The breakdown strength of dielectric decreases with addition of powder particles, resulting in minimum loss of input energy and thereby increasing the MRR.

The S/N ratio of MRR increases with increase in Peak current. For 16 A of peak current, S/N ratio of MRR is maximum. It can be concluded that Metal Removal Rate is proportional to the peak current.

By rising pulse on time from 50 µs to 100 µs, the S/N ratio increases & it slightly decreases with increase in pulse on time from 100 µs to 150 µs. It shows that the pulse on time should neither be too small nor too large. It should be capable of producing enough vaporization of material. The effect of duty cycle is not so significant on SNR of MRR.

The interaction plot for MRR is shown in figure 5, in which interaction of all four parameters with each other is represented. The interaction of powder concentration with peak current, pulse on time and duty cycle shows that powder concentration of 4 g/l gives maximum MRR. It can be concluded that maximum value of MRR is obtained for powder concentration 4 g/l, peak current 16 A, pulse on time 100 µs and duty cycle 48%.

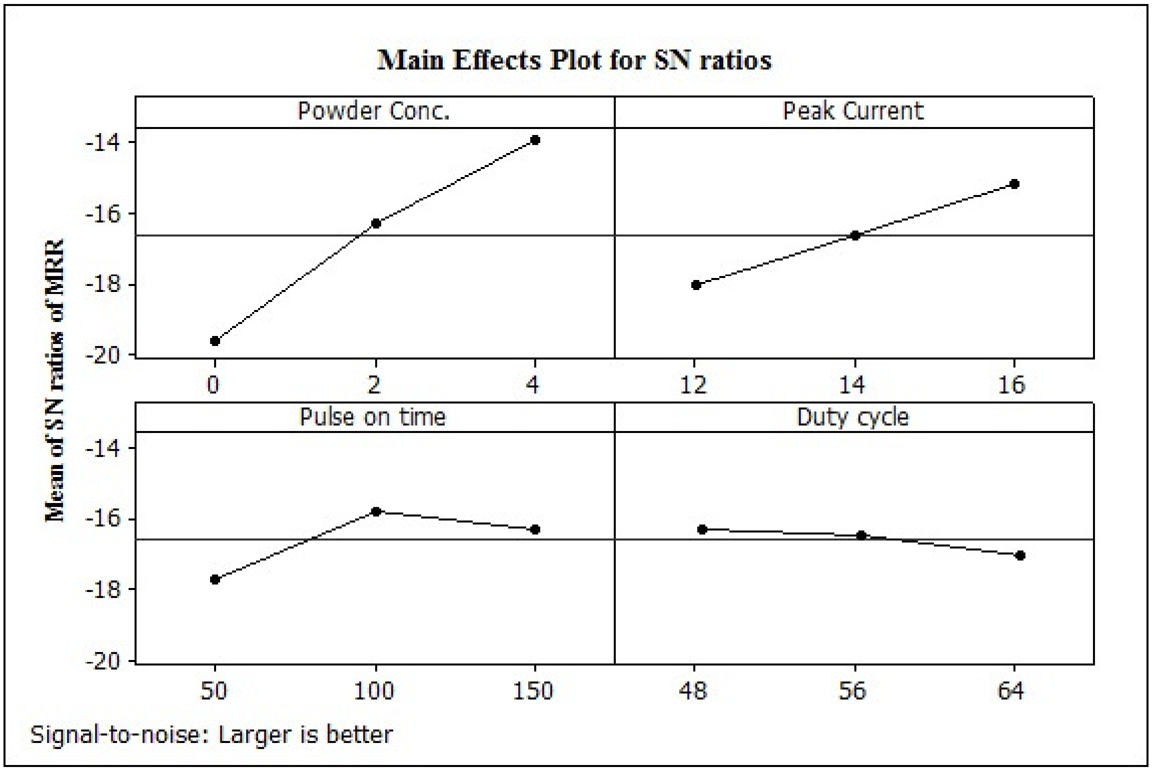


Fig. 4: Mean of S/N ratios for MRR.

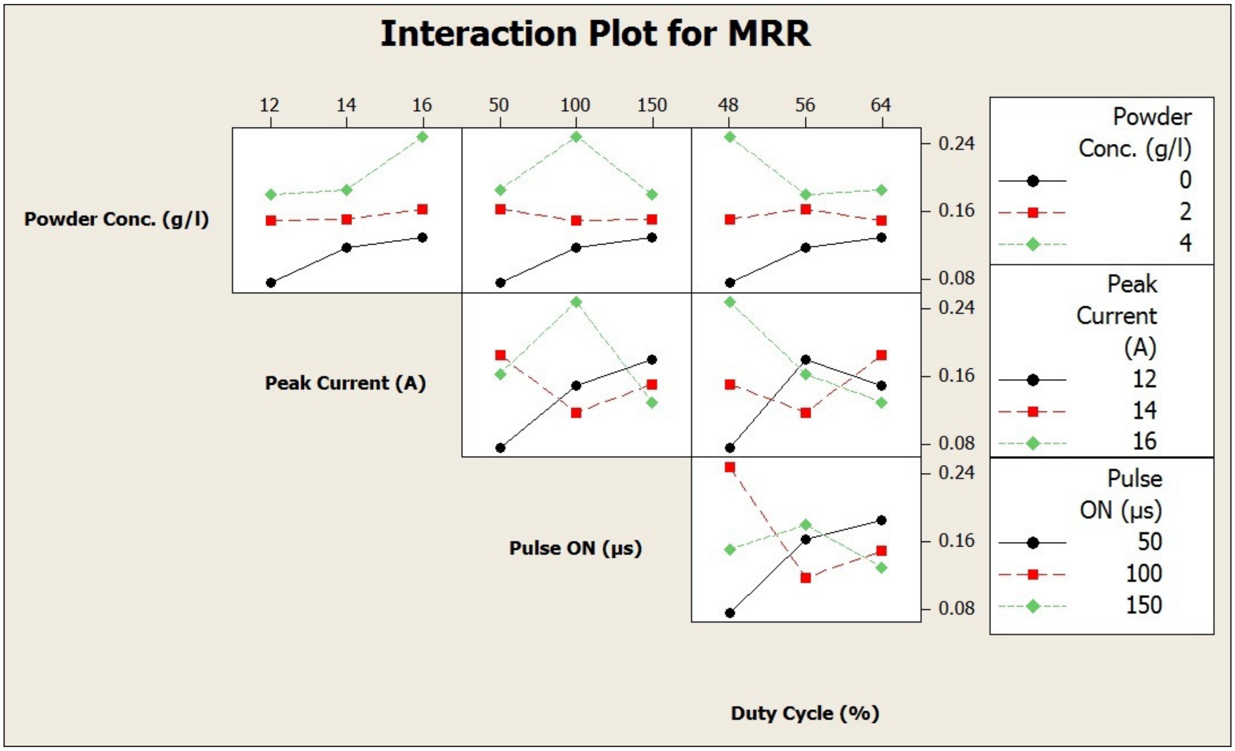


Fig. 5: Interaction plots of all parameters for MRR.

Response table for S/N ratios of MRR is shown in Table 3. The ranking of parameters is provided on the basis of delta values. Maximum value of delta is 5.79 for powder concentration; therefore, first rank has been given to powder concentration. It clearly indicates that Powder concentration is most significant factor then peak current and pulse on time. Duty cycle has least effect on MRR.

Table 3: Response Table for Signal to Noise Ratios of MRR.

Level	Powder concentration	Peak Current	Pulse ON time	Duty Cycle
1	-19.69	-18.00	-17.68	-17.03
2	-16.26	-16.59	-15.78	-16.46
3	-13.90	-15.26	-16.40	-16.37
Delta	5.79	2.74	1.89	0.65
Rank	1	2	3	4

VI. CONCLUSIONS

In this paper, an experimental investigation of PMEDM with tungsten powder mixed in dielectric was performed on EN 24 steel. MRR was analysed for effects of different input parameters. The following conclusions have been found out from the experimentation and analysis:

1. Concentration of tungsten powder, peak current and pulse on time have been found to be influential parameters of PMEDM.
2. MRR shows an increasing trend with increase in powder concentration. Larger MRR has been achieved in Powder Mixed EDM as compared to conventional EDM.
3. By increasing Powder Concentration from 0 to 2 g/l, the mean of means of MRR is increased by 43.76% and from 0 to 4 g/l Powder Concentration, mean of means of MRR is increased by 90.78%.
4. The effect of powder concentration was most significant and that of duty cycle was least significant.
5. MRR firstly increases and then decreases with increase in pulse on time.
6. MRR also showed a proportional increase with increase in peak current.
7. The optimum levels of various process parameters obtained in present work are: powder concentration 4 g/l; peak current 16 A, pulse on time 100 µs and duty cycle 48%.

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