Comparative Study for the Effect Powder Mixed Dielectric on Performance Measures in Wire EDM

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***Abstract* -Requirements of the good surface finish, cost effective ness, intricate geometry, better MRR and minimum overcut have evolved the area of the Advanced Machining processes. Wire EDM is an extended form of Electrical Discharge Machining working on principle of spark erosion. Input parameters of Wire EDM such as Pulse ON time, Pulse Off time, Peak current, wire tension, wire speed etc. have major effect on the performance of the process. Wire cut EDM process is evaluated on the basis of surface finish, MRR, machining time, power consumption and wire erosion. Main emphasis in this research is given to study the effect of PMD (Powder Mixed Dielectric) on optimization results. Use of powder mixed dielectric is the main domain to focus. For experimentation, Taguchi method has been applied to select orthogonal array with using of Minitab 17. To achieve optimized combination of process parameters for best performance, optimization using Grey relational analysis is carried out. Adding the powder in dielectric improve the surface finish and kerf width. In this work, comparative optimization for process parameters of Wire EDM with using simple deionized water and graphite mixed dielectric has been carried out.**

***Keywords* – Wire EDM, Grey Relational analysis, DM water (De-mineralized water), GMDM water (graphite mixed De-mineralized water)**

I INTRODUCTION

Wire EDM process was introduced in late 1960's and it had revolutionized the tool and die, metal working, mold industries. It is probably the most exciting and diversified machine tool developed for manufacturing industry.It can machine anything that is electrically conductive regardless of the hardness, from relatively common materials such as tool steel, aluminum, copper, and graphite, to exotic space-age alloys including hast alloy, wasp alloy, Inconel, titanium, carbide, polycrystalline diamond compacts and conductive ceramics. It is single step process. Wire electrical-discharge machining is an adaptation of the basic EDM process. In wire EDM process metal removal process is carried out by spark erosion mechanism. When high frequency of alternating or direct current is discharged from wire to work piece with a very small spark gap through dielectric fluid, many sparks can be observed at one time. The heat of each electrical spark, estimated at around15,000° to 21,000° Fahrenheit, erodes away a tiny bit of material that is vaporized and separated from the parent material.The resulting particles (chips) are flushed away from the gap with a stream of clean, de-ionized water from the top and bottom flushing nozzles [1].

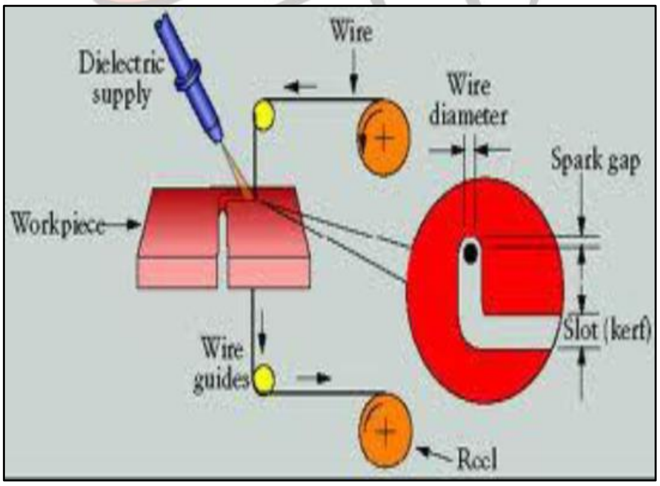

Fig. 1 principle of Wire EDM [6]

There are some parameters which control the quality of the product made by wire EDM. And they are as given below diagram.

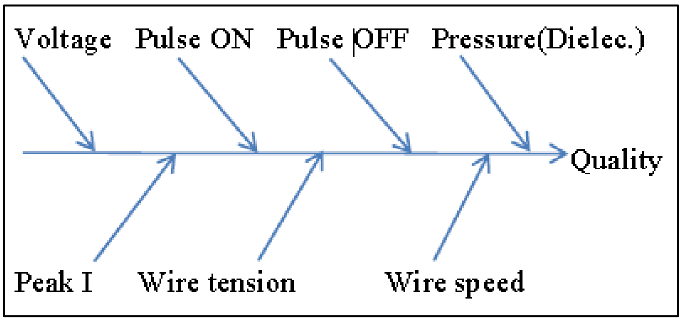

Fig .2 Fishbone diagram showing process parameter

II LITERATURE SURVEY

Wire electrical discharge machining (WEDM)

The emphasis is on the generation of mathematical modeling having quadratic nature (respond surface model). Multi-objective optimization with considering discharge current, pulse duration, pulse frequency, wire speed, wire tension and dielectric flow rate as the process parameters are done. Taguchi method with L_{27} orthogonal array has been selected for experiment and to convert multi objective criterion to equivalent single objective function grey relational analysis has been adopted. Mathematical model and effects of the highlighted parameters on the performance measures are established with the use of statistical software MINITAB 13 [2]. Optimization of process parameters (peak current, duty factor, wire tension and dielectric pressure) with number of nontraditional optimization techniques (genetic algorithm, particle swarm optimization, sheep flock algorithm, ant colony optimization, artificial bee colony and biogeography-based optimization) is done for wear ratio, surface finish and MRR as performance measures. Among all biogeography based technique provides best results [3]. Prediction and modeling of the surface finish in wire EDM titanium alloy (Ti-6Al-4v) with the use of two levels full factorial method. And experimental values are compared with predicted values. Pulse on time, pulse off time, voltage and dielectric flushing pressure. The WEDM experiments are conducted in Electronica ultra-cut s1 machine using 0.25 mm brass wire as the tool electrode. Comparison between experimental values and predicted values has been carried out and error margin is found to be 7% [4]. Parametric optimization of composite material (Al+3%Sic) with the use of Taguchi method (L_{13} orthogonal array) is done and compared with ANNOVA method. Surface finish and MRR decreases when work piece is machined with air as a dielectric fluid [5]. Graphical representation for effect of input parameters on MRR and surface roughness has been carried out and studied using respond surface methodology. Work piece and tool material are SS304 and brass wire. CCD (central composite rotatable factorial design) is adopted as DOE [6]. Mathematical model has been developed using design expert system software and optimization is carried out using MATLAB (GA algorithm). Desired responses are maximum MRR and minimum surface roughness [7]. Mathematical modeling has been done with the use of respond surface modeling with quadratic nature. Pulse on time, pulse of time, wire speed and wire feed are the parameters. Performance measures are MRR and Surface roughness [8]. Wire failure occurred in wire cut EDM is a result of severity in wire wear rate, which is function of discharge current and discharge time. For the same MRR, wire wear rate is observed to be lower with zinc coated brass but with bare wire high erosion rate is observed [9]. WEDM (wire electro discharge grinding) is a one of the hybrid machining process for micro machining the fine electrodes or pins with a large aspect ratio [10].

Use of Powder mixed dielectric in EDM

Electrical conductive powder used in dielectric reduces the insulating strength of dielectric fluid and increases the spark gap between tool & workpiece. It improves MRR and surface finish. Aluminum, chromium, graphite, silicon, copper and silicon carbide are the powders can be used. Powder creates bridging effect [11]. Use of Silicon powder in Wire electro discharge machining has positive influence on the operating time and surface finish and best results are achieved when powder grain size is below 15 µm with AIHI H13 steel [12]. Thin electrode and rotating disk are used to keep powder concentration in gap between workpiece and electrode. TiC layer is grown on carbon steel when titanium powder is used in dielectric [13]. Aluminum powder leads the thinnest rim zone and highest MRR and silicon powder produces grey zone beneath the actual 'white zone'. Powder addition produces the thinner rim zone [14]. With smaller electrode area surface finish is good with simple EDM but with the use of powder mixed dielectric, sensitivity to surface quality is lower. There is linear relationship between electrode area and surface quality [15]. Pick current is emerged as a most significant parameter and tungsten carbide formation in workpiece indicate the reaction of tungsten powder with carbon present in it. Surface alloying with tungsten and carbon has a significant effect on properties of workpiece material [16]. Introduction of the MoS_2 micro powder in dielectric fluid using ultrasonic vibration significantly improves the MRR and surface quality by providing a flat surface free of black carbon spots [17]. Features of powder mixed dielectric EDM are shorter machining time, more uniform dispersion of electrical discharges and stable machining [18].setting of peak current at a high level (16 A), pulse-on time at a medium level (100 µs), pulse-off time at a low level (15 µs), powder concentration at a high level (4 g/l), and gain at a low level (0.83 mm/s) produced optimum MR from AISI D2 surfaces when machined by silicon powder mixed EDM [19]. Pulse on time, duty cycle, peak current and concentration of the silicon powder added into the dielectric fluid of EDM are the variables to study the process performance in terms of material removal rate and surface roughness [20].

Lots of work has been done on the wire EDM process by researchers with traditional optimization techniques (Taguchi method) as well as nontraditional optimization techniques (genetic algorithm, particle swarm optimization, sheep flock algorithm, ant colony optimization, artificial bee colony and biogeography-based optimization). Parameter optimization covers major portion of research. Use of powder mixed dielectric in electrical discharge machining directs the new way of thinking for the improvements. But main gap found is:

- Comparative study for use of powder mixed dielectric and simple dielectric in Wire EDM process.
- Check the effect of concentrations of powder in dielectric on performance measures (surface finish, machining time and kerf width) in Wire EDM.
- Use of powder mixed dielectric through nozzle directly.
- Use of various mesh sized powder in wire EDM and checking the effect.
- Design stirring system for powder mixing in dielectric.
- Comparative study for the different types of powders mixed with dielectric in wire EDM process.

Conductive powder addition in dielectric creates "bridging effect" and lowers down the breakdown voltage, which leads early explosion improving MRR. Uniformly distributed sparking in series improves surface roughness. Aluminums, silicon, graphite, are some powder which can be added to enhance the performance of the process. SS304 is a steel material applicable in milk processing equipment and chemical handling due to anti corrosive characteristic against acids. Parametric optimization of wire EDM with simple dielectric on SS304 has been done by previous researcher. But as per literature reviewed, Comparative optimization has not been done for SS304 with PMD use. Hence, for further research it is taken as research gap and accordingly following research objectives has been derived.

1. To experimentally investigate, with the use of Taguchi experimental design, the effect of powder addition (Graphite) on performance characteristics (surface roughness, machining time and kerf width).
2. To carry out grey relation analysis to find optimized combination of control parameters

III DESIGN OF EXPERIMENT

Selection of Process parameters, Performance measures, Material and type of Dielectric

- Pulse ON time, Pulse OFF time and Peak current are selected as control parameters.
- Machining time, kerf width and Surface roughness are taken as quality characteristics.
- SS304 is selected as Work piece. Two types of Dielectrics have been selected. First one is, De-mineralized water and second one is Graphite mixed de-mineralized water (Concentration = 2g/litre, fineness = 200 mesh).

Table 1 Selection of orthogonal array and levels of process parameters L_{27}

No of trials	Parameters		
	Pulse ON time (µs)	Pulse OFF time (µs)	Peak current (Amp.)
1	15	4	2
2	15	4	4
3	15	4	6
4	15	6	2
5	15	6	4
6	15	6	6
7	15	8	2
8	15	8	4
9	15	8	6
10	20	4	2
11	20	4	4
12	20	4	6
13	20	6	2
14	20	6	4
15	20	6	6
16	20	8	2
17	20	8	4
18	20	8	6
19	25	4	2
20	25	4	4
21	25	4	6
22	25	6	2
23	25	6	4
24	25	6	6
25	25	8	2
26	25	8	4
27	25	8	6

Experimentation

Experiments are performed on the NC controlled Wire Electrical discharge machine (DK – 7712) manufactured by Concord United Pvt. Ltd, Bangalore. It is installed in laboratory of Mechanical Department of Government Engineering College, Patan (N.G)

Table 2 Work table Specifications

Specifications	Metric
Longitudinal Travel	160 mm
Transverse Travel	120 mm
Movement of work table per revolution of hand wheel	4 mm
Movement of work table per graduation on hand wheel	0.04 mm

Table 3 Specifications for workpiece handling

Specification	Metric
Max length	270 mm
Maximum width	160 mm
Maximum weight of w/p	80 kg
Maximum thickness of cutting	100 mm
Maximum fineness of surface	R_a = 1.252 to 2.5 µm
Maximum productivity	80 mm^2 / min

Experimental procedure

- Select the work pieces of appropriate dimension. Total no of work pieces are 54, 27 for use of de-ionized water and 27 for use PMD.
- Fix the work piece on machine table.
- Turn on the computer and open the serial port communication program.
- Edit the parameter values of pulse ON time, Pulse OFF time and Peak current as per the combination of experimental trial.
- Open the HF control system installed in computer, go in “program” tab then prepare the drawing of profile we want to cut according to the drawing G code is generated. Save the G code file and close the tab.
- In HF control system, open another tab “machining”, the go to the “read” and select the program file having G code.
- Now, turn ON the machine. Select the “CUT +” tab. Machining will be started according to the prepared program with the movement of table against the wire as a tool.
- To retract the tool select “CUT”. When cutting will be finish. Machine will stop..
- One cut is made throughout cut along length 25 mm, which is used to measure the surface roughness but one more cut is of approximately 10 mm is made to measure the kerf width.
- Whole procedure is done for all nine experimental trials.
- Replace the dielectric (de-ionized water) of machine tank with 25 litre of new graphite powder (2g/l) mixed de-ionized water.
- Whole procedure is repeated for another nine experimental trials of usage of PMD.
- Generally Time is measured by digital watch, but in this experiments time has been calculated by HF control system, it shows the time between cutting starting and end of the programmed cut. In this method of time calculation researcher’s error does not come in picture.
- Surface roughness values are measured by “surface roughness tester” in non-conventional machining laboratory of M.S. University of Baroda. Three readings are taken for each workpiece. Mean value is considered for further work.
- Kerf width is measured with the use of “measuring microscope” in metallurgy laboratory of M.S University of Baroda. For accurate measurement, eight readings are taken for each work piece at various points. Mean of them is selected for further work

Fig. 3 Machining Setup (a)

Fig. 4 Machining Setup (b)

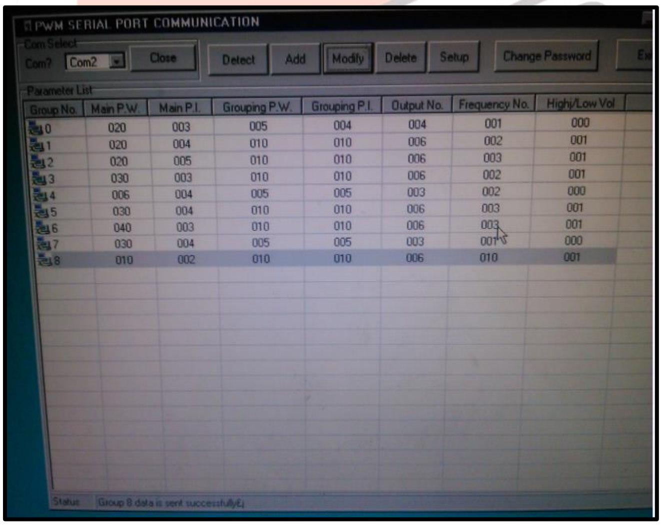

Fig. 5 Serial port communication

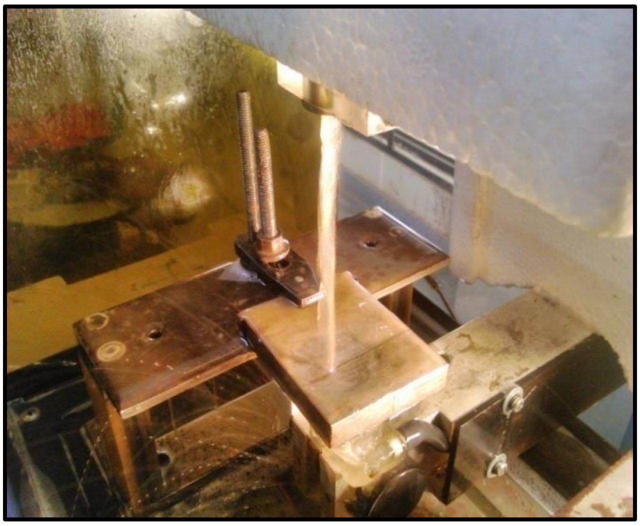

Fig. 6 actual machining of piece

Table 4 Measured Data

For DM water			For GMDM water		
R_a (µm)	**W_k (mm)**	**T_m (min)**	**R_a (µm)**	**W_k (mm)**	**T_m (min)**
2.06	0.2241	38.25	2.06	0.2223	37.13
2.28	0.2543	18.01	2.31	0.2456	19.11
2.29	0.2741	11.58	2.34	0.2634	12
2.29	0.2223	53.17	1.9	0.2212	53.33
2.58	0.2427	25.39	2.57	0.2412	26.07
3.08	0.2629	16.21	1.97	0.25	16.29
2.06	0.2141	59.22	2.97	0.2123	59.57
2.6	0.2328	32.31	2.68	0.2317	32.36
2.94	0.25	20.43	2.92	0.2456	20.48
2.43	0.2414	36.27	2.39	0.2401	36.44
3.43	0.2619	17.12	3.14	0.2545	18.02
2.54	0.2672	11.51	3.58	0.259	12
1.96	0.2413	47.5	1.92	0.2322	48.17
2.65	0.25	24.25	2.62	0.25	21.35
3.32	0.2671	16.18	3.38	0.259	16.31
1.82	0.2412	59.01	1.77	0.2322	59.51
2.69	0.25	31.48	2.56	0.25	32.02
2.99	0.2586	19.44	2.73	0.259	19.47
2.31	0.2414	35.13	2.45	0.2411	35.28
4.34	0.2686	16.02	3.51	0.2689	16.15
4.42	0.2967	11.06	4.37	0.2918	11.23
2.88	0.2385	49.03	2.53	0.2384	49.2
2.89	0.2675	24.03	2.63	0.2624	24.09
3.39	0.2701	15.08	3.32	0.2719	15.29
2.11	0.2335	55.16	1.93	0.2383	57.26
2.9	0.2578	30.29	2.78	0.253	30.32
3.17	0.2627	19.37	3.05	0.2617	19.48

IV GREY RELATIONAL ANALYSIS

Grey analysis is a new technology used for data analysis. It is also called as grey logic or grey system theory. It is useful in the case of uncertain information. It is particularly applicable in case of little system knowledge.

Grey analysis was invented by professor Deng Julong of Huazhong University of Science and Technology in Wuhan, China. Grey analysis has been successfully used in a wide range of fields diverse as agriculture, ecology, economic planning and forecasting, traffic planning, industrial planning and analysis, management and decision making, irrigation strategy, crop yield forecasting, military affairs, target tracking, population control, communication system design, geology, oil exploration, earthquake prediction, material science, manufacturing, biological protection, environmental impact studies, medical management and the judicial system [21].

Step – 1 Data preprocessing : If the number of experimental trials and number of output parameters (performance measures) is "m" and "n" respectively, then i^{th} trial can be expressed as $Y_i = (y_{i1}, y_{i2}, y_{i3}, \ldots\ldots, y_{in})$ in decision matrix, where y_{ij} is the performance characteristic's (j = 1, 2, 3, …..,n) value. Hence decision matrix "D" can be expressed as,

$$D = \begin{bmatrix} y11 \dots\dots & y1j \dots\dots & y1n \\ \dots\dots & yij \dots\dots & \dots\dots \\ ym1 \dots\dots & ymj \dots\dots & ymn \end{bmatrix} \quad (1)$$

Decision matrix D can be converted into normality decision matrix D'. And all y_{ij} values are replaced by x_{ij}. Hence D' can be expressed as,

$$D' = \begin{bmatrix} x11 \dots\dots & x1j \dots\dots & x1n \\ \dots\dots & xij \dots\dots & \dots\dots \\ xm1 \dots\dots & xmj \dots\dots & xmn \end{bmatrix} \quad (2)$$

Normalized values of x_{ij} are determined by following equations. There are three types of responses larger the better, smaller the better and nominal the best.

If the expectancy of response is beneficial type (larger the better), then it can be expressed as

$X_{ij} = (Y_{ij} - min\ Y_{ij}) / (max\ Y_j - min\ Y_j)$ (3)

If the expectancy of response is non-beneficial type (Smaller the better), then it can be expressed as

$X_{ij} = (max\ Y_{ij} - Y_{ij}) / (max\ Y_j - min\ Y_j)$ (4)

If the expectancy of response is for target value (nominal the best), then it can be expressed as

$X_{ij} = 1-[(Y_j^* - Y_{ij}) / (max\ Y_{ij} - min\ Y_{ij})]$ (5)

Where Y_j^* is the closer to the desired value of response.

Step 2 Reference sequence definition: All the values of normalized matrix D' are in [0,1]. Now, if any x_{ij} values are equal to 1 or nearer to 1, then performance of their respective experiment is best for respective response. Reference sequence X is defined as $(x_1, x_2, \dots x_j, \dots\dots x_n) = (1, 1, 1, \dots\dots, 1)$. Where, x_j is the reference value for j^{th} response. It is used to find experiment whose comparability sequence is nearest to the reference sequence.

Step 3 Grey relational coefficient calculations: Grey relational coefficient is applicable to show the closeness of x_{ij} to x_j. As larger the coefficient value, more is the closeness of x_{ij} to x_j. Coefficients can be expressed as

$$\gamma_{ij} = \frac{(\Delta min + (\xi \times \Delta max))}{(\Delta ij + \Delta max))} \quad (6)$$

For i = 1, 2, 3….,m and j = 1, 2, 3,….n

Where, γ = grey relational grade between x_{ij} and x_j.

$$\Delta\, min = min\, ij|xj - xij| \quad (7)$$

$$\Delta\, max = max\, ij|xj - xij| \quad (8)$$

$$\Delta\, ij = |xj - xij| \quad (9)$$

ξ = distinguishing coefficient $\xi \in (0, 1)$

Distinguishing coefficient is also called as index for distinguishing ability. It represents the "contrast control" of equation. Smaller the value of coefficient, higher is the distinguishing ability. Application of this coefficient is to expend or compress the range of grey relational coefficient. Different values can give different values. Here, we take value $\xi = 0.4$.

Step 4 Calculation of grey relational grades (grey relational degree): It is a weighted sum of grey relational coefficients. It can be calculated using following equation,

$$\gamma_j = \sum_{j=1}^{n} wj.\gamma ij \quad (10)$$

For i = 1, 2…, m. and j = 1, 2…, n.

γ_j is the grey relational grade between comparability sequence and reference sequence.

W_j is the Weightage factor for particular response j and it depends on priorities of researcher.

Table 5 Y_{ij} values (i = 1,2,….,27) for Machining time, surface roughness, kerf width.

				For DM water			For GMDM water		
No.	**T_{on} (µs)**	**T_{off} (µs)**	**I_p (A)**	**R_a (µm)**	**W_k (mm)**	**T_m (min)**	**R_a (µm)**	**W_k (mm)**	**T_m (min)**
1	15	4	2	2.06	0.2241	38.25	2.06	0.2223	37.13
2	15	4	4	2.28	0.2543	18.01	2.31	0.2456	19.11
3	15	4	6	2.29	0.2741	11.58	2.34	0.2634	12
4	15	6	2	2.29	0.2223	53.17	1.9	0.2212	53.33
5	15	6	4	2.58	0.2427	25.39	2.57	0.2412	26.07
6	15	6	6	3.08	0.2629	16.21	1.97	0.25	16.29
7	15	8	2	2.06	**0.2141**	**59.22**	2.97	**0.2123**	**59.57**
8	15	8	4	2.6	0.2328	32.31	2.68	0.2317	32.36
9	15	8	6	2.94	0.25	20.43	2.92	0.2456	20.48
10	20	4	2	2.43	0.2414	36.27	2.39	0.2401	36.44
11	20	4	4	3.43	0.2619	17.12	3.14	0.2545	18.02
12	20	4	6	2.54	0.2672	11.51	3.58	0.259	12
13	20	6	2	1.96	0.2413	47.5	1.92	0.2322	48.17
14	20	6	4	2.65	0.25	24.25	2.62	0.25	21.35
15	20	6	6	3.32	0.2671	16.18	3.38	0.259	16.31
16	20	8	2	**1.82**	0.2412	59.01	1.77	0.2322	59.51
17	20	8	4	2.69	0.25	31.48	2.56	0.25	32.02
18	20	8	6	2.99	0.2586	19.44	2.73	0.259	19.47
19	25	4	2	2.31	0.2414	35.13	2.45	0.2411	35.28

20	25	4	4	4.34	0.2686	16.02	3.51	0.2689	16.15
21	25	4	6	**4.42**	**0.2967**	**11.06**	4.37	**0.2918**	**11.23**
22	25	6	2	2.88	0.2385	49.03	2.53	0.2384	49.2
23	25	6	4	2.89	0.2675	24.03	2.63	0.2624	24.09
24	25	6	6	3.39	0.2701	15.08	3.32	0.2719	15.29
25	25	8	2	2.11	0.2335	55.16	1.93	0.2383	57.26
26	25	8	4	2.9	0.2578	30.29	2.78	0.253	30.32
27	25	8	6	3.17	0.2627	19.37	3.05	0.2617	19.48
Max				**4.42**	**0.2967**	**59.22**	**4.37**	**0.2918**	**59.57**
Min				**1.82**	**0.2141**	**11.06**	**1.77**	**0.2123**	**11.23**
Max - Min				**2.6**	**0.0826**	**48.16**	**2.6**	**0.0795**	**48.34**

Table 6 Sequence of each performance measures after data processing for wire EDM with DM water

No.	X (R_a)	X (W_k)	X (T_m)	Δ (R_a)	Δ (W_k)	Δ (T_m)
1	0.90769	0.87893	0.43542	0.09230	0.12106	0.56457
2	0.82307	0.51331	0.85568	0.17692	0.48668	0.14431
3	0.81923	0.27360	0.98920	0.18076	0.72639	0.01079
4	0.81923	0.90072	0.12562	0.18076	0.09927	0.87437
5	0.70769	0.65375	0.70245	0.29230	0.34624	0.29754
6	0.51538	0.40920	0.89306	0.48461	0.59079	0.10693
7	0.90769	1	0	0.09230	**0 (min)**	**1(max)**
8	0.7	0.77360	0.55876	0.3	0.22639	0.44123
9	0.56923	0.56537	0.80544	0.43076	0.43462	0.19455
10	0.76538	0.66949	0.47653	0.23461	0.33050	0.52346
11	0.38076	0.42130	0.87416	0.61923	0.57869	0.12583
12	0.72307	0.35714	0.99065	0.27692	0.64285	0.00934
13	0.94615	0.67070	0.24335	0.05384	0.32929	0.75664
14	0.68076	0.56537	0.72612	0.31923	0.43462	0.27387
15	0.42307	0.35835	0.89368	0.57692	0.64164	0.10631
16	1	0.67191	0.00436	**0 (min)**	0.32808	0.99563
17	0.66538	0.56537	0.57599	0.33461	0.43462	0.42400
18	0.55	0.46125	0.82599	0.45	0.53874	0.17400
19	0.81153	0.66949	0.50020	0.18846	0.33050	0.49979
20	0.03076	0.34019	0.89700	0.96923	0.65980	0.10299
21	0	0	1	**1(max)**	**1(msx)**	**0 (min)**
22	0.59230	0.70460	0.21158	0.40769	0.29539	0.78841
23	0.58846	0.35351	0.73068	0.41153	0.64648	0.26931
24	0.39615	0.32203	0.91652	0.60384	0.67796	0.08347
25	0.88846	0.76513	0.08430	0.11153	0.23486	0.91569
26	0.58461	0.47094	0.60070	0.41538	0.52905	0.39929
27	0.48076	0.41162	0.82745	0.51923	0.58837	0.17254

Table 7 Sequence of each performance measures after data processing for wire EDM with GMDM water

No.	X (R_a)	X (W_k)	X (T_m)	Δ (R_a)	Δ (W_k)	Δ (T_m)
1	0.88846	0.87421	0.46421	0.11153	0.12578	0.53578
2	0.79230	0.58113	0.83698	0.20769	0.41886	0.16301
3	0.78076	0.35723	0.98407	0.21923	0.64276	0.01592
4	0.95	0.88805	0.12908	0.05	0.11194	0.87091
5	0.69230	0.63647	0.69300	0.30769	0.36352	0.30699
6	0.92307	0.52578	0.89532	0.07692	0.47421	0.10467
7	0.53846	1	0	0.46153	**0(min)**	**1(max)**
8	0.65	0.75597	0.56288	0.35	0.24402	0.43711
9	0.55769	0.58113	0.80864	0.44230	0.41886	0.19135
10	0.76153	0.65031	0.47848	0.23846	0.34968	0.52151
11	0.47307	0.46918	0.85953	0.52692	0.53081	0.14046
12	0.30384	0.41257	0.98407	0.69615	0.58742	0.01592
13	0.94230	0.74968	0.23582	0.05769	0.25031	0.76417
14	0.67307	0.52578	0.79064	0.32692	0.47421	0.20935
15	0.38076	0.41257	0.89491	0.61923	0.58742	0.10508
16	1	0.74968	0.00124	**0(min)**	0.25031	0.99875
17	0.69615	0.52578	0.56992	0.30384	0.47421	0.43007

18	0.63076	0.41257	0.82954	0.36923	0.58742	0.17045
19	0.73846	0.63773	0.50248	0.26153	0.36226	0.49751
20	0.33076	0.28805	0.89822	0.66923	0.71194	0.10177
21	0	0	1	**1(max)**	**1(max)**	**0(min)**
22	0.70769	0.67169	0.21452	0.29230	0.32830	0.78547
23	0.66923	0.36981	0.73396	0.33076	0.63018	0.26603
24	0.40384	0.25031	0.91601	0.59615	0.74968	0.08398
25	0.93846	0.67295	0.04778	0.06153	0.32704	0.95221
26	0.61153	0.48805	0.60508	0.38846	0.51194	0.39491
27	0.50769	0.37861	0.82933	0.49230	0.62138	0.17066

Table 8 Grey relational coefficients for individual performance characteristics for wire EDM using DM water

No.	X (R_a)	X (W_k)	X (T_m)	Δ (R_a)	Δ (W_k)	Δ (T_m)	γ (R_a)	γ (W_k)	γ (T_m)
1	0.90769	0.87893	0.43542	0.09230	0.12106	0.56457	0.8125	0.76765	0.41468
2	0.82307	0.51331	0.85568	0.17692	0.48668	0.14431	0.69333	0.45111	0.73487
3	0.81923	0.27360	0.98920	0.18076	0.72639	0.01079	0.68874	0.35511	0.97371
4	0.81923	0.90072	0.12562	0.18076	0.09927	0.87437	0.68874	0.80116	0.31387
5	0.70769	0.65375	0.70245	0.29230	0.34624	0.29754	0.57777	0.53601	0.57343
6	0.51538	0.40920	0.89306	0.48461	0.59079	0.10693	0.45217	0.40371	0.78905
7	0.90769	1	0	0.09230	**0 (min)**	**1(max)**	0.8125	1	0.28571
8	0.7	0.77360	0.55876	0.3	0.22639	0.44123	0.57142	0.63857	0.47548
9	0.56923	0.56537	0.80544	0.43076	0.43462	0.19455	0.48148	0.47925	0.67276
10	0.76538	0.66949	0.47653	0.23461	0.33050	0.52346	0.63030	0.54756	0.43315
11	0.38076	0.42130	0.87416	0.61923	0.57869	0.12583	0.39245	0.40870	0.76070
12	0.72307	0.35714	0.99065	0.27692	0.64285	0.00934	0.59090	0.38356	0.97717
13	0.94615	0.67070	0.24335	0.05384	0.32929	0.75664	0.88135	0.54847	0.34582
14	0.68076	0.56537	0.72612	0.31923	0.43462	0.27387	0.55614	0.47925	0.59357
15	0.42307	0.35835	0.89368	0.57692	0.64164	0.10631	0.40944	0.38400	0.79002
16	1	0.67191	0.00436	**0 (min)**	0.32808	0.99563	1	0.54938	0.28660
17	0.66538	0.56537	0.57599	0.33461	0.43462	0.42400	0.54450	0.47925	0.48543
18	0.55	0.46125	0.82599	0.45	0.53874	0.17400	0.47058	0.42610	0.69686
19	0.81153	0.66949	0.50020	0.18846	0.33050	0.49979	0.67973	0.54756	0.44454
20	0.03076	0.34019	0.89700	0.96923	0.65980	0.10299	0.29213	0.37742	0.79524
21	0	0	1	**1(max)**	**1(max)**	**0 (min)**	0.28571	0.28571	1
22	0.59230	0.70460	0.21158	0.40769	0.29539	0.78841	0.49523	0.57520	0.33658
23	0.58846	0.35351	0.73068	0.41153	0.64648	0.26931	0.49289	0.38223	0.59762
24	0.39615	0.32203	0.91652	0.60384	0.67796	0.08347	0.39846	0.37106	0.82734
25	0.88846	0.76513	0.08430	0.11153	0.23486	0.91569	0.78195	0.63005	0.30402
26	0.58461	0.47094	0.60070	0.41538	0.52905	0.39929	0.49056	0.43054	0.50044
27	0.48076	0.41162	0.82745	0.51923	0.58837	0.17254	0.43514	0.40470	0.69862

Table 9 Grey relational coefficients for individual performance characteristics for wire EDM using GMDM water

No.	X (R_a)	X (W_k)	X (T_m)	Δ (R_a)	Δ (W_k)	Δ (T_m)	γ (R_a)	γ (W_k)	γ (T_m)
1	0.88846	0.87421	0.46421	0.11153	0.12578	0.53578	0.78195	0.76076	0.42744
2	0.79230	0.58113	0.83698	0.20769	0.41886	0.16301	0.65822	0.48847	0.71046
3	0.78076	0.35723	0.98407	0.21923	0.64276	0.01592	0.64596	0.38359	0.96170
4	0.95	0.88805	0.12908	0.05	0.11194	0.87091	0.88888	0.78132	0.31473
5	0.69230	0.63647	0.69300	0.30769	0.36352	0.30699	0.56521	0.52388	0.56577
6	0.92307	0.52578	0.89532	0.07692	0.47421	0.10467	0.83870	0.45755	0.79258
7	0.53846	1	0	0.46153	**0(min)**	**1(max)**	0.46428	1	0.28571
8	0.65	0.75597	0.56288	0.35	0.24402	0.43711	0.53333	0.62109	0.47783
9	0.55769	0.58113	0.80864	0.44230	0.41886	0.19135	0.47488	0.48847	0.67641
10	0.76153	0.65031	0.47848	0.23846	0.34968	0.52151	0.62650	0.53355	0.43406
11	0.47307	0.46918	0.85953	0.52692	0.53081	0.14046	0.43153	0.42972	0.74010
12	0.30384	0.41257	0.98407	0.69615	0.58742	0.01592	0.36491	0.40509	0.96170
13	0.94230	0.74968	0.23582	0.05769	0.25031	0.76417	0.87394	0.61508	0.34359
14	0.67307	0.52578	0.79064	0.32692	0.47421	0.20935	0.55026	0.45755	0.65643
15	0.38076	0.41257	0.89491	0.61923	0.58742	0.10508	0.39245	0.40509	0.79193
16	1	0.74968	0.00124	**0(min)**	0.25031	0.99875	1	0.61508	0.28596
17	0.69615	0.52578	0.56992	0.30384	0.47421	0.43007	0.56830	0.45755	0.48188
18	0.63076	0.41257	0.82954	0.36923	0.58742	0.17045	0.52	0.40509	0.70118

19	0.73846	0.63773	0.50248	0.26153	0.36226	0.49751	0.60465	0.52475	0.44567
20	0.33076	0.28805	0.89822	0.66923	0.71194	0.10177	0.37410	0.35972	0.79716
21	0	0	1	**1(max)**	**1(max)**	**0(min)**	0.28571	0.28571	1
22	0.70769	0.67169	0.21452	0.29230	0.32830	0.78547	0.57777	0.54922	0.33741
23	0.66923	0.36981	0.73396	0.33076	0.63018	0.26603	0.54736	0.38827	0.60057
24	0.40384	0.25031	0.91601	0.59615	0.74968	0.08398	0.40154	0.34792	0.82646
25	0.93846	0.67295	0.04778	0.06153	0.32704	0.95221	0.86666	0.55017	0.29581
26	0.61153	0.48805	0.60508	0.38846	0.51194	0.39491	0.50731	0.43862	0.50320
27	0.50769	0.37861	0.82933	0.49230	0.62138	0.17066	0.44827	0.39162	0.70093

Table 10 Calculation of Grey relational grades for wire EDM using DM water

No.	γ (R_a)	γ (W_k)	γ (T_m)	Grey relational grade	Rank
	0.60	0.20	0.20		
1	0.4875	0.15353	0.08293	0.72396	3
2	0.416	0.09022	0.14697	0.65319	7
3	0.41324	0.07102	0.19474	0.67901	5
4	0.41324	0.16023	0.06277	0.63625	8
5	0.34666	0.10720	0.11468	0.56855	12
6	0.27130	0.08074	0.15781	0.50985	17
7	0.4875	0.2	0.05714	0.74464	2
8	0.34285	0.12771	0.09509	0.56567	13
9	0.28888	0.09585	0.13455	0.51929	16
10	0.37818	0.10951	0.08663	0.57432	11
11	0.23547	0.08174	0.15214	0.46935	25
12	0.35454	0.07671	0.19543	0.62669	9
13	0.52881	0.10969	0.06916	0.70767	4
14	0.33368	0.09585	0.11871	0.54825	14
15	0.24566	0.07680	0.15800	0.48047	22
16	0.6	0.10987	0.05732	**0.76719**	**1**
17	0.32670	0.09585	0.09708	0.51964	15
18	0.28235	0.08522	0.13937	0.50694	18
19	0.40784	0.10951	0.08890	0.60626	10
20	0.17528	0.07548	0.15904	0.40981	27
21	0.17142	0.05714	0.2	0.42857	26
22	0.29714	0.11504	0.06731	0.47950	23
23	0.29573	0.07644	0.11952	0.49170	19
24	0.23908	0.07421	0.16546	0.47876	24
25	0.46917	0.12601	0.06080	0.65598	6
26	0.29433	0.08610	0.10008	0.48053	21
27	0.26108	0.08094	0.13972	0.48175	20

Table 11 Calculation of Grey relational grades for wire EDM using GMDM water

No.	γ (R_a)	γ (W_k)	γ (T_m)	Grey relational grade	Rank
	0.60	0.20	0.20		
1	0.46917	0.15215	0.08548	0.70681	5
2	0.39493	0.09769	0.14209	0.63472	8
3	0.38757	0.07671	0.19234	0.65663	7
4	0.53333	0.15626	0.06294	0.75254	3
5	0.33913	0.10477	0.11315	0.55706	10
6	0.50322	0.09151	0.15851	0.75325	2
7	0.27857	0.2	0.05714	0.53571	14
8	0.32	0.12421	0.09556	0.53978	13
9	0.28493	0.09769	0.13528	0.51791	19
10	0.37590	0.10671	0.08681	0.56942	9
11	0.25892	0.08594	0.14802	0.49288	20
12	0.21894	0.08101	0.19234	0.49230	22
13	0.52436	0.12301	0.06871	0.71610	4
14	0.33015	0.09151	0.13128	0.55295	12
15	0.23547	0.08101	0.15838	0.47487	25
16	0.6	0.12301	0.05719	**0.78021**	**1**
17	0.34098	0.09151	0.09637	0.52887	16

18	0.312	0.08101	0.14023	0.53325	15
19	0.36279	0.10495	0.08913	0.55687	11
20	0.22446	0.07194	0.15943	0.45583	26
21	0.17142	0.05714	0.2	0.42857	27
22	0.34666	0.10984	0.06748	0.52399	18
23	0.32842	0.07765	0.12011	0.52619	17
24	0.24092	0.06958	0.16529	0.47580	24
25	0.52	0.11003	0.05916	0.68919	6
26	0.30439	0.08772	0.10064	0.49275	21
27	0.26896	0.07832	0.14018	0.48747	23

Optimization Results

Table 10 and 11 show the grey relational grades and rankings for Wire EDM with simple DM water and GMDM water respectively. From both tables it can be observed that, DOE serial 16th is an optimized combination of parameter for both cases (0.76719 and 0.78021 grades respectively).

Experimentally it is observed that, use of powder mixed Dielectric (Graphite) gives better performance with Optimized combination of parameters (DOE serial 16) than simple dielectric usage. There is a matching in experimental findings and optimized result showing improvement insurface finish and kerf width with larger pulse ON time and pulse off time.

It is observed that, ξ = 0.40 and weight factor (0.6,0.2 and 0.4 for SR, kerf and machining time respectively, give optimization result (pulse on time = 40 sec, pulse off time = 4 sec, peak current = 2 amp).

V CONCLUSION

- Graphite powder addition with 2g/litre concentration in dielectric has positive effect on surface roughness and kerf width but negative effect on Machining time.
- Optimization of both cases give 16th combination of parameter **(Pulse On time = 20 μs, Pulse off time = 4 μs, peak current = 2 A)** considering ξ = 0.4 for best performance.
- In surface roughness and kerf width optimum parameter combination gives improved value **(2.74 % decrement)** and **(3.73 % decrement)** respectively due to graphite powder mixing in simple DM water. But in contrast, for machining time optimum parameter combination gives more value **(0.84% increment)**.

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