Effect of Electrode Materials and Optimization of Electric Discharge Machining of M_2 Tool Steel Using Grey-Taguchi Analysis

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Abstract - *Electric Discharge Machining (EDM) is one of the most efficient employed non-traditional machining processes for cutting hard-to-cut materials. .Modern ED machinery is capable of machining geometrically complex or hard material components. Heat treated tool steel, composites, super alloys, ceramics, etc. In the present work, an experimental investigation has been carried out to study the effect of pulsed current on Material Removal Rate, Electrode Wear Rate and surface roughness in M_2 tool steel. The present material used for the work were Harden up to 62 HRC and then machined with electrode materials of copper and Tungsten copper (75:25 grade) with square section of 10×10 mm and 35 mm in length. Then in second part of present work optimization of output parameters such as Material Removal Rate (MRR) and Surface Roughness during electric discharge machining of M_2 tool steel using Grey-Taguchi analysis with L9 Orthogonal Array has been done.*

The Result shows that Copper can be replacing by Tungsten Copper electrode. The results reveal that High Material Removal Rate and Depth have been achieved with Tungsten copper electrode at process parameters Discharge current 15A, Pulse on time 45µs, pulse off time 9µs and Spark gap of 20µm and for Surface Roughness at Discharge current 5A, Pulse on time 15µs, pulse off time 6µs and Spark gap of 20µm using Taguchi approach, whereas using Grey Relational Analysis approach shows best result at Discharge current 15A, Pulse on time 15µs, pulse off time 9µs and Spark gap of 20µm.

Key Words: Electric Discharge Machining; AISI type tool Steel M_2; Tungsten copper; Taguchi analysis; Grey Relational Analysis.

1. INTRODUCTION

Lately, there has been an expanded enthusiasm in newer and advanced materials with high strength, hardness, thermal stability and high wear resistance used in tool and die making, automotive, aircraft, aerospace, medical appliances etc. More and more challenging problems are faced in producing complex geometries in such hard and difficult to machine materials by conventional machining processes. To overcome such challenges several of unconventional machining processes have been developed. Electric discharge machining (EDM), also name as spark erosion, electro-erosion or spark machining is one of the essential unconventional machining process, broadly utilized for producing complex dies, tools and other components in hard and electrically conductive materials such as tool steel, die steel, composites, ceramics etc.[7]. The present work aims to investigate the feasibility of tungsten copper electrode in place of copper electrode while machining M_2 tool steel in first section. In this first section of experimentation effect of discharge current at five levels at 2, 4, 6, 8, 10 Amp Machined M_2 tool steel taking response as MRR, TWR and SR has studied. There after optimizes the process parameters like discharge current, pulse on time, pulse off time and spark gap during electric discharge machining of M_2 tool steel using Grey relational analysis with a L9 orthogonal array. Experimentation was performed on this condition with machining time 15 min. taken for each experiment and measures the performance. After comparison of performance MRR, TWR and SR using copper and tungsten copper as electrode and M_2 tool steel work material, it is concluded that tungsten copper is feasible for existing experimental conditions. It is observed that the output parameters such as material removal rate, depth and surface roughness of EDM increase with increase in pulsed current. The results reveal that high material removal rate and higher depth have been achieved with tungsten copper electrode at process parameters discharge current 15A, pulse on time 45µs, pulse off time 9µs and spark gap of 20µm and for surface roughness at discharge current 5A, pulse on time 15µs, pulse off time 6µs and spark gap of 20µm using Taguchi approach, whereas using Grey Relational Analysis approach shows best result at discharge current 15A, Pulse on time 15µs, pulse off time 9µs and Spark gap of 20µm. In present study optimize process parameter is investigated as mention above. Levels of process parameters are different depending on desired performance parameters. Investigated work finds applications in industry for requirements such as 1) Higher metal removal rate and depth of M_2 tool steel. 2) Lower surface roughness for M_2 tool steel. 3) In case higher metal removal rate, higher depth and lower surface roughness simultaneously for M_2 tool steel. According to requirements this conditions are useful to the user.

1.1 History of EDM

Electrical Discharge Machining (EDM) was not totally being used until 1943. When established up how the erosive properties of the method could be used and make use of machining functions. Once that one was founded by Joseph Priestly in 1770, admits 1980s machining processes on EDM were changed to a production instrument.

1.2 Introduction of EDM

Electrical Discharge Machining is a most essential nontraditional machining process. EDM is generally utilized for machining of electrically conductive hard metals and alloys in automotive, aerospace and die making industries. EDM process is removing undesirable material in the form of debris and produce shape of the tool surface as of a metal portion by means of a recurring electrical ejection stuck between tool i.e. cathode and the work piece i.e. anode material in the presence of dielectric liquid Dielectric fluid might be kerosene, transformer oil, distilled water, etc. [1]

1.3 Principle of EDM

In this machining strategy the metallic particle is removed as of the w/p owed to controlled wearing away action by means of repeatedly occurring spark ejection with assistance of discharge current applied by power supply taking place in small gap in the range of 10 –125 μm between the tool and work piece. The below schematic fig. 1 demonstrates that the mechanical and in addition electrical control system and electrical path for Electric Discharge Machining. A little break is maintain between the tool and work piece through a servo control arrangement in which the tool in attached. Both the electrode and w/p stay immersed in a dielectric liquid. [4]

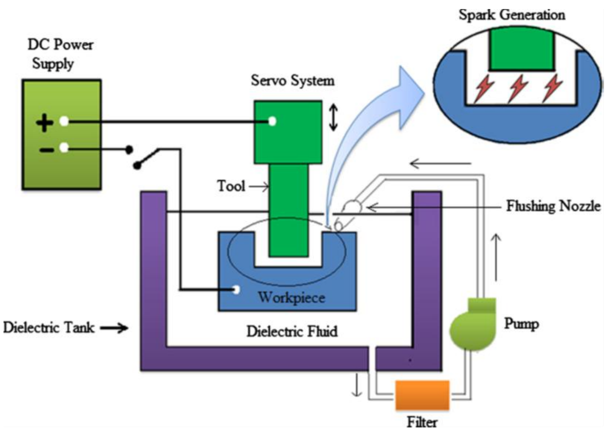

Fig-1*:* schematic diagram of experimental set-up for Electro Discharge [11]

1.4 Classification of EDM

Mainly, there are two disparate kinds of EDM:

A) Die-sinking EDM

B) Wire-cut EDM

A. Die-sinking EDM

With the Die Sinker EDM Machining process, initially the two electrodes are fitted on their places on the machine parts which is work bench and tool holder. Both the electrodes should be electrically conductive. After that both the electrodes are immersed in an insulating liquid dielectric with the assistance of pump. Then set the machining parameters on the CNC controller for machining on the work piece to get the required shape and size. The connected voltage initiate the current to discharge on to the work piece in the pulse form otherwise in continuous form it produces arc which is unsafe for machining. Spark energy is discrete and controlled enough to melt and vaporize within a thin gap from the work piece surface. In this period the discharge current is varied within range of 0.5 to 400 A, at 40-300 V connected voltage range and pulse duration can be differed from 2 to 2000 micro second. Distinctive kind of flushing technique is connected to remove and prevent from aggregation of melted material from the work piece.

B. Wire-cut EDM

Wire EDM also called electric discharge wire cutting process utilized for producing two or three dimensional complex shapes using an electro thermal mechanism for eroding the material from a thin single stranded by guide ruler's metal wire encompassed by deionized water which is utilized to conduct electricity. Any hard material can cut by wire EDM process, but the material should have an electrical conductive properties.

1.5 Machining Parameters of EDM

A. **Pulse On time (T_{on}):** It is the duration of time expressed in micro seconds in whom the peak current is ready to flow in each cycle. This is the time in which energy removes the metallic particles from the work piece.

B. **Pulse Off time (T_{off}):** It is the period of time expressed in micro seconds between the two pulses on time. This time allows the melted particle to coagulate on to the work piece and to be wash away by flushing technique of the arc gap.

C. **Spark gap (Sg):** It is gap between the electrode and work piece in which the spark generate for eroding the metal from the work piece. It is very thin gap in the range of 10 – 125 μm.

D. **Discharge current (Ip)**: Current is measured in ampere (A). Discharge current is dependable directly for material removal. It contains energy for melting and evaporation.

E. **Duty cycle (τ):** It is a ratio of the pulse on-time relative to the total cycle time expressed in percentage.

F. **Voltage (V):** It is a potential difference that can be connected by the power supply in a controlled way.

G. **Diameter of electrode (D):** It is the diameter of electrode or tool material.

H. **Over cut** – It is a measurement of clearance amongst tool and work piece after completing each experiment by outline of the tool material.

2. PAST WORK

Manisha Priyadarshini et.al. [8] Demonstrates the parametric optimization of EDM for desired responses using grey relational Taguchi analysis. Taguchi method was used to design the experiments using L25 orthogonal array and the effect of each parameter on the responses while machining Ti-6Al-4V alloy using a copper electrode was studied collectively.

Rajesh Purohit et.al. [9] Aims to optimize the output parameters like Metal Removal Rate (MRR), Electrode Wear Ratio (EWR) and over cut (OC) with respect to the input parameters like tool rotation speed, voltage and spark time during electric discharge machining of tool steel M_2 using Grey relational analysis with a L9 orthogonal array. The electrode rotation speed was found to affects the output parameters most followed by voltage and the spark time.

Vikas et.al. [10] Reported an idea about the effect of the various input process parameters like Pulse ON time, Pulse OFF time, Discharge Current and Voltage over the Surface Roughness for an EN41 material. Here, 5 different output parameters concerned with surface roughness like R_a, R_q, R_{sk}, R_{ku} and R_{sm} are taken and optimized accordingly, using the Grey-Taguchi method. On the basis of their Grade, the S/N ratio is obtained and accordingly the ANOVA table is generated. It was found that the Current had larger impact over the Surface Roughness value, followed by the Voltage.

P. Narender Singh et.al. [11] Investigated Orthogonal array with Grey relational analysis was employed to optimize the multi response characteristics of Electric Discharge Machining of Al–10%SiCP composites. The experimental result for the optimal setting shows that there is considerable improvement in the process. The application of this technique converts the multi response variable to a single response Grey relational grade and, therefore, simplifies the optimization procedure.

J.L. Lin et.al.[13] Reviews the new approach for the optimization of the electrical discharge machining (EDM) process with multiple performance characteristics based on the orthogonal array with the grey relational analysis has been studied. In this study, the machining parameters, namely workpiece polarity, pulse on time, duty factor, open discharge voltage, discharge current, and dielectric fluid are optimized with considerations of multiple performance characteristics including material removal rate, surface roughness, and electrode wear ratio. Experimental results have shown that machining performance in the EDM process can be improved effectively through this approach.

3. EXPERIMENTAL DESIGN

3.1 Experimental Set-Up

Experiments were carried out in an electrical discharge machine (Electronica PSR 35 model; Electronica Tools Ltd., India) installed at OM Mahesh Engineering, MIDC Walunj as shown in fig 2.

3.2 Selection of Work Piece

In this experiment AISI M_2 tool steel of size 50×20×6 mm^3 plate is decided for conducting the experiment. AISI type tool steel M_2 is a molybdenum based high speed steel. It has hardness value of 62 HRC; it is harden up to 62 HRC by using Vacuum Hardening process at S.N. metallurgical services Aurangabad for making it an ideal workpiece material for EDM.

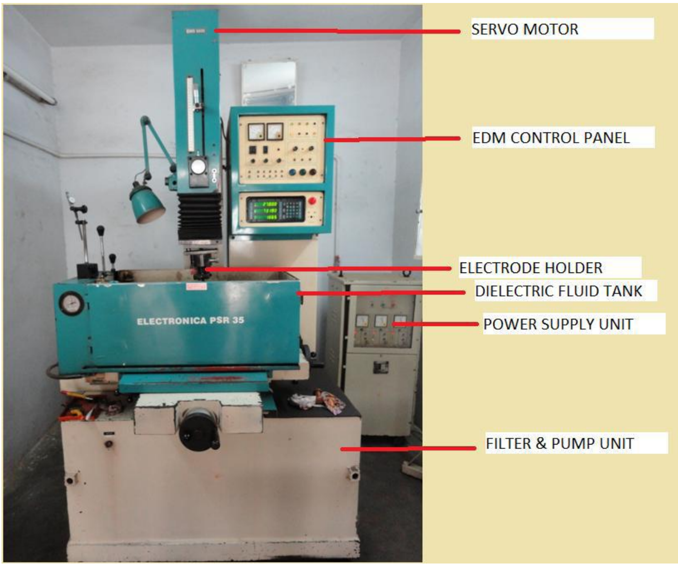

Fig-2: Photographic view of Electro discharge Machine

3.3 Selection of Tool Material

In present experiment copper and tungsten copper square rod of 10×10 mm^2 of length with 35 mm is to be utilized. Many shops in existing scenario prefer to use copper as a primary electrode, because their tool making culture. Because of its structural integrity, copper can produce fine surface finishes, even without extraordinary polishing circuits this same structural integrity is also makes Copper electrode highly resistance to DC arching in poor flushing conditions. Tungsten copper is a powder metal product intended to combine the best EDM properties of copper and tungsten. Tungsten copper combines the high electric conductivity of copper with the high melting point of tungsten. For optimization purpose tungsten copper of 75: 25 grades is used, as shown in figure 3.

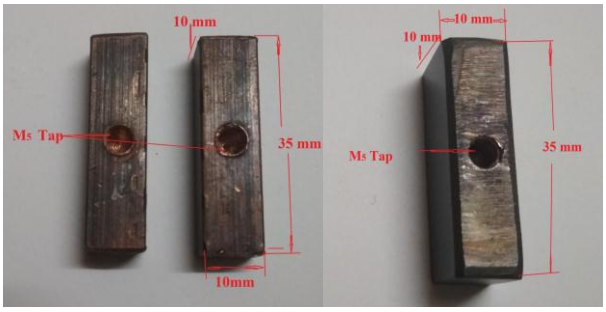

Fig-3: Photographic view of Copper and Tungsten-Copper electrode

3.4 Mechanism of MRR

Mechanism behind material removal of EDM processed is based on conversion of electric energy to thermal energy that categorized it to electro thermal process. During machining both the surfaces may have present smooth and irregularities causes' minimum and maximum gap in between tool and work piece. At a given instant at minimum point suitable voltage is developed produces electrostatic field for emission of electrons from the cathode there electron accelerated towards the anode. MRR is calculated as the proportion of the change of weight of the work piece before and after machining to machining time period.

$$MRR = \frac{W_{bm} - W_{am}}{t_m} \quad \text{........ [eq}^{n}\text{-1]}$$

Whereas:

W_{bm} = Weight of workpiece before machining, W_{bm} = Weight of workpiece after machining, t_m = Machining period = 15 min.

3.5 Measurement of Surface Roughness

Surface Roughness is the size of surface texture. It is expressed in µm and denoted by Ra. Surface roughness values measure by means of portable surface roughness tester SURFTEST SJ-210 series.

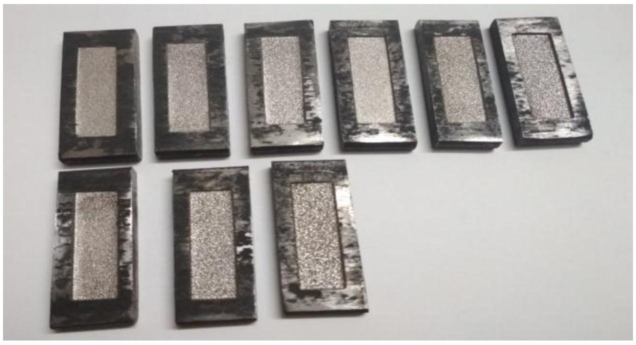

Fig-4: Machined work pieces

4. Result and Discussion

The experimentation of current work can be divided in to two main sections; in first half of this experiment only discharge current will vary keeping all other machining parameters constant. The Weight of work material and tool electrode with surface roughness of both materials is measure after experimentations. 20 min constant time is estimated for each experiment. As shown in below table 1 & 2. In second half of experimentation four factors with three levels as per DOE are attempted with an overall number of 9 trials completed on die sinking EDM. The Weight of work material with surface roughness is measure after experimentations. For experimentation No 1 to 6, 15 min time is allowed and for experiment no 7, 8 and 9 constant time of 10 min is given for experimentation. As shown in below Table 3.

After analysis of the effect of discharge current at five levels at 2, 4, 6, 8, 10 Amp Machined M_2 tool steel taking response as MRR, TWR and SR. there is mentionable difference between metal removal rate by copper and tungsten copper, but it is acceptable by the manufacturer, so it can replace the copper electrode with the tungsten copper electrode.

Table -1: Response table for MRR, TWR and SR for Copper

Expt. No.	Discharge current(A)	Copper		
		MRR (gm/min)	TWR (gm/min)	SR (µm)
1	2	0.0284	0.0022	5.72
2	4	0.0631	0.0042	7.089
3	6	0.1482	0.0052	9.036
4	8	0.2453	0.006	10.303
5	10	0.3997	0.0068	13.348

Table -2: Response table for MRR, TWR and SR for W-Cu

Expt. No.	Discharge current(A)	Tungsten Copper		
		MRR (gm/min)	TWR (gm/min)	SR (µm)
1	2	0.0284	0.0022	5.72
2	4	0.0631	0.0042	7.089
3	6	0.1482	0.0052	9.036
4	8	0.2453	0.006	10.303
5	10	0.3997	0.0068	13.348

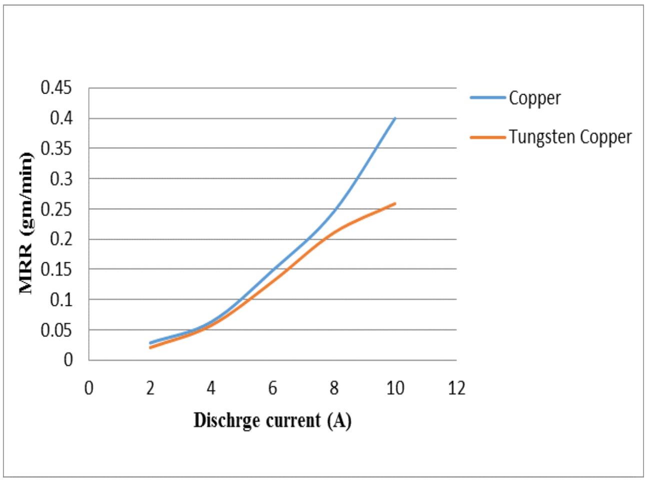

Chart-1: Variation of discharge current verses metal removal rate (MRR) for copper and tungsten copper electrode

While comparing about the tool wear rate of copper and copper tungsten electrode, it is seen that from Chart-2, there is profitable tool wear rate of the copper-tungsten as compare to the copper electrode. This was one of the prime requirements of the existing manufacturer.

So while considering about tool wear rate there is marginable scope for the copper tungsten electrode for ED machining for M_2 tool steel. Surface roughness is also prime requirement for any type of machining process. Comparison of SR of work material while machining with the copper and copper-tungsten electrode as swoon in chart-3, there is better surface finish while machining with high discharge current, So copper can be replace by the Tungsten copper electrode.

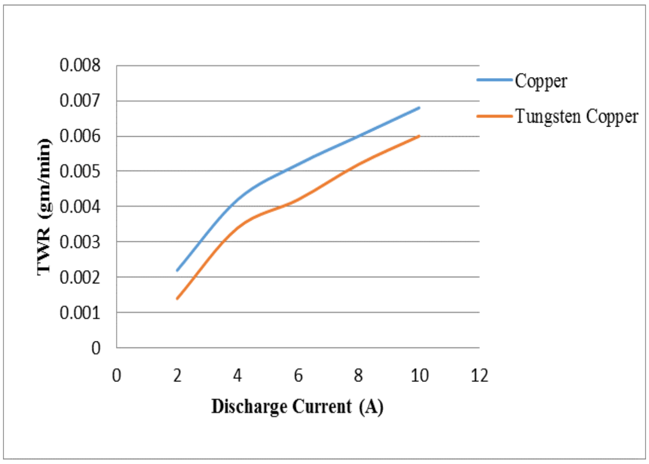

Chart-2: Variation of discharge current verses tool wear rate (TWR) for copper and tungsten copper electrode

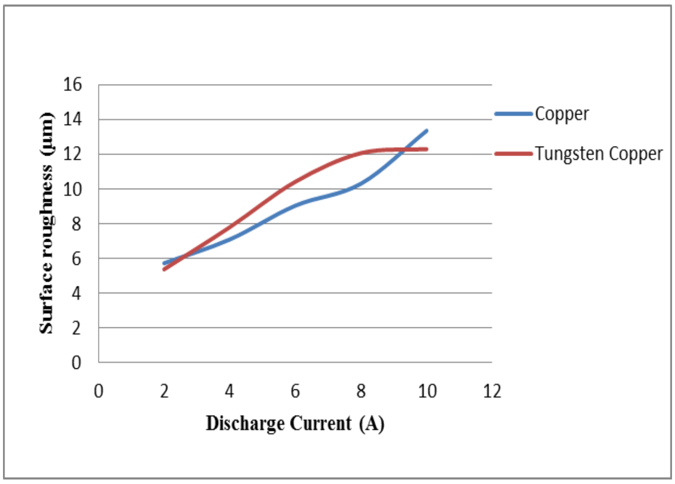

Chart-3: Variation of discharge current verses surface roughness (SR) for copper and tungsten copper electrode

4.1 Optimization of Machining Parameters

Second half of study deals with the optimization of machining parameters using taguchi method and Grey Relational Analysis technique. According to design of experiment there is 9 different orthogonal arrays i.e. 9 different machining conditions. Taguchi method is implemented for optimization of process parameters. Experimentations are done for each experimental condition and measure the performance.

Influences on MRR

The S/N ratios for MRR are calculated as given in eq^n-2. Taguchi method is used to analysis the result of response of machining parameters for "larger is better" criteria.

$$LB: \eta = -10 \log \left[\frac{1}{n} \sum_{i=1}^{n} y_i^{-2} \right] \qquad \text{………… [eq}^n\text{-2]}$$

Table-3: Response table for MRR along with the input factors

Ex.no.	I_p (A)	T_{on} (µs)	T_{off} (µs)	S_g (µm)	MRR (gm/min)
1	5	15	3	10	0.0274
2	5	30	6	20	0.652
3	5	45	9	30	0.0662
4	10	15	6	30	0.1333
5	10	30	9	10	0.1276
6	10	45	3	20	0.2013
7	15	15	9	20	0.2835
8	15	30	3	30	0.1985
9	15	45	6	10	0.1899

When η denotes the S/N ratios calculated from observed values, y_i represents the experimentally observed value of the Ith experiment and n=1 is the repeated number of each experiment in L-9 Orthogonal Array was conducted.

Table 4. Response Table for Signal to Noise Ratios Larger is better for MRR

Level	Current	ON time	OFF time	Spark gap
1	-26.18	-19.90	-19.74	-21.19
2	-16.44	-18.55	-18.55	-16.20
3	-13.14	-17.31	-17.47	-18.38
Delta	13.04	2.59	2.27	4.99
Rank	1	3	4	2

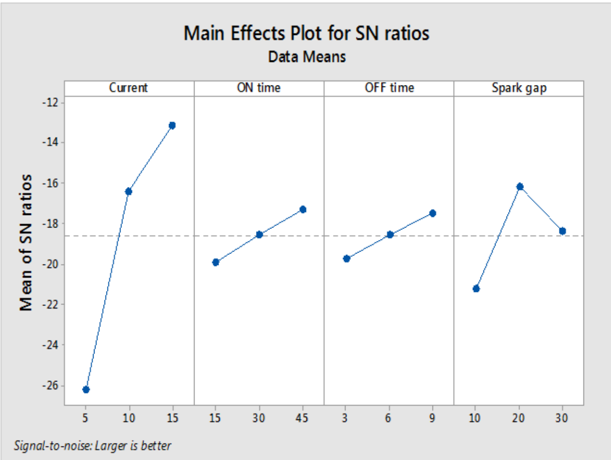

Fig -5: Main effect plot for Sn ratios for MRR

Table 4.4 Response Table for Means for MRR

Level	Current	ON time	OFF time	Spark gap
1	0.05293	0.14807	0.14240	0.11497
2	0.15407	0.13043	0.12947	0.18333
3	0.22397	0.15247	0.15910	0.13267
Delta	0.17103	0.02203	0.02963	0.06837
Rank	1	4	3	2

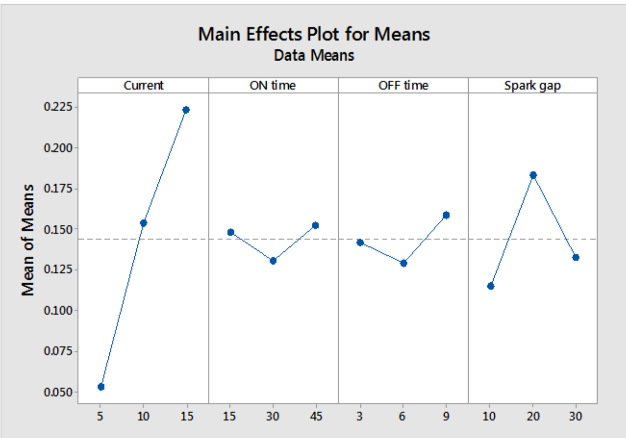

Fig-6: Main effect plots of Means for MRR

From above analysis of response table for signal to noise ratios and response table for means of existing experimental conditions, setting for process parameters which ultimately result to higher MRR. As follows;

1) Current – 15 A
2) ON time – 45 µs
3) OFF time - 9 µs
4) Spark gap – 20 µm.

4.2 Validation of Experiment

Validation of experiment is also important part of any experimentation. For validation of experiment we perform experiment by Taking tungsten-copper as an electrode and perform experiment at optimal process parameters for material removal rate and measure MRR which was tabulated as given in table 4.

Table-4: Confirmation Test Results

Technique used ↓	Optimization for ↓	Process parameters				Result outcome
		I_p (A)	T_{on} (µs)	T_{off} (µs)	S_g (µm)	
Taguchi	MRR	15	45	9	20	0.3035

5. CONCLUSION

1. After comparison of performance MRR, TWR and SR using copper and tungsten copper as electrode and M_2 tool steel work material, it is concluded that Tungsten copper is feasible for existing experimental conditions.
2. Optimize process parameters for MRR, with tungsten-copper electrode is tabulated as follows:

Table-7: Optimized Process Parameters

Details ↓	Process Parameters			
Parameters →	I_p (A)	T_{on} (µs)	T_{off} (µs)	S_g (µm)
Optimized value →	15	45	9	20

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Software

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