Modeling and analysis of process parameters on metal removal rate and surface roughness in near-dry WEDM of EN 32 steel by RSM approach

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Abstract

This paper reveals that the development of Near-dry Wire Electrical Discharge Machining (WEDM) is considered as an Environmental friendly machining process. Near-dry WEDM liquid-gas mixture is used as the dielectric fluid to improve the metal removal rate (MRR) and reduce the surface roughness (Ra). Near-dry WEDM exhibits the advantages of good machining stability and surface finish under low discharge energy as input. Response surface methodology has been applied to investigate the effect of applied voltage, discharge current, pulse width, pulse interval, pressurized oxygen on the MRR and surface roughness in Near-dry WEDM. The empirical model for the two output parameters are developed based on regression analysis. The optimum output and significant input cutting parameters has been predicted using Box-Behnken method.

Key words: Near-dry WEDM; liquid-gas; MRR; Ra; Box- Behnken method

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1. INTRODUCTION

Today, the environment friendly manufacturing is the new trend even in the field of machining hard materials. Researchers are focused to reduce the pollution during machining that also ensures that technical requirements like high metal removal rate and minimum roughness. In WEDM process kerosene and de-ionized water is mainly used as a dielectric fluid so it will generate toxic fumes sometimes even fire hazards. From this experiment environmental friendly WEDM setup can be modeled and to replace oxygen mixed with water as a dielectric fluid to eliminate harmful effects generated while machining hard materials with complex shapes.

F.R.M. Romlay et al [1] the wire EDM cutting process is conducted by welded area of the gear teeth. The parameter of the cutting process such as wire speed, wire tension, wire voltages are considered to be optimized. Shajan Kuriakose et al [2] Cutting velocity and surface finish are most important output parameters, which decide the cutting performance. There is no single optimal combination of cutting parameters, as their influences on the cutting velocity and the surface finish are quite the opposite. By using Non-Dominated Sorting Genetic Algorithm is used to optimize Wire-EDM process. Yusuf Keskin et al [3] in this study, experiments were performed to determine parameters effecting surface roughness. In the experiments, power, spark time, and pause time parameters are considered while other parameters were assumed to be constant. The data obtained for performance measures have been analyzed using design of experiments. H.K. Kansal et al. [4] the electrically conductive powder is mixed in the dielectric of EDM, which reduces the insulating strength of the dielectric fluid and increases the spark gap between the tool and workpiece. As a result, the process becomes more stable, thereby, improving the material removal rate and surface finish. Moreover, the surface develops high resistance to corrosion and abrasion. Chika Furudate et al [5] to improve the accuracy of finish cutting by using atmospheric gas are used as a dielectric medium. However, some drawbacks of dry WEDM include lower MRR compared to conventional WEDM. Fu-chen Chen et al [6] The most important factors affecting the precision and accuracy of the high-speed EDM process have been identified as pulse time, duty cycle, and peak value of discharge current can be optimized using a Taguchi fuzzy-based approach. C. C. Kao et al. [7] found that when the Near-dry EDM water-air mixture is used as a dielectric medium to improved MRR and eliminates the problem of debris deposition. Jia Tao et al. [8] In Near-dry EDM milling the mirror-like surface finish can be achieved Using the kerosene mist and copper infiltrated graphite electrode with less pulse energy. Sourabh K. Saha et al [9] by changing six input parameters such as Gap voltage, discharge current, pulse–on time, duty factor, air pressure and spindle speed. Finished surface were obtained at low current, high pulse–on time and low duty factor. Rough surface were obtained at high current, low pulse–on time and high duty factor. Dr. R. Saravanan et al. [10] Instead of dielectric fluid use ionized oxygen to eliminate harmful effects generated while machining in wire-EDM. Using TRIZ, how novelty in EDM research could be achieved with maximum results with minimal effort through a new design of E-EDM.

Nomenclature

I_d	discharge current (amps)
MRR	material removal rate (mm^3/min)
P	oxygen inlet pressure (bar)
P_I	pulse interval (μs)

P_w	pulse width (µs)
R_a	Surface roughness (µm)
V_a	applied voltage (volts)

2. EXPERIMENTAL DATA COLLECTION

This section describes the experimental setup, explains the method of conducting experiments and data collection.

2.1. Experimental set up

Experiments were conducted on ST CNC-E3 (MCJ) wire cut EDM machine. It was made by Steer Corporation this machine is numerically controlled wire EDM machine. The X and Y axis of the table movement can be controlled by using servo controller. In X axis the table will move at a distance of 300mm and in Y axis the table will move at a distance of 250mm. According to the convention of normal polarity, the work-piece is connected to the positive terminal of the source and the tool is attached to the negative terminal of the source.

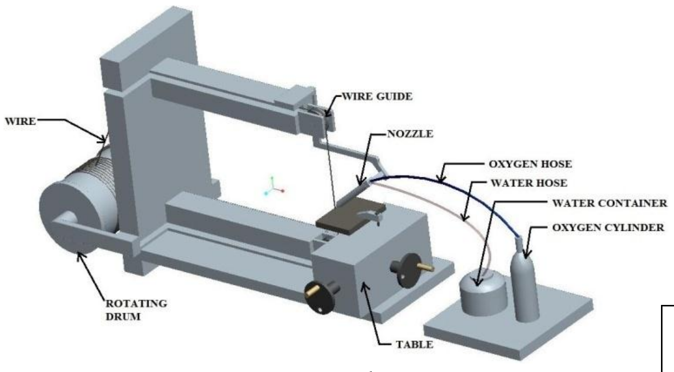

Fig. 1. Experimental setup

Figure 1 shows that modification of dielectric medium in wire cut EDM machine The experimental data based on the DOE were collected to study the effect of various machining parameters of the EDM process. These studies had been undertaken to investigate the effect of applied voltage, discharge current, pulse width, pulse interval, pressurized oxygen on the Metal removal rate and surface roughness.

2.2. Experimental procedure

The experiments were conducted on 817M40 also known as EN 32 (1.5 percentage of nickel-chromium-molybdenum steel with density of 7840 kg/m^3) as a work specimen. The work piece is in the form of rectangle plate having dimensions of $75mm \times 50mm \times 5mm \cdot$ Work piece had been machined using molybdenum wire is used as a tool having diameter of 0.20mm and oxygen mixed with water as a dielectric fluid. Each sample had been machined for a length of 4mm. machining time were measured using a stop watch. After machining to calculate the MRR and SR values were measured using Mitutoyo SJ.201P surface tester. Meter has a stylus stroke of 350µm, Resolution of 0.01 µm, minimum cutoff of 0.25mm and 2µm stylus radius was used. The measurement length was set to 3mm.

2.3. Data collection

The Input variables, namely applied voltage, discharge current, pulse width, pulse interval and pressurized oxygen were identified and their ranges had been decided through some trial experiments. The experiments were carried out according to the DOE so that the ANNOVA could be carried out.

3. PARAMETRIC ANALYSIS

In order to study the effect of the input parameters and the effect of their interactions, a Box-Behnken designed experiment has been conducted which is capable of fitting a second order polynomial function.

3.1. Box-Behnken observations

The experimental results obtained from the Box-Behnken runs are shown in Table 1. The runs were randomized and experiments were conducted in a single block. It is interesting to note that although the MRR and Ra values seem to change when the factors were changed.

Table 1. MRR and Ra observations of the Box-Behnken Design of Experiments

s.no	Input Parameters					Output Response	
	Voltage	pulse width	pulse interval	pressure	current	MRR	Ra
	Volt	µs	µs	bar	amps	mm^3/min	µm
1	100	8	36	5	1.6	4.982	1.93
2	100	8	24	5	2.4	11.739	2.56
3	87.5	8	36	5	2.4	4.033	1.9
4	100	8	48	5	2.4	3.96	2.94
5	87.5	8	48	5	3.2	6.476	2.92
6	87.5	8	24	7	2.4	10.778	1.01
7	75	12	36	5	2.4	4.976	3.01
8	100	8	36	7	2.4	4.033	1.07
9	87.5	8	24	3	2.4	12.924	2.97
10	75	8	36	5	3.2	6.487	2.1
11	87.5	4	48	5	2.4	2.533	1.7
12	87.5	8	48	5	1.6	2.617	2.95
13	87.5	4	36	3	2.4	10.739	1.74
14	100	4	36	5	2.4	9.621	1.28
15	87.5	12	36	5	3.2	8.47	3.18
16	87.5	8	36	5	2.4	4.033	1.9
17	87.5	4	24	5	2.4	9.273	1.12

18	87.5	8	36	5	2.4	4.033	1.9
19	100	12	36	5	2.4	5.622	2.42
20	75	8	24	5	2.4	12.239	1.45
21	75	8	36	5	1.6	3.488	1.62
22	87.5	12	36	3	2.4	10.829	3.14
23	87.5	8	36	7	3.2	5.538	1.08
24	75	8	36	3	2.4	8.908	3.14
25	87.5	8	36	5	2.4	4.033	1.9
26	87.5	8	24	5	3.2	9.144	1.16
27	87.5	8	36	3	1.6	8.869	2.96
28	87.5	4	36	7	2.4	4.679	1.09
29	87.5	12	48	5	2.4	2.662	3.23
30	87.5	8	36	3	3.2	12.671	3.19
31	75	4	36	5	2.4	4.746	1.58
32	87.5	12	24	5	2.4	12.318	2.71
33	87.5	4	36	5	1.6	3.364	1.05
34	100	8	36	3	2.4	12.638	2.5
35	87.5	8	48	7	2.4	2.409	1.21
36	75	8	36	7	2.4	6.369	1.1
37	87.5	4	36	5	3.2	5.15	1.32
38	87.5	12	36	5	1.6	6.128	2.97
39	75	8	48	5	2.4	2.51	2.85
40	87.5	12	36	7	2.4	3.168	1.13
41	87.5	8	36	7	1.6	2.786	1.01
42	100	8	36	5	3.2	11.537	2.79
43	87.5	8	24	5	1.6	7.757	1.16
44	87.5	8	36	5	2.4	4.033	1.9
45	87.5	8	48	3	2.4	5.308	3.24
46	87.5	8	36	5	2.4	4.033	1.9

4. REGRESSION ANALYSIS AND MODEL FITTING

Regression analysis of the experimental results obtained from the Box-Behnken runs has been done using the software Design Expert 8.0.7 Models with significant factor effects were obtained for MRR and Ra. The regression analysis for each response is discussed below.

4.1. Regression analysis for MRR

First of all, ANOVA based sequential sum of squares test was done to select the most appropriate model to be fitted.

Table 2. Model prediction test for MRR

Source	Sum of Squares	DOF	Mean square	F value	p-value Prob > F	Comments
Mean vs Total	2017.551	1	2017.551	-	-	-
Linear vs Mean	378.894	5	75.779	21.571	< 0.0001	Suggested
2FI vs Linear	22.571	10	2.257	0.574	0.8217	-
Quadratic vs 2FI	65.105	5	13.021	6.160	0.0008	Suggested
Cubic vs Quadratic	51.775	15	3.452	32.330	< 0.0001	Aliased
Residual	1.068	10	0.107	-	-	-
Total	2536.964	46	55.151	-	-	-

The test result is shown in Table 2. Quadratic model were selected to improve the fitting as indicated by the F value in the Fischer's F test. The F values can be converted into the p value by using the F probability distribution curve. The model significance can be tested either by comparing the F value to a threshold F value or by comparing the corresponding p value to the threshold p value. The threshold p value depends on the chosen significance level which was set here to 5%. The highest order polynomial for which the additional terms were significant and the model was not aliased was chosen. Based on the test result, the two factor interaction model was chosen for fitting.

Table 3. ANOVA table for response surface reduced two-factor Interaction model of MRR

Source	Sum of Squares	DOF	Mean Square	F value	p-value Prob > F	Test result
Model	466.570	20	23.329	11.037	< 0.0001	Significant
A-voltage	12.976	1	12.976	6.139	0.0203	-
B-pulse width	1.034	1	1.034	0.489	0.4907	-
C-pulse interval	208.059	1	208.059	98.434	< 0.0001	-
D-pressure	116.241	1	116.241	54.994	< 0.0001	-
E-current	40.583	1	40.583	19.200	0.0002	-
AB	4.471	1	4.471	2.115	0.1583	-
AC	0.951	1	0.951	0.450	0.5086	-
AD	9.199	1	9.199	4.352	0.0473	-
AE	3.161	1	3.161	1.496	0.2328	-
BC	2.126	1	2.126	1.006	0.3255	-
BD	0.641	1	0.641	0.303	0.5868	-
BE	0.077	1	0.077	0.037	0.8499	-
CD	0.142	1	0.142	0.067	0.7978	-
CE	1.528	1	1.528	0.723	0.4033	-
DE	0.276	1	0.276	0.130	0.7211	-
A^2	23.154	1	23.154	10.954	0.0028	-
B^2	6.023	1	6.023	2.849	0.1038	-
C^2	25.068	1	25.068	11.860	0.0020	-
D^2	48.665	1	48.665	23.024	<	-

					0.0001	
E^2	7.541	1	7.541	3.568	0.0706	-
Residual	52.842	25	2.114	-	-	-
Lack of Fit	52.842	20	2.642	-	-	-
Pure Error	0.000	5	0.000	-	-	-
Corrected Total Sum of square	519.412	45	-	-	-	-

The ANOVA table for the reduced two factor interaction model is shown in Table 3. The Model F-value of 11.04 implies the model is significant. There is only a 0.01% chance that a "Model F-value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, C, D, E, AD, A^2, C^2, D^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

The final regression equation for MRR in terms of the actual parameter values is:

$$\mathrm{MRR} = 115\cdot 71852 - 1\cdot 61013\times V_a + 1\cdot 77568\times \mathrm{P_w} - 1\cdot 42607\times \mathrm{P}_I - 0\cdot 86705\times \mathrm{P} - 14\cdot 60437\times I_d$$

$$-0\cdot 015188\times \mathrm{P_w}\times \mathrm{P}_I - 0\cdot 050031\times \mathrm{P_w}\times \mathrm{P} + 0\cdot 043437\times \mathrm{P_w}\times I_d + 0\cdot 010424\times V_a^{\;2}$$

$$+0\cdot 051921\times \mathrm{P_w}^{2} + 0\cdot 011770\times \mathrm{P}_I^{\;2} + 0\cdot 59035\times P^2 + 1\cdot 45244\times I_d^{\;2}$$

4.2. Regression Analysis for Ra

ANOVA-based sequential sum of squares test was done to select the most appropriate model to be fitted.

Table 4. Model prediction test for Ra

Source	Sum of Squares	DOF	Mean Square	F value	p-value Prob > F	Comments
Mean vs Total	196.113	1	196.113	-	-	-
Linear vs Mean	23.281	5	4.656	32.983	< 0.0001	Suggested
2FI vs Linear	0.882	10	0.088	0.556	0.8361	-
Quadratic vs 2FI	0.845	5	0.169	1.078	0.3963	-
Cubic vs Quadratic	3.525	15	0.235	5.957	0.0036	Aliased
Residual	0.395	10	0.039	-	-	-
Total	225.040	46	4.892	-	-	-

The test result is shown in Table 4. Select the highest order polynomial for which the additional terms were significant and the model was not aliased was chosen. Based on the test result, a linear model is suggested.

Table 5. ANOVA table for response surface reduced quadratic model of Ra.

Source	Sum of Squares (SS)	DOF	Mean Square	F value	p-value Prob > F	Test result
Model	23.281	5	4.656	32.983	< 0.0001	Significant
A-voltage	0.026	1	0.026	0.181	0.6725	-
B-pulse width	7.439	1	7.439	52.699	< 0.0001	-
C-pulse interval	2.976	1	2.976	21.079	< 0.0001	-
D-pressure	12.567	1	12.567	89.023	< 0.0001	-
E-current	0.273	1	0.273	1.934	0.1720	-
Residual	5.647	40	0.141	-	-	-
Lack of Fit	5.647	35	0.161	-	-	-
Pure Error	0.000	5	0.000	-	-	-
Corrected Total Sum of Squares	28.927	45	-	-	-	-

The Model F-value of 32.98 implies the model is significant. There is only a 0.01% chance that a "Model F-value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case B, C, D are significant model terms. values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

The final regression equation for Ra in terms of the actual parameter values is:

$$R_a = 0\cdot 95103 + 3\cdot 20000^{E-003} \times V_a + 0\cdot 17047 \times \mathrm{P_w} + 0\cdot 035938 \times \mathrm{P}_I - 0\cdot 44313 \times P\text{ -}$$

5. RESULT AND DISCUSSIONS

5.1. MRR Response Surface

The response surfaces of MRR were obtained for the interaction terms in the Reduced two-factor interaction model

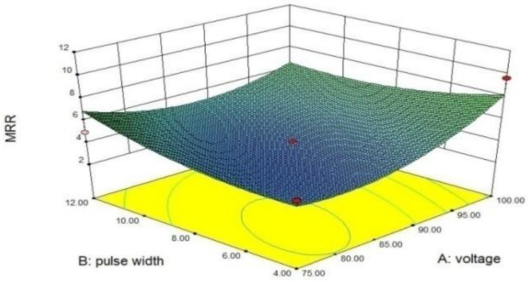

Fig. 1. Response surface of MRR versus voltage and pulse width

From the figure it can be seen that when the voltage increases MRR will be decreased gradually at certain point further increasing voltage MRR will be increased. When the pulse width increases MRR will be decreased gradually at certain point further increasing pulse width MRR will be increased.

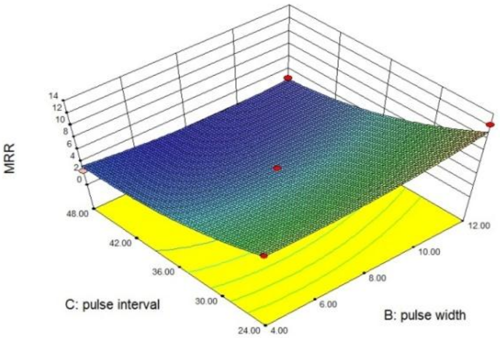

Fig. 2. Response surface of MRR versus pulse width and pulse interval

When the pulse width increases MRR will be decreased gradually at certain point further increase in pulse width MRR will be increased. When the pulse interval increases MRR will be decreased gradually.

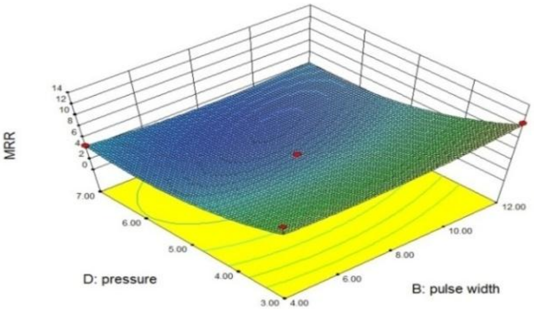

Fig. 3. Response surface of MRR versus pulse width and pressure

When the pulse width increases MRR will be decreased gradually at certain point further increase in pulse width MRR will be increased. When the pressure increases MRR will be decreased gradually at certain point further increasing pressure MRR will be increased.

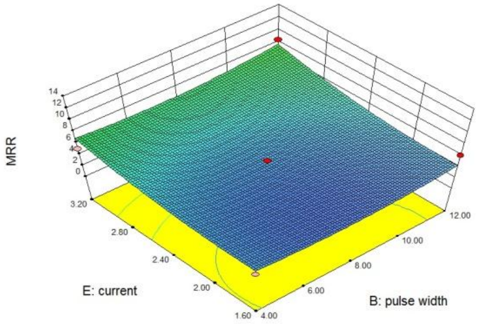

Fig. 4. Response surface of MRR versus pulse width and Current

When the pulse width increases MRR will be decreased gradually at certain point further increase in pulse width MRR will be increased. When the current increases the MRR will be increased gradually.

5. 2. R_a Response Surface

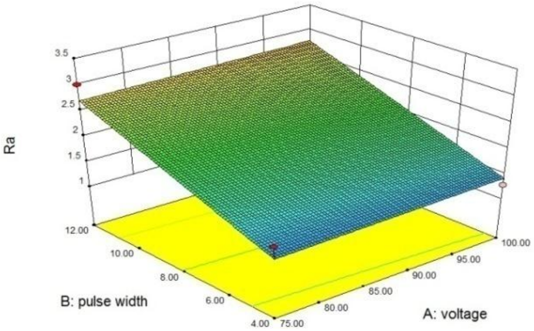

Fig. 5. Response surface of Ra versus voltage and pulse width

From the figure it can be seen that when the voltage increases Ra will be slightly increases. When the pulse width increases Ra will be increased gradually.

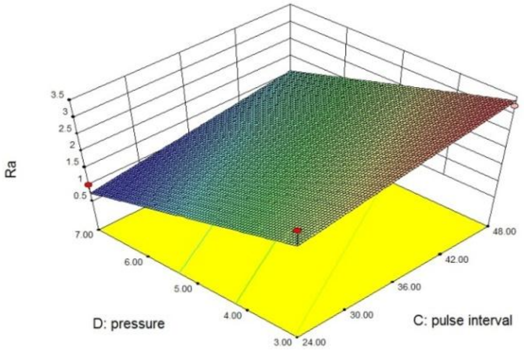

Fig. 6. Response surface of Ra versus pulse interval and pressure

When the pulse interval increases Ra will be increased gradually. When the pressure increases at the time Ra will be decreased gradually.

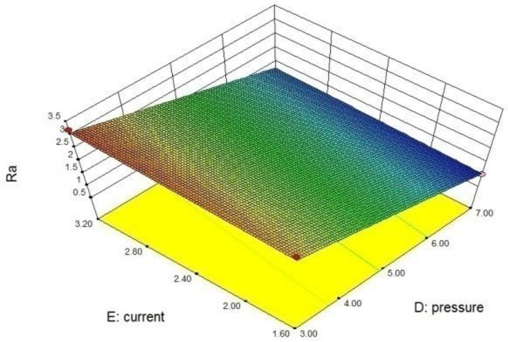

Fig. 7. Response surface of Ra versus pressure and Current

When the pressure increases at the time Ra will be decreased gradually. When the current increases at the time Ra will be slightly increased.

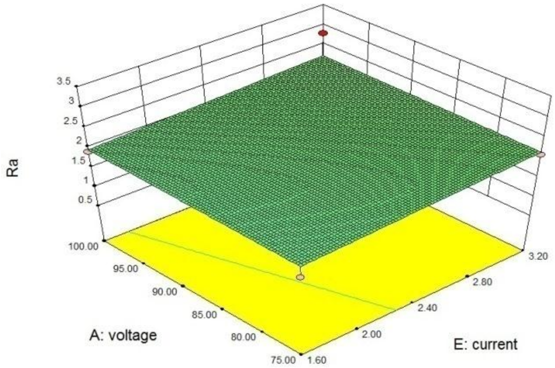

Fig. 8. Response surface of Ra versus Current and voltage

When the current increases at the time Ra will be slightly increased. When the voltage increases Ra will be slightly increases.

6. CONCLUSION

- In this article, parametric analysis of the near dry EDM process has been done based on experimental setup. Experimental are conducted based on the Box-Behnken to develop empirical models of the process.

- From the designed set of experiments based on the Box-Behnken. It was found that voltage, pulse width and current are a significant factor which affects the MRR. When MRR increase with an increase in any one of the factors. Another two factors pressure and pulse interval are the insignificant parameters for MRR.
- From the Box-Behnken experiment all input parameters (voltage, current, pulse width, pulse interval, pressure) have significant effect on Ra. Ra value decrease with increasing liquid gas pressure. Also, Ra value increase with increase in current, voltage, pulse width and pulse interval.

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