Optimization of Process Parameters of Powder Mixed Wire-cut Electric Discharge Machining on NIMONIC 90 Using Taguchi Method and Grey Relational Analysis

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Abstract - *Powder mixed wire cut EDM (PMWEDM) is one of the recent advancements in EDM process where the addition of powder particles to the dielectric results in higher machining rate and better surface quality. In this paper work on the effect of process parameter of material NIMONIC 90 by adding powder concentration of Titanium carbide with different percentage. The experiment performed by considering the process parameter such as pulse on time(T-on), pulse off time(T-off), servo voltage(SV), wire feed rate(WF) and powder concentration(PC) are to be varied and response variable i.e. kerf width(Kw), material removal rate(MRR) and surface roughness (SR) obtain at optimal level. In this experimentation NIMONIC 90 alloy is used as material and addition of titanium carbide into de-ionized water with different percentage and Study of with and without mixed powder concentration in de-ionized water. Single objective optimization done by using Taguchi L27 orthogonal array and for multi objective optimization by Grey relational analysis. ANOVA which determine the most affecting process parameter on the kerf width, material removal rate and surface roughness. The result obtains from taguchi reduced in kerf width and surface roughness by 3.27% and 21.85% and increases in material removal rate. Whereas using grey relational analysis best result as T-0n = 110 µs, T-off = 55 µs, SV = 15 V, WF =m/min, PC = 4%.*

***Key Words*: WEDM, NIOMONIC 90, Taguchi, Grey relational analysis, ANOVA**

Nomenclature

WEDM	Wire cut electric discharge machining
PC	Powder concentration
SR	Surface roughness
T-on	Pulse on time
T-off	Pulse off time
GRA	Grey relational analysis
SV	Servo voltage
ANOVA	analysis of variance
KW	Kerf width

1. INTRODUCTION

In this developing world of innovation, plan, and manufacturing we need more precise and defect free expectation like product, service, plan and innovation. With the development of mechanical industry, the demand for compound material having high hardness, strength, and effect resistance is expanding. Wire-cut Electric Discharge Machining is used to cut conductive metal of any hardness or that are impossible or difficult to cut with conventional method. This machine additionally has some cutting complex form or fragile geometric that would be difficult to be produce using conventional cutting method. Machine tool industry has made development in manufacturing. The objective of the present of the various WEDM process parameter on the machining quality and to obtain the optimal sets of process parameter so that the quality of machined part can be optimized. The working ranges and level of WEDM process parameter are found using one factor at a time approach. Work is to investigate the effect.

2. LITERATURE SURVEY

Puranjay Pratap, Jogrndra Kumar, Rajesh Kumar Verma [1] used Taguchi L9 orthogonal array method to performed machining operation using copper electrode. Optimization done by grey relational analysis (GRA) and weight age principle component analysis (WPCA) method of material InconelX-750. Design used for optimization of input parameter pulse on time (T-on), pulse off time (T-off), servo voltage (SV) which improve material removal rate(MRR), surface roughness(SR). Outcome of the experiment shows WPCA give better agreement with actual result and WPCA improve solution value by 12.66%. B.V. Dharmendra, Shyam Prasad Kodali [2] In this experiment modified Taguchi is adopted in multi objective optimization to obtain optimum peck current, pulse on time (T-on), pulse off time (T-off) by mixing Nano powder in deionized water for machining Inconel 800 with copper electrode for higher material removal rate and low surface roughness. Anil Kumawat, Ashish Goyal, Manish Dadich, Ravikant Gupta [3] In this experiment work the triangular profile fabricated on EN-31 steel material, and the effect of process parameter on material removal rate (MRR) investigate by design of experiment methodology and develop the empirical model. Working range and level of wire EDM process parameter are found using one factor at the time approach. Bijaya Bijeta Nayak, Saab Sankar Mahapatra [4] investigate material removal rate (MRR) and surface roughness (SR) for wire cut electric discharge machining of Inconel 780 during taper cutting of deep cryo-treated. Experiment run by considering six input parameter such as part thickness, taper angle, pulse duration, discharge current, wire speed and tension. In which maximum deviation theory is applied to convert multiple performance characteristic into single performance characteristic, because of these there is difficult to obtain the good functional relationship between performance characteristic and process parameter and relationship is obtain by using BPNN for faster training ANN, Levenberg-Marquardt algorithm is used at the last bat algorithm has been successfully used to predict optimal result. Prasath. K, R. Prasanna, Milon D. Selvam [5] used Taguchi for developing robust design while machining the mild steel and stainless steel. This design involves the process parameter such as pulse on, voltage and wire feed rate. Material removal rate and surface roughness where studied by using regression model. Higher rate of MRR and lower surface roughness value from workpiece material is obtain. Kashid D. V, S. G. Bhatwadekar [6] performed optimization process parameter of Wire Electric Discharge Machining using Taguchi method. In that experiment they used steel grade AISI D7 as a workpiece and brass wire of o.25mm diameter as an electrode, and using Taguchi L9 orthogonal array. They tried to optimize the material removal rate for considering input parameter pulse on time, pulse off time, wire feed rate. The results analyzed using analysis of variance (ANOVA) and response graph and obtain the optimum combination of parameter. Ashish Ghoyal [7] studied the machining behavior of Inconel 625 super alloy during wire cutting electrical discharge machining process using zinc coated cryogenic treated tool electrode. The optimization of process parameter was done by the Taguchi L18 array for experimental work, they used zinc coated brass wire of 0.25mm dia. used as electrode and result obtain from cryogenic treated tool gives the best result for material removal rate and surface roughness. Devidas M. Kolse [8] In this work, the experimental investigation has been done to carry out the impact of input current on Material Removal Rate, Electrode Wear Rate and surface roughness in M2 tool steel. The material for the work were Harden up to 62 HRC and after that machined tool materials of copper and Tungsten copper (75:25 grade. next part of the work is optimization of response parameter like, Material Removal Rate (MRR) and Surface Roughness during electric release machining of M2 apparatus steel utilizing Gray-Taguchi method investigation with L9 Orthogonal Array has been applied. Swarup S. Deshmukh [9] in this paper optimization of wire cut EDM for material AISI 4140 using taguchi and grey relational analysis. Single objective optimization by taguchi orthogonal L_9 orthogonal and multi objective optimization by grey relational analysis. They considered four input parameter i.e. pulse on time, pulse off time, servo voltage, wire feed rate and response parameter like surface roughness and kerf width. The result of analysis shows that reduced the values of surface roughness and kerf width individually by 15.65% and 19.35% respectively. And by using the grey relational analysis reduced the surface roughness by 9.39% and 7.62% respectively.

3. METHODOLOGY

3.1 Design of Experiments

Design of experiment is a scientific procedure of planning and conducting experiment of any task that aim to describe the various information under the condition that are hypothesis to reflect the variation. The term is normally related with true experiment in which the design introduce condition that directly affect the variation, but may also refer to the design of experiment, in which physical condition that influence the variation are selected for observation. An experiment aims to predicting the effect by introducing the change of preconditions, which is reflected in a variable called a independent variable. The change in predictor is generally hypothesized to result in a change in second variable, hence called the dependent variable. Experimental design involves not only the selection of suitable independent and dependent but planning delivery of experiment under statistically optimal condition gives the constraints of available resources.

3.1.1 Taguchi method

During machining of workpiece certain outside boundaries are to acted like vibration, natural condition, because of these variable more effect is on the observed data. For controlling such fact or we need to pay more expense or now it is not possible. After noticing such thing Taguchi proposed that it is important to make robust design instead of apparatus and instrument. Two significant apparatus utilized in Taguchi method:-

1. Orthogonal array
2. Signal to noise ratio

1. Orthogonal array:-

Orthogonal array is set of matrix which helps in decrease in total number of experiments; indirectly it helps for making process robust. Selection of orthogonal array it totally depends on degree of freedom of process. Orthogonal array is greater and equal to degree of freedom of process.

Degree of freedom of variable = Number of level – 1

Degree of freedom of process = ∑ Degree of freedom of factor

Taguchi represent an orthogonal array as: -

$L_N(S^K)$

Where,

S = number of levels for each factor

K = maximum number of factor whose effect can be estimate without any interaction

N = total number of trial during experimentation.

2. Signal to noise ratio: -

Variation between trial values and desired value can be determined with the help of Taguchi quality loss function. Loss function is change into utility function. Utility function is also called as signal to noise ratio. Signal is generally represent desirable quantity and noise quantity. Higher values of signal to noise ratio is selected because it contain the lower noise value, signal to noise ratio has three type is as follow: -

1. Higher the best.
2. Nominal the best.
3. Lower the better.

In case of electric discharge machining the response variable such as material removal rate is required to be maximum because of that it undergoes third category i.e. higher the best. Surface roughness and kerf width it undergoes lower the better type category. [10]

S/N ratio = -10 log (L_{ij})

Where,

L_{ij} = loss function

Loss function for lower the better type and higher best type is can be calculated as follow: -

For lower the better type,

$$L_{ij}=[\frac{1}{n}\sum_{i=1}^{n} y_i{}^2]$$

For higher the best type,

$$L_{ij}=[\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i{}^2}]$$

3.1.2 Grey relational analysis: -

When information is insufficient then it is preferred to use grey relational analysis. The relationship between process parameter and response variable can be discovered with help of grey relational analysis. For single objective optimization Taguchi method is used but for multi objective optimization problem is not solve by taguchi with the help of grey relational analysis multi objective optimization problem can be solved.

Step wise procedure of grey relational analysis is as follows: -

Step 1 Normalization collected data

1. Larger is better

$$x_i^*(k) = \frac{x_i^0(k) - \min x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k)}$$

2. smaller-the-better

$$x_i^*(k) = \frac{\max x_i^0(k) - x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k)}$$

Step 2 Calculation of deviation sequence

$\Delta 0_i(k) = |x_0^*(k) - xi^*(k)|$

Step 3 Determination of grey relational coefficient (GRC):

The grey relational coefficient (k) for Kth performance characteristics in the ith experiment can be expressed as follow,

$$\xi_i^{(k)} = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_{oi}(k) + \zeta\Delta_{max}}$$

Where,

$\Delta_{min} = \min||X_0^*(k)|| = ||1-1|| = 0$ $\Delta_{max} = \max||X_0^*(k)|| = ||1-0|| = 1$

ζ= distinguishing coefficient and generally is set as 0.5.

Step 4 calculation of grey relational grade: -

$\gamma_i = \sum W_i(k) \times \xi_i(k)$

Where,

γ_i = Grey relational grade,

$W_i(k)$ = Weight age given to response variable.

4. EXPERIMENTAL SETUP

4.1 Selection of workpiece material

The experiment were conducted on "ECOCUT CNC Wire-cut EDM" Machine (supplied by Electronica India Pvt. Ltd.). The experimental setup in fig.1. Selection of material for this work is NIMONIC 90 alloy. The chemical composition of NIMONIC 90 alloy is shown in table no.1. The size of workpiece material is 125*50*10mm. 27 square specimen of 10*10mm are being cut using Wire-cut EDM. The specimen is cut according to taguchi L27 orthogonal array method. The specimen as shown in fig.2

Fig. 1 Machining setup

Table 1. Chemical composition of NIMONIC 90

Element	Fe	Cr	Co	Ti	Al
Content (%)	58.8	19.5	18	2.5	1.5

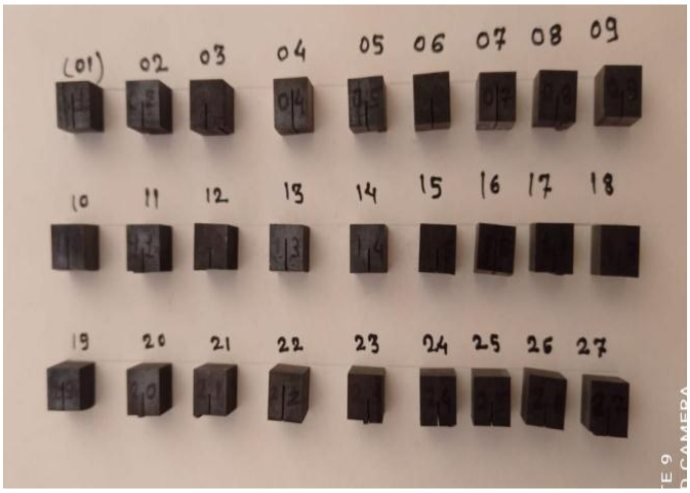

Fig. 2 Machine specimen

The zinc coated brass wire of 0.25mm measurements is utilized as a cathode. De-ionized water is utilized as adielectric liquid and Nano powder of titanium carbide. During measurement of surface roughness probe of surface roughness tester is moved perpendicular to lay direction and set cut off length =0.8mm. Kerf width of the machined specimen is measured using SuXma Met-I metallurgical inverted microscope which is shown in Fig 3 and Fig 4.

Fig 3. Mitutoyo surface roughness tester

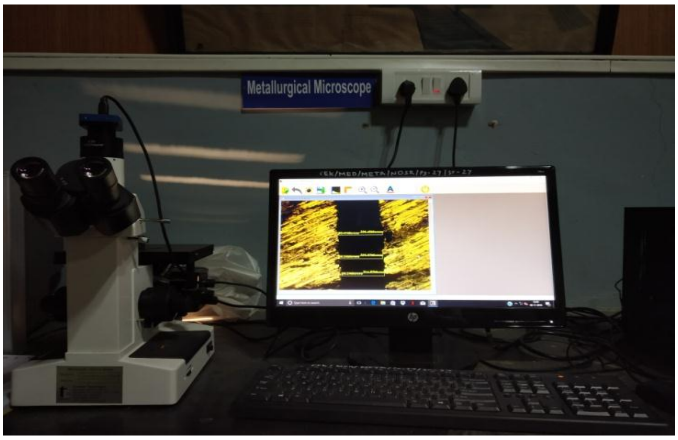

Fig. 4 SuXma Met-I metallurgical inverted microscope

4.2 Specification of wire-cut EDM

<u>Range of wire-cut EDM</u>

The machining parameters ranges for the experiment were listed in Table 2.

Table 2. Range of wire-cut EDM parameters.

Sr. no.	Parameter	Range
1	Pulse on time (T-on)	100-131
2	Pulse off time (T-off)	16-63
3	Servo voltage (V)	0-99
4	Peak current (A)	Upto-230
5	Wire feed rate (WF)	1-15

Table 3. Control factor and their level

Parameter	Unit	Symbol	Level 1	Level 2	Level 3
Pulse on time	µs	A	110	115	120
Pulse off time	µs	B	51	53	55
Servo voltage	V	C	15	30	45
Wire feed rate	m/min	D	3	6	9
Powder concentration	%	E	0	2	4

Table 4. Experiment according to Taguchi L27 Orthogonal array design of Wire-cut EDM on NIMONIC 90 ALLOY

Sr. no.	Pulse on time (µs)	Pulse off time (µs)	Servo voltage (V)	Wire feed rate (m/min)	Powder concentration (%)
1	110	51	15	3	0
2	110	51	15	3	2
3	110	51	15	3	4
4	110	53	30	6	0
5	110	53	30	6	2
6	110	53	30	6	4
7	110	55	45	9	0
8	110	55	45	9	2
9	110	55	45	9	4
10	115	51	30	9	0
11	115	51	30	9	2
12	115	51	30	9	4
13	115	53	45	3	0
14	115	53	45	3	2
15	115	53	45	3	4
16	115	55	15	6	0
17	115	55	15	6	2
18	115	55	15	6	4
19	120	51	45	6	0
20	120	51	45	6	2
21	120	51	45	6	4
22	120	53	15	9	0
23	120	53	15	9	2
24	120	53	15	9	4
25	120	55	30	3	0
26	120	55	30	3	2
27	120	55	30	3	4

5. RESULT AND DISCUSSION

The experiment is done according to Taguchi L27 orthogonal array and the result for kerf width, material removal rate and surface roughness obtain from the experiment as shown in table 5.

Table 5. Experimental result

Pulse on time	Pulse off time	Servo voltage	Wire feed rate	PC	Kw	MRR	SR
110	51	15	3	0	0.305	0.026	1.908
110	51	15	3	2	0.299	0.025	1.735
110	51	15	3	4	0.295	0.024	1.720
110	53	30	6	0	0.311	0.021	1.624
110	53	30	6	2	0.309	0.020	1.365
110	53	30	6	4	0.304	0.019	1.308
110	55	45	9	0	0.349	0.016	1.426
110	55	45	9	2	0.342	0.015	0.958
110	55	45	9	4	0.330	0.015	1.440
115	51	30	9	0	0.324	0.043	1.850
115	51	30	9	2	0.318	0.040	1.715
115	51	30	9	4	0.316	0.040	2.207
115	53	45	3	0	0.333	0.034	2.148
115	53	45	3	2	0.329	0.038	1.837
115	53	45	3	4	0.323	0.031	1.972
115	55	15	6	0	0.319	0.021	2.024
115	55	15	6	2	0.315	0.021	1.457
115	55	15	6	4	0.311	0.020	1.338
120	51	45	6	0	0.334	0.059	2.273
120	51	45	6	2	0.329	0.057	1.990
120	51	45	6	4	0.326	0.056	1.854
120	53	15	9	0	0.323	0.033	2.108
120	53	15	9	2	0.317	0.031	1.892
120	53	15	9	4	0.315	0.029	1.747
120	55	30	3	0	0.325	0.031	1.918
120	55	30	3	2	0.319	0.027	1.801
120	55	30	3	4	0.314	0.026	1.799

5.1 Factor influencing Kerf width of NIMONIC 90

For kerf width minimum values is obtained when the pulse on time, pulse off time, servo voltage, wire feed rate at first level, and powder concentration at third level i.e. T-on=110, T-off=51, V=15, WF=3, PC=4 has been plotted and identified in fig 5 and fig 6.

- From the investigation the most affecting parameter on kerf width is servo voltage.
- Pulse on time influences the kerf width, as we increase the pulse on time, kerf width is increases.
- Pulse off time and wire feed rate likewise influence the kerf width, as we increase the pulse off time and wire feed rate kerf width increase.
- When the servo voltage expanded the kerf width is increases.
- When percentage of powder concentration increase, kerf width decreases.

Table 6. Response table signal to noise ratio of kerf width

Level	Pulse on time	Pulse off time	Servo voltage	Wire feed rate	PC
1	**10.021**	**10.008**	**10.148**	**10.019**	9.774
2	9.875	9.949	10.020	9.968	9.912
3	9.833	9.771	9.559	9.741	**10.042**
Delta	0.188	0.236	0.589	0.279	0.267
Rank	5	4	1	2	3

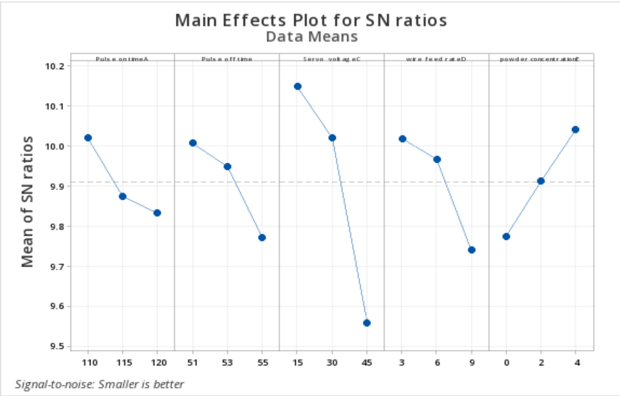

Fig. 5. S/N ratio of Kerf width on NIMONIC 90 using zinc coated brass electrode.

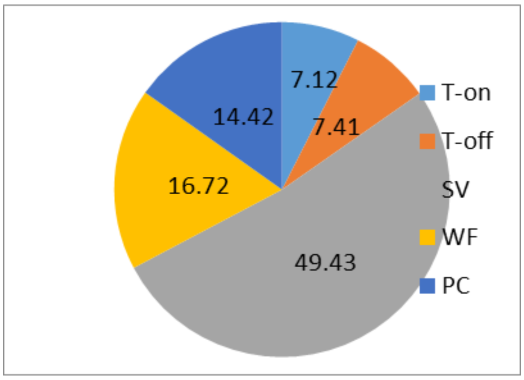

Fig. 6. Contribution of process parameter for Kerf width

Table 7. Analysis of variance result for Kerf width.

Parameter	DF	SS	MS	F-value	P-value	%Contribution
Pulse on time	2	0.2322	0.10827	9.87	0.002	7.12
Pulse off time	2	0.2417	0.08497	7.75	0.005	7.41
Servo voltage	2	1.6104	0.81735	74.53	0.000	49.43
Wire feed rate	2	0.5447	0.27481	25.06	0.000	16.72
Powder concentration	2	0.4642	0.23209	21.16	0.000	14.24
Error	16	0.1645	0.01097	-	-	-
Total	26	3.2577	-	-	-	-

5.2 Factor influencing MRR of NIMONIC 90

For Material removal rate maximum values is obtained when the pulse on time at third level, pulse off time at first level, servo voltage at third level, wire feed rate at third level, and powder concentration at third level i.e. T-on=120, T-off=51, V=45, WF=6, PC=4 has been plotted and identified in fig. 7 and fig. 8.

- From the investigation the most affecting parameter on material removal rate is pulse on time.
- Pulse on time influences the material removal rate, as we increase the pulse on time, material removal rate increases.
- Pulse off time likewise influence the material removal rate, as we increase the pulse off time, material removal rate is decreases.
- When the servo voltage expanded the material removal rate is increases.
- As a percentage of powder concentration is increases, decreases in material removal rate.

Table 8. Response table signal to noise ratio of MRR.

level	Pulse on time	Pulse off time	Servo voltage	Wire feed rate	PC
1	-34.11	**-28.21**	-30.93	-30.81	-30.65
2	-29.21	-31.16	-30.94	**-29.80**	-30.98
3	**-28.70**	-32.65	**-30.15**	-31.41	**-30.39**
Delta	5.41	4.44	0.79	1.61	0.59
Rank	1	2	4	3	5

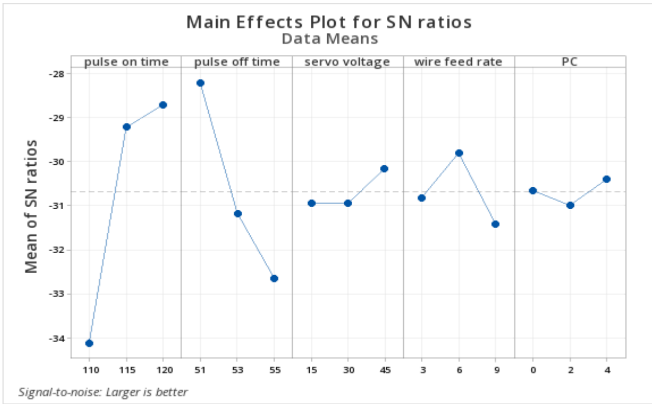

Fig. 7. S/N ratio of MRR on NIMONIC 90 using zinc coated brass electrode.

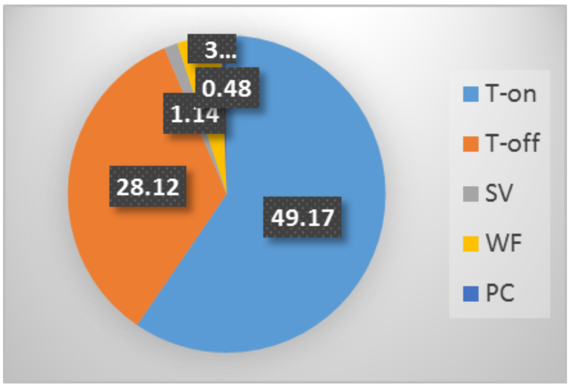

Fig. 8. Contribution of process parameter for MRR

Table 9. Analysis of variance result for MRR.

Parameter	DF	SS	MS	F-value	P-value	%Contribution
Pulse on time	2	160.478	80.2390	22.62	0.000	49.17
Pulse off time	2	91.801	45.9006	12.94	0.000	28.12
Servo voltage	2	3.731	1.8656	0.53	0.601	1.14
Wire feed rate	2	11.986	5.9929	1.69	0.216	3.67
Powder concentration	2	1.596	0.7978	0.22	0.801	0.48
Error	16	56.767	3.5479	-	-	-
Total	26	326.359	-	-	-	-

5.3 Factor influencing Surface Roughness of NIMONIC 90

For surface roughness minimum values is obtained when the pulse on time at first level, pulse off time at third level, servo voltage at third level, wire feed rate at second level, and powder concentration at second level. T-on=110, T-off=55, V=45, WF=6, PC=2 has been plotted and identified in fig. 9 and fig. 10.

- From the investigation the most affecting parameter on surface roughness is pulse on time.
- Pulse on time influences the surface roughness, as we increase the pulse on time, increases surface roughness
- Pulse off time likewise influence the surface roughness, as we increase the pulse off time, decreases in surface roughness
- When the servo voltage and wire feed rate expanded the surface roughness decreases.
- Powder concentration also effect on surface roughness, increases in powder concentration there is decreases in surface roughness.

Table 10. Response table signal to noise ratio of surface roughness

Level	Pulse on time	Pulse off time	Servo voltage	Wire feed rate	PC
1	**-3.359**	-5.563	-4.877	-5.270	-5.455
2	-5.001	-4.661	-4.669	**-4.208**	**-3.875**
3	-5.653	**-3.741**	**-4.222**	-4.405	-4.536
Delta	2.294	1.823	0.655	1.062	1.580
Rank	1	2	3	4	3

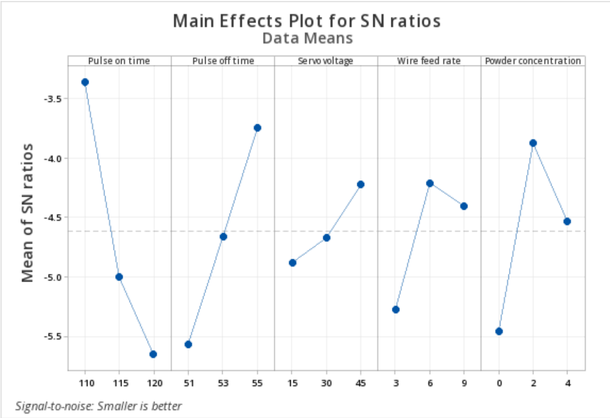

Fig. 9. S/N ratio of SR on NIMONIC 90 using zinc coated brass electrode.

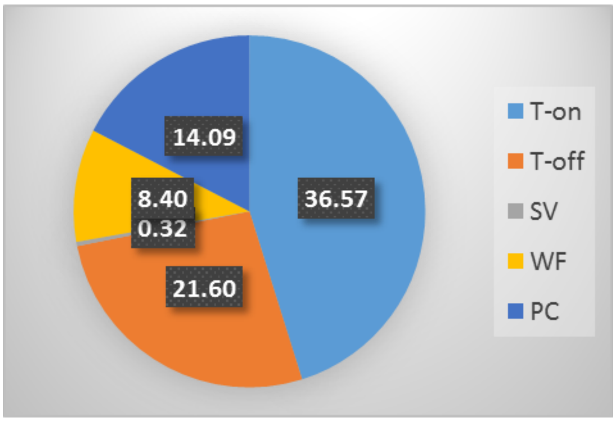

Fig. 10. Contribution of process parameter for SR

Table 11. Analysis of variance result for surface roughness

Parameter	DF	SS	MS	F-value	P-value	%Contribution
Pulse on time	2	27.0348	13.517	15.40	0.000	36.57
Pulse off time	2	15.9658	7.9829	9.09	0.002	21.60
Servo voltage	2	0.2408	0.1204	0.14	0.873	0.32
Wire feed rate	2	6.2087	3.1043	3.54	0.053	8.40
Powder concentration	2	10.4140	5.2070	5.93	0.012	14.09
Error	16	14.0458	0.8779	-	-	-
Total	26	73.9099	-	-	-	-

Grey relational analysis

Table 12. Grey relational analysis

Exp no.	EXP. data			GRD
	Kw	MRR	SR	
1	0.305	0.027	1.908	0.594
2	0.299	0.026	1.735	0.665
3	0.295	0.024	1.72	0.721
4	0.311	0.021	1.624	0.635
5	0.309	0.020	1.365	0.696
6	0.304	0.019	1.308	0.744
7	0.349	0.016	1.426	0.619
8	0.342	0.015	0.958	0.785
9	0.33	0.015	1.44	0.671
10	0.342	0.043	1.85	0.449
11	0.318	0.040	1.715	0.491
12	0.316	0.040	2.207	0.459
13	0.333	0.034	2.148	0.437
14	0.329	0.038	1.837	0.453
15	0.323	0.031	1.972	0.486
16	0.319	0.021	2.024	0.561
17	0.315	0.021	1.457	0.638
18	0.311	0.020	1.338	0.693
19	0.334	0.059	2.273	0.359
20	0.329	0.057	1.99	0.393
21	0.326	0.056	1.854	0.413
22	0.323	0.033	2.108	0.467
23	0.317	0.031	1.892	0.511
24	0.315	0.029	1.747	0.544
25	0.325	0.031	1.918	0.487
26	0.319	0.027	1.801	0.534
27	0.314	0.026	1.799	0.559

Table 13. Response table for grey relational grade

Level	Pulse on time	Pulse off time	Servo voltage	Wire feed rate	Powder concentration
1	**0.6811**	0.5049	**0.5993**	0.5484	0.5120
2	0.5186	0.5526	0.5616	**0.5740**	0.5740
3	0.4741	**0.6163**	0.5129	0.5551	**0.5878**
Delta	0.2070	0.1114	0.0864	0.0218	0.0758
Rank	1	2	3	5	4

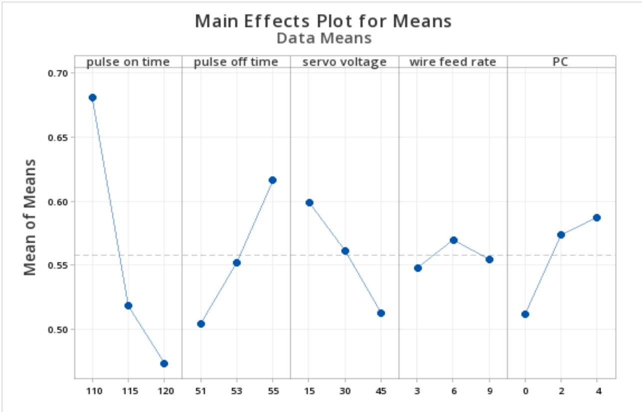

Fig. 11. Main effect plot for grey relational grade.

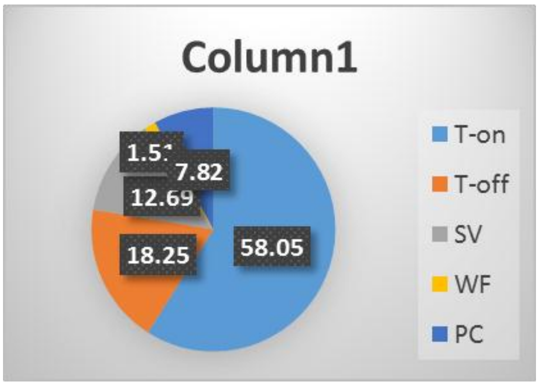

Fig. 12. Contribution of process parameter for GRD

Table 14. Analysis of variance result for the gray relational grade.

source	DF	SS	MS	F	P	% contribution
Pulse on time	2	50.5878	25.2939	153.38	0.000	58.05
Pulse off time	2	15.9079	7.9539	48.23	0.000	18.25
Servo voltage	2	11.0586	5.5293	33.53	0.000	12.69
Wire feed rate	2	0.1320	0.0660	0.40	0.677	1.51
Powder concentration	2	6.8207	3.4103	20.68	0.000	7.82
Error	16	2.6386	0.1649	-	-	-
Total	26	87.1456	-	-	-	-

After the experimentation, it is observed that the gray relation analysis optimum result obtain at the process parameter level at T-on = 110 µs, T-off =55 µs, SV = 15 V, WF

= 6 m/min, PC= 4%. Pulse on time is most effective parameter on grey relational grade

Table 15. 0ptimum condition using Taguchi optimization method

Sr no .	parameter	Kerf width		Material removal rate		Surface roughness	
		Best level	value	Best level	value	Best level	value
1	Pulse on time	1	110	3	120	1	110
2	Pulse off time	1	51	1	51	3	55
3	Servo voltage	1	15	3	45	3	45
4	Wire feed rate	1	3	2	6	2	6
5	Powder concentration	3	4	3	4	2	2

Table 16. Optimum condition using grey relational analysis

Sr. no.	Parameter	Best level	value
1	Pulse on time	1	110
2	Pulse off time	3	55
3	Servo voltage	1	15
4	Wire feed rate	2	6
5	Powder concentration	3	4

6. CONCLUSION

The experimental investigations done according to the Design of Experiments (DOE) through Taguchi Method L27 Orthogonal array, during the powder mixed wire cut electric discharge machine (PMWEDM) of titanium carbide in deionized water and process parameter are specified and optimize the working condition. The novelty of work can be found in powder mixed WEDM machining of sheet of Nimonic 90.

I. In single objective optimization of optimum parameter there is a decrease in kerf width and surface roughness value as compared to the initial process parameter by 3.27% and 21.85% respectively and increases in MRR was observed at powder concentration at 4%.

II. ANOVA result for kerf width (Kw) is mostly affected by servo voltage (V), wire feed rate and powder concentration (PC) is also affect the kerf width, hence these three parameter most significant for response kerf width and the pulse on time (T-on) and pulse off time(T-off) is a not effective than wire feed WF and PC. The minimum value of Kerf width is obtain which is 0.295 mm.

III. ANOVA result for Material removal rate(MRR) is mainly influence by pulse on time (T-on) and pulse off time (T-off) which is most affecting parameter and the servo voltage (V) and powder concentration having no any significant effect on the value on MRR. The maximum value of MRR is obtain at which is 0.056 gm/min.

IV. ANOVA result for surface roughness is mostly affected by pulse on time (T-on) and the pulse off time (T-off) and powder concentration is less effective as compared to T-on. The minimum surface roughness is 1.327 µm observed at 2% of powder concentration.

V. Result getting from multi-objective optimization using grey relational analysis shows Optimum level of process parameters for achieving optimum value of material removal rate, surface roughness and kerf width the is at T-on = 110 µs, T-off = 55 µs, SV = 15 V, WF = 6m/min PC= 4%.

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