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Experimental Investigation of Machining Parameters of Powder Mixed EDM and Optimization of MRR, Surface Roughness & Tool Wear Rate Using Taguchi Method

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ABSTRACT
Electrical discharge machining (EDM) is a capable technique of machining geometrically complex or hard material components, that are precise and difficult-to-machine such as heat treated tool steels, composites, super alloys, ceramics, carbides, heat resistant steels etc. being widely used in die and mould making industries, aerospace, aeronautics and nuclear industries.

Since there is no direct contact between work piece and tool electrode in EDM, machining problems like mechanical stresses, chattering and vibrations dose not arise during machining. In spite of remarkable advantages of the process, disadvantages like poor surface finish and low volumetric material removal limits its use in the industry. To diffuse this problem, EDM in the presence of powder suspended in the dielectric fluid is used and known as powder mixed EDM (PMEDM).[14]

In this research work the effect of aluminium powder mixed with EDM oil on Surface Roughness, Material Removal Rate (MRR) & Tool wear rate is investigated and the results are optimized by using the Taguchi method. The experiments are conducted by keeping various parameters like Voltage, Current, Pulse on time, Duty factor constant and by varying two parameters i.e. Grain size of Aluminium powder & Concentration of Aluminium powder. We selected an L9 orthogonal array based on the no. of parameters and used Minitab17 to form the combination of parameters. The signal-to-noise (S/N) ratio are employed to study the performance characteristics in the machining of AISI 1018 steel using Powder mixed EDM machine. As a result we found that surface roughness, Material Removal Rate (MRR) & Tool wear Rate is highly influenced by Grain size & Concentration of powder mixed with EDM oil. As a result we found that at medium Sized Aluminium powder and at concentration 5 gm./ltr. of aluminium powder we get the optimum level for MRR, Ra & TWR. So to get higher value of MRR alongwith improved surface finish and lower tool wear rate machining should be done aluminium powder of medium grain size mixed with EDM oil in the concentration of 5 gm./ltr.

Keywords
AISI 1018 steel work-piece, copper electrode, concentration of aluminium powder, grain size of aluminium powder, S/N ratio, Minitab17, Taguchi, MRR, Surface Roughness, Tool wear Rate.

1. INTRODUCTION
The development of super tough electrical conductive materials such as carbides, stainless steels, hastalloy, nitralloy, waspalloy, nomonics, etc., arisen the requirement of non-traditional manufacturing processes. These materials are very difficult to machine by conventional methods. Many of these materials find applications in industry where high strength to weight ratio, hardness and heat resisting qualities are required. Electric discharge machining (EDM) is one of the most extensively used non conventional machining processes. It uses thermal energy to machine all electrically conductive materials of any hardness and toughness for applications like manufacturing of dies, automobile components and aerospace parts. Since there is no direct contact between work piece and tool electrode in EDM, machining problems like mechanical stresses, chattering and vibrations dose not arise during machining. In spite of remarkable advantages of the process, disadvantages like poor surface finish and low volumetric material removal limits its use in the industry. To diffuse this problem, EDM in the presence of powder suspended in the dielectric fluid is used and known as powder mixed EDM (PMEDM). It has been experimentally demonstrated that the presence of suspended particle in dielectric fluid significantly increases the surface finish and machining efficiency of EDM process and reduces the tool wear rate.

In PMEDM, a suitable material (aluminum, chromium, copper, silicon carbide, etc.) in powder form is mixed into the dielectric fluid used in EDM. When a voltage is applied between the tool electrode and the work piece placed close to each other, an electric field is generated. The additive particles fill up the spark gap. It increases the spark gap. These high electric field energies powder particles. These particles act as conductors. These conductive particles form chains at different places under sparking area, which bridges the gap between tool electrode and work piece material. Due to this bridging effect, the gap voltage and insulting strength of dielectric fluid reduces which facilitates easy short circuiting and hence early explosion in the gap between tool electrode and work piece material. Due to this, series discharges takes place within the gap. Due to increase in number of discharging per unit time, rapid sparking takes place that causes faster erosion from work piece surface. At the same time the added powder particles enlarged the plasma channel. Due to this, electric density decreases and hence uniform distribution of sparking takes place. This leads to uniform erosion on work piece which results in improvement in surface finish.

The study demonstrates detailed methodology of the proposed optimization technique which is based on Taguchi method; and ranks the parameters namely grain size of aluminium powder and concentration of aluminium powder through S/N ratio. MRR, & Surface roughness of a machined work piece along with Tool Wear Rate of electrode (tool) have been optimized. [14]

2. POWDER MIXED ELECTRO-DISCHARGE MACHINING (PMEDM):

2.1 Construction and Working of Powder Mixed Electro-Discharge machining (PMEDM):
Machining mechanism in PMEDM is slightly different from conventional EDM process. In this process, a suitable material in the powder form is mixed into the dielectric fluid in the machining tank.

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Machining is performed in this tank and workpiece is placed in it, holding it with the help of a work-piece fixture assembly. The machining tank is filled up with dielectric fluid (kerosene oil) and to avoid particle settling, a stirring system is incorporated. A small dielectric circulation pump is installed for proper circulation of the powder mixed dielectric fluid into the discharge gap. The distance between powder mixed dielectric suction point and nozzle outlet is kept as short as possible (250 mm) in order to ensure the complete suspension of powder in the discharge gap. Two permanent magnets are placed at the bottom of machining tank to separate the debris from the dielectric fluid. Electric sparks are generated between two electrodes when the electrodes are held at a small distance from each other in a dielectric medium and a high potential difference is applied across them in conventional EDM.

But the presence of suspended powder decreases the break down strength of the dielectric fluid and reduces the electrical density on the machining spot. Localized regions of high temperatures are formed due to the sparks occurring between the two electrode surfaces. Workpiece material in this localized zone melts and vaporizes. Most of the molten and vaporized material is carried away from the inter-electrode gap by the dielectric flow in the form of debris particles. To prevent excessive heating, electric power is supplied in the form of short pulses. Spark occurs wherever the gap between the tool and the workpiece surface reaches a point to which the powder had lowered the electric density. The spark gap used to produce spark in PMEDM is twice as much as the gap needed to produce spark in conventional EDM. This way several sparks occur at various locations over the entire surface of the work piece corresponding to the workpiece–tool gap. A schematic diagram of PMEDM is shown in figu

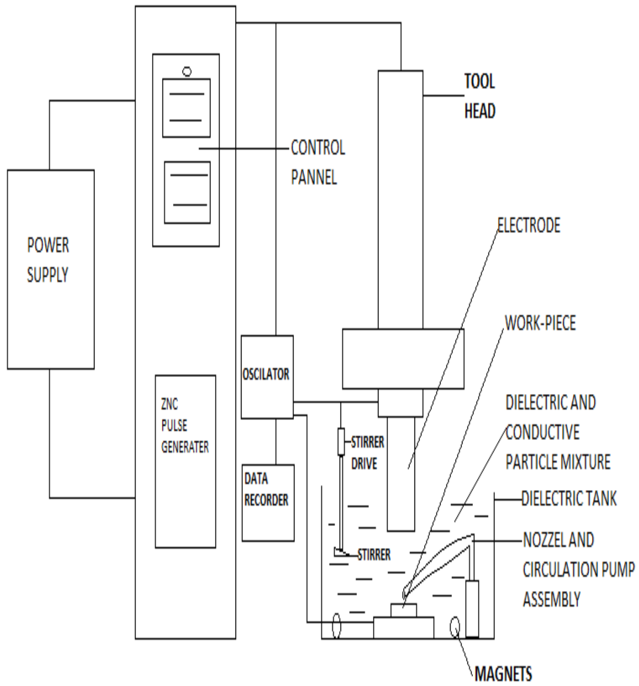

Fig.1: Powder Mixed EDM Machine

1. 2.1.1 Powder Mixed EDM machine (Press Mach-A25)

A Powder Mixed EDM Machine "Press Mach-A25" made by TOOLCRAFT is used to carry out the experimentation.

TABLE – 1: SPECIFICATION OF THE PMEDM MACHINE (PRESS MACH - A25)

Pulse Generator	A25
Working Current	5 amps
Type of Pulse	STD/EQUI-ENERGY
Pulse Time ON/OFF	2-2000 micro sec.
Max. MRR Cu-Steel Gr-Steel	165mm./min. 190 mm./min.
Working Voltage	40 volts
Surface Finish Cu-Steel	≤ 0.5 microns CLA
Electrode Wear	≤ 0.3 %

3. SELECTION OF MACHINING TOOL (ELECTRODE)

The machining tool selected for present work is circular shaped copper electrode of diameter 13 mm.

Density of copper is 8.96 gm/cm³.

4. SELECTION OF WORK PIECE MATERIAL

The work piece material used for current work is AISI 1018 Steel.

Density of AISI 1018 Steel is 7.87 gm/cm³.

TABLE – 2: COMPOSITION OF AISI 1018 STEEL

Elements	Weight %
Carbon, C	0.14 - 0.20
Iron, Fe	98.81 - 99.26
Manganese, Mn	0.60 - 0.90
Phosphorus, P	≤0.04
Sulphur, S	≤0.05

5. SELECTION OF CONDUCTIVE MATERIAL (POWDER)

We used aluminium powder as conductive material (powder) to mix with EDM oil.

TABLE – 3: PROPERTIES OF ALUMINIUM POWDER

Powder	Aluminium
Density	2.70 (g/cm^3)
Thermal Conductivity (at 300K)	237 W.m^{-1}.K^{-1}
Electrical Resistivity (at 20˚C)	28.2 nΩ.m
Melting Point	933.47 K
Specific heat capacity (at 25˚C)	24.200 J.mol^{-1}.K^{-1}

6. SELECTION OF MACHINING PARAMETERS

The various machining parameters, used in this work, are shown in figure.

TABLE – 4: EXPERIMENTAL SETTINGS

Polarity	Positive

Current	5 Amp.
Voltage	40 Volt
Pulse on time	150 µs.
Duty factor	0.7

7. PROCESS PARAMETERS & LEVELS USED IN THE EXPERIMENT

The machining is done on Powder mixed EDM by keeping various parameters like Current, Voltage, Pulse on time, Duty factor constant and by varying two parameters i.e. Grain size of aluminium powder & Concentration of aluminium powder. The parameters and levels used in the experiment are shown in Table.

TABLE – 5: PROCESS PARAMETERS AND LEVELS

Levels	Variables	
	Grain Size of Aluminium Powder	**Concentration of Aluminium Powder**
Level 1	Fine (< 125)	2
Level 2	Medium (125-250)	5
Level 3	Coarse (250 – 375)	8

8. DESIGN MATRIX

In the present work there are three levels, two factors. According to Taguchi approach L9 has been selected. We performed 10 experiments instead of 9 experiments to get the clear difference between the readings found with the use of aluminium powder and without the use of aluminium powder. So the first reading is the reference readings and remaining 9 are according to L9 array. According to Taguchi L9 array design matrix of variables are formed.

TABLE – 6: DESIGN MATRIX OF VARIABLES

Experiment	Grain/Mesh Size of Aluminium Powder (µm)	Concentration of Aluminium Powder (gm/ltr.)
1	Null	0
2	Fine (< 125)	2
3	Fine (< 125)	5
4	Fine (< 125)	8
5	Medium (125-250)	2
6	Medium (125-250)	5
7	Medium (125-250)	8
8	Coarse (250 – 375)	2
9	Coarse (250 – 375)	5
10	Coarse (250 – 375)	8

9. RESULTS AND DISCUSSIONS

9.1 Material Removal Rate (MRR)

The material removal rate is generally described as the volume of metal removed per unit time. To calculate MRR following equation is used to calculate the Material Removal Rate (MRR):

$$MRR(mm^3/min.) = \frac{[\text{Initial Weight of workpiece (gm.)} - \text{Final Weight of workpiece (gm.)}]}{\text{Density (gm./mm}^3) \times \text{Machining Time (min.)}}$$

The density of the mild steel is taken as 7.69612 x 10-3 g/mm3.

9.2 Surface Roughness (R_a)

Roughness measurement has been done using a portable stylus-type profilometer, Mitutoyo- Surftest SJ- 201P/M. The evaluation length of 2.5 mm is used to measure response Ra value in µm.

9.3 Tool Wear Rate (TWR)

The Tool Wear Rate is generally described as the volume of metal removed per unit time. To calculate TWR, following equation is used:

$$TWR(mm^3/min.) = \frac{[\text{Initial Weight of Tool (gm.)} - \text{Final Weight of Tool (gm.)}]}{\text{Density (gm./mm}^3) \times \text{Machining Time (min.)}}$$

9.4 RESPONSE TABLE

Response table for the experimental design matrix is shown in table.

TABLE – 7: RESPONSETABLE OF MRR, R_a & TWR

Experiment No.	Grain/Mesh Size of Aluminium Powder (µm)	Concentration of Aluminium Powder (gm/ltr.)	Work-piece Material Loss(gm.)	Machining Time (Min.)	MRR (mm3/Min.)	Surface Roughness (µm) Length Of Cut =2.5mm	Tool Weight Loss (gm)	Tool wear Rate
1	0	0	1.387	12	14.68635	3.4897	0.0038	0.035342262
2	Fine (< 125)	2	1.591	12	16.846418	3.4211	0.0036	0.033482143
3	Fine (< 125)	5	1.599	12	16.931127	3.3889	0.0031	0.028831845
4	Fine (< 125)	8	1.601	12	16.952304	3.3465	0.0034	0.031622024
5	Medium(125–250)	2	1.611	12	17.05819	3.3998	0.0029	0.026971726
6	Medium(125–250)	5	1.621	12	17.164075	3.3211	0.0028	0.026041667
7	Medium(125–250)	8	1.591	12	16.846418	3.0124	0.0031	0.028831845

8	Coarse (250 – 375)	2	1.522	12	16.115807	3.4111	0.0035	0.032552083
9	Coarse (250 – 375)	5	1.528	12	16.179338	3.2998	0.0034	0.031622024
10	Coarse (250 – 375)	8	1.5523	12	16.436641	3.2114	0.0039	0.036272321

9.5 ANALYSIS OF SINGLE RESPONSE STAGE

The optimal settings and the predicted optimal values for MRR, surface roughness and TWR are determined individually by Taguchi's approach. These individual optimal values and its corresponding settings of the process parameters for the specified performance characteristics is shown in table.

TABLE – 8: MEANS OF MRR, Ra & TWR AT DIFFERENT LEVELS

Level	Mean Value of MRR		Mean Value of Ra		Mean Value of TWR	
	Grain Size	Concentration	Grain Size	Concentration	Grain Size	Concentration
1	16.909	16.673	3.385	3.410	0.031	0.031
2	17.022	16.758	3.244	3.336	0.027	0.028
3	16.243	16.745	3.307	3.190	0.033	0.032

TABLE – 9: INDIVIDUAL OPTIMAL VALUES &

Performance Characteristic	Optimal Parameter Level	Optimum Level
MRR	A2B2	17.164075
R_a	A2B3	3.0124
TWR	A2B2	0.026041667

CORRESPONDING SETTING OF PROCESS PARAMETERS

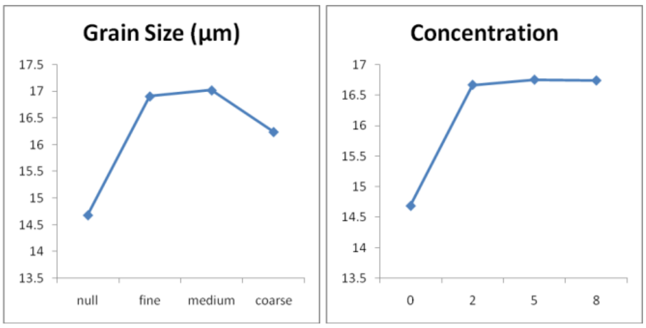

Fig. 2: RESPONSE GRAPH FOR MRR

9.6 ANALYSIS OF PLOT FOR MRR

The data gathered from the experimental work is analysed using single response S/N ratio method to obtain the optimal values of the process parameters. These optimal values for MRR are plotted in two graphs: one based on Grain size of powder and other based on concentration of powder.

9.6.1 Based on Grain Size of Powder

As shown in graph, MRR is low when no aluminium powder is mixed with EDM oil. With the addition of fine sized aluminium powder in the EDM oil, MRR increases. With the further increase in Grain size of aluminium powder i.e. medium size powder particles, MRR increases further. But as we increase the grain size of aluminium powder further i.e. coarse grain size, MRR decreases. So as a result we get best MRR on Medium sized Powder mixed with EDM oil.

9.6.2 Based on Concentration of Powder

As shown in graph initially MRR is low in absence of powder mixed with EDM oil. As we mix aluminium powder in the EDM oil in 2 gm/ltr. concentration, MRR increases. With further increase in concentration of aluminium powder, MRR also increases. So as a result we get best MRR on concentration 8 gm/ltr. of aluminium Powder mixed with EDM oil.

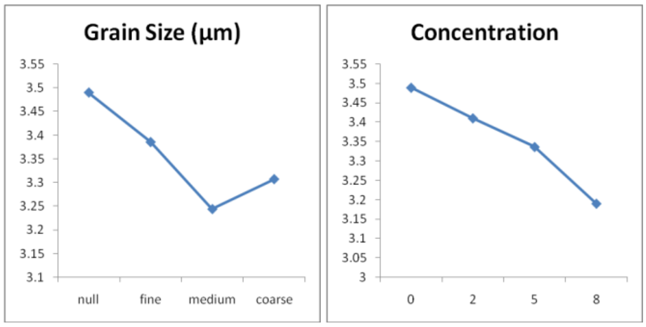

Fig. 3: RESPONSE GRAPH FOR Ra

9.7 ANALYSIS OF PLOT FOR SURFACE ROUGHNESS

The optimal values for Surface Roughness obtained from single response S/N ratio Table are plotted in two graphs: one based on Grain size of powder and other based on concentration of powder.

9.7.1 Based on Grain Size of Powder

As shown in graph Surface Roughness is high when no aluminium powder is mixed with EDM oil. As we mix fine sized aluminium powder in the EDM oil, Surface Roughness decreases. With the further increase in Grain size of aluminium powder i.e. medium size powder particles, Surface Roughness further decreases. As we further increase the grain size of aluminium powder i.e. coarse grain size, Surface Roughness increases. So as a result we get lowest surface roughness on medium sized Aluminium Powder. This means that medium sized Aluminium Powder gives the best surface finish.

9.7.2 Based on Concentration of Powder

As shown in graph initially when there is no powder mixed with EDM oil, Surface Roughness is high. As we mix aluminium powder in the EDM oil in 2 gm/ltr. Concentration, Surface Roughness decreases slightly. Surface roughness keeps on decreasing with the increases in the concentration of aluminium powder. So as a result we get lowest surface roughness on concentration 8 gm/ltr. of aluminium Powder mixed with EDM oil. This means that the best surface finish is achieved on concentration of 8 gm/ltr. of aluminium Powder mixed with EDM oil.

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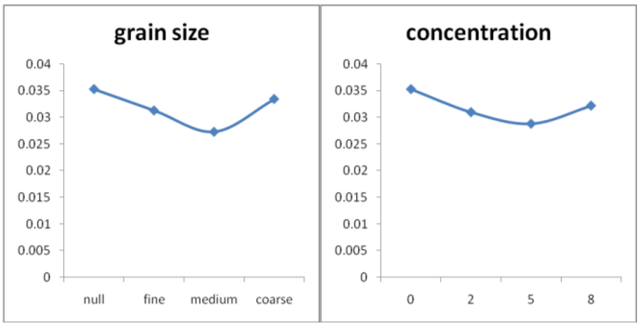

Fig. 4: RESPONSE GRAPH FOR TWR

9.8 ANALYSIS OF PLOT FOR TOOL WEAR RATE

The optimal values for Surface Roughness obtained from single response S/N ratio Table are plotted in two graphs: one based on Grain size of powder and other based on concentration of powder.

9.8.1 Based on Grain Size of Powder

As shown in graph, when there is no powder mixed in the EDM oil the tool wear rate is high, after mixing fine grain size aluminium powder the tool wear rate decreases and further decreases when medium grain size aluminium powder is added to the EDM oil. When grain size further increases i.e. coarse grain the tool wear rate increases. This shows that to get minimum tool wear rate medium grain size of aluminium powder should be used in EDM oil.

9.8.2 Based on Concentration of Powder

Graph represents that when there is no aluminium powder mixed with EDM oil, Tool Wear Rate (TWR) is high. As we mix aluminium powder in the EDM oil in 2 gm/ltr. Concentration, Tool Wear Rate decreases slightly. As we further increases the concentration of aluminium powder upto 5 gm/ltr., Tool Wear Rate decreases further. With the further increase in the concentration of aluminium powder upto 8 gm/ltr., Tool Wear Rate sudenly increases. So as a result we get lowest Tool Wear Rate on concentration 5 gm/ltr. of aluminium Powder mixed with EDM oil.

9.9 ANALYSIS OF MULTI-RESPONSE STAGE

The S/N ratio considers both the mean and the variability. In the present work, a multi- response methodology based on Taguchi technique and Utility concept is used for optimizing MRR, Ra & TWR. Taguchi proposed many different possible S/N ratios to obtain the optimal process efficiency. Two of them are selected for the present work. Those are,

9.9.1 Larger the better S/N ratio for MRR:

$$\eta_1 = -10\log_{10}\left[\frac{1}{MRR^2}\right]$$

9.9.2 Smaller the better type S/N ratio for R_a :

$$\eta_2 = -10\log_{10} \mathrm{Ra}^2$$

9.9.3 Smaller the better type S/N ratio for TWR:

$$\eta_3 = -10\log_{10} TWR^2$$

9.9.4 From the utility concept, the multi-response S/N ratio of the overall utility value is given by:

$$\eta_{obs} = W_1\eta_1 + W_2\eta_2 + W_3\eta_3$$

Where W1, W2 & W3 are the weights assigned to the MRR, Ra & TWR. Weights are defined according to the importance and choice of the operator, customer's requirements. Weights values taken for W1, W2 & W3 are as follows:

W1 for MRR = 0.4, W2 for Ra = 0.4.

W3 for TWR = 0.2.

The best combination for process parameters for simultaneous optimization of Material removal rate (MRR), Surface roughness (Ra), &Tool Wear Rate (TWR) is obtained by the mean values of the multi-response S/N ratio shown in Table.

TABLE – 10: DESIGN MATRIX WITH MULTI-RESPONSE S/N RATIO

S. No.	Grain/Mesh Size of Aluminium Powder (µm)	Concentration of Aluminium Powder (gm/ltr.)	MRR (mm^3/min.)	η_1 for MRR	Surface Roughness (µm)	η_2 for Ra	TWR (mm^3/min.)	η_3 for TWR	η_{obs}
1	0	0	14.68635	23.33827721	3.4897	-10.85576187	0.035342262	29.03411318	34.22711932
2	Fine (< 125)	2	16.846418	24.53015159	3.4211	-10.68331538	0.033482143	29.5037351	35.24246958
3	Fine (< 125)	5	16.931127	24.57371727	3.3889	-10.60117508	0.028831845	30.80255124	36.59156811
4	Fine (< 125)	8	16.952304	24.58457463	3.3465	-10.49181659	0.031622024	30.00020677	35.83730999
5	Medium(125–250)	2	17.05819	24.6386588	3.3998	-10.62906739	0.026971726	31.38182516	37.18566172
6	Medium(125–250)	5	17.164075	24.69240829	3.3211	-10.42563905	0.026041667	31.68662449	37.59333218
7	Medium(125–250)	8	16.846418	24.53015159	3.0124	-9.578252779	0.028831845	30.80255124	36.98331076
8	Coarse(250 – 375)	2	16.115807	24.14504104	3.4111	-10.65788903	0.032552083	29.74842423	35.34328503

9	Coarse(250 – 375)	5	16.179338	24.17921508	3.2998	-10.36975236	0.031622024	30.00020677	35.72399186
10	Coarse(250 – 375)	8	16.436641	24.31626114	3.2114	-10.13388806	0.036272321	28.80849297	34.68144221

TABLE – 11: MEAN VALUES OF η_{obs} AT DIFFERENT LEVELS

Levels	Mean Value of η_{obs} for Process Parameters	
	Grain Size	Concentration
Level 1	35.89044923	35.92380544
Level 2	37.25410155	36.63629738
Level 3	35.24957303	35.83402099

TABLE – 12: INDIVIDUAL OPTIMAL VALUES AND ITS CORRESPONDING SETTINGS OF PROCESS PARAMETERS

Performance Characteristics	Optimum Parameter Level	Optimum Level
η_{obs}	A2-B2	37.59333218

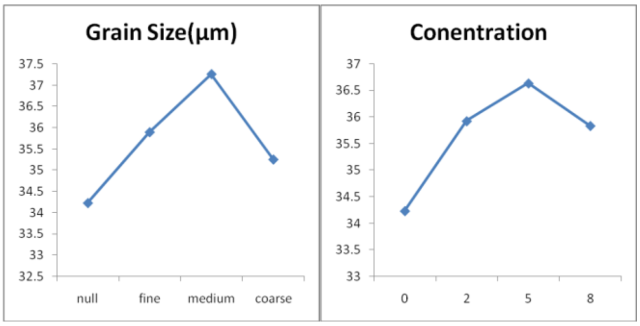

Fig. 5: MULTI-RESPONSE S/N RATIO GRAPH

9.10 INTERPRETATION OF PLOTS

The multi response S/N ratio graphs shows the optimal level of MRR, Ra & TWR with the variation in parameters i.e. Grain Size of aluminium powder and Concentration of aluminium powder. As there are two process parameters, so there are two graphs: one based on Grain size of powder and other based on concentration of powder.

9.10.1 Based on Grain Size of Powder

This graph is a plot between the process parameter i.e. Grain size of aluminium powder on x-axis and the values obtained from Multi-response table on y-axis. This graph gives the combined result for MRR, TWR and Surface Roughness. Initially when there is no powder mixed with EDM oil, the multi response value plotted is low. As we mix fine grain size aluminium powder in the EDM oil, the multi response value increases. With the increase in Grain size of aluminium powder i.e. medium size powder particles, the multi response value increases further. But with further increase in grain size of aluminium powder i.e. coarse grain size, the multi response value reduces. So we get the best result on medium sized Aluminium Powder. On medium sized aluminium powder mixed with EDM oil we get the optimum value for MRR Surface Roughness & Tool Wear Rate.

9.10.2 Based on Concentration of Powder

This graph is a plot between the Concentration of aluminium powder on x-axis and the values obtained from Multi-response table on y-axis. This graph shows the combined result for MRR, TWR and Surface Roughness. Initially when no powder is mixed with EDM oil, the optimum value plotted is low. As we mix aluminium powder in the EDM oil in concentration of 2 gm./ltr., the multi response value increases. With the increase in concentration of aluminium powder i.e. at 5 gm./ltr., the multi response value increases further. But as we further increase the concentration of aluminium powder i.e. 8gm./ltr., the multi response value decreases. So as a result, optimum value of MRR, TWR and Surface Roughness is achieved at a concentration of 5 gm./ltr. of aluminium powder mixed with EDM oil.

10. CONCLUSION

A set of experiments are performed on AISI 1018 steel work pieces by using copper electrode in aluminium powder mixed EDM. The experimental studies are conducted by keeping various parameters like Current, Voltage, Pulse on time, Duty factor constant and by varying two parameters i.e. Grain size of aluminium powder & Concentration of aluminium powder. Mixing of Aluminium powder in Di-electric fluid ensures improved MRR, Surface finishing and minimized TWR. Based on the results obtained, the following conclusions have been drawn:

[1] The analysis of the experimental observations highlights that Grain size of aluminium powder and concentration of aluminium powder mixed with EDM oil have a great influence on MRR, Surface finish and TWR.

[2] Too low and too high Grain size of aluminium powder in EDM oil reduces MRR of AISI 1018 Steel. So we get the best MRR on medium sized aluminium powder mixed with EDM oil.

[3] With the increase in concentration of aluminium powder in EDM oil, MRR of AISI 1018 Steel increases.

[4] Too low and too high Grain size of aluminium powder in EDM oil reduces Surface finish of AISI 1018 Steel. So we get the best surface finish on medium sized aluminium powder mixed with EDM oil.

[5] With the increase in concentration of aluminium powder in EDM oil, Surface finish of AISI 1018 Steel increases.

[6] At medium sized aluminium powder mixed with EDM oil, we get the least Tool wear Rate.

[7] At low and high concentration of aluminium powder in EDM oil, TWR is also high. We get least TWR at medium concentration of aluminium powder i.e. 5 gm./ltr.

[8] If we give 40 % weightage to MRR, 40% weightage to Ra, and 20% weightage to TWR, then at medium grain

sized Aluminium powder mixed with EDM oil, we get the optimum level for MRR, Ra & TWR.

[9] If we give 40 % weightage to MRR, 40% weightage to Ra, and 20% weightage to TWR, then at concentration 5 gm./ltr. of Aluminium powder mixed with EDM oil, we get the optimum level for MRR, Ra & TWR.

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