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Experimental Investigations on the Performance Characteristics in Powder Mixed EDM of OHNS Steel

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Abstract: OHNS steel is a general-purpose tool steel that is typically used in applications where alloy steels cannot provide sufficient hardness, strength and wear resistance. It is used for manufacturing of blanking and stamping dies, rotary shear blades, thread cutting tools, milling cutters, measuring tools, gauging tools, wood working tools, reamers, etc. OHNS is a difficult to shape and machine using traditional techniques due to rapid work hardening. After the first machining pass, work hardening tends to plastically deform either the workpiece or the tool on subsequent passes. Hence advanced non-traditional machining like Powder Mixed Electric Discharge Machining (PMEDM) has been performed. Powder Mixed Electric Discharge Machining (PMEDM) is hybrid manufacturing process used in various industries for machining of advanced materials with complex profiles. PMEDM enhances the machining capabilities of the EDM process by mixing the powder to the dielectric fluid. In this research article, various machining characteristics like Material Removal Rate (MRR), Surface Roughness (SR), Tool Wear Rate (TWR) and Micro Hardness are studied and the input parameters viz. flushing, pulse on-time (T_{on}), powder concentration (C_p), peak current (I_p) are optimized for obtaining maximum material removal rate and minimum values for surface roughness and tool wear rate. Experiments were designed and conducted according to Taguchi's L18 orthogonal array. Grey Relational Analysis (GRA) method was employed to determine the optimal set of parameters for best machining performance.

Keywords: EDM, PMEDM, Taguchi design, L18 Orthogonal Array, MRR, TWR, SR, optimization, GRA.

I. INTRODUCTION

There is a growing trend to use light, slim and compact mechanical components in recent years. Thus there has been an increased interest in development of new generation of advanced materials having high hardness, temperature resistance, and high strength to weight ratio to be used in mould and die making industries, aerospace component, medical appliance and automotive industries. There is a heavy demand for new manufacturing technologies to meet with productivity and accuracy requirements with these materials. The traditional processes are unable to cope up with these challenges. Electric Discharge Machining (EDM) has been a mainstay manufacturing process providing unique capabilities to machine "difficult to machine" materials with desired shape, size and required dimensional accuracy. It is the most widely and successfully applied non-traditional machining process for various workpiece materials in the said advanced industries. Powder mixed EDM (PMEDM) has emerged as one of the advanced techniques in the direction of the enhancement of the capabilities of EDM. In this process, a suitable material in fine powder form is mixed into the dielectric fluid of EDM. The spark gap is filled up with additive particles. The added powder significantly affects the performance of EDM process. The electrically conductive powder reduces the insulating strength of the dielectric fluid and increases the spark gap distance between the tool electrode and work piece. As a result, the process becomes more stable, thereby improving machining rate (MR) and surface finish. In principle of powder mixed EDM process shown in Fig. 1, electrical powder having conductive nature is mixed in dielectric fluid in the tank. When voltage of 90-330 V is applied between the tool electrode and the workpiece, electric field is generated when spark gap of 25-50 µm is maintained. These powder particles under the influence of electric field get energized and behave in zigzag manner. However the powder particles congregate together under the sparking areas and arrange themselves in the form of chain like structure. The interlocking between the powder particles occurs in the direction of flow of current. Bridging gap between the tool and workpiece occurs due to chain formation which reduces the insulating strength of the dielectric fluid causing easy short circuit. Due to easy short circuit, early explosion occurs in the gap and series of discharge takes place

under the electrode area. Due to increase in frequency of the discharging, the faster sparking occurs within a discharge, which causes faster erosion or material from the workpiece surface thereby increasing the material removal rate. However the plasma channel is modified by adding the powder to dielectric fluid decreasing the electric density. Thus sparking is uniformly distributed among the powder particles. Due to uniform distribution, shallow craters with uniform erosion are formed on the workpiece improving the surface finish.

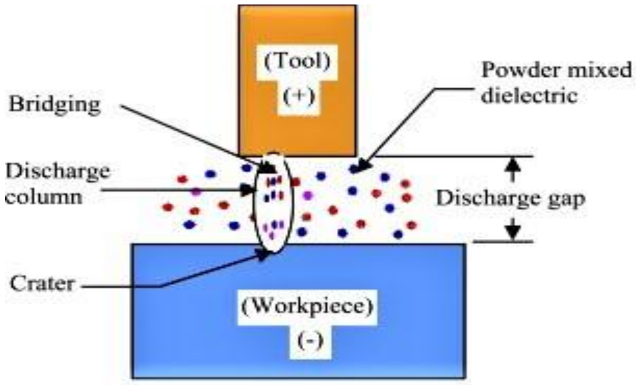

Fig. 1 Principle of Powder mixed EDM process

II. LITERATURE REVIEW

Some researchers have carried out powder mixed EDM to investigate the influence of process parameters on the performance. Neelabh Jyoti Saharia et.al [1] conducted research work on EN19 alloy steel to observe the machining of the EN19 alloy steel under the influence of various input process parameters peak current (Ip), gap voltage (Vg), and concentration of aluminium and graphite powder. They concluded that MRR and TWR increase with increase in the peak current, and concentrations of the mixed powders. B.Surekha et.al [2] carried out experimental investigations to find the influence of the various input parameters on the surface roughness and hardness of the EN19 machined surface. Arun Kumar Rouniyar et.al [3] conducted experimental design using Taguchi L27 orthogonal array combined with grey relational analysis is used to determine the optimal set of process parameters for multi-objective responses on machining of titanium alloy Ti-6Al-4V. Amit Kumar et.al [4] performed the machining of Inconel 825 super alloy where 0.6 mg/liter graphene nano powder has been mixed in kerosene dielectric. The effect of IP, TON and GV on the MRR, SR and TWR have been investigated using RSM methodology. Results shows that MRR increases with increase in peak current and pulse on time and decrease with increase in gap. Vinay Kumar et.al [5] conducted a comparative study of powder mixed EDM and conventional EDM with Inconel 825 and aluminium oxide micro powder. The input process parameters are gap voltage, pulse on time, powder concentration and peak current. The output process parameters are surface roughness (SR), material removal rate (MRR) and surface integrity. It was observed that value of MRR increases in by increasing the peak current due to the presence of micro powder particle providing the bridging effect during machining. Surface finish is directly influenced by all three parameter Ip, TON and GV. P. Mathan Kumar et.al [6] conducted a study on OHNS workpiece using CrB2-Cu powder metallurgy electrode. Chromium di boride percentage, pulse current and pulse on time were selected as process parameters. Material Transfer Rate (MTR) and Surface Roughness (SR) were selected as output response. The effect of each parameter on MTR and SR was addressed using ANOVA technique. Vineet Dubet et.al [7] conducted a study that investigates the MRR for the machining of aluminium alloy 7075 reinforced with 5% boron carbide particles using powder mixed EDM using chromium powder at 4g/L concentration. Goutam Mondal et.al [8] have conducted experiments to study the effect of various powders such as aluminum, Graphite, titanium carbide and CNT powders by mixing them with the dielectric medium during the EDM process on EN 19. They concluded that, among all the powders CNT is found to provide higher MRR and better SR when compared with other powders mixed in the dielectric. Yoo Seok Kim et.al [9] proposed a new explanation of how tool wear is reduced during powder-mixed micro electrical discharge machining with experiments conducted on tungsten carbide with graphite powder. Experiment concludes the three advantages of PMEDM, i.e., low surface roughness, low tool wear, and a high MRR. According to their experimental study, machining occurs at the initial stage of discharge and the remaining discharge energy is used for arc plasma expansion until the temperature of the plasma reaches the melting point of the workpiece. Therefore, using more discharge channels could increase the MRR despite the fact that the discharge energy of each is lower. P. Sivaparakasam et.al [10] investigated the effect of graphite nano powder suspended in dielectric medium of Micro- Wire EDM process of Inconel alloy.

B.C Koli et.al [11] conducted experiments for the analysis of powder assisted reverse micro electric discharge machining (µ-EDM). They showed that the lowest dimensional variation in percentage was achieved in powder assisted R-µEDM and powder assisted R-µEDM process was generates projected parts with more accuracy and precision. S. Tripathy et.al [12] investigated the effect of process parameters like powder concentration (Cp), peak current (Ip), pulse on time (Ton), duty cycle (DC) and gap voltage (Vg) on MRR, Surface Roughness (SR), Recast Layer Thickness (RLT) and micro hardness (HVN) simultaneously during PMEDM of H-11 die steel. Taguchi's L27 orthogonal array was used to carry out the experiments with silicon carbide (SiC) powder suspended to the dielectric fluid using copper as tool electrode. Mohammadreza Shabgard et.al [13] investigated the influence of carbon nano tube adding into dielectric on machining characteristics of Ti–6Al–4V alloy in EDM process. And they concluded that adding MWCNTs into the dielectric causes considerable betterment in machining stability because of the decrease of inappropriate sparks especially during low energy pulses and long pulse on times. Marashi Houriyeh et.al [14] investigated the influence of powder mixed dielectric in EDM process. Findings indicate that the smallest particles cause less gap expansion, higher MRR, lower TWR and a thicker recast layer, which overall increase EDM performance. C. Gnanavel et.al [15] investigated a detailed study of different EDM processes including PMEDM and made conclusions on the comparative study of

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conventional EDM and PMEDM processes. And their results include MRR got increased by adding powder in dielectric medium, MRR increases by the increasing peak current, High peak current leads to high MRR, TWR, SR, MRR is less responded by increase in pulse off time. Ryota Toshimitsu et.al [16] conducted an experiment on alloy steel SKD11 using PMEDM with chromium powder in dielectric with concentration varying from 1 to 5g/L.

Marashi Houriyeh et.al [17] conducted a study to enhance the characteristics of AISI D2 steel surface machined with EDM through adding Ti nano-powder to dielectric under various machining parameters, including discharge duration (Ton) and peak current (I). The findings derived includes addition of Ti nano-powder to dielectric, both material removal rate (MRR) and surface roughness significantly improved in all machining conditions. Ti nano-powder dielectric enhanced the morphology of D2 steel surface as a result of shallower craters and the formation of low-height ridges. Murahari Kolli et.al [18] employed Taguchi method to optimize the surfactant and graphite powder concentration in dielectric fluid for the machining of Ti-6Al-4V using Electrical Discharge Machining (EDM). H.K. Kansal et.al [19] investigated the effect of silicon powder mixing into the dielectric fluid of EDM on machining characteristics of AISI D2 (a variant of high carbon high chrome) die steel has been studied. W.S Zhao et.al [20] carried out a research work to compare PMEDM and conventional EDM processes and they performed experimental research on the machining efficiency and surface roughness of PMEDM in rough machining. And their result shows that PMEDM machining can clearly improve machining efficiency at the same time surface roughness by selecting proper discharging parameters, and can provide reference accordingly for the application of PMEDM machining technology in rough machining.

III. EXPERIMENTAL DETAILS

3.1 Experimental Materials

OHNS die steel of diameter 12mm and height 12mm is taken as the work piece. 18 similar pieces are prepared for the experiments, since three parameters with three levels and one parameter with two levels are considered. The fig.2 and fig.3 shows the work piece and tool respectively. Electrolytic Copper of diameter 16mm and height 12mm is taken as the tool. 18 similar pieces are prepared for the experiments, since three parameters with three levels and one parameter with two levels are considered. Graphite powder in micro level (35µm) is the powder used and EDM oil is dielectric used. The chemical composition of tool and workpiece are shown in Table 1 and Table 2 respectively.

Fig 2: Work piece

Fig 3: Tool

Table 1: Composition of copper electrode

Composition of electrode	
Elements	**Composition (wt.%)**
Copper	99.77
Zinc	0.09
Nickel	0.054
Lead	0.044
Tin	0.018
Aluminium	0.009

Table 2: Material composition of OHNS steel

Material composition of OHNS steel	
Elements	**Composition (wt.%)**
Carbon	0.85
Silicon	0.18
Manganese	0.52
Chromium	0.49
Molybdenum	0.13
Vanadium	0.19
Tungsten	-
Nickel	0.05
Cobalt	-
Iron	Balance

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3.2 Experimental Equipments and Procedure

Experiments were conducted on a 5530 E-35 die-sinking EDM machine. It is energized by a PS fuzzy logic 50-Ampere pulse generator and a controller to produce rectangular-shaped current pulses. The existing dielectric circulation system of the EMTL EDM machine needs about 60 liters of dielectric fluid (EDM oil) in circulation. The mixing of graphite powder with the whole of the dielectric fluid is avoided. This is because different levels of concentration of powders were to be mixed into dielectric for experimentation. Moreover, it is also not possible to circulate the powder-mixed dielectric through the existing circulation system because the filter might clog due to the presence of powder particles and debris. Therefore, there was a need to develop a new powder-mixed dielectric circulation system for the experimentation. The new PMEDM system was designed for 16 liters of dielectric fluid for experimentation. The system consists of a steel container, called the machining tank. It is placed in the work tank of the EDM, and the machining is performed in this container. To hold the workpiece, a workpiece fixture assembly is placed in the machining tank. The machining tank is filled up with dielectric fluid (EDM oil). To avoid particle settling, a stirring system is incorporated.

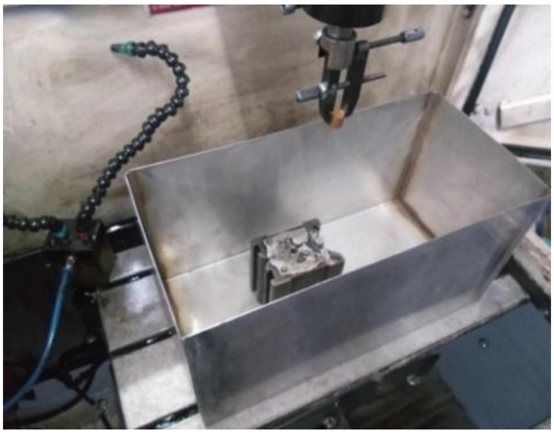

Fig 3: Arrangement of workpiece, tool and tank

Fig 4: Die sinking EDM used in experimentation

Magnetic forces are used to separate the debris from the dielectric fluid. For this purpose, permanent magnet is placed around the gap (machining contact point) at which machining takes place. The machining is performed in commercially available EDM oil. It was decided to add the graphite powder (average particle size 30 µm) into the EDM oil. Figure 5 shows the magnetic flushing provided in the system.

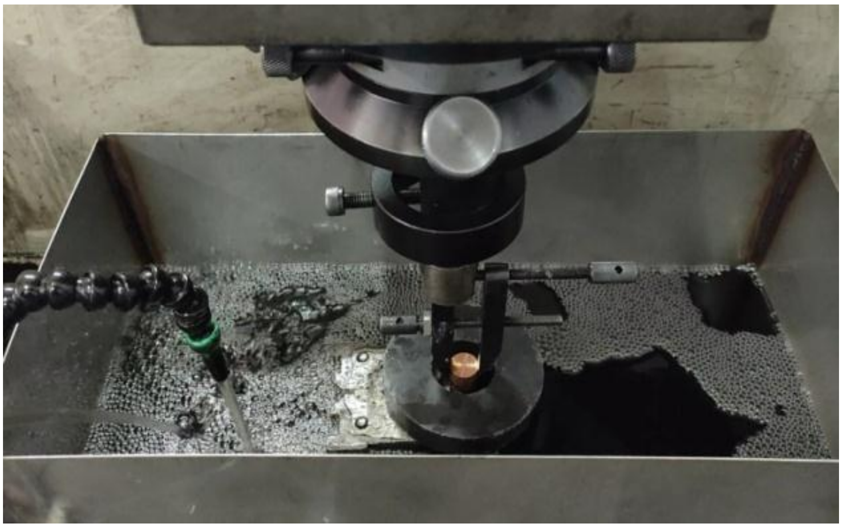

Fig 5: Magnetic flushing provided in the experimentation

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Figure 6 shows the pictorial representation of the machining process done in the EDM with magnetic flushing.

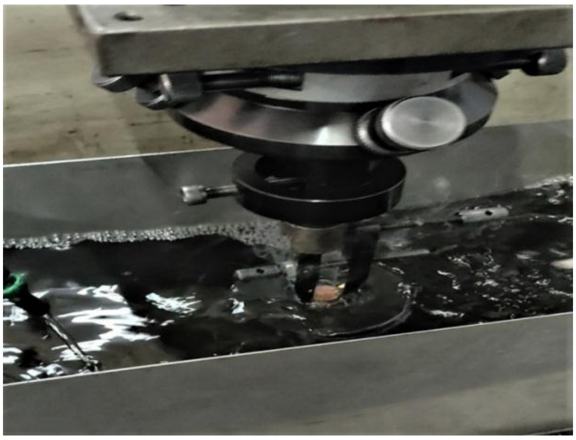

Fig 6: Machining Process

3.3 Design of Experiment

In this work, pulse on time, peak current, powder concentration and eviction are selected as the control parameters. Proper selections of levels are carried out based on the data available from the previous literatures and operator's opinion. The orthogonal array chosen is the L18 array. Table 3 shows the process parameters and levels chosen and Table 4 shows the L18 OA chosen.

Table 3: Process parameters and their levels

Parameter	**No. of levels**	**Levels**
Peak Current(Ip)	3	5A 10A 15A
Pulse on time (Ton)	3	15µs 30µs 45µs
Powder conc. (Cp)	3	3g/L 6g/L 9g/L of dielectric
Flushing (Eviction)	2	None Magnetic flushing

Table 4: L18 OA chosen in the experimentation

Exp no.	**Flushing**	**I_p (A)**	**T_{on} (µs)**	**C_p (g/l)**
1	None	5	15	3
2	None	5	30	6
3	None	5	45	9
4	None	10	15	3
5	None	10	30	6
6	None	10	45	9
7	None	15	15	6
8	None	15	30	9
9	None	15	45	3
10	Magnetic	5	15	9
11	Magnetic	5	30	3
12	Magnetic	5	45	6
13	Magnetic	10	15	6
14	Magnetic	10	30	9
15	Magnetic	10	45	3
16	Magnetic	15	15	9
17	Magnetic	15	30	3
18	Magnetic	15	45	6

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3.4 Performance Characteristic

The performance characteristics considered for the experiment are surface roughness (SR), material removal rate (MRR), tool wear rate (TWR) and micro hardness. The measurement of surface roughness of the machined work pieces are carried out using the Talysurf surface roughness tester (Model Mitutoyo SJ-410). A cone shaped diamond stylus with tip angle of 900and diameter of5 µm was used. Total sampling length of 4mm, cut off length as 0.8 mm, and traverse speed of 0.5 mm/s were kept constant throughout the measurement. The surface roughness values at five different regions are measured. Further for analysis purpose, the average surface roughness value is considered. The micro hardness machine used in this project is HVD 1000 MA. For MRR, first the weights of work pieces are taken before and after machining with the help of digital weighing balance with resolution of 0.1 mg and capacity of 300 grams. Then MRR is calculated by using the following formula shown in Eq. 1.

Material removal rate is defined as the amount of material removed per unit time. Material removal rate is calculated as the ratio of amount of material removed to the time taken for machining.

$$MRR = (W_b - W_a) / t \quad \text{(Eqn 1)}$$

Where,

W_b – weight of the specimen before machining

W_a – weight of the specimen after machining

t– Machining time

Tool wear rate is defined as the amount of tool worn per unit time. Tool wear rate is calculated as the ratio of amount of tool worn to the time taken for machining.

$$TWR = (T_b - T_a) / t \quad \text{(Eqn 2)}$$

Where,

T_b – weight of the specimen before machining

T_a – weight of the specimen after machining

t– Machining time

Grey relational analysis is applied to find out the best combination of process parameters for PMEDM process. The following formulas given by equations are applied to find normalization, grey relational coefficient and grey relational grades. Normalization of original sequence for "larger the better" as in case of MRR is calculated applying Eq. 3.

$$x_i(q) = \frac{y_i(q) - \text{Min } y_i(q)}{\text{Max } y_i(q) - \text{Min } y_i(q)} \quad \text{(Eqn 3)}$$

TWR and SR subsequent to "lower the better" condition are specified as:

$$x_i(q) = \frac{\text{Max } y_i(q) - y_i(q)}{\text{Max } y_i(q) - \text{Min } y_i(q)} \quad \text{(Eqn 4)}$$

Where xi(q) is the value obtained for "grey relational generation", min yi (q) is the least value of yi(q) for the qth response and max yi(q) is the largest value for the qth response where q = 1,2,3,4 for the various output responses considered in a sequence. The data after normalization for the 'grey relational generation' is calculated. The GRC is computed to establish a correlation between the finest data and the definite normalized data. The GRC is calculated as:

$$GRC = \frac{\Delta min + \alpha \, \Delta max}{\Delta^* oi + \Delta max} \quad \text{(Eqn 5)}$$

Where, α = distinguishing coefficient. Generally the value of $\alpha = 0.5$ is used. $0 < GRC < 1$

$$\Delta^* oi = \frac{1}{n} \sum \Delta oi\,(i) \quad \text{(Eqn 6)}$$

$\Delta oi\,(i)$ is the deviation sequence of the reference sequence $x0^*(k)$.

After calculating the grey relational coefficient of the performance measures, the average value of the grey relational coefficient is calculated as the grey relational grade (GRG). The grey relational grade is calculated.

$$GRG = \frac{1}{n} \sum GRC\,(i) \quad \text{(Eqn 7)}$$

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IV. RESULTS AND DISCUSSION

During the experimentation, OHNS steel material is machined using copper electrode and graphite powder is suspended in the dielectric medium. Machining was done by varying peak current, pulse on-time, flushing and powder concentration according to L18 orthogonal array of Taguchi design of experiments.

Pictorial view of a sample machined using PMEDM with graphite powder is shown in the figure 7.

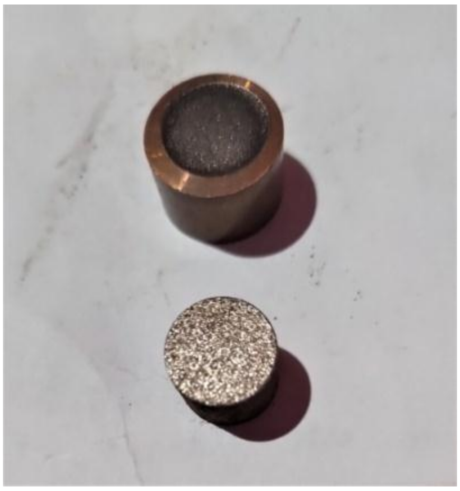

Fig 7: Sample of machined workpiece and tool

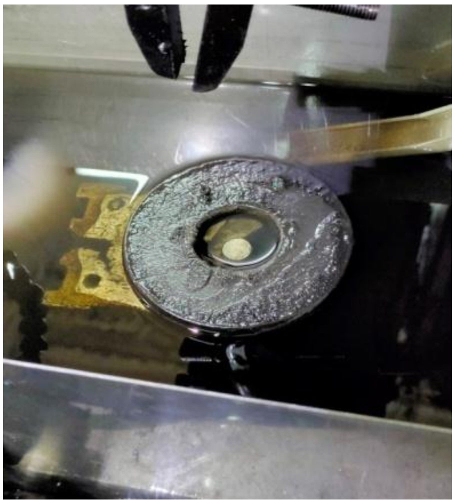

Fig 8: Magnetic debris eviction taken place in experimentation

Figure 8 shows the debris eviction using magnetic flushing. From the figure it is clear that particles removed during machining are evicted using magnetic eviction (flushing) and this improves the MRR. If not removed, molten metal can cool down to form recast layer. So, magnetic flushing can selectively evict the debris. In this present experimental work, for multi objective parametric optimization analysis grey relational analysis is used. Average values of experimental data of SR, TWR and MRR are shown in Table 5 according to L18 Taguchi design matrix.

Table 5: Experimental Data Along With the Combination Using L18 OA

Exp No.	MRR(g/min)	TWR(g/min)	SR (μm)
1	0.0745	0.0035	2.443
2	0.0965	0	2.519
3	0.0950	0	1.734
4	0.1335	0.0215	3.499
5	0.2980	0.0020	3.581
6	0.2655	0.0010	3.244
7	0.2225	0.0635	3.410
8	0.3695	0.0045	4.240
9	0.4080	0.0015	3.964
10	0.0605	0.0030	3.664
11	0.0815	0.0005	2.868
12	0.0760	0.0005	2.387
13	0.1485	0.0130	3.794
14	0.2845	0.0020	4.855
15	0.3165	0.0005	3.776
16	0.2415	0.0590	5.243
17	0.4045	0.0050	4.444
18	0.3615	0.0015	2.869

4.1 Material Removal Rate

The influence of process parameters on MRR is shown in the figure 9. This figure indicates that the value of MRR is mainly affected by the current and pulse on time. MRR is least affected by eviction. The MRR is high when the powder concentration is low i.e. 3g/L. From the figure, it is clear that magnetic eviction, 15A current, pulse on time of 30μs and powder conc. of 3g/L are the optimum conditions of better MRR. 5. It was found out that magnetic flushing selectively evicts the debris formed but the graphite was not evicted since it is non conductive and this led to the improvement in MRR.

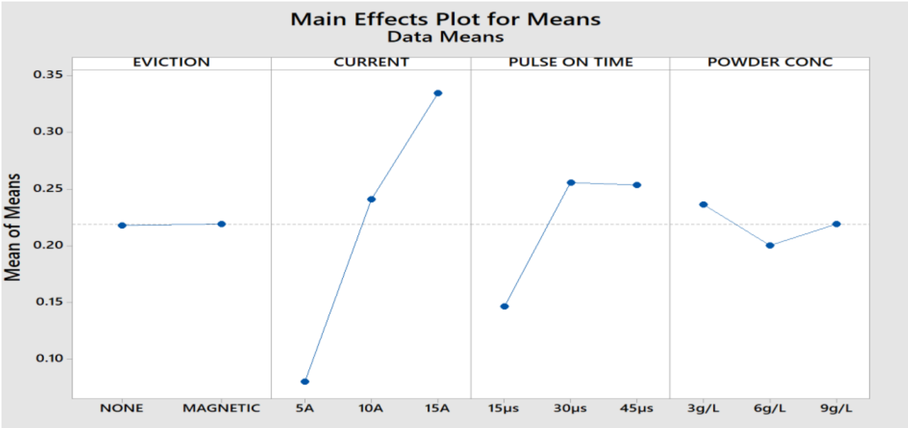

Fig 9: Effect of process parameters on MRR

4.2 *Tool Wear Rate*

The influence of process parameters on TWR is shown in the figure10. This figure indicates that the value of TWR is mainly affected by the current and pulse on time. TWR is least affected by eviction. Tool wear Rate increases with the increase in current and decreases with the increase in pulse on time. The TWR is seen maximum at 6g/L powder concentration. From the figure, it is clear that current at 5A, pulse on time of 45µs and powder concentration of 3g/L and magnetic eviction gives the optimum conditions of TWR.

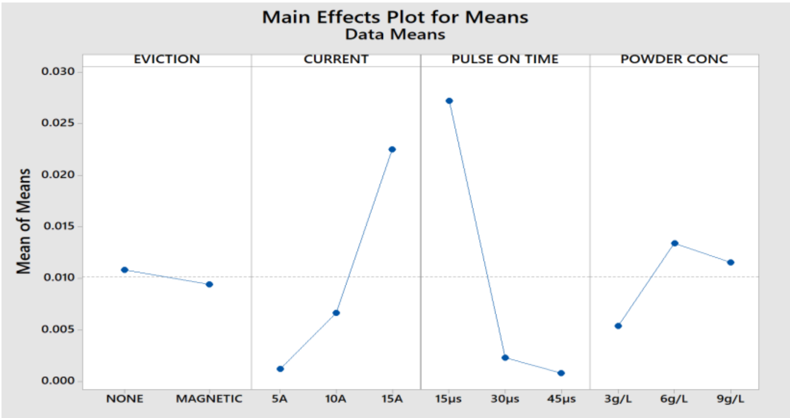

Fig 10: Effect of process parameters on TWR

4.3 *Surface Roughness*

The influence of process parameters on SR is shown in the figure 11. This figure indicates that the value of SR is mainly affected by the current and pulse on time. Surface Roughness is least affected by eviction. Surface Roughness increases with the increase in current and decreases with the increase in pulse on time but showed a slight increase at 30µs. The SR is seen maximum at 9g/L powder concentration. From the figure, it is clear that current at 5A, pulse on time of 45µs and powder concentration of 6g/L and no eviction gives the optimum conditions of SR.

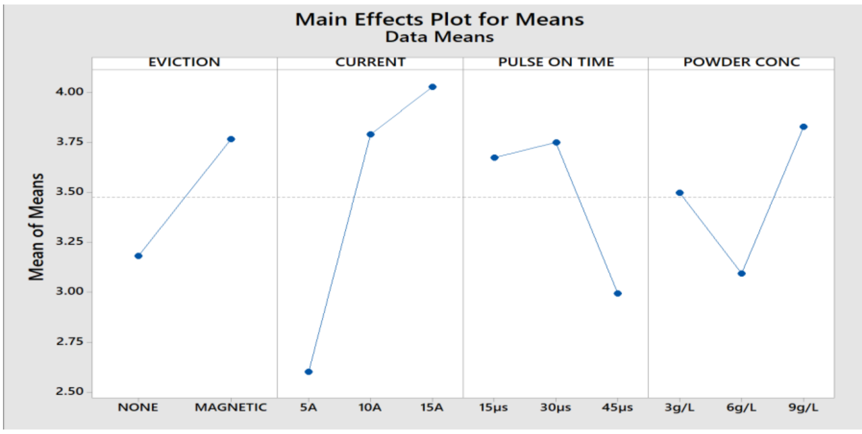

Fig 11: Effect of process parameters on SR

4.4 Grey Relational Analysis

Normalized and deviation data for each performance measure as surface roughness (SR) and material removal rate (MRR) are calculated using Eq. 3 is shown in Table 6.

Table 6: Normalized and Deviation Data for MRR, TWR and SR

Exp No.	MRR	TWR	SR
1	0.040288	0.944882	0.797948
2	0.103597	1	0.77629
3	0.099281	1	1
4	0.210072	0.661417	0.497008
5	0.683453	0.968504	0.473639
6	0.589928	0.984252	0.569678
7	0.466187	0	0.522371
8	0.889209	0.929134	0.285836
9	1	0.976378	0.364491
10	0	0.952756	0.449986
11	0.060432	0.992126	0.676831
12	0.044604	0.992126	0.813907
13	0.253237	0.795276	0.412938
14	0.644604	0.968504	0.110573
15	0.736691	0.992126	0.418068
16	0.520863	0.070866	0
17	0.989928	0.92126	0.2277
18	0.866187	0.976378	0.676546

From Table 6,
Δ min = 0, Δ max = 1

GRC and GRG for each experimental run of L18 OA are shown in Table 7 and Table 8 respectively.

Table 7: GRC for the experimental runs

Exp No.	MRR	TWR	SR
1	0.342533	0.900709	0.712198
2	0.358063	1	0.690884
3	0.356959	1	1
4	0.387619	0.596244	0.498508
5	0.612335	0.940741	0.487158
6	0.549407	0.969466	0.537448
7	0.483646	0.333333	0.511441
8	0.81861	0.875862	0.411806
9	1	0.954887	0.440331
10	0.333333	0.913669	0.476184
11	0.347326	0.984496	0.607409
12	0.343549	0.984496	0.728764
13	0.401039	0.709497	0.459955
14	0.584525	0.940741	0.359861
15	0.655042	0.984496	0.462136
16	0.510654	0.349862	0.333333
17	0.980254	0.863946	0.392989
18	0.788876	0.954887	0.607198

Table 8: GRG for the experimental runs

Exp No.	GRG	Rank
1	0.651814	11
2	0.682982	9
3	0.785653	2
4	0.494124	16
5	0.680078	10
6	0.68544	8
7	0.442807	17

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8	0.702093	5
9	0.798406	1
10	0.574395	14
11	0.64641	12
12	0.685603	7
13	0.523497	15
14	0.628375	13
15	0.700558	6
16	0.39795	18
17	0.74573	4
18	0.783654	3

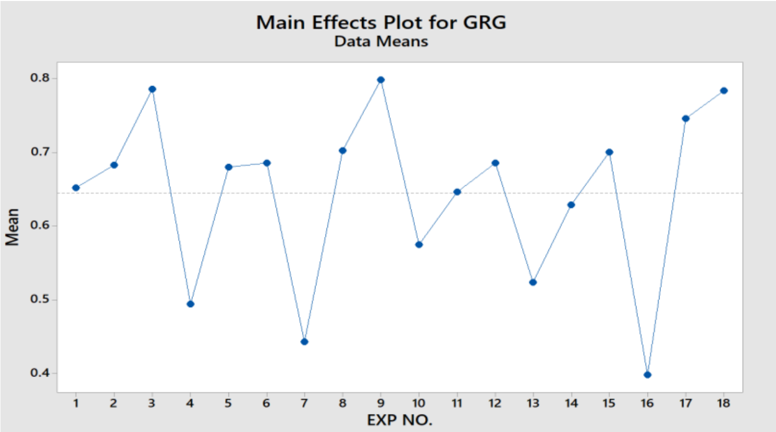

Fig 12: Graph of average Grey Relation Grade for experimental runs

From table 8 and Fig. 12, for the experimental runs highest GRG is obtained for Exp No. 09. Thus among the 18 experimental runs, the 09th experiment gives the best multi-performance characteristics.

4.5 Micro hardness

Table 9: Range of Micro hardness values of work piece

Work Piece	Micro hardness (HV)	
	Before Machining	After Machining
OHNS	612	651-723

Table 10: Micro hardness values for the experimental runs

SL NO.	Flushing	I_P(A)	T_{ON} (µs)	C_P (g/L)	HV
1	NONE	5	15	3	655
2	NONE	10	30	6	721
3	NONE	15	45	3	710
4	MAGNETIC	5	15	9	651
5	MAGNETIC	10	30	9	723
6	MAGNETIC	15	45	6	708

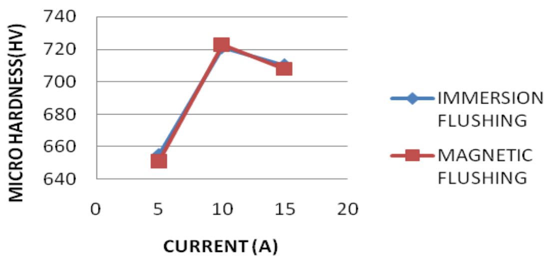

Fig 13: Effect of micro hardness on current

From the table 10 and figure 13, it is clear that machining using PMEDM improved the micro hardness of the workpiece. The micro hardness of the work piece before machining was 612 HV. After machining, the value ranges from 651HV to 723 HV.

V. CONCLUSIONS

Experimental investigations were conducted on the optimization of PMEDM process parameters for maximum MRR, minimum surface roughness and minimum TWR on OHNS steel by suspending the graphite powder in dielectric fluid. The Taguchi L18 orthogonal array along with grey relational was used for optimizing the EDM process parameters for machining the OHNS.
From the present experimental study following conclusions are drawn:

1. The most influential factor affecting the performance was peak current. Then pulse on time, powder concentration and flushing respectively.
2. From the obtained response table and graph of the average GRG, the optimum set of process parameters were found at I=15A, TON=45μs, concentration of 3g/L and with no flushing.
3. Magnetic flushing has a much more effect in TWR and SR. Magnetic flushing reduces TWR but since it is a selective flushing it slightly increases MRR hence there occurs the increase in SR due to the impurities present.
4. Use of graphite powder improved MRR and SR.
5. It was found out that magnetic flushing selectively evicts the debris formed but the graphite was not evicted since it is non conductive and this led to the improvement in MRR and SR.

VI. FUTURE SCOPE

1. Prediction can be done in PMEDM using Artificial neural network by which desired outputs can be achieved using suitable inputs.
2. More study can be done on the surface quality parameters, dimensional accuracy, and white layer thickness. Experiments are being conducted to decrease white layer without secondary techniques.
3. Experimental investigations on performance characteristics using rotary PMEDM can be conducted to know the efficiency of this process and its effect on the various process parameters.

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