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EFFECT OF GRAPHITE AND COPPER TOOLS ON MRR AND SURFACE ROUGHNESS BY USING MINERAL OIL WHILE MACHINING INCONEL600 ON EDM

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Abstract- **The correct selection of manufacturing conditions is one of the most important aspects to take into consideration in the majority of manufacturing processes and, particularly, in processes related to Electrical Discharge Machining (EDM). It is a capable of machining geometrically complex or hard material components, that are precise and difficult-to-machine such as heat treated tool steels, composites, super alloys, ceramics, carbides, heat resistant steels etc. being widely used in die and mould making industries, aerospace, aeronautics and nuclear industries.**

Inconel 600 is a nickel-chromium alloy with good oxidation resistance at higher temperatures, with good resistance in carburizing and chloride containing environments.

Inconel 600 is a nickel-chromium alloy designed for use from cryogenic to elevated temperatures in the range of 2000 deg F (1093 deg C). The high nickel content of the alloy enables it to retain considerable resistance under reducing conditions and makes it resistant to corrosion by a number of organic and inorganic compounds.

The chromium content of the alloy makes it superior to commercially pure nickel under oxidizing conditions. In strong oxidizing solutions like hot, concentrated nitric acid, 600 has poor resistance. Alloy 600 is relatively un-attacked by the majority of neutral and alkaline salt solutions and is used in some caustic environments. The alloy resists steam and mixtures of steam, air and carbon dioxide.

Alloy 600 is non-magnetic, has excellent mechanical properties and a combination of high strength and good workability and is readily weldable. Inconel 600 exhibits cold forming characteristics normally associated with chromium-nickel stainless steels.

Typical corrosion applications include titanium dioxide production (chloride route), perchlorethylene syntheses, vinyl chloride monomer (VCM), and magnesium chloride. Alloy 600 is used in chemical and food processing, heat treating, phenol condensers, soap manufacture, vegetable and fatty acid vessels and many more.The Electric discharge machining process is finding out the effect of machining parameter such as discharge current, pulse on time and gap voltage on INCONEL 600 work material using square shaped cut tool. A well-designed experimental scheme was used to reduce the total number of experiments. Parts of the experiment were conducted with the L9 orthogonal array based on the Taguchi method. Moreover, the experiments were determined by which factor is most affected by the Responses of Material Removal Rate (MRR) and Surface roughness by using graphite and copper tools.

I. INTRODUCTION

Electrical Discharge Machining (EDM) is a well-known machining technique since more than fifty years. Nowadays it is the most widely-used non-traditional machining process, mainly to produce injection molds and dies, for mass production of very common objects. It can also produce finished parts, such as cutting tools and items with complex shapes. EDM is used in a large number of industrial areas: automotive industry, electronics, domestic appliances, machines, packaging, telecommunications, watches, aeronautic, toys, surgical instruments. The advantages of EDM over traditional methods such as milling or grinding are multiple. Any material that conducts electricity can be machined, whatever its hardness (hardened steel, tungsten carbide, special alloys for aerospace applications, for example). Furthermore, complex cutting geometry, sharp angles and internal corners can be produced. Final surface state with low rugosity (< 100 nm) and precise machining (» 1 ¹m) are other important advantages. Moreover, there is no mechanical stress on the machined piece, no rotation of work piece or tool is necessary, and the machines have a high autonomy. On the other hand, the disadvantages are the relatively low material removal rate (order of 100 mm3/minute), surface modification of the machined work piece ("white layer" and heat affected zone, typical depth » 50 ¹m), and limited size of work piece and tool, for example.

Figure 1. Examples of parts machined with EDM: high speed turbine and mold for the screw thread of PET bottles, produced by die-sinking.

II. LITERATURE REVIEW

C.D. Shah1, J.R.Mevada2, B.C.Khatri3 [1] From the experiments that were conducted on Inconel600 material in Wire Cut EDM and the RSM models developed, the following interesting conclusions were drawn.

1. The effects of Pulse On time, Pulse Off time, Peak Current, Wire Feed rate setting are experimentally investigated in machining of Inconel-600 using CNC Wire-cut EDM process. The level of importance of the machining parameters on the material removal rate is determined by using ANOVA and it is shown that Pulse on, Pulse Off, Pea current are most significant

2. An optimum parametric combination for the maximum material removal rate was obtained by using Signal-to-Noise (S/N) ratio. Improved S/N ratio and conformation test indicated that it is possible to increase material removal rate by using the proposed statistical technique.

D.Vinoth Kumar1, P.Siva Kumar2, B.Kumaragurubharan3, T.Senthil kumar4 [2] Based on the Results and Discussion the following conclusions are drawn in this article,

- A trial was created to work out the numerous machining parameters on electrical discharge Machining of Inconel 600 has been done using copper electrode for performance measures supported by Taguchi-Grey Relational Analysis.
- The optimized input parameter combinations to urge the utmost Material Removal Rate and Tool Wear Rate are Pulse on 500 µs,
- Pulse off 40 µs, Current 4 amps. The experimental results are validated with ANOVA.

1BUTA SINGH, 2MANPREET SINGH [3] This work evaluates the feasibility of machining Inconel600 by electrical discharge machining. Based on the results presented here in, we conclude the following:
a) The suggested optimal machining parameters for material removal rate are: Em (Copper), Ip (15), Pon (120), Vg (35).The parameter with the greatest effect on the material removal rate was peak current and copper electrode showed the highest MRR. while brass electrode showed the the least MRR.
b) The suggested optimal machining parameters for electrode wear rate are: Em (Copper tunsten),IP (9),Pon (120), Vg (40). The significant parameters with the greatest effects on the electrode wear rate were electrode material and peak current. Copper tungsten electrode showed the minimum EWR than other two electrodes.
c) The suggested optimal parameters for surface roughness are: Em (Brass),IP(9),Pon (120), Vg(45). The significant parameters with the greatest effects on the electrode wear rate were electrode material and peak current. Brass electrode showed the minimum SR than other two electrodes

Dattatray Vishnu Wagh1, Prof.D.R.Dolas2 [4] The response surface methodology based on three variables, face centered composite design was used to determine the effect of time (ranging 30-70 min), concentrations of etchant (ranging 300– 700 gm/lit) and temperature (55-65 0C) on the Undercut during the PCM process of Inconel 600 material. The regression analysis, statistical significance and response surface were applied using Design Expert Software for forecasting the responses in all experimental areas. Quadratic models were developed to show a relationship between variables and the responses. Through analysis of the response surfaces derived from the models, role of time was found to have the most significant effect on Undercut. Process optimization was carried out and the experimental values acquired for the Undercut during the PCM process of Inconel 600 material are found to agree satisfactorily with the values predicted by the models. Since experimentally obtained and model predicted values are residual which shows the effectiveness of model, based on the designed experiment. The optimal predicted Undercut 0.0029 mm of Inconel 600 was obtained as Ferric chloride concentration, time and temperature of etching and these were found to be 470.781gm/lit, 32.39 min and 55.276 0C respectively.

D Sudhakara1*, B Venkataramana Naik1 and B Sreenivasulu2. [5] When current increases, the MRR also increases. The higher the current, intensity of spark is increased and results in high metal removal will takes place.

- When the current is increased, surface roughness is also increased. Because due to increase in current, the spark intensity is also increases. So the MRR per minute increases. Finally the surface roughness is increases.

- When current is increases, hardness will decreased. Because due to increase current, the intensity of spark increases. Due high spark intensity the carbon layer will depleted. So that the hardness is decreased.
- When current is increased, the crack length, crack widths are also increased due to the high temperature generation at high currents.
- When duty factor is increases, the MRR is also increases. The higher the duty factor, intensity of spark and machining time is increased and results in high metal removal will takes place. • When the Duty factor is increased, surface roughness is also increased, because due to increase in duty factor, the spark intensity, machining time is also increases. So the MRR per minute increases. Finally the surface roughness is increases.
- When Duty factor is increases, hardness will decreased. Because due to increase Duty factor, the intensity of spark increases. Due high spark intensity, the carbon layer will depleted. So that the hardness is decreased. When duty factor is increased, the crack length, crack widths are also increased due to the high temperature generation at high duty factors.
- When pulse on time is increases, the MRR is decreased. The higher the pulse on time, intensity of spark is decrease due expansion of plasma channel and results in less metal removal will takes place.
  - When the Pulse on time is increased, surface roughness is decreased, because due to increase in pulse on time, the spark intensity is also decreases due to the expansion of plasma channel. So the MRR per minute decreases. Finally the surface roughness is decrease.
  - When the Pulse on time is increases, hardness will increased. Because increase in pulse on time, the intensity of spark decreases due to the expansion of plasma channel. Due low spark intensity, the carbon layer will deposited, so that the hardness is increased.
  - When pulse on time is increased, the crack length, crack widths are increased due to the low temperature generation at high pulse on time due the expansion of plasma channel.

Balram Jakhar, Puneet Katyal, Vishal Gulati [6] Here Taguchi's method has been used for single response optimization. And in the present set of study, five control factors have been studied simultaneously to establish the trend of variation of a few important machining criteria with these control factors. From present study, the following conclusions are drawn: 1. The cutting speed (CS) is mostly affected by the peak current, pulse-on time, pulse off-time, and taper angle. The third level of peak current is highly affected the CS. 2. The surface roughness values (SR) are influenced mostly by peak current, pulse-on time, taper angle, pulse off-time, and dielectric flow rate. 3. The comparison of the predicted Surface Roughness and Cutting Speed with the experimental Surface Roughness and Cutting Speed using the optimum process parameters in WEDM has shown a good agreement between the predicted and experimental results but there are error in 0.46% error in cutting speed and 6.02% error in surface roughness respectively.

Wang and Lin [7] discuss the optimization of W/Cu composite martial are used the Taguchi method. W/Cu composites are a type of cooling material highly resistant to heat corrosion produced through powder metallurgy. The Taguchi method and L18 orthogonal array to obtain the polarity, peak current, pulse duration, duty factor, rotary electrode rotational speed, and gap- load voltage in order to explore the material removal rate, electrode wear rate, and surface roughness. The influenced of each variable and optimal processing parameter will be obtained through ANOVA analysis through experimentation to improve the process.

Sudhir Ashok Shardul1, Sachin K. Dahake2 [8] Experimental investigation on wire electrical discharge machining On graphite material has been done using brass wire of 0.25mm. The following conclusions are made

- Based on taguchi optimization optimized input parameter combinations to get the minimum surface roughness are 5A current,7 pulse on time ,30bpulse off time,12 g wire tension. similarly to optimized conditions to get the maximum MRR are 5A current,7 pulse on time, 25 pulse off time, 10g wire tension.
- Increase in the pulse on-time leads to the increase in MRR. With the increase in all input parameter SR increases.
- The Analysis of Variance resulted that the Pulse off time has major influence on the MRR and Wire tension on surface roughness.
- The objectives such as surface roughness and MRR are optimized using a single objective taguchi method
- Eventually, mathematical models were developed using regression analysis for both MRR and SR to establish the relation between process parameters and response characteristics.

Senkathir S, Arun Raj A C, Vaddi Thulasikanth, Manoj Samson R [9] A study on machining Inconel 718 with brass tool electrodes having different bottom shape like Flat and Convex ends using the EDM process is to studied and analyzed the effects of different bottom shape tool electrodes on response in the thermal erosion process. The conclusions of the experimental results could be summarized as follows: The Machining time is decreased while using convex tool electrode over flat tool electrode but the Machining time is increased with increasing in diameter of convex tool electrode. Electrode wear is also reduce when electrode chance from flat to convex thus electrode wear is increase when radius of convex tool electrode increase. The cylindricity factor increases with increase in the radius of curvature of convex tool electrode. Finally, it is observed that the small diameter of convex tool electrode has been achieved lower cylindricity factor. The peak current and pulse off time significantly affects the machining characteristics in the EDM process.

Sharanjit Singh*and Arvind Bhardwaj [10] Because of EDM enormous improvement in machining process has been achieved in recent years. The capability of machining intricate parts and difficult to cut material has made EDM as one of the most popular machining processes. The contribution of EDM to industries such as cutting new hard materials make EDM technology remains indispensable. The review of the research trends in EDM in water and EDM with powder additives is presented. In each topic, the development of the methods for the last 25 years is discussed & noticed much work in PMEDM rather than by using water as dielectric fluid as shown in Figure 18. The progress of development in each area is presented using block diagrams Figures19 and 20. EDM in water is introduced for safe and conducive working environment; EDM with powder additives is concerning more on increasing SQ, MRR and tool wear using dielectric oil and EDM modeling is introduced to predict the output parameters which leads towards the development of precise and accurate EDM performance. For each and every method introduced and employed in EDM process, the objectives are the same: to enhance the capability of machining performance, to get better output product, to develop technique to machine new materials and to have better working conditions.

Jinming Zhoua*, Volodymyr Bushlyaa, Ru Lin Pengb, Zhe Chenb, Sten Johanssonb and Jan Eric Stahla [11] Subsurface microstructural alterations and residual stresses caused by machining significantly affect component lifetime and performance by influencing fatigue, creep, and stress corrosion cracking resistance. Assessing the surface quality of a machined part by characterizing subsurface microstructural alterations and residual stresses is essential for ensuring part performance and lifetime in aero-engines and power generators. This comparative study characterizes and analyzes subsurface microstructural alterations and residual stresses in Inconel 718 subjected to high-speed machining with PCBN and whisker-reinforced ceramic cutting tools. Effects of cutting tool materials and microgeometry on subsurface deformation, microstructural alterations, and residual stresses were investigated. Surface and subsurface regions of machined specimens were investigated using X-ray diffraction, electron channeling contrast imaging, and electron back-scatter diffraction to characterize microstructural alterations and measure deformation intensity and depth.

H. L. Eiselstein and D. J. Tillack [12] From an initial plan to develop an alloy for service in critical steam applications evolved a material that is used in a wide range of industries. Alloy 625 is used in the aerospace industry because of its high strength, outstanding fatigue and thermal fatigue resistance, oxidation resistance and excellent weldability and brazeability. The 'outstanding and versatile corrosion resistance of the alloy under a wide range of temperatures and pressures is a primary reason for its wide acceptance in the chemical processing field. Its resistance to stress cracking and excellent pitting resistance in a wide range of water temperatures have enabled it to be used extensively in nuclear applications. Its choice in sea-water applications is a result of a resistance to pitting and crevice corrosion, high corrosion-fatigue strength, high tensile strength and resistance to chloride-ion stress-corrosion cracking. It is often used as a welding material to join dissimilar metals because of its strength and ductility and its ability to tolerate a considerable amount of dilution from other alloys.

As versatile and impressive as alloy 625 is, one of the truly amazing facts about its development history is that it was the seed for the development of alloy 718, the most successful age-hardenable nickel alloy ever developed. Numerous other spin-off alloy compositions have been, and continue to be, developed. But even after over 30 years of existence, alloy 625 is still very much alive.

III. DIELECTRIC MEDIUM IN EDM

Functions of dielectric

Dielectric fluid plays an important role in the EDM process. Because of a high dielectric strength, the dielectric medium prevents premature discharge between the electrodes until a low discharge gap is established between them. Continuous dielectric flow in the discharge gap helps in carrying away the debris formed during the discharge and ensures a proper flushing. Also, dielectric medium cools the machining zone by carrying away excess heat from the tool electrode and the work piece.

Properties of dielectric

The most important properties of dielectric are its dielectric strength, viscosity, thermal conductivity and thermal capacity. Dielectric strength characterizes the fluid's ability to maintain high resistivity before spark discharge and the ability to recover rapidly after the discharge. High dielectric strength leads to a lower discharge gap which in turn leads to a low gap resistance. Hence, high discharge currents may flow leading to a higher material removal rate. Also, fluids with high dielectric strength need lower time for the recovery of dielectric strength.

Thus, low pulse-off times are sufficient. This not only improves the MRR but also provides better cutting efficiency because of a reduced probability of arcing. Liquids with low viscosity generally provide better accuracies because of a better flow ability of the oil leading to improved flushing. Also, the sideward expansion of the discharge plasma channel is restricted by high viscosity fluids. This focuses the discharge energy over a small region and leads to a deeper crater which reduces the surface finish. Dielectric fluids with high thermal conductivity and thermal heat capacity can easily carry away excess heat from the discharge spot and lead to a lower thermal damage.

Types of dielectric

Selection of dielectric medium is an important consideration for EDM performance. Mineral oils are commonly used as the dielectric medium for die sinking EDM operations. Mineral oils exhibiting high dielectric strength and a low viscosity are preferred because of their higher performance. For safety reasons oils with a high flash point are usually used. Kerosene is one such oil which is used commonly for EDM. Water based dielectrics are used almost extensively for wire EDM operations. Water has a high specific heat capacity which leads to a better cooling effect required for wire cut operations. To prevent chemical reactions, deionized water is used in such applications.

In comparison to mineral oils and water, air has the lowest dielectric strength, viscosity, thermal conductivity and thermal capacity as shown in Table 3.1. A low viscosity air medium favors higher cutting accuracy and better surface finish. However, low dielectric constant suggests a lower MRR with air medium. Low thermal capacity and thermal conductivity suggests higher thermal damage of work piece. However, for a complete analysis of the thermal damage an opposing effect caused by the expansion of plasma channel due to low viscosity must also be accounted. Thus, overall it seems that using air as dielectric may be a better alternative for improving some of the process performance such as surface finish and accuracy at the expense of the MRR.

Table 3.1: Comparison of electrical, thermal and mechanical properties of mineral oil, deionized water and air

Properties	Dielectric Strength	Dynamic Viscosity	Thermal Conductivity	Specific Heat Capacity
Medium	(MV/m)	(g/m-s)	(W/m-K)	(J/g-K)
Mineral oil (Grade 2)	0.6	96	0.1	1966

Specification of Work Material

Inconel 600 is a *nickel-chromium* super alloy that is resistant to steam at high temperatures and sea water as well as to caustic and salt solutions. A solid solution alloy (Inconel 600) that can only hardened by cold working. Inconel 600 exhibits characteristics like high strength, toughness, good weldability and good corrosion resistance. Alloy 600 is non magnetic at room temperature.

Chemical Composition

A. **Chemical Composition Limits**								
B. **Weight %**	*C.* **Ni**	*D.* **C**	*E.* **Mn**	*F.* **S**	*G.* **Si**	*H.* **Cr**	*I.* **Fe**	*J.* **Cu**
K. **ALLOY 600**	*L.* **72**	*M.* **0.15**	*N.* **1**	*O.* **0.015**	*P.* **0.5**	*Q.* **14.0-17.0**	*R.* **6.0-10.0**	*S.* **0.5**

Mechanical Properties – Inconel 600

Yield strength (0.2% Offset)		**Tensile Strength**		**Elongation (%)**
Psi	**MPa**	**Psi**	**MPa**	**45**
45000	310	95000	60	

Physical properties - Inconel 600

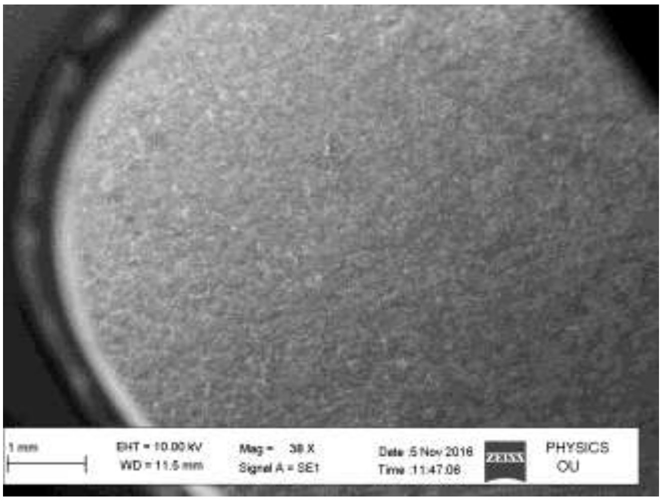
Density	8497 g/cm³
Melting point	1370-1425 ℃

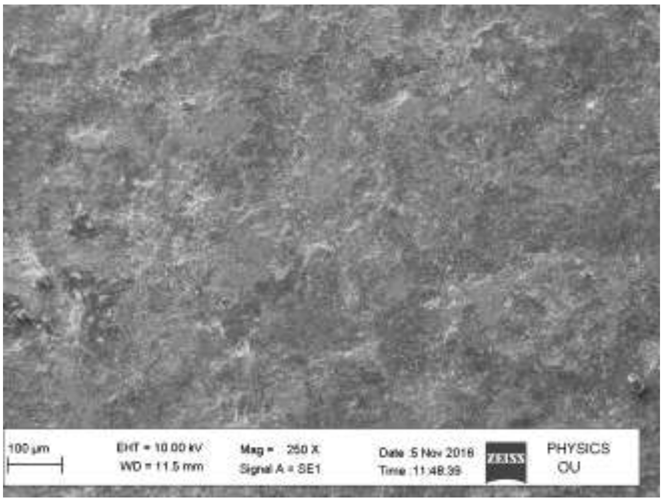
Equipment used

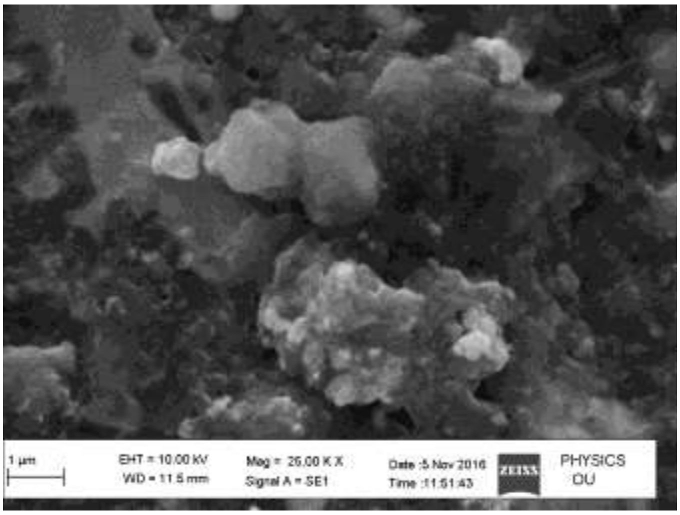
Fig.3.2 EDM Equipment

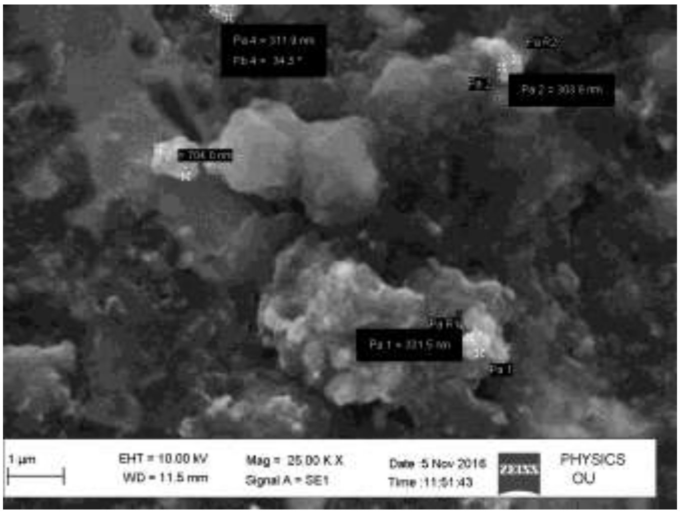
SPECIFICATIONS OF MACHINE TOOL (EDM X 3040)	UNITS	X 3040
TABLE DIMENSION	MM	600 x 400
WORK TANK DIMENSION	MM	900 x 550 x 375
X TRAVEL	MM	400
Y TRAVEL	MM	275
Z TRAVEL	MM	220
BACK SLIDE TRAVEL	MM	200

SEM IMAGES OF COPPER TOOL



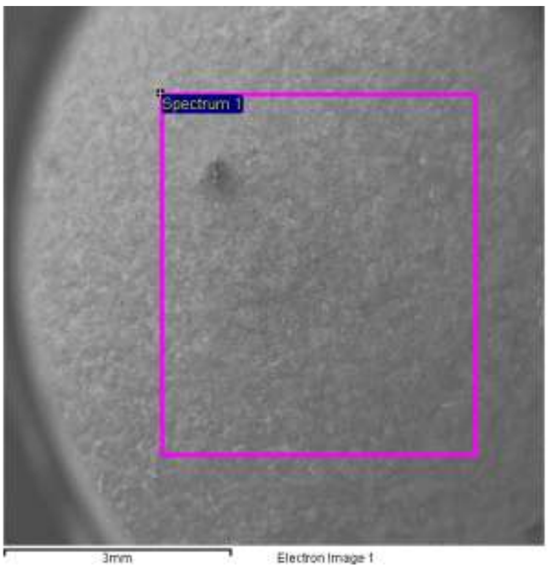


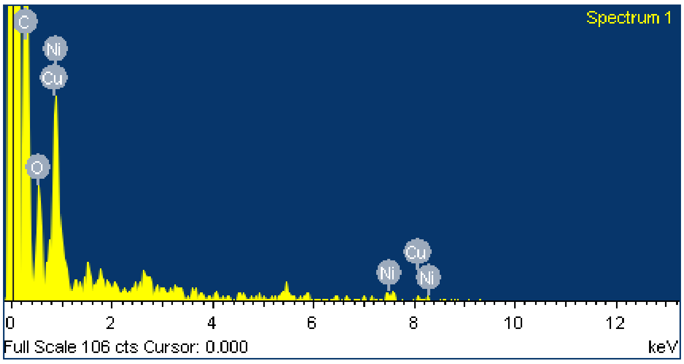




PROJECT 1

EDS IMAGES OF COPPER TOOL





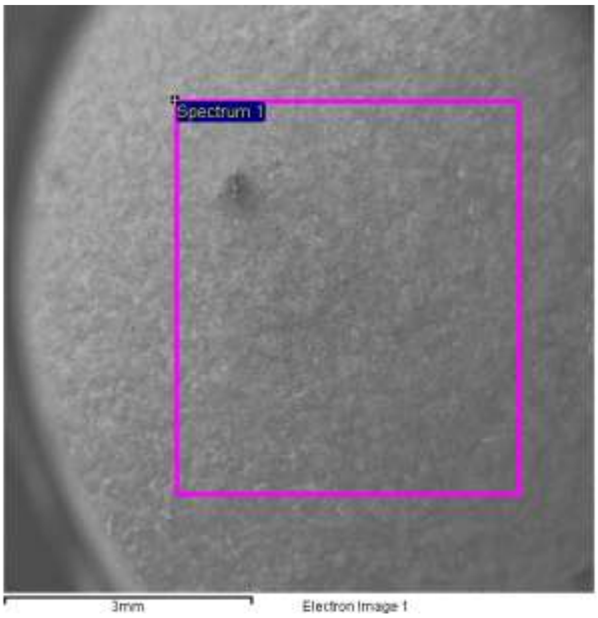
Spectrum processing:
No peaks omitted

Processing option : All elements analyzed (Normalised)
Number of iterations = 2

Standard:
C CaCO3 1-Jun-1999 12:00 AM
O SiO2 1-Jun-1999 12:00 AM
Ni Ni 1-Jun-1999 12:00 AM
Cu Cu 1-Jun-1999 12:00 AM

Element	Weight %	Atomic %
C K	67.31	84.25
O K	10.84	10.18
Ni L	20.07	5.14
Cu L	1.79	0.42
Totals		100.00

PROJECT 2



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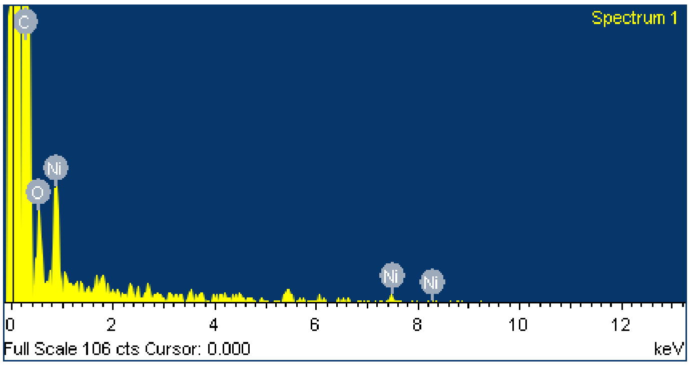

Spectrum processing:
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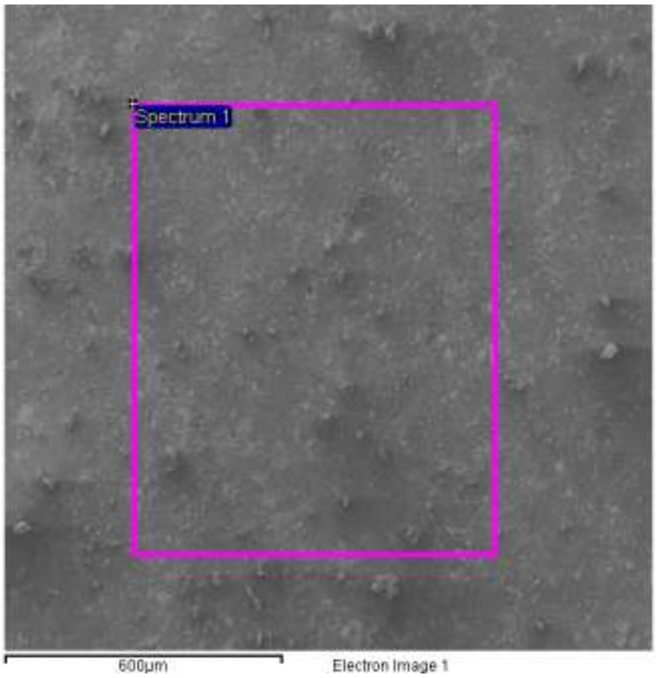
Processing option: All elements analyzed (Normalised)
Number of iterations = 1

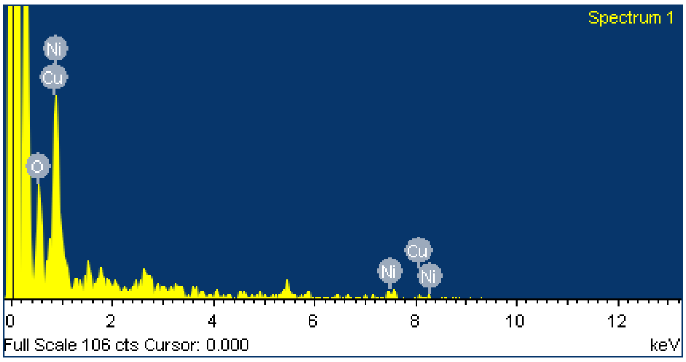
Standard:
O SiO2 1-Jun-1999 12:00 AM
Ni Ni 1-Jun-1999 12:00 AM
Cu Cu 1-Jun-1999 12:00 AM

Element	Weight %	Atomic %
O K	25.47	55.85
Ni L	66.11	39.50
Cu L	8.42	4.65
Totals	100.00	

EDS IMAGES OF GRAPHITE TOOL

PROJECT 1





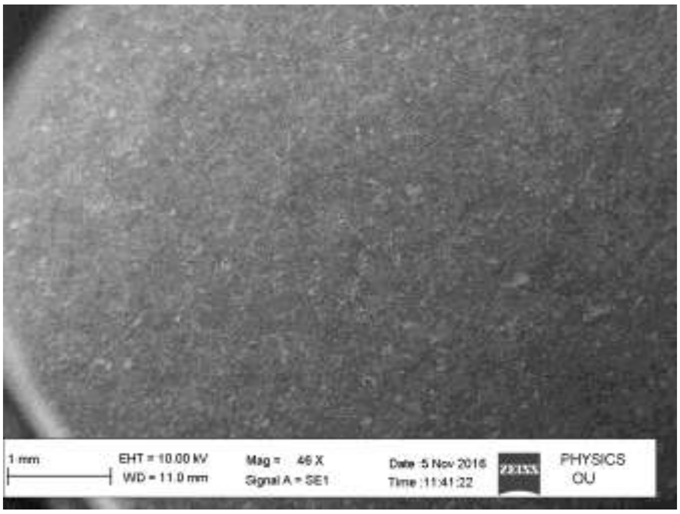
Spectrum processing :
No peaks omitted

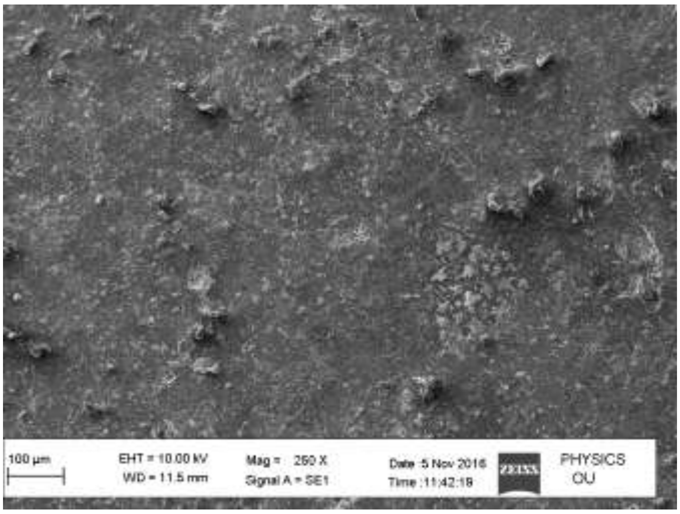
Processing option : All elements analyzed (Normalised)
Number of iterations = 2

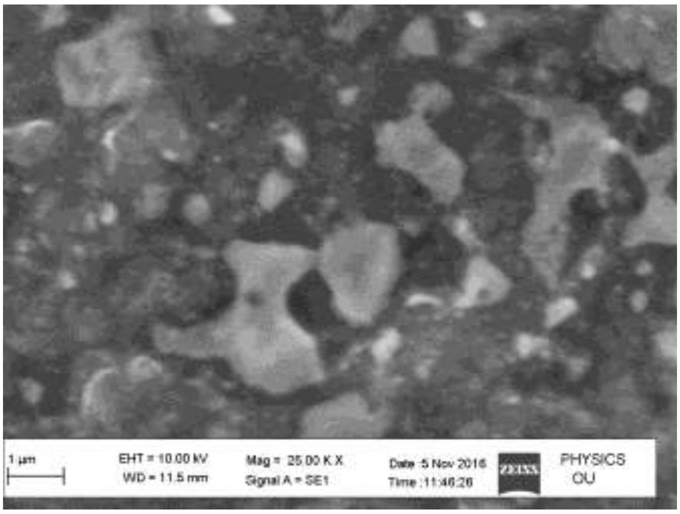
Standard :
C CaCO3 1-Jun-1999 12:00 AM
O SiO2 1-Jun-1999 12:00 AM
Ni Ni 1-Jun-1999 12:00 AM

Element	Weight %	Atomic %
C K	79.44	91.13
O K	6.46	5.57
Ni L	14.09	3.31
Totals	100.00	

SEM IMAGES OF GRAPHITE TOOL







Design matrix and Observation table

Table 3.4 Observation Table for Copper Tool

Sl.no	Peak Current (A)	Ton (µs)	Gap Voltage(V)	Initial wt.(gm)	Final wt.(gm)	Mrr (milligm/min)	Ra (µm)
1	3	45	40	730.00	729.10	0.09	4.208
2	3	90	45	729.10	727.98	0.112	4.182
3	3	200	50	727.98	726.41	0.128	4.108
4	6	45	40	726.41	725.61	0.8	4.202
5	6	90	45	725.61	724.00	0.161	4.256
6	6	200	50	724.00	722.47	0.153	4.270
7	9	45	40	722.47	720.89	0.158	4.301
8	9	90	45	720.89	718.98	0.191	4.391
9	9	200	50	718.98	716.78	0.22	4.397

Table 3.5 Observation Table for Graphite Tool

Sl.no	Peak Current (A)	Ton (µs)	Gap Voltage(V)	Initial wt.(gm)	Final wt.(gm)	Mrr (milligm/min)	Ra (µm)
1	3	45	40	716.78	716.14	0.064	4.623

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2	3	90	45	716.14	715.77	0.037	4.627
3	3	200	50	715.77	715.40	0.037	4.641
4	6	45	40	715.40	714.13	0.127	4.721
5	6	90	45	714.13	713.08	0.205	4.727
6	6	200	50	713.08	710.28	0.280	4.784
7	9	45	40	710.28	706.17	0.411	4.817
8	9	90	45	706.17	701.28	0.489	4.844
9	9	200	50	701.28	696.17	0.511	4.897

Sample Calculation

For the Material Removal Rate of Copper

(a) Overall Mean:

$\bar{y}$= (Sum of means of response variable)/Total number of means

$= \sum y/n = 2.013/9 = 0.22366$

(b) Sum of squares of Total:

$SS_T = \sum y$

$= 0.836202$

(c) Sum of squares due to mean:

$S_m = n\bar{y}^2$

$= 0.45021416$

(d) Sum of squares:

SS = Mean of levels

SS_A = Sum of squares due to Peak Current

$= (\text{Mean of A1})^2 \times n1 + (\text{Mean of A2})^2 \times n2 + (\text{Mean of A3})^2 \times n3 - S_m$

$= 3(0.11^2 + 0.37133^2 + 0.189^2) - 0.45021416 = 0.106906$

SS_B = Sum of squares due to Ton

$= (\text{Mean of B1})^2 \times n1 + (\text{Mean of B2})^2 \times n2 + (\text{Mean of B3})^2 \times n3 - S_m$

$= 0.070614$

SS_C = Sum of squares due to Gap Voltage

$= (\text{Mean of C1})^2 \times n1 + (\text{Mean of C2})^2 \times n2 + (\text{Mean of C3})^2 \times n3 - S_m$

(e) Sum of squares of error:

$SS_E = (SS_T - (SS_A + SS_B + SS_C)) - S_m$

$= 0.137$

(f) Degree of freedom:

DOF = Level-1 =3-1 =2

(g) Mean squares:

MSS= Sum of squares/DOF

MSS_A = Mean squares due to Peak Current $SS_A/2$ =

MSS_B = Mean squares due to Ton = $SS_B/2$ = 0.1300

MSS_C = Mean squares due to Gap Voltage = $SS_C/2$ = 0.0055

(h) Percentage of contribution:

P = (Sum of squares/ S_t)

$S_t = SS_T - S_m = 0.385988$

PA = Percentage contribution of Peak Current

$= (SS_A/ S_t)*100$
$= 27.69\%$

PB = Percentage contribution of Ton

$= (SS_B/ S_t)*100$
$= 18.294\%$

PC = Percentage contribution of Gap Voltage

$= (SSC/ St)*100$
$= 18.294\%$

(i) Material Removal Rate (MRR):

MRR = (Initial Wt – Final Wt) / Total Machining Time

= 48.33 – 48.28 = 0.05/12 = 0.417 milli gm

IV. RESULTS AND DISCUSSION

In This chapter are related about influences of control factors and different dielectric medium on MRR and Surface roughness and finding the result which factors Peak current , Ton and Gap Voltage is most important with help of Taguchi method.

4.1 Response table for Copper Tool

The response table for MRR and Surface roughness is shown in Table 4.1 along with the input factors for Kerosene.

Table 4.1 Response table for Copper Tool

Peak current	Ton	Gap voltage	MRR(mg/min)	Ra(µm)
3	45	40	0.09	4.208
3	90	45	0.112	4.182
3	200	50	0.128	4.108
6	45	40	0.8	4.202
6	90	45	0.161	4.256
6	200	50	0.153	4.270
9	45	40	0.158	4.301
9	90	45	0.191	4.391
9	200	50	0.22	4.397

Response table for MRR with copper as a tool

Table 4.1.2 Response table for MRR with copper as a Tool

Level	Peak current(A)	Ton(B)	Gap voltage(C)
1	0.11	0.34	0.34

2	0.37	0.15	0.15
3	0.18	0.16	0.16
Delta	0.26	0.19	0.19
Rank	1	2	3

Optimum process parameters: A1, B2, C2

Peak current = 3 Amps
Ton = 90 Micro seconds
Gap voltage = 45Volts

ANALYSIS OF VARIANCE TABLE FOR MRR

Symbol	Process parameters	Degrees of Freedom	Sum of squares	Mean squares	Contribution (%)
A	Peak current	2	0.106906	0.05345	27.6
B	Ton	2	0.070614	0.03530	18.2
C	Gap voltage	2	0.070614	0.35307	18.2
Error			0.137	-	-
St		8	0.3859	-	-
Mean			0.45021	-	-
ST			0.8362	-	-

Predicted MRR for copper tool:

μ (predicted Mean) = $\bar{y} + (A_m - \bar{y}) + (B_m - \bar{y}) + (C_m - \bar{y})$

= 0.2236 + (-0.2236 +0.11) + (-0.2236 +0.154) + (-0.2236 +0.154)
=-0.0292

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Response table for Surface Roughness with copper as Tool

Table 4.1.4 Response table for Surface Roughness with copper as Tool

Level	Peak current(A)	Ton(B)	Gap voltage(C)
1	4.166	4.237	4.237
2	4.242	4.276	4.276
3	4.363	4.258	4.258
Delta	0.197	0.039	0.039
Rank	1	2	3

Optimum process parameters: A1, B1, C1

Peak current = 3 Amps
Ton = 45Micro seconds
Gap voltage = 40Volts

ANALYSIS OF VARIANCE TABLE FOR SURFACE ROUGHNESS

Symbol	Process parameters	Degrees of Freedom	Sum of squares	Mean squares	Contribution (%)
A	Peak current	2	0.057	0.0285	7.8
B	Ton	2	0.006	0.003	82
C	Gap voltage	2	0.006	0.003	82
Error			0.028	-	-
St		8	0.73	-	-

Mean			163.115	-	-
ST			163.188	-	-

Predicted Surface Roughness for Copper:

μ (predicted Mean) = y-+ (Am-y-) + (Bm-y-) + (Cm-y-)

= 4.257+ (-4.257+4.166) + (-4.257+4.237) + (-4.257+4.237)
=4.166

Response table for Graphite Tool

The response table for MRR and Surface roughness is shown in Table 4.1 along with the input factors for Copper tool

Table 4.1.6 Response table

Peak current	Ton	Gap voltage	MRR(mg/min)	Ra(μm)
3	45	40	0.064	4.623
3	90	45	0.037	4.627
3	200	50	0.037	4.641
6	45	40	0.127	4.721
6	90	45	0.205	4.727
6	200	50	0.280	4.784
9	45	40	0.411	4.817
9	90	45	0.489	4.844
9	200	50	0.511	4.897

Response table for MRR with Graphite as Tool:

Table 4.1.7 Response table for MRR with Graphite as Tool

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Level	Peak current(A)	Ton(B)	Gap voltage(C)
1	0.046	0.392	0.392
2	0.204	0.243	0.243
3	0.470	0.276	0.276
Delta	0.424	0.149	0.149
Rank	1	2	3

Optimum process parameters: A1, B2, C2
Peak current = 3Amps
Ton = 90Micro seconds
Gap voltage = 45Volts

ANALYSIS OF VARIANCE TABLE FOR MRR:

Symbol	Process parameters	Degrees of Freedom	Sum of squares	Mean squares	Contribution (%)
A	Peak current	2	0.2759	0.1379	93
B	Ton	2	0.3503	0.17515	119
C	Gap voltage	2	0.3503	0.17515	119
Error			-0.68291	-	-
St		8	0.29368	-	-
Mean			0.5188	-	-

ST			0.8125	-	-

Predicted MRR for graphite tool:

μ (predicted Mean) = $\bar{y}$+ (A_m-$\bar{y}$) + (B_m-$\bar{y}$) + (C_m-$\bar{y}$)

= 0.2401 + (-0.2401 +0.046) + (-0.2401 +0.243) + (-0.2401 +0.243)

=0.0518

Response table for Surface Roughness with Graphite as a tool

Table 4.1.9 Response table for Surface Roughness with Distilled water as dielectric

Level	Peak current(A)	Ton(B)	Gap voltage(C)
1	4.63	4.72	4.72
2	4.74	4.73	4.73
3	4.82	4.77	4.77
Delta	0.19	0.05	0.05
Rank	1	2	3

Optimum process parameters: A1, B1, C1
Peak current = 3 Amps
Ton = 45 Micro seconds
Gap voltage = 40 Volts

ANALYSIS OF VARIANCE TABLE FOR SURFACE ROUGHNESS

Symbol	Process parameters	Degrees of Freedom	Sum of squares	Mean squares	Contribution (%)
A	Peak current	2	1.69	0.847	99.6

B	Ton	2	1.62	0.8121	95.4
C	Gap voltage	2	1.62	0.8121	95.4
Error	-	-	-3.242	-	-
St	-	8	1.7015	-	-
Mean	-	-	200.78	-	-
ST	-	-	202.48	-	-

Predicted Surface Roughness for Graphite Tool:

μ (predicted Mean) $= \bar{y} + (A_m - \bar{y}) + (B_m - \bar{y}) + (C_m - \bar{y})$

$= 4.742 + (-4.742 + 4.630) + (-4.742 + 4.720) + (-4.742 + 4.720)$
$= 4.586$

Confirmation Experiment:

Table 4.2.1 Surface Roughness, MRR for optimal Machining parameters obtained while machining with Copper as tool

Output Parameter	Cutting Parameters			Predicted Value	Experimental Value
	Peak Current	Ton	Gap Voltage		
MRR	3	90	45	-0.0292mg/min	0.03012mg/min
Surface Roughness	3	45	40	4.166µm	4.231µm

Table 4.2.2 Surface Roughness, MRR for optimal Machining parameters obtained while machining with Graphite as tool.

Output Parameter	Cutting Parameters			Predicted Value	Experimental Value
	Peak Current	Ton	Gap Voltage		
MRR	3	90	45	0.0518mg/min	0.0621mg/min
Surface Roughness	3	45	40	4.586µm	4.5932µm

V. CONCLUSION

In this study, the EDM characteristics of Nickel-copper alloy (INCONEL 600) were examined using copper and graphite tool as the dielectric. The important results are summarized as follows:

(1) The material removal rate and Surface roughness of INCONEL 600 is greater when using copper as tool.
(2) The tool directly influences the surface properties of INCONEL 600. Carbide is formed on the work piece surface when using graphite
(3) The material removal mechanism of nickel-chromium alloy in copper is more, which is due to melting and vaporization is differ from that in graphite where the material removal is less compared to copper. This is due to the melting point of nickel-chromium which is formed while using copper as tool is -17.2 °C and the melting point of Nickel Oxide is 1984°C which is formed while using graphite as tool.
(4) When using copper as tool the oxygen adhere to the surface of the electrode and oxide is formed on the work piece surface but since oxide has higher melting point, the impulsive force of discharge is unstable thus reducing the metal removal rate. By substituting graphite as tool, no oxide adheres to the surface of the electrode and carbide is formed on the work piece surface. The carbide has lower melting point so that the impulsive force of discharge is much more stable and the metal removal rate is improved.
(5) Surface roughness increased with increasing pulsed current and pulse time. Low current and pulse time with constant pulse pause time produced minimum surface roughness that means good surface finish quality. The selection of these machining parameters is not useful because machining process generally becomes very slow. Material removal rate will be low and thus machining cost increases. This combination should be used in finish machining step of EDM process.
(6) High pulsed current and pulse time provide low surface finish quality. However, this combination would increase material removal rate and reduce machining cost. As a result, this combination (high pulsed current and pulse time) should be used for rough machining step of EDM process.

VI. REFERENCES

[1] C.D. Shah1, J.R.Mevada2, B.C.Khatri3 [1], (2013) Optimization of Process Parameter of Wire Electrical Discharge Machine by Response Surface Methodology on Inconel-600 Volume 3, Issue 4

[2] D.Vinoth Kumar1, P.Siva Kumar2, B.Kumaragurubharan3, T.Senthil kumar4, (2016) Experimental Investigation of Process Parameters in EDM for Incoloy 600 Using Taguchi-GRA

[3] 1BUTA SINGH, 2MANPREET SINGH, (2014) PERFORMANCE OF DIFFERENT ELECTRODE MATERIALS IN ELECTRIC DISCHARGE MACHINING (EDM) INCONEL 600 Proceedings of 12th IRF International Conference

[4] Dattatray Vishnu Wagh1, Prof.D.R.Dolas2, (2015) Experimental Investigation of PCM on Inconel 600 Using Response Surface Methodology International Journal of Engineering Research and General Science Volume 3, Issue 1

[5] D Sudhakara1*, B Venkataramana Naik1 and B Sreenivasulu2, (2013) THE EXPERIMENTAL ANALYSIS OF SURFACE CHARACTERISTICS OF INCONEL-718 USING ELECTRICAL DISCHARGE MACHINING International Journal of Engineering Research and General Science Volume 3, Issue 1

[6] Balram Jakhar, Puneet Katyal, Vishal Gulati, (2015) Investigating the Process Parameters for optimization on Inconel 600 using wire cut EDM International Journal of Advance Research and Innovation

[8] Lin C.L, Lin J.L, Ko T.C, (2002) Optimization of EDM process based on the orthogonal array with fuzzy logic and grey relational analysis method, International Journal of Advanced Manufacturing Technology, Vol.19, pp: 271-277.

[9] Sudhir Ashok Shardul1, Sachin K. Dahake2, (2015) PARAMETRIC OPTIMIZATION ON GRAPHITE PLATE BY WEDM International Research Journal of Engineering and Technology (IRJET)

[10] Senkathir S, Arun Raj A C, Vaddi Thulasikanth, Manoj Samson R, (1997) Performance analysis of process parameters on machining of Inconel 718 using electrical discharge machining with brass electrode Journal of Chemical and Pharmaceutical Sciences

[11] Sharanjit Singh*and Arvind Bhardwaj, (2011) Review to EDM by Using Water and Powder-Mixed Dielectric Fluid Journal of Minerals & Materials Characterization & Engineering, Vol. 10, No.2, pp.199-230

[12] Jinming Zhoua*, Volodymyr Bushlyaa, Ru Lin Pengb, Zhe Chenb, Sten Johanssonb
and Jan Eric Stahla, (2014) Optimization of EDM Process Parameters Using Taguchi Method with Graphite Electrode, International Journal of Engineering Trends and Technology, Vol. 7, No. 2, pp: 48-51.

[13] H. L. Eiselstein and D. J. Tillack, (1962) The Invention And Definition Of Alloy 625 The Minerals, Metals & Materials Society,