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Comparative study of near dry and dry EDM process

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ABSTRACT

The electric discharge machining (EDM) is an un-conventional machining process. It is extensively used to generate complex profiles on electrically conductive materials having high temperature resistance and high strength. Due to its wide applicability in manufacturing industries, EDM has become the most popular machining process after conventional machining processes such as turning, milling and drilling, etc. Despite several advantages, EDM process suffers from some limitations such as low material removal rate (MRR), high tool wear rate (TWR) and poor surface integrity in some cases. In past, several attempts have been made to overcome these limitations by augmenting EDM with techniques such as electrode rotation, ultrasonic vibrations and suspensions of powders into the dielectric fluid. Although these techniques are excellent from research perspective, but in practice, are applicable only for fewer applications. Another limitation in EDM process is its possible environmental pollution causing characteristic. During EDM process, material removal is a consequent of thermal energy produced by series of discrete electrical sparks occurring between tool and work electrodes which are immersed in a dielectric medium mostly hydrocarbon oils. These oils produce serious toxic fumes causing health hazard to the machine operator and environmental pollution. To overcome these limitations of EDM process, dry and near-dry variants of EDM were introduced. Dry EDM process utilizes a pressurized gaseous medium as a dielectric whereas, near-dry EDM process uses a combination of liquid and gas as a dielectric medium and are environmentally friendly.

Near-dry electric discharge machining (EDM) and dry EDM are the process variants of the EDM process. This project reveals comparative study and optimum method between near-dry and dry EDM process to achieve the high material removal rate (MRR) and low tool wear rate (TWR).Two-phase dielectric (liquid and air) was utilized in near-dry EDM while only air was used in dry EDM. L27 orthogonal array was used to determine the effect of pulse current, voltage, pulse on time, pulse off time and pressure on MRR and TWR in near-dry and dry EDM.

Keywords: *EDM, Taguchi, Analysis of variance, Pulse on time, Pulse of time, Grey relational analysis, Dry EDM, Near dry EDM, Electrical discharge machining, Graphite, Spring steel.*

1. INTRODUCTION

An Engineer is always focused towards challenges of bringing ideas and concepts to life. Therefore, sophisticated machines and modern techniques have to be constantly developed and implemented for economical manufacturing of products. At the same time, we should take care that there has been no compromise made with quality and accuracy.

Electrical discharge machining (EDM) has become a well-known non-conventional machining process because of its widely application in die making industries, aerospace and surgical equipment manufacturing industries. It is widely used in aerospace industries.EDM process is based on removing material from a part by means of a series of repeated electrical discharges between tool called the electrode and the work piece in the presence of a dielectric fluid. The material is removed with the erosive effect of the electrical discharge from tool and work piece. EDM also has the advantage of being able to machine difficult-to-cut material like Titanium, Spring steel etc. However, its low machining efficiency, higher tool wear rate (TWR), poor surface finish and environmental pollution constrained its further applications. The EDM process utilizes hydrocarbon oils as dielectric medium. This dielectric medium results in serious toxic fumes and pose a health hazard to machine operator.

Near-dry and dry EDM are the process variants of the EDM process. Both are the environmental friendly process. These processes do not produce toxic fumes and consequent health hazards. Near-dry utilizes liquid- air mixture as dielectric medium and dry EDM uses high velocity air or gases as dielectric medium through a tubular electrode. In this comparative study near-dry and dry EDM were investigated to analyze the effect of current, pulse on time, pulse off time and gap control on MRR and TWR. Taguchi's L27 orthogonal array was used for design of experimentation.

2. LITERATURE SURVEY

Present Theories & Practices:

The following researchers have worked on near dry EDM by taking material removal rate and tool wear rate as a response variable:

C.C. Kao.et al. [1] has studied near dry EDM experimental setup and procedures are presented first in this paper. The MRR envelopes in near dry wire EDM are compared with those in wet and dry wire EDM. The groove width and debris deposition are examined and compared. The MRR and gap width in EDM drilling are investigated. Finally, a mathematical model and experimental validation of gap distance are presented. In this study, MRR envelopes of near dry wire EDM at two flow rates were compared with those of wet and dry.

Albert J. Shih. [2] has studied high MRR near-dry EDM milling processes. Oxygen demonstrated the capability to promote MRR and exothermal oxidation in near-dry EDM. Near-dry EDM was proven beneficial for the finishing operation. Liquid phase dispersed in the gas medium is hypothesized to enhance the electric field and thus results in a large discharge gap distance and a stable discharge at low energy input. Nitrogen and helium gases could prevent the electrolysis and yield better surface finish in near-dry EDM. Reducing the discharge energy input by reducing ie, reducing ti, and increasing t0 is the key to further reduce the surface finish in near-dry finishing EDM.

V. P. Astakhov. [3] has studied manufacturing system are suitable for this technology and if there is clear understanding of the essence, particularities and limitation of the technology. This understanding should stem not from sales pitches by NDM equipment manufacturers and reports by environmentally concerned enthusiastic amateur groups, but rather from an all-round analysis of all the components of the machining system in terms of their suitability for NDM. One should clearly realize this truth: at the present stage of development, NDM can substitute for flood and high-pressure MWF supply only in particularly special cases. From the steps that must be taken to implement NDM, it is apparent that, to make this technology reliable, environmentally friendly and cost efficient, the whole picture has to be considered. To do this, a certain qualification and system thinking of a responsible manager/specialist are prerequisites. Ideally, the part to be machined, the machine tool and cutting tools should be designed specifically for NDM.

Masahiro Fujiki et al. [4] has studied Electrode tool path planning strategy, including the engaging method, edge machining, curvature machining, and path interval to improve the MRR for five-axis near-dry EDM milling was presented. Each strategy was experimentally validated on the MRR. To maximize MRR, mist flow rate through MDR is the first priority to plan a path for five-axis near-dry EDM milling, rather than minimization tool path length, which is prioritized in conventional milling. The electrode tip must remain below the work piece surface when lead angle is used and the electrode hole must not be exposed to the open atmosphere. This maximizes mist flow rate through MDR and results in maximum MRR.

Jagdeep Sharma [5] has studied Near dry machining is a technique that could reduce many problems coming from high consumptions of petroleum based lubricant, like high machining costs or environmental and worker health problems. Therefore, it is important to know all advantages and limits of this technique. The results from experimental tests are summarized here. It can thus be concluded that the use of cutting fluid at minute amounts can potentially improve the surface integrity. Surface finishes also improved mainly due to reduction of cutting temperatures and damage at the tool-tip by the application of near dry machining. As the results indicate the cutting temperature are decreased by almost 50% by the use near dry machining.

Mane S.G. [6] has studied The MRR, TWR and SR in near dry EDM process are mainly affected by the discharge current and electrode material. Copper-tungsten electrode material exhibited lower SR and low TWR than that of the copper electrode but higher MRR was obtained with copper electrode. Increase in the discharge current leads to an increase in the MRR but deteriorating the surface finish (higher SR values).However, an increase in discharge current initially increases the TWR but at higher discharge currents TWR was found to be decreasing. The process parameters cycle time and duty factor were found to be insignificant to affect the selected responses under study viz. MRR, TWR, and. SR. Air pressure was found to be significant to affect only SR. Higher material removal rate (MRR) can be achieved with high discharge current and high gap voltage with copper electrode.

The following researchers have worked on dry EDM by taking material removal rate and tool wear rate as a response variable:

Kunieda and Yoshida [7] has studied In 1996 the feasibility of using air as the dielectric medium was first demonstrated by Kunieda and Yoshida They have steel as a work piece, copper as tool electrode and compressed air as a dielectric. They found that the material removal rate is much higher when the polarity of the tool electrode is negative compared with the case in which the polarity of the tool electrode is positive. In contrast, in the case of EDM in a liquid, there is higher material removal rate when the polarity of the tool electrode is positive. Therefore, machining characteristics were compared between EDM in air with a negative tool electrode and EDM in oil with a positive tool electrode. Then they used oxygen as a dielectric then they found the material removal rate was doubled. They conclude that the material removal rate is improved as the concentration of oxygen in air is increased due to heat generation caused by oxidation of the electrode materials

Kunieda et al. [8] have used a piezoelectric actuator to improve the dry EDM characteristics by controlling the discharge gap distance. They have used copper as tool electrode, carbon steel as a work piece and compressed air as dielectric. They found that with increasing gain of the driver for the piezoelectric actuator, the probability of short circuiting decreases, resulting in considerable increase of the material removal rate.

Kunieda and Furudate [9] have worked on high precision finish cutting by dry WEDM in 2001. In their experiment, they worked on flat surface of carbon steel or tool steel was finish-cut by conventional and dry-WEDM. They conclude that MMR of dry WEDM is considerably lower than that of conventional WEDM and this is because of frequent occurrence of short circuiting due to narrower gap length in dry WEDM causes unfavourable repetition of the turning back and forth of the wire electrode in the feed direction. From the experiments it was also found that increasing the wire winding speed and decreasing the depth of cut could lead to an improvement in MRR and waviness.

Govindan and Joshi [10] have worked on experimental characterization of material removal in dry electrical discharge drilling. They have used copper as tool electrode, steel as work piece material and oxygen as a medium. All the experiments were performed in a ‘quasi-explosion’ mode by controlling pulse ‘off-time’ so as to maximize the material removal rate (MRR).From their experiments it was observed that MMR increases with increase in spark energy, MMR decreases with increase in voltage, MMR increases as increase in rotational speed. The study also analyzed erosion characteristics of a single- discharge in the dry EDM process in relation to the conventional liquid dielectric EDM. It was observed that at low discharge energies, single-discharge in dry EDM could give larger MRR and crater radius as compared to that of the conventional liquid dielectric EDM

3. HARDWARE DETAILS

Schematic Diagram

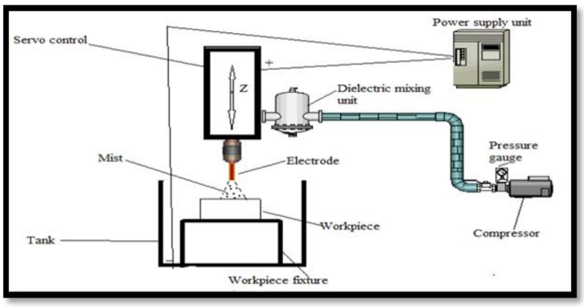


Fig. schematic diagram of EDM Setup

Working Principle

Dry electric discharge machining (dry EDM) is a modification of the oil EDM process in which the liquid dielectric is replaced by a gaseous dielectric. High velocity gas flowing through the tool electrode into the inter-electrode gap substitutes the liquid dielectric. The flow of high velocity gas into the gap facilitates removal of debris and prevents excessive heating of the tool and work piece at the discharge spots. Providing rotation or planetary motion to the tool has been found to be essential for maintaining the stability of the dry EDM process.

4. EXPERIMENTAL WORK

This chapter focused on overall experimental setup and work. Also, it includes methodology used for dissertation work. The details of trial experimental work and final experimental work are mentioned in this chapter.

DESIGN OF EXPERIMENT (DOE)

In this dissertation work, experimentation is performed according to design of experiments. Design of experiment is used to manipulate the conditions of the experiment and can control the factors that are irrelevant to the research objectives. Also, it is process of planning to meet specified objectives. The details of design of experiment are discussed below.

Taguchi method-based design of experiments

Among the available methods, Taguchi design is one of the most powerful DoE methods for analyzing of experiments. It is widely recognized in many fields particularly in development of new products and processes in quality control.
Taguchi method- based design of experiments involved following steps.
The details regarding Taguchi method- based design and its steps are given below:

Selection of the response variables

In any process, the response variables need to be chosen so that they provide useful information about the performance of the process under study. The response variables chosen for study are material removal rate (MRR) & tool wear rate (TWR)

Selection of the process parameters and their levels-

The process parameters can be divided in to two categories i.e. electrical and non-electrical parameters .Major electrical parameters are discharge voltage, peak current, pulse duration, pulse interval and electrode gap. Non electrical EDM process parameters such as dielectric fluid, fluid flow rate and electrode rotation. Due to limitations of machine we are selected only three parameters such as current, cycle time and dielectric pressure.

MATERIAL & DIELECRIC MEDIUM SELECTION

Selection of material for tool of EDM
Materials selected –Graphite

Graphite is produced with a wide range of material characteristics in order to allow matching the electrode material properties to the EDM application.

Copper does not have the ability to handle current density as effectively as graphite, which performs exceptionally well at a high current density even with complex geometry, allowing for various intricate machined details to be designed on the same electrode. The result is that the number of electrodes required to perform a job is significantly reduced.

EDM operators know that excessive wear results in the use of extra electrodes or frequent redressing. Graphite is able to achieve electrode wear of less than 1% in relation to the depth of cut, while working to more aggressive machine parameters. This means, unlike copper, the high amperage and longer on-times actually preserve the graphite electrode
Chemical Formula: C
Composition: Carbon
Colour: Silver-gray to black
Tenacity: Brittle; thin flakes are flexible
Other Marks: 1) Has a greasy feel.
2) Smudges the hands when touched.
3) Good conductor of electricity (though a poor conductor of heat)
Striking Features: Low weight, greasy feel, smudge, and low hardness.

Selection of material for work piece
Materials selected – Spring Steel

All stainless steels have a high resistance to corrosion. Low alloyed grades resist corrosion in atmospheric conditions; highly alloyed grades can resist corrosion in most acids, alkaline solutions, and chloride bearing environments, even at elevated temperatures and pressures. Some grades will resist scaling and maintain high strength at very high temperatures,

while others show exceptional toughness at cryogenic temperatures. The majority of stainless steels can be cut, welded, formed, machined and fabricated readily. The cold work hardening properties of many stainless steels can be used in design to reduce material thicknesses and reduce weight and costs. Other stainless steels may be heat treated to make very high strength components. Stainless steel is available in many surface finishes. It is easily and simply maintained resulting in a high quality, pleasing appearance.
The clean ability of stainless steel makes it the first choice in hospitals, kitchens, food and pharmaceutical processing facilities. Stainless steel is a durable, low maintenance material and is often the least expensive choice in a life cycle cost comparison.

Selection of Dielectric medium
•Gas selected- Compressed air
•Liquid selected- Distilled water
Compressed air is selected because of following properties
•Naturally available.
•No chances of explosion.
•It has low cost compared to other gas.

Distilled water is selected because of following properties
•Distilled water is non toxic
•Colour of distilled should not be affected by Hydro Sulphuric acid
•It works as a coolant
•Boiling point =100c.

5. EXPERIMENTAL SETUP

Figure: Setup of Near dry & dryEDM

Figure shows experimental setup of Dry and Near dry EDM. The experimental setup consists of oil EDM, Compressor, MQL and Graphite electrode. The Compressed air has passed through hose via MQL to the electrode and dielectric medium (compressed air & destilled water) blowed on the workpiece. The pressure of the dielectric medium can be vary by using MQL regulator. The electrode has fitted to tool holder with connector.

6. OBSERVATION

Observation Table-

Table no.1

Sr. No.	Current	Voltage	Ton	Toff	Pressure	For NEAR DRY Process			For DRY Process		
						Initial Weight	Final Weight	t	Initial weight	Final weight	t
1	10	40	30	10	2	t=4.9 p=107.7	t=4.8 p=107.6	7.51	t=8.9 p=102.6	t=8.8 p=102.5	9.19
2	10	40	30	10	3	t=5.1 p=107.6	t=4.8 p=107.5	9.1	t=7.9 p=102.4	t=9.3 p=102.4	9.12
3	10	40	30	10	4	t=5.0 p=107.5	t=5.0 p=107.3	6.8	t=7.9 p=102.4	t=7.8 p=102.3	12.34
4	10	50	40	20	2	t=5.1 p=107.3	t=5.0 p=107.2	8.3	t=8.9 p=102.3	t=8.7 p=102.2	9.47
5	10	50	40	20	3	t=5.1 p=107.2	t=5.0 p=107	10.14	t=9.1 p=102.2	t=9.0 p=102.1	9.3
6	10	50	40	20	4	t=5.4 p=107	t=5.4 p=106.9	7.48	t=8.7 p=102.1	t=8.8 p=102.00	14.52
7	10	60	50	30	2	t=5.1 p=106.9	t=5.0 p=106.8	8.3	t=8.8 p=102.0	t=8.9 p=101.9	12.56
8	10	60	50	30	3	t=5.3 p=106.8	t=5.3 p=106.7	7.36	t=7.9 p=101.9	t=7.9 p=101.7	10.25
9	10	60	50	30	4	t=5.2 p=106.7	t=5.1 p=106.6	9.1	t=8.6 p=101.7	t=8.5 p=101.6	17.28

Table No.2

10	12	40	40	30	2	t=5.2 p=106.6	t=5.1 p=106.4	6.9	t=9.0 p=101.6	t=8.9 p=101.5	12.3
11	12	40	40	30	3	t=5.2 p=106.4	t=5.1 p=106.2	3.24	t=4.9 p=101.5	t=4.8 p=101.43	13.5
12	12	40	40	30	4	t=5.1 p=106.2	t=5.0 p=106.1	4.52	t=5.4 p=101.43	t=5.2 p=101.00	14.7
13	12	50	50	10	2	t=4.9 p=106.1	t=4.9 p=105.9	5.9	t=5.0 p=101.00	t=4.9 p=100	11.5
14	12	50	50	10	3	t=5.2 p=105.9	t=5.2 p=105.7	7.1	t=5.2 p=100.0	t=5.3 p=99.3	15.18
15	12	50	50	10	4	t=4.9 p=105.7	t=4.8 p=105.6	7.18	t=5.0 p=99.3	t=4.8 p=98	14.37
16	12	60	30	20	2	t=5.0 p=105.6	t=5.0 p=105.4	6.4	t=5.4 p=98	t=5.3 p=97	12.24
17	12	60	30	20	3	t=5.1 p=105.4	t=5.1 p=105.3	4.1	t=4.8 p=97	t=4.8 p=96	16.56
18	12	60	30	20	4	t=5.2 p=105.3	t=5.1 p=105.2	5.3	t=5.2 p=96	t=5.1 p=95.1	11.86

Table No.3

19	14	40	50	20	2	t=4.6 p=105.2	t=4.6 p=105.1	6.14	t=5.4 p=95.1	t=5.4 p=94	10.57
20	14	40	50	20	3	t=5.6 p=105.1	t=5.6 p=105.0	5.55	t=5.4 p=94	t=5.2 p=93.1	12.33
21	14	40	50	20	4	t=4.8 p=105.0	t=4.7 p=104.9	6.58	t=5.0 p=109	t=4.9 p=108.9	10.21
22	14	50	30	30	2	t=4.8 p=104.9	t=4.9 p=104.7	10.41	t=5.1 p=108.9	t=5.0 p=108.6	8.37
23	14	50	30	30	3	t=4.8 p=104.7	t=4.6 p=104.5	5.1	t=5.0 p=108.6	t=5.1 p=108.4	7.6
24	14	50	30	30	4	t=5.3 p=104.5	t=5.3 p=104.4	5.58	t=5.0 p=108.4	t=4.9 p=108.3	7.2
25	14	60	40	10	2	t=4.7 p=104.4	t=4.6 p=104.1	3.52	t=4.9 p=108.3	t=4.9 p=108.2	11.4
26	14	60	40	10	3	t=4.1 p=104.1	t=4.0 p=104	6.58	t=5.2 p=108.2	t=5.1 p=108	8.12
27	14	60	40	10	4	t=4.9 p=107.7	t=4.8 p=107.6	5.64	t=5.2 p=108	t=5.2 p=107.9	9.97

7. RESULTS AND ANALYSIS

Dry EDM Process:

Based on the experimental work, the final experiment was performed on stainless steel as a work piece and copper as a electrode material. Material removal rates (MRR) and Tool wear rate (TWR) were measured as per methodology described. The results and analysis obtained by performing experiment are given as follows. The photograph shows the machining (drilling) of spring steel plate of 1 mm by using dry EDM process as per L_{27} orthogonal array. The drills are arranged as per array and numbering is given to them.

Figure: Drills as per L_{27} orthogonal array by Dry EDM.

EXPERIMENTAL RESULTS FOR L27 ORTHOGONAL ARRAY

Table shows the results for material removal rate and tool wear rate by varying current, cycle time and dielectric pressure as per L27 orthogonal array.

Table 6.1 Experimental Results for L_{27} Orthogonal Array of DRY EDM

Sr.No.	current	voltage	Ton	Toff	Pressure	TWR	MRR
1	10	40	30	10	2	-0.0033	0.0133
2	10	40	30	10	3	0.0029	0.0109
3	10	40	30	10	4	0.0012	0.0294
4	10	50	40	20	2	0.0020	0.0120
5	10	50	40	20	3	0.0098	0.0197
6	10	50	40	20	4	0.0042	0.0133
7	10	60	50	30	2	0.0012	0.0120
8	10	60	50	30	3	0.0015	0.0136
9	10	60	50	30	4	0.0109	0.0107
10	12	40	40	30	2	0.0145	0.0289
11	12	40	40	30	3	0.0308	0.0617
12	12	40	40	30	4	0.0221	0.0221
13	12	50	50	10	2	0.0470	0.0139
14	12	50	50	10	3	0.0048	0.0481
15	12	50	50	10	4	0.0139	0.0439
16	12	60	30	20	2	0.0014	0.0112
17	12	60	30	20	3	0.0420	0.0243
18	12	60	30	20	4	0.0188	0.0487
19	14	40	50	20	2	0.0100	0.0169
20	14	40	50	20	3	0.0240	0.0180
21	14	40	50	20	4	-0.0152	0.0452
22	14	50	30	30	2	-0.0096	0.0192
23	14	50	30	30	3	-0.0392	0.0392
24	14	50	30	30	4	0.0780	0.0479
25	14	60	40	10	2	0.0284	0.0852
26	14	60	40	10	3	0.0352	0.0152
27	14	60	40	10	4	0.0310	0.0485

Table -ANOVA for MRR

Source	DF	Adj SS	Adj MS	F-Value	P-Value
current	2	0.007550	0.003775	3.05	0.076
voltage	2	0.002163	0.001082	0.87	0.050
Ton	2	0.000898	0.000449	0.36	0.042
Toff	2	0.004946	0.002473	1.99	0.168
Pressure	2	0.001534	0.000767	0.62	0.040
Error	16	0.019835	0.001240		
Total	26	0.036926			

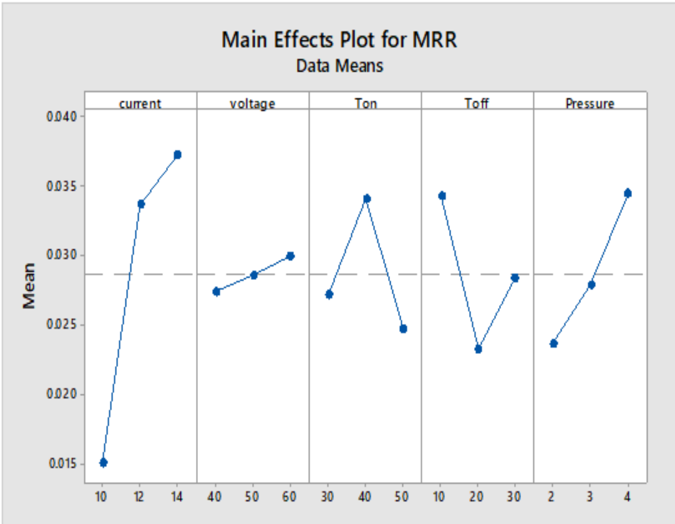


Figure: Main Effect Plot for MRR

ANOVA FOR MATERIAL REMOVAL RATE (MRR) :

ANOVA for MRR has given in the Table below. From ANOVA table we found that, cycle time is most significant parameter for the higher material removal rate at 99% confidence level. We can say that current also a significant parameter for higher material removal rate at 80% confidence level. The remaining parameter, dielectric pressure (oxygen gas pressure) is non-significant parameter for material removal rate.

Graph gives main effect plot for MRR. These graphs show behaviour of process parameters with respect to MRR. The MRR graph is a linear graph which increases from 10 amp to 12 amp. As we know material removal increases with increase in spark energy and spark energy is directly proportional to discharge current. The higher level current gives large craters which increase the material removal. We found same trends in the literature review; number researchers supported the statement and we did not find contradictory statement during literature review. The experiments were conducted at 2 bar, 3 bar and 4 bar by keeping pressure constant. From main effect plot for MRR, it can seen that material removal rate increase with an increase in cycle time. For higher cycle time deeper discharge are formed and more material is removed per spark since spark energy is directly proportional to cycle time. MRR increases with cycle time. For very large values of cycle time, the drop can be explained by the high values of pulse off time.

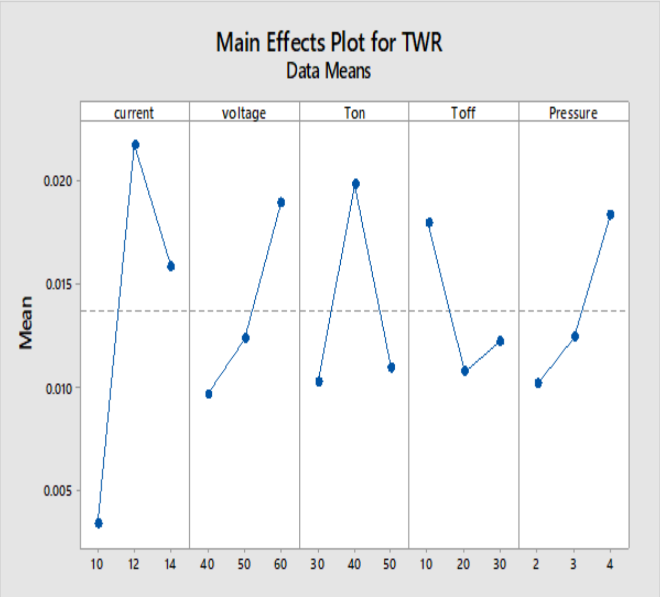
ANOVA FOR TOOL WEAR RATE (TWR)

ANOVA for TWR is given in Table. From the results we found that, current and pulse on time are most significant parameter for TWR but remaining parameter dielectric pressure is non-significant parameter for TWR

From main effect plot we can say that tool wear increases as increase in current. This is due to at higher current stronger spark is generated so melting starts at earlier, also spark energy is low at low lower discharge current. Hence, as the current increases the tool wear rate is increases due to increasing spark energy. In case of pulse on time, tool wear rate increases as increase in the pulse on time. This is due to short pulse which causes less vaporization and long pulse duration cause the plasma channel to expand. But after 200 µs tool wear rate increased because experiments were conducted at constant duty cycle. As earlier discussed constant duty cycle provides longer pulse off time for longer pulse on time and because of insufficient flushing of debris, work piece material deposited on tool.

Table- ANOVA for TWR

Source	DF	Adj SS	Adj MS	F-Value	P-Value
current	2	0.000851	0.000426	3.48	0.055
voltage	2	0.000200	0.000100	0.82	0.459
Ton	2	0.000586	0.000293	2.40	0.123
Toff	2	0.000520	0.000260	2.13	0.015
Pressure	2	0.000233	0.000117	0.95	0.040
Error	16	0.001954	0.000122		
Total	26	0.004344			



FOR NEAR DRY EDM PROCESS:

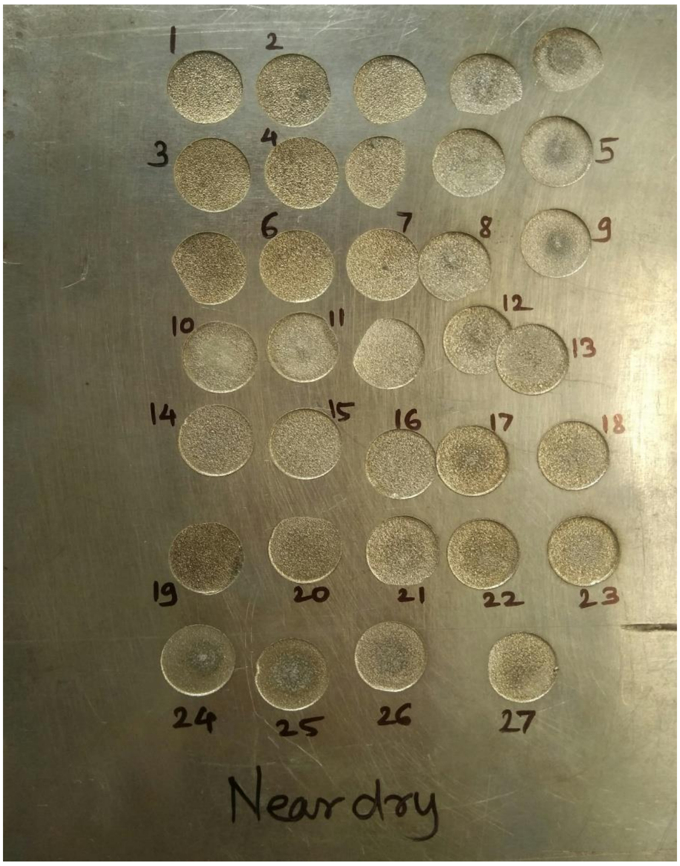


Figure: Drills as per L_{27} orthogonal array by near Dry EDM.

EXPERIMENTAL RESULTS FOR L_{27} ORTHOGONAL ARRAY

Sr.No.	current	voltage	Ton	Toff	Pressure	TWR	MRR
1	10	40	30	10	2	-0.0010	0.0110
2	10	40	30	10	3	-0.0219	0.0190
3	10	40	30	10	4	0.0081	0.0081
4	10	50	40	20	2	0.1110	0.0105
5	10	50	40	20	3	0.0107	0.0107
6	10	50	40	20	4	0.0068	0.0169
7	10	60	50	30	2	-0.0079	0.0279
8	10	60	50	30	3	0.0139	0.0295
9	10	60	50	30	4	0.0058	0.0158
10	12	40	40	30	2	0.0081	0.0080
11	12	40	40	30	3	0.0274	0.0152
12	12	40	40	30	4	0.0136	0.0292
13	12	50	50	10	2	0.0087	0.0270
14	12	50	50	10	3	0.0266	0.0261
15	12	50	50	10	4	0.0239	0.0204
16	12	60	30	20	2	0.0081	0.0816
17	12	60	30	20	3	0.0225	0.0604
18	12	60	30	20	4	0.0284	0.0758
19	14	40	50	20	2	0.0090	0.0230
20	14	40	50	20	3	0.0362	0.0229
21	14	40	50	20	4	0.0298	0.0098
22	14	50	30	30	2	0.0219	0.0239
23	14	50	30	30	3	0.0131	0.0263
24	14	50	30	30	4	0.0038	0.0138
25	14	60	40	10	2	0.0045	0.0087
26	14	60	40	10	3	0.0423	0.1477
27	14	60	40	10	4	0.0189	0.2380

Analysis of Variance for MRR

Table -ANOVA for MRR

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Current	2	0.001065	0.000533	1.97	0.171
voltage	2	0.000059	0.000029	0.11	0.897
Ton	2	0.000741	0.000370	1.37	0.281
Toff	2	0.000368	0.000184	0.68	0.519
Pressure	2	0.000522	0.000261	0.97	0.401
Error	16	0.004314	0.000270		
Total	26	0.007069			

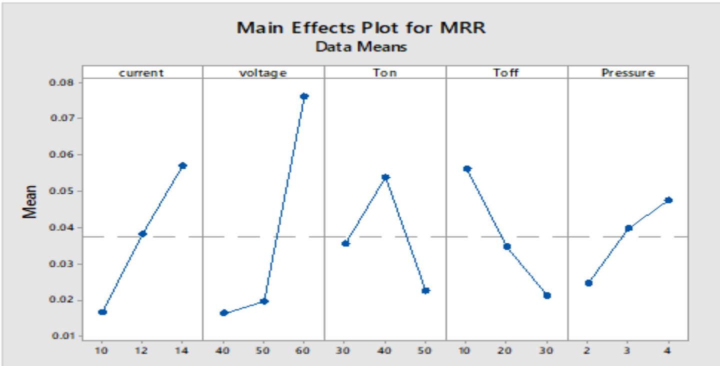
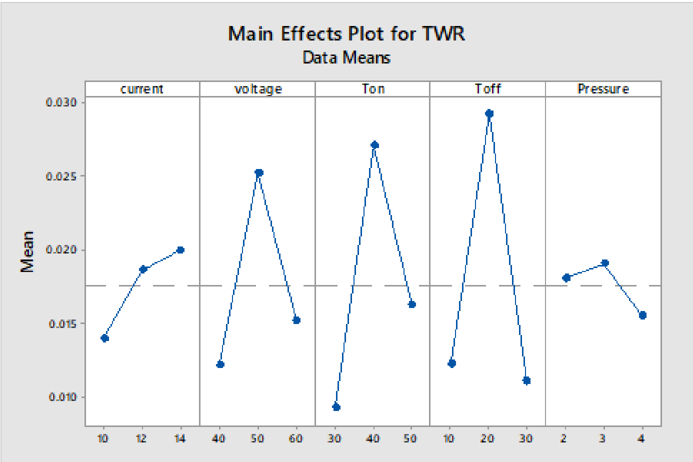


Figure: Main Effect Plot for MRR

Analysis of Variance of TWR:

Table ANOVA for TWR

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Current	2	0.000030	0.000015	0.10	0.902
voltage	2	0.000181	0.000091	0.64	0.542
Ton	2	0.000293	0.000147	1.03	0.380
Toff	2	0.000181	0.000090	0.64	0.047
Pressure	2	0.000168	0.000084	0.59	0.0425
Error	16	0.002277	0.000142		
Total	26	0.003130			



GREY RELATIONAL ANALYSIS (GRA):

The Grey Relational Analysis (GRA) associated with the Taguchi method represents a rather new approach to optimization. The grey theory is based on the random uncertainty of small samples which developed into an evaluation technique to solve certain problems of system that are complex and having incomplete information. A System for which the relevant information is completely known is a 'white' system, while a system for which the relevant information is completely unknown is a 'black' system. Any system between these limits is a 'grey' system having poor and limited information. Grey Relational Analysis (GRA) a normalization evaluation technique is extended to solve the complicated multi-performance characteristics optimization effectively. Grey relational analysis consists calculation of grey relational rationalization which is based on response variable using formula.

The grey relational coefficient (GRC) is calculated by following equation,

$$\gamma(x_0(k)) = \frac{\Delta min + \zeta \Delta max}{\Delta_{0i}(k) + \zeta \Delta max}, \qquad \zeta \in [0,1]$$

Where,

- $i = 1, 2......27; k = 1, 2, 3$
- $\Delta min = min_i \; min_j \; \| x_0(k) - x_i$
- $\Delta max = max_i \; max_j \; \| x_0(k) - x_i($

The Grey Relational Grade (GRG) is obtained by following equation,

$$\gamma(x_0, x_i) = \frac{1}{m} \sum_{k=1}^{m} \gamma(x_o(k), x_i(K))$$

GRA for DRY EDM:

Table no- GRA for DRY EDM

TWR	MRR	MRR (GRR)	TWR (GRR)	MRR (GRC)	TWR (GRC)	GRG	Rank	REMARK
-0.0033	0.0133	0.0348993	0.693686	0.5088798	0.7655127	0.6371963	11	
0.0029	0.0109	0.0026846	0.640785	0.500672	0.7357188	0.6181954	19	
0.0012	0.0294	0.2510067	0.6552901	0.5717575	0.7436548	0.6577062	9	
0.0020	0.0120	0.0174497	0.6484642	0.5044008	0.739899	0.6221499	16	
0.0098	0.0197	0.1208054	0.5819113	0.5321429	0.7051745	0.6186587	18	
0.0042	0.0133	0.0348993	0.6296928	0.5088798	0.7297634	0.6193216	17	
0.0012	0.0120	0.0174497	0.6552901	0.5044008	0.7436548	0.6240278	14	
0.0015	0.0136	0.0389262	0.6527304	0.5099247	0.7422419	0.6260833	13	
0.0109	0.0107	0	0.5725256	0.5	0.700538	0.600269	21	
0.0145	0.0289	0.2442953	0.5418089	0.5695719	0.6857812	0.6276765	12	
0.0308	0.0617	0.6845638	0.4027304	0.7602041	0.6260684	0.6931362	5	
0.0221	0.0221	0.1530201	0.4769625	0.5414244	0.6565826	0.5990035	22	
0.0470	0.0139	0.042953	0.2645051	0.5109739	0.5762045	0.5435892	27	Worst
0.0048	0.0481	0.5020134	0.6245734	0.6675627	0.7270471	0.6973049	4	
0.0139	0.0439	0.4456376	0.5469283	0.6433506	0.6881973	0.665774	7	
0.0014	0.0112	0.0067114	0.6535836	0.5016835	0.7427123	0.6221979	15	
0.0420	0.0243	0.1825503	0.3071672	0.5502216	0.5907258	0.5704737	25	
0.0188	0.0487	0.5100671	0.5051195	0.6711712	0.6689498	0.6700605	6	
0.0100	0.0169	0.0832215	0.5802048	0.5217087	0.7043269	0.6130178	20	
0.0240	0.0180	0.0979866	0.4607509	0.5257586	0.6496674	0.587713	23	
-0.0152	0.0452	0.4630872	0.7952218	0.650655	0.8300283	0.7403417	3	
-0.0096	0.0192	0.114094	0.7474403	0.5302491	0.7983651	0.6643071	8	
-0.0392	0.0392	0.3825503	1	0.6182573	1	0.8091286	2	
0.0780	0.0479	0.4993289	0	0.6663685	0.5	0.5831843	24	
0.0284	0.0852	1	0.4232082	1	0.6341991	0.8170996	1	Best
0.0352	0.0152	0.0604027	0.3651877	0.5155709	0.611691	0.563631	26	
0.0310	0.0485	0.5073826	0.4011348	0.669964	0.6254436	0.6477038	10	

GRA For NEAR DRY EDM:

Table- GRA For Near DRY EDM

TWR	MRR	MRR (GRR)	TWR (GRR)	MRR (GRC)	SF (GRC)	GRG	Rank	REMARK
-0.0010	0.0110	0.0130435	0.8427389	0.5032823	0.8641092	0.6836958	6	
-0.0219	0.0190	0.0478261	1	0.5122494	1	0.7561247	2	
0.0081	0.0081	0.0004348	0.7742664	0.5001087	0.8158379	0.6579733	13	
0.1110	0.0105	0.0108696	0	0.5027322	0.5	0.5013661	27	Worst
0.0107	0.0107	0.0117391	0.7547028	0.5029521	0.8030211	0.6529866	20	
0.0068	0.0169	0.0386957	0.7840482	0.5098648	0.822401	0.6661329	11	
-0.0079	0.0279	0.0865217	0.8946576	0.5226085	0.9046971	0.7136528	3	
0.0139	0.0295	0.0934783	0.7306245	0.5245154	0.787789	0.6561522	17	
0.0058	0.0158	0.033913	0.7915726	0.5086245	0.8275218	0.6680731	8	
0.0081	0.0080	0	0.7742664	0.5	0.8158379	0.657919	14	
0.0274	0.0152	0.0313043	0.6290444	0.5079505	0.7294182	0.6186844	24	
0.0136	0.0292	0.0921739	0.7328819	0.5241568	0.7891924	0.6566746	16	
0.0087	0.0270	0.0826087	0.7697517	0.521542	0.812844	0.667193	10	
0.0266	0.0261	0.0786957	0.635064	0.5204797	0.7326351	0.6265574	23	
0.0239	0.0204	0.053913	0.65538	0.5138517	0.7437045	0.6287781	22	
0.0081	0.0816	0.32	0.7742664	0.5952381	0.8158379	0.705538	4	
0.0225	0.0604	0.2278261	0.6659142	0.5642787	0.749577	0.6569278	15	
0.0284	0.0758	0.2947826	0.6215199	0.5864355	0.7254367	0.6559361	19	
0.0090	0.0230	0.0652174	0.7674944	0.5168539	0.8113553	0.6641046	12	
0.0362	0.0229	0.0647826	0.5628292	0.5167378	0.6958115	0.6062747	26	
0.0298	0.0098	0.0078261	0.6109857	0.5019642	0.719935	0.6109496	25	
0.0219	0.0239	0.0691304	0.6704289	0.5179014	0.7521222	0.6350118	21	
0.0131	0.0263	0.0795652	0.7366441	0.5207154	0.7915426	0.656129	18	
0.0038	0.0138	0.0252174	0.8066215	0.5063849	0.8379571	0.672171	7	
0.0045	0.0087	0.0030435	0.8013544	0.500762	0.834275	0.6675185	9	
0.0423	0.1477	0.6073913	0.51693	0.7180768	0.674277	0.6961769	5	
0.0189	0.2380	1	0.6930023	1	0.7651123	0.8825561	1	Best

8. CONCLUSIONS

Study of dry and near dry EDM process is helpful for drilling process. It shows that near dry EDM gives higher MRR and lower TWR as compare to dry EDM process. In near dry EDM dielectric fluid helps for formation plasma channel between electrode and work piece.
Present work has performed for drilling operation by dry and near dry EDM process. The experiments were performed using Taguchi method of design of experiments. Analysis was carried out using Minitab16 software. The final experiments were performed on Spring Steel work material, for two response variables such as MRR, TWR. Five process parameters were selected such as current, voltage, pulse off time, and pulse on time and dielectric fluid pressure.

- From the ANOVA table we can say that pulse on time is the most significant parameter for MRR at 95 % confidence level and current also a significant parameter at 80% confidence level. It was evident that current and pulse on time influence MRR.
- In case of tool wear rate we can say that TWR is lower in near dry EDM process and Current and pressure were statically significant (at 95 % confidence) influencing TWR

9. FUTURE SCOPE

- The work can be done for different operations like milling turning etc.
- The mathematical model can be developed different work piece and electrode materials for EDM and WEDM processes,
- Responses like roundness, circularity, cylindricity, machining cost etc. are to be considered in further research.

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