

Research Article

## Characteristics of Titanium by EDM Process using Taguchi Methods of Analysis

R.Thamaraikannan<sup>A\*</sup>, P.Prabhuraj<sup>B</sup>, S.Sathiyaraj<sup>B</sup> and A.Elanthiraiyan<sup>B</sup>

<sup>A</sup>Department of Mechanical Engineering, Sathyabama University, Chennai

<sup>B</sup>Department of Mechanical Engineering, Vinayaka Mission University, Chennai

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### Abstract

The investigation of machining characteristics is one of the most important aspects to take into consideration in the majority of manufacturing processes. Titanium is a super alloy which achieves a high degree of hardness with compressive strength and abrasion resistance. Due to these properties; it is one of the most widely used materials in aerospace, aeronautics and nuclear industries. Hence its wide use and high hardness requires unconventional machining such as EDM, the investigation of machining characteristics of Titanium will provide a more economic and efficient method in it. The work material (Ti) was EDM machined with copper electrode by varying process parameters. The machining parameters that we are going to investigate are peak current, Pulse on time and pulse off time and analyse the output parameters such as material removal rate (MRR) and surface roughness (Ra), with the help of Taguchi methods of analysis to obtain the best operating parameter. Investigation indicates that the material removal rate increases with increasing peak current.

**Keywords:** Electrical Discharge machining, Titanium, Metal Removal Rate, Surface roughness, Analysis of variance, Taguchi methods

### 1. Introduction

Electrical Discharge Machine (EDM) is now become the most important accepted technologies in manufacturing industries since many complex 3D shapes can be machined using a simple shaped tool electrode. Traditional machining techniques are often based on the material removal using tool material harder than the work material and is unable to machine economically. An EDM is based on the eroding effect of an electric spark on both the electrodes used. EDM actually is a process of utilizing the removal phenomenon of electrical discharge in dielectric. Therefore, the electrode plays an important role, which affects the material removal rate and surface roughness.

### Construction & Working

Fig 1 shows the schematic layout of the electric discharge machining process. The main components are the electric power supply, dielectric medium, work piece, tool and a servo control mechanism. The work piece and the tool are electrically connected to a D.C. power supply. The work piece is connected to the positive terminal of the electric source, so that it becomes the anode. The tool is connected to the negative terminal of the electric source, so that it becomes the cathode. The tool and work piece are submerged in a dielectric fluid medium such as paraffin, white spirit or transformer oil having poor electrical conductivity. The

function of the servo mechanism is to maintain a very small gap, known as 'spark gap' ranges of 0.005 to 0.05mm between the work piece and the tool.

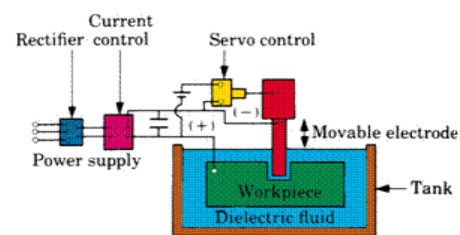


Figure 1 Schematic layout of the EDM process

When the D.C supply is given to the circuit, spark is produced across the gap between the tool and the work piece. When the voltage across the gap becomes sufficiently large (more than 250 V), the high power spark is produced. So, the dielectric breaks down and electrons are emitted from the cathode (tool) and the gap is ionized. This spark occurs in an interval of 10 to 30 microseconds and with a current density of 15 – 500A per mm<sup>2</sup> approximately. So, thousands of spark – discharge occur per second across the gap between the tool and the work, which results in increasing temperature of about 10,000°C. At this high pressure and temperature, work piece metal is melted, eroded and some of it is vaporized. In this way the metal is thus removed from the work piece. The removed fine material particles are carried away by dielectric fluid circulated around it. The metal removal

\*Corresponding author: R.Thamaraikannan

rate depends on the spark gap maintained. If anode and cathode are made of same material, it has been found that the greatest erosion takes place at anode. Therefore, in order to remove maximum metal and have minimum wear on the tools, the tool is made as cathode the work piece as anode. When the voltage drops to about 12 volts, the spark discharge extinguishes and the dielectric fluid one again becomes deionized.

**2. Experimental Method and Setup**

The electric discharge machine, model EMS 5030 (Ram type) with servo head (constant gap) and positive polarity for the electrode was used to conduct the experiments. The work material was mounted on the T-slot table and positioned at the desired place and clamped. The electrode (copper) was clamped on the V-block and its alignment was checked with help of the try square. The tool and material was immersed in EDM Oil 3 as die-electric fluid. A depth of cut 2mm was set for the machining of all work materials. Machining test was carried out according to the design of experiment table. The cycle time was measured in every machining process at different levels. The same machining procedure was repeated for Graphite electrode.

**Table 1** Specification of the EMS5030 EDM machine tool

<b>Manufactured by</b>	ElemechEngineers,pune-51(Model-Ems5030)
<b>Travel</b>	
X-axis	300mm
Y-axis	200mm
Z-axis	200mm
<b>Table</b>	
Table work surface	500mm x 300mm
T-slot configuration	13mm x 3 (qty) x 5mm
<b>Power Requirement</b>	
Electrical power supply	240V/100V,50Hz
Pneumatic	5.5 to 6 bar
<b>Machine size</b>	
Height	1200mm x 1200mm x 2010mm
<b>Weight</b>	800 kg



**Figure 2** EDM Experiment setup

The work piece material used in this study was Titanium. Titanium materials are used mostly employed in die and mould manufacturing industries. It is a lustrous transition metal with a silver colour, low density and high strength.

It is highly resistant to corrosion in sea water, aqua regia and chlorine. Titanium can be alloyed with iron, aluminium, vanadium, molybdenum, among other elements, to produce strong lightweight alloys for aerospace (jet engines, missiles, and spacecraft), military, industrial process (chemicals and petro-chemicals, desalination plants, pulp, and paper), automotive, agro-food, medical prostheses, orthopaedic implants, dental and endodontic instruments and files, dental implants, sporting goods, jewellery, mobile phones, and other applications. It has exhibits the following properties.

**3. Results and Discussion**

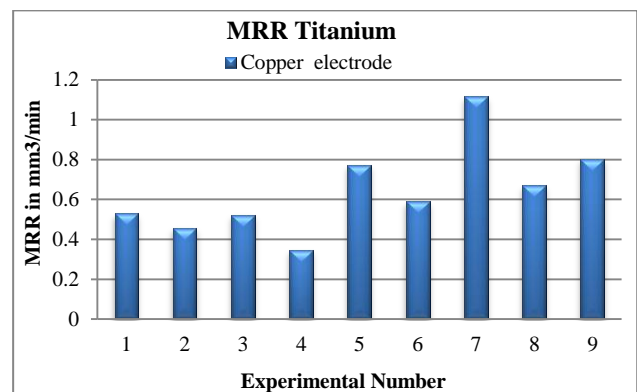
**Metal Removal Rate**

MRR= Volume of the material removed from the work piece mm<sup>3</sup>/min  
 Time of machining  
 Where D- Diameter of the hole in mm  
 I-Depth of the hole in mm

The results of MRR for all the experiments in this study are calculated by using the above formula and the values are tabulated in Table 1.The variations of MRR between the experiments were graphically represented in Figure 3.

**Table 2** Values of Metal Removal Rate (MRR)

Exp.No	Peak current in amps	Pulse on time in µsec	Pulse off time in µsec	Time of machining in mins	MRR in mm <sup>3</sup> /min
1	5	4.5	2	190	0.529
2	5	9.5	4	220	0.456
3	5	20	8	192	0.523
4	10	9.5	8	290	0.346
5	10	20	2	130	0.773
6	10	4.5	4	170	0.591
7	15	20	4	90	1.117
8	15	4.5	8	150	0.67
9	15	9.5	2	125	0.804



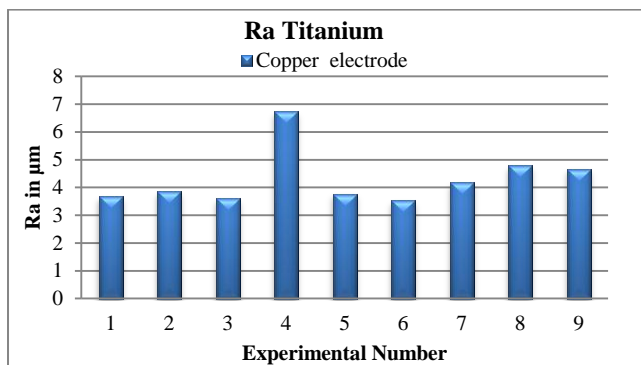
**Figure 3** Variation of MRR between experiments

**Surface Roughness**

The surface roughness of the hole was measured by using Surfcomder.

**Table 2** Values of Surface Roughness ( $R_a$ )

Exp. No	Peak current in amps	Pulse on time in $\mu$ sec	Pulse off time in $\mu$ sec	Surface Roughness in $\mu$ m
1	5	4.5	2.0	3.379
2	5	9.5	4.0	3.856
3	5	20	8.0	3.585
4	10	9.5	8.0	6.371
5	10	20	2.0	3.761
6	10	4.5	4.0	3.536
7	15	20	4.0	4.185
8	15	4.5	8.0	4.781
9	15	9.5	2.0	4.656



**Figure 4** Variation of  $R_a$  between experiments

The variations of the surface roughness between the experiments were graphically represented in Figure 4.

**Taguchi Method**

The fundamental principle of the Taguchi method is to improve the quality of a product by minimizing the effect of the causes of variation without eliminating the causes. Taguchi approach provides systematic, simple and efficient methodology for the optimization of the near-optimum design parameters with only a few well-defined experimental sets.

The objective of this study is to maximize the material removal rate, therefore the S/N ratio for larger the better was selected and it is given by

$$\eta = -10 \log_{10} (1/Y_i^2)$$

Where  $\eta$  – S/N ratio

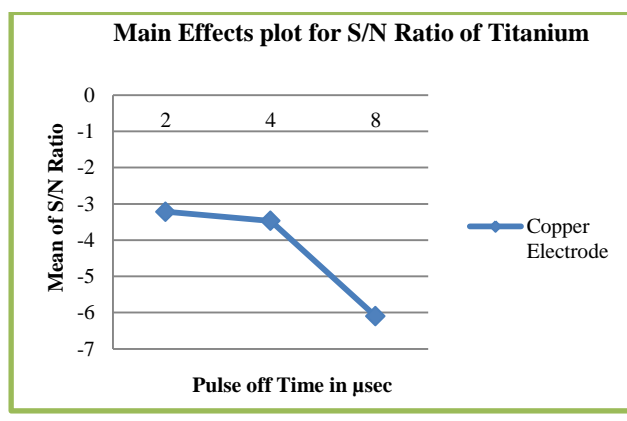
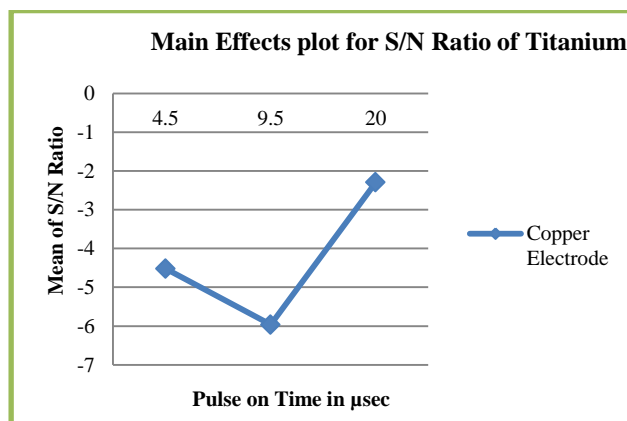
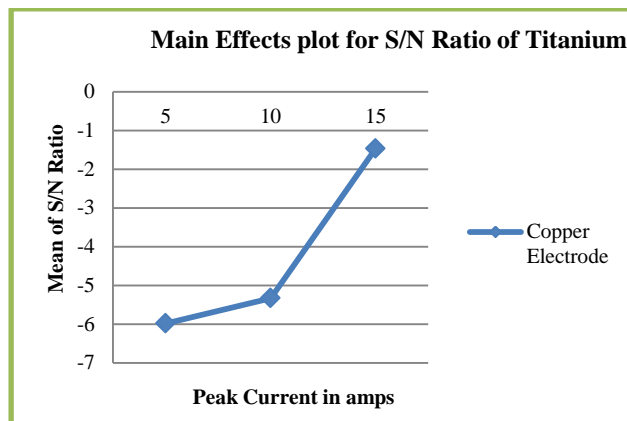
$Y_i$  -measured value of output parameter

The S/N ratios for MRR were calculated and it is given in Table 3

**Table 3** S/N ratio for Metal Removal Rate (MRR)

Exp.No	Peak current in amps	Pulseon time in $\mu$ sec	Pulseoff time in $\mu$ sec	MRR in mm <sup>3</sup> /min	S/N Ratio $\eta = -10 \log_{10} (1/Y_i^2)$
1	5	4.5	2	0.529	-5.529
2	5	9.5	4	0.456	-6.802

3	5	20	8	0.523	-5.62
4	10	9.5	8	0.346	-9.202
5	10	20	2	0.773	-2.232
6	10	4.5	4	0.591	-4.563
7	15	20	4	1.117	0.961
8	15	4.5	8	0.67	-3.475
9	15	9.5	2	0.804	-1.892



**Figure 5** Main effects plot for means of S/N ratios for MRR

The main effects plot for mean of S/N ratio are graphically represented in Figure 5

Regardless of the category of the performance characteristics, a greater S/N value corresponds to a better performance to a better performance. Therefore, the optimal level of the machining parameters is the level with the greatest value. From the graph, it is observed that the

optimal combination of process parameters for material removal rate is given below.

**Peak current**

The effect of parameter peak current on metal removal rate values is the shown above figure for S/N ratio. Its effect is increasing with increase in peak current. So the optimum peak current is level 3 i.e. 15 amps.

**Pulse on time**

The effect of parameter peak current on metal removal rate values is the shown above figure for S/N ratio. Its effect is decreasing with increase in peak pulse on time upto 9.5  $\mu$ sec beyond that it is increasing. So the optimum pulse on time is level 3 i.e. 20  $\mu$ sec.

**Pulse off time**

The effect of parameters pulse off time on the metal removal rate value is shown above figure for S/N ratio. Its effects are decreasing with increase in pulse off time. So the optimum pulse off time is level 1 i.e.2  $\mu$ sec

**Calculation on S/N ratio for surface roughness**

The objective of this study is to minimize the surface roughness, therefore the S/N ratio for smaller the better was selected and it is given by

$$\eta = -10 \log_{10} (Y_i^2)$$

Where  $\eta$  – S/N ratio

$Y_i$  -measured value of output parameter

The S/N ratios for MRR were calculated and it is given in Table 4.5.

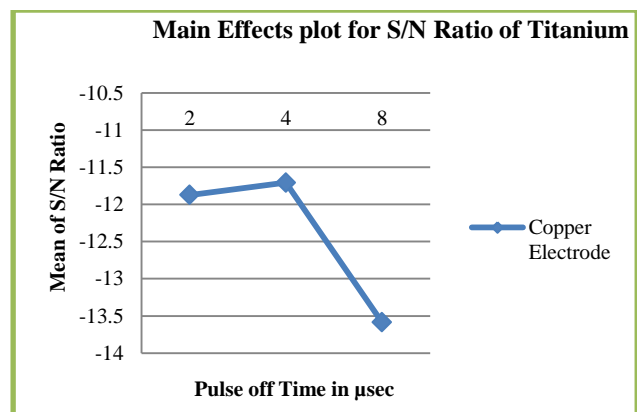
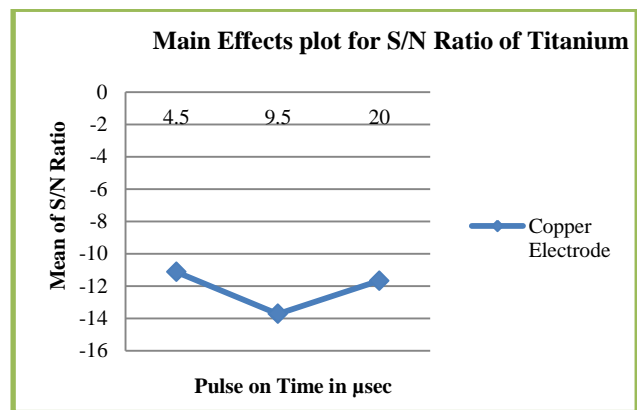
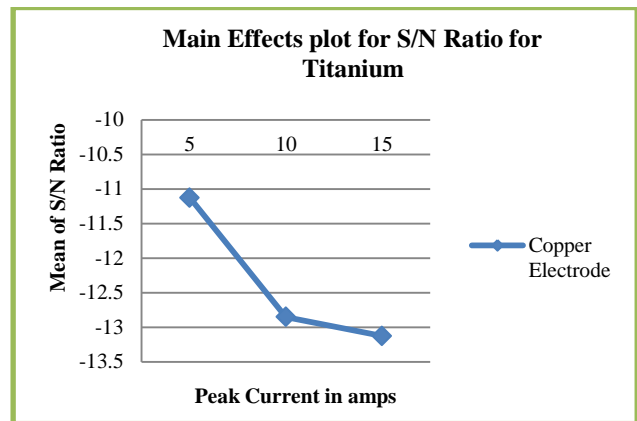
**Table 4** S/N ratio for Surface Roughness ( $R_a$ )

Exp.No	Peak current in amps	Pulse on time in $\mu$ sec	Pulse off time in $\mu$ sec	Surface Roughness in $\mu$ m	S/N Ratio $\eta = -10 \log_{10} (Y_i^2)$
1	5	4.5	2	3.379	-10.575
2	5	9.5	4	3.856	-11.722
3	5	20	8	3.585	-11.089
4	10	9.5	8	6.371	-16.084
5	10	20	2	3.761	-11.506
6	10	4.5	4	3.536	-10.97
7	15	20	4	4.185	-12.433
8	15	4.5	8	4.781	-13.59
9	15	9.5	2	4.656	-13.36

The main effects plot for mean of S/N ratio are graphically represented in Figure 4.4

Regardless of the category of the performance characteristics, a greater S/N value corresponds to a better performance to a better performance. Therefore, the optimal level of the machining parameters is the level with

the smallest value. From the graph, it is observed that the optimal combination of process parameters for material removal rate is given below.



**Peak current**

The effect of parameter peak current on surface roughness values is the shown above figure for S/N ratio. Its effect is decreasing with increase in peak current. So the optimum peak current is level 3 i.e. 15 amps.

**Pulse on time**

The effect of parameter peak current on metal removal rate values is the shown above figure for S/N ratio. Its effect is decreasing with increase in peak pulse on time upto 9.5  $\mu$ sec beyond that it is increasing. So the optimum pulse on time is level 2 i.e. 9.5  $\mu$ sec.

### Pulse off time

The effect of parameters pulse off time on the metal removal rate value is shown above figure for S/N ratio. Its effects are increasing with increase in pulse off time upto 4  $\mu$ sec beyond that it is decreasing. So the optimum pulse off time is level 3 i.e.8  $\mu$ sec

### Conclusion

An extensive experimental study has been conducted to investigate the effects of the machining parameters on machining characteristics in EDM of Titanium. The machining parameters are the peak current, pulse on time and pulse off time. The machining characteristics are the metal removal rate and surface roughness. Finally, it was concluded.

The optimal combination of process parameters for obtaining maximum MRR through Taguchi method for machining Titanium using EDM is given below:

- Peak current-15 amps
- Pulse on time-20  $\mu$ sec
- Pulse off time-2  $\mu$ sec

The optimal combination of process parameters for obtaining minimum surface roughness through Taguchi method for machining Titanium using EDM is given below:

- Peak current-15 amps
- Pulse on time-9.5  $\mu$ sec
- Pulse off time-8  $\mu$ sec

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