Experimental Investigation of EDM over Superalloys with copper and brass tube electrodes using Tagchui's optimization

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Titanium, Duplex stainless steel and Monel alloys are being widely used numerous application areas including aerospace, automobile, shipbuilding and medical industries. In addition to have unique iconic properties, these materials are considered as challenging material in machining perspective that is why it has captured global research focus. In this research, electric discharge machining of above mentioned superalloys have been carried out by employing two different types of electrode materials namely, copper, and brass. Selection of the most appropriate tool material is the main objective to be explored for this superalloys. In additions, discharge current, and pulse on-time have been considered as process paramters owing to have their direct influence in electric discharge machining. Taguchi L18 mixed level orthogonal array has been designed for each of the three different workpiece materials with positive polarity. Thus, a total number of 54 experiments have been conducted. Material Removal Rate (MRR) around the machined surfaces are the response characteristics to be investigated in order to achieve maximum material removal from the work-pieces. Selection of the most suitable tool with common tool polarity has been carried out meeting the decision criteria of maximum MRR.

Keywords: superalloys, MRR, copper and brass tool electrode

1. Introduction

Electro discharge machining (EDM) process is a non-conventional and non-contact machining operation which is used in industry for high precision products especially in manufacturing industries, aerospace and automotive industries, communication and biotechnology industries. EDM is a type of thermal machining where the material from the work piece is removed by the thermal energy created by the electrical spark.

The work piece machined by EDM depends on thermal conductivity, electrical resistivity, and melting points of the materials. A series of electrical sparks or discharges occur rapidly in a short span of time within a constant spark gap between micro sized tool electrode and work piece material. The nature of sparks is repetitive and discrete. The non-contact nature of the process with nearly force free machining allows a soft and easy to machine electrode materials to machine a very hard, fragile or thin work pieces. Thus, due to its non-contact nature; mechanical stresses, chatter, and vibration problems during machining can be eliminated . This paper is reviewed comprehensively on types of EDM operation. A brief discussion is also done on the machining responses and mathematical modelling.

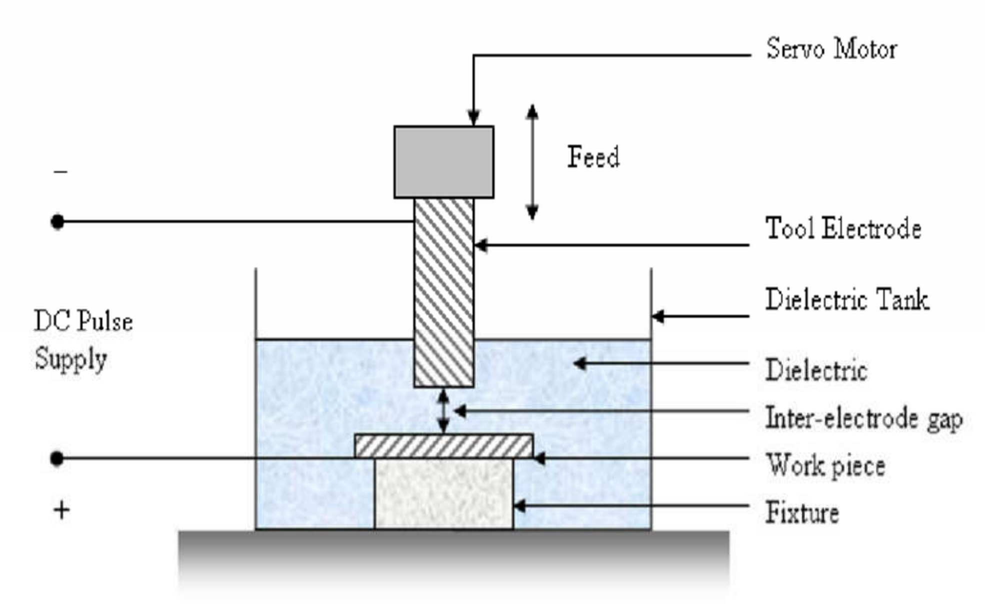

Fig.1 Schematic diagram of EDM

2. EXPERIMENTAL SETUP

2.1Work piece material

The work piece materials used in this experiment was Titanium [grade 2], Duplex stainless [2205], Monal Alloy [grade 1] sheets with 6mm thickness. Due to its unique properties like hardness, toughness, wear resistance, chemical stability and strength it is widely used in many industries.

Table 1.1- chemical composition of the titanium workpiece

s.no	Element	Percentage %
1.	Carbon	0.08%
2.	Iron	0.30%
3.	Titanium	99.68%

Figure. 2.1 titanium work piece

Table 1.2- Chemical composition of the duplex stainless steel workpiece

S.no	Elements	Percentage %
1.	Carbon	0.020 %
2.	Manganese	1.648 %
3.	Silicon	0.326 %
4.	Phosphorous	0.029 5
5.	Nickel	5.765 %
6.	Chromium	22.722 %
7.	Molybdenum	3.014 %
8.	nitrogen	0.146 %
9.	sulphur	0.001 %

Fig.2.2- Duplex Stainless Steel

Table 1.3- Chemical composition of the monal alloy workpiece

S.no	Elements	Percentage %
1.	Nickel	66.10 %
2.	Copper	31.451 %
3.	Iron	1.131 %
4.	Manganese	0.842 %
5.	Silicon	0.084 %
6.	Carbon	0.150 %
7.	sulplur	0.0030 %

Fig.-2.3 Monal alloy workpiece

2.2Tool material

The tool electrodes used were brass tube (0.5 mm outer diameter, 0.123 mm inner diameter), copper tube (0.5 mm outer diameter, 0.123 mm inner diameter).

Table 1.4- shows the properties of brass tool material

Properties	Value	Condition Temp (° C)
Density(x1000 kg/m3)	7.8	25
Elastic modulus(Gpa)	200	25
Tensile stress(MPa)	965	-
Thermal conductivity(W/M-K)	20.2	100
Electrical resistivity(10-9 Ω-m)	720	25

Table 1.5 – shows the properties of copper tool material

s.no	Properties	value
1.	**Thermal conductivity**	**380.7 w/m-k**
2.	Melting point	1083° C
3.	Specific heat	0.092Cal/g-$^\circ$ C
4.	Specific gravity	8.9g/cm3
5.	Coefficient of thermal expansion	17x10-6/$^\circ$ C

2.3 Machine tool setup

Figure 2.4 Photograph of the experimental set-up

2.3.1 Components of Electric Discharge Machining

DC Pulse Generator

This is a power source for the machining operation. DC power is supplied.

Voltmeter

We know that the voltmeter measures the voltage. Here in this device the same for use.

Ammeter

It measures or checks the flow of the current. If Ammeter is not connected we might not see or check current is flowing or not.

Tool

A tool connected to negative sources of power whereas the workpiece is connected to positive sources. From the filter, the fluid comes to the tool for the operation.

When Power supply will increase, between tools workpiece the spark generates and then machining starts.

Die electric fluid

Insulation means no current flows from one to another.The Die electric fluid will be ionized in the form of ion which will help between the tool and work piece again when power supply stops the fluid comes to its initial position.

Pump

The pump is connected there for sending the fluid to the filter. This works like flowing the fluid from one source to another one.

Filter

As the name indicates the filter, is used to filtrate the different particles like: In this device, if there is dust particles presence the filter will remove that particle and then it will send to the tool for the operation. The main role of EDM filters is to filter out mechanical impurities from the dielectric fluid to maintain the quality of the EDM machines' working process and to further protect the machine from untimely wear and tear and blockages.

Servo controlled feed

The constant feed will be supplied by the servo for the operation. EDM machines are equipped with a servo control mechanism that automatically maintains a constant gap of about the thickness of a human hair between the electrode and the work piece.

It is important because, that there is no physical contact between the electrode and the workpiece, otherwise arcing could damage the work piece and break the wire in case of wire EDM.The servomechanism advances the electrode into the work piece as the operation progresses and senses the work-wire spacing and controls it to maintain the proper are gap which is essential to a successful machining operation.

Fixture

To hold the table. A fixture's primary purpose is to create a secure mounting point for a workpiece, allowing for support during operation and increased accuracy, precision, reliability, and interchangeability in the finished parts.

3.Results And Discussion

3.1 Graph for Titanium

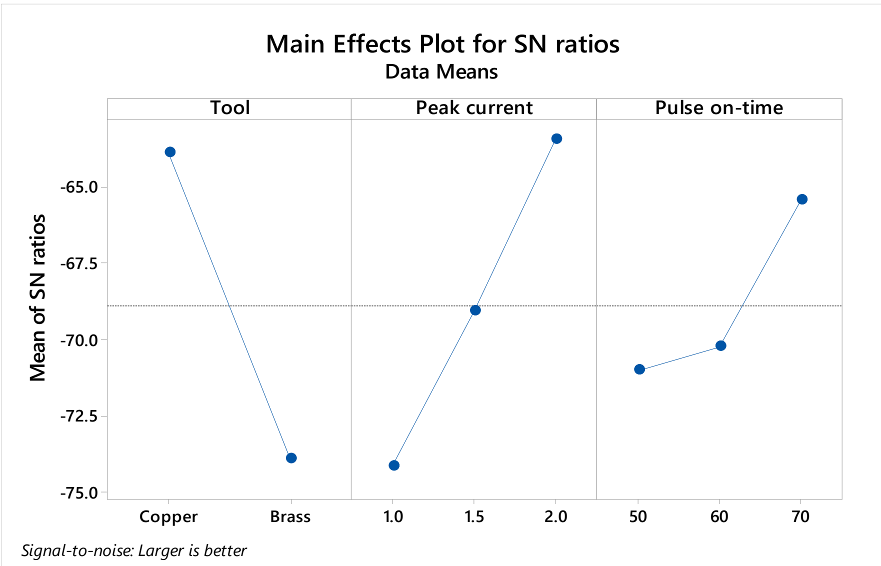

Fig 3.1 - Graph for Main effect plot for SN ratios

Moreover, higher spark energy would accelerate the electrolytic reaction at the spark gap when using tap water as a dielectric that imparts unstable machining. Considering the effect of duty factor, its increase in value degrades the machining performance. Larger the duty factor, lesser is the off time in a cycle. So, if sufficient pulse-off time is not provided, the dielectric will not be able to regain its insulating property before the subsequent discharge. This incites arcing instead of EDM sparking at the spark gap that eventually leads to unstable machining. It can be construed that lesser discharge energy and ample off time bolster stable machining at the spark gap. Hence, the lower levels of gap voltage, peak current, pulse on-time and duty factor were found to be the optimal machine setting.

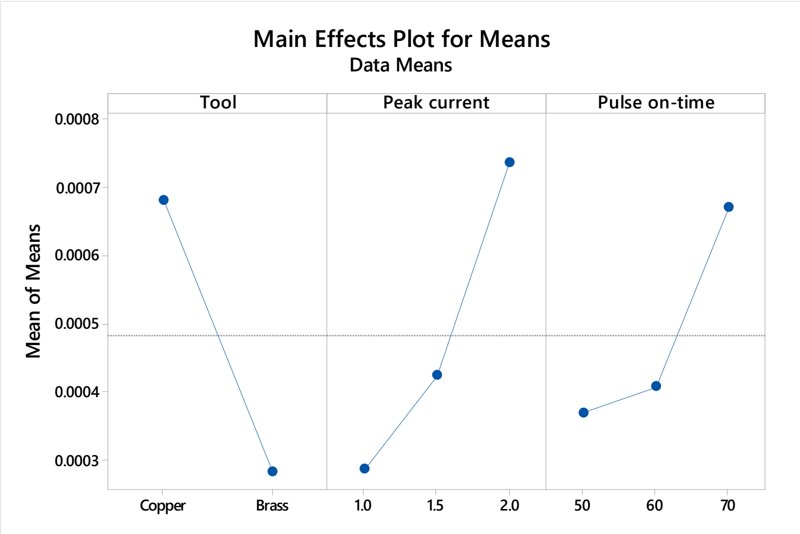

Figure 3.2- Mean of Means

From this figure 5.1.1 and 5.5 shows the Experimentation has been successfully completed under L18 Taguchi design of experiments. After that, MRR of the machined specimen were measured and calculated. The results of MRR and obtained under the action of each electrode are presented in graph. High melting temperature of graphite electrode is the primary reason for high value of MRR. In EDM, material erosion took place by thermal energy produced due to the electric sparking between electrode and work surface. Higher the value of thermal energy produced, the higher will be MRR. In titanium work piece MRR is increased by the copper tool.

Table 2.4 - Response Table for Signal to Noise Ratios

Level	Tool	Peak current	Pulse on-time
1	-63.86	-74.15	-71.00
2	-73.90	-69.07	-70.22
3		-63.43	-65.43
Delta	10.04	10.71	5.57
Rank	2	1	3

Table 2.5- Response Table for Means

Level	Tool	Peak current	Pulse on-time
1	0.000681	0.000287	0.000370
2	0.000283	0.000423	0.000407
3		0.000737	0.000670
Delta	0.000398	0.000450	0.000300
Rank	2	1	3

Table 2.6- Analysis of Variance Tabulation

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Tool	1	0.000001	39.41%	0.000001	0.000001	63.53	0.000
Peak current	2	0.000001	35.35%	0.000001	0.000000	28.50	0.000
Pulse on-time	2	0.000000	17.79%	0.000000	0.000000	14.34	0.001
Error	12	0.000000	7.44%	0.000000	0.000000		
Total	17	0.000002	100.00%				

3.2 Graph for Monel alloy

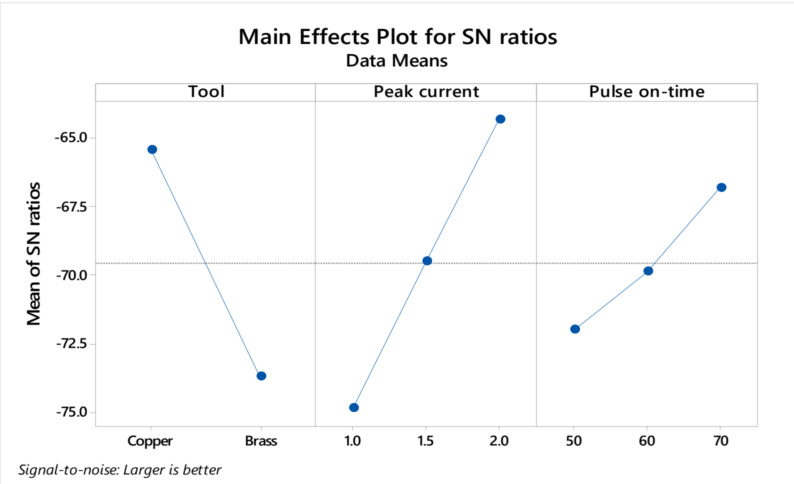

Fig 3.3 Monal alloy – Main effects plot for SN ratio

From this graph, the MRR for monal alloy as decreased. In this copper tool producing higher Material removal rate as compare to brass tool. Peak current is also increases and it shows the improvement of MRR. Therefore MRR improves, but further increase in pulse time ratio causes a reduction in MRR, because long pulse duration promotes the chances of arcing during spark generation which eventually reduces MRR. Although increase in pulse time ratio increases the pulse duration for copper electrode, due to their high thermal conductivities, heat is sunk by the tool material. Therefore, no appreciable expansion of plasma channel takes place which in turn ensures higher MRR. Thereof, more material gets removed from the tool electrode, whereas shallow craters are imparted to the work piece surface. Thus, surface finish is improved.

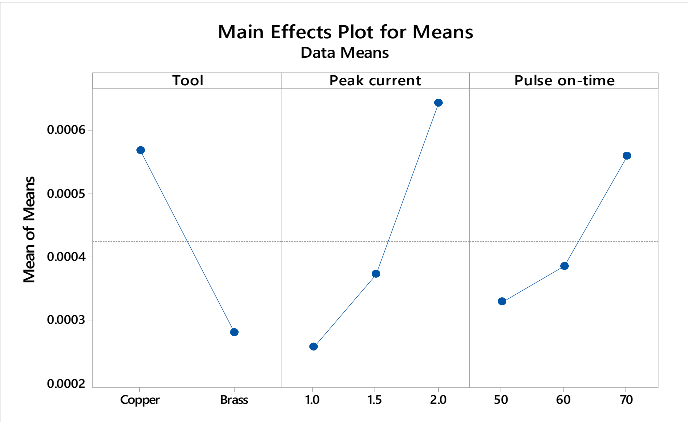

Figure 3.4 Mean of Means

Table 2.7- Response Table for Signal to Noise Ratios

Level	Tool	Peak current	Pulse on-time
1	-65.42	-74.88	-72.01
2	-73.71	-69.51	-69.88
3		-64.31	-66.81
Delta	8.29	10.57	5.20
Rank	2	1	3

Table2.8- Response Table for means

Level	Tool	Peak current	Pulse on-time
1	0.000568	0.000257	0.000328
2	0.000280	0.000372	0.000385
3		0.000642	0.000559
Delta	0.000288	0.000385	0.000230
Rank	2	1	3

Table 1.11- Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Tool	1	0.000000	33.15%	0.000000	0.000000	41.12	0.000
Peak current	2	0.000000	41.78%	0.000000	0.000000	25.92	0.000
Pulse on-time	2	0.000000	15.40%	0.000000	0.000000	9.55	0.003
Error	12	0.000000	9.67%	0.000000	0.000000		
Total	17	0.000001	100.00%				

3.3 Graph for Duplex stainless steel

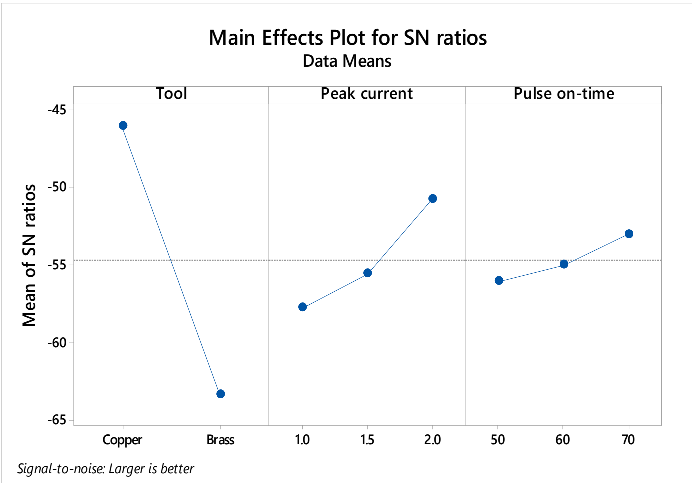

Fig 3.5- Graph for Main effect plot for SN ratios

From this graph the duplex stainless steel as higher material removal rate compare to other two alloy metals. Because, it contains higher carbon content of [0.30%] Analyzed by chemical composition test. In this Graph copper tool as the highest Material removal rate and brass tool as the lowest material removal rate.

The MRR are calculated as the mass loss of the work piece and electrode, **MRR=** initial work piece weight-final work piece weight machining /time.

It can be observed from Fig. 5.5 that all the tool materials exhibit a similar trend for MRR at different settings of pulse time ratio irrespective to copper and aluminum. An increase in the value of pulse time ratio form 0.5 to 1.0 tends to increase the MRR, whereas further increase in pulse time ratio reduces the amount of material removed. Pulse time ratio is the ratio of on-time to off-time.

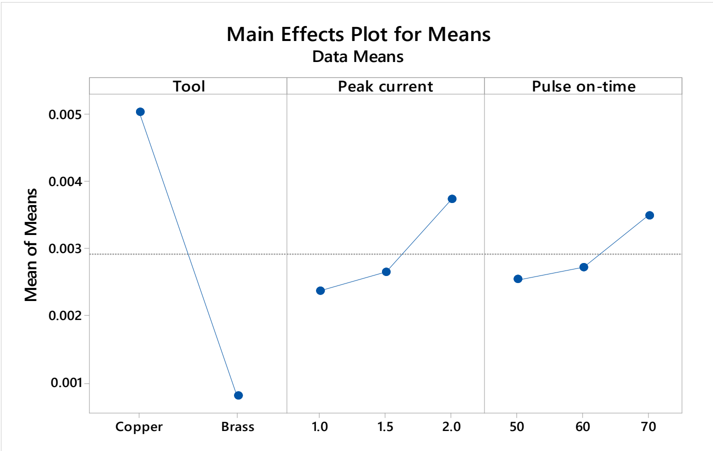

Fig 3.6- Graph for Main effect plot for Means

Table 1.12- Response table for signal to noise ratios

Level	Tool	Peak current	Pulse on-time
1	-46.12	-57.80	-56.10
2	-63.38	-55.64	-55.08
3		-50.81	-53.07
Delta	17.26	6.99	3.03
Rank	1	2	3

Table 1.13- Response Table for Means

Level	Tool	Peak current	Pulse on-time
1	0.005039	0.002370	0.002538
2	0.000801	0.002658	0.002722
3		0.003732	0.003500
Delta	0.004238	0.001361	0.000962
Rank	1	2	3

Table 1.14- Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Tool	1	0.000081	86.44%	0.000081	0.000081	287.33	0.000
Peak current	2	0.000006	6.61%	0.000006	0.000003	10.98	0.002
Pulse on-time	2	0.000003	3.35%	0.000003	0.000002	5.56	0.020
Error	12	0.000003	3.61%	0.000003	0.000000		
Total	17	0.000093	100.00%				

4.Conclusion

i. This review on the state-of-the-art studies on the EDM processing of stainless steels leads to the following conclusions:

ii. A number of research studies have been carried out in the field of EDM and significant improvements in the properties of the machined surfaces have been reported.

iii. Despite promising results, EDM processes for new materials used in industry still have problems, including low MRR and high TWR. These issues require further investigation.

iv. The reported results generally agree, for machining different stainless steel grades on the EDM the main factor influencing the MRR is the discharge current. However, pulse duration time, gas pressure and electrode tool rotation speed also have a significant influence on the MRR and the MRR can be further improved by using strip-EDM instead of wire-EDM.

v. The review reveals that the crack length is significantly influenced by voltage, current, pulse off-time and speed in the wall and bottom regions of holes machined using dry EDM.

vi. The review also reveals that workpiece vibration caused by ultrasonic action can improve the performance and efficiency of the micro-EDM process by many times compared to the EDM processes without ultrasonic vibration.

vii. The orbiting technique provides more uniform geometries of the machined hole and greatly improves the bottom quality for blind holes. The technique also reduces the tooling needs and the electrode tool wear but increases machining times.

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