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By Krishan Kant

Chandigarh University, India

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EXPERIMENTAL INVESTIGATION OF MAGNETIC FIELD ASSISTED EDM PROCESS BY USING TAGUCHI METHOD ON EN-19 TOOL STEEL

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Experimental Investigation of Magnetic Field Assisted on EDM-2.00] Process by using Taguchi Method on En-19 Tool Steel

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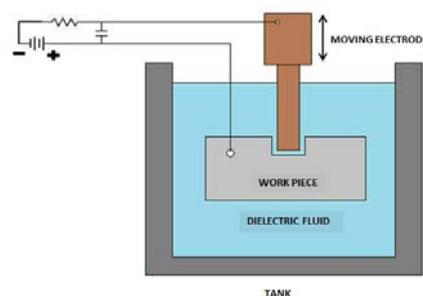
In the case of Tool wear rate the most important factor is discharge current then pulse on time and after that diameter of tool. From the experimental investigation copper tool followed by C18000 tool has been found to give the best MRR results and high tool wear, whereas tungsten tool has been found to give the least MRR accompanied by least tool wear. The dimensional accuracy of the tools in terms of corner wear, side wear and overcut has also been studied.

Keywords: electric discharge machining, taguchi technique, l18 orthogonal array, En-19 tool steel.

1. INTRODUCTION

It is clear that the past few years have seen an increasing interest in the novel applications of electrical discharge machining to see the potential of

this technique for better process performances it is obvious that lot of work has been done to optimize the EDM process and the work related to finding the feasibility of harder material. 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 tool steels, composites, super alloys, ceramics, carbides, heat resistant steels pulse on time and diameter of tool of En-19 tool steel material.



Parts of the experiment were conducted with the L18 orthogonal array based on the Taguchi method. And non-conventional machining. The Electric discharge machining process is finding out the effect of machining parameter such as discharge current, materials, possess greater strength and toughness are usually known to create major challenges during conventional forming tools. These steel are categorized as difficult to machine range of application in Plastic moulds, frames for plastic pressure dies, hydro better polish ability, it has a grooving tempered condition. Good machinability, hardened and as preferred particle size, sintering temperatures and pressures. Despite the promising results, electric discharge and nuclear industries. En-19 Plastic mould steel that is usually supplied in a making industries, aerospace, aeronautics etc. being widely used in die and mold.

Author: Assistant Professor in Mechanical Engineering Department, Chandigarh University, Gharuan.e-mail: kriishan26@gmail.com

a) Objective of the present work

1. To find feasibility of machining EN-19 tool steel using U-shaped tubular copper electrode and internal flushing.
2. To analyze the responses MRR, TWR, and over cut by using the machining parameter selected for discharge current, pulse on time, and diameter of the tool using Taguchi design approach.
3. To Find the influence of MRR With discharge current, pulse duration time, and diameter of the tool. To find the influence tool wear rate with discharge current, pulse on time and diameter of tool.
4. To find the influence on over cut with discharge current, diameter of the tool and, pulse on time.
5. To investigate the machining parameters for EDM using shaped electrode of EN-19 tool steel.

II. PARAMETERS AFFECTING PERFORMANCE OF EDM

a) Discharge Voltage

Discharge voltage in EDM is related to the spark gap and breakdown strength of the dielectric. Before current flows, open gap voltage increases until it creates an ionization path through the dielectric. Once the current starts flowing, voltage drops and gets stabilized at the working gap level. Higher is the voltage, more is

the gap, that improves the flushing conditions and helps to stabilize the cut. MRR, tool wear rate (TWR) and surface roughness increases, by increasing open circuit voltage, because electric field strength increases [Fuller, 1996].

b) Peak Current

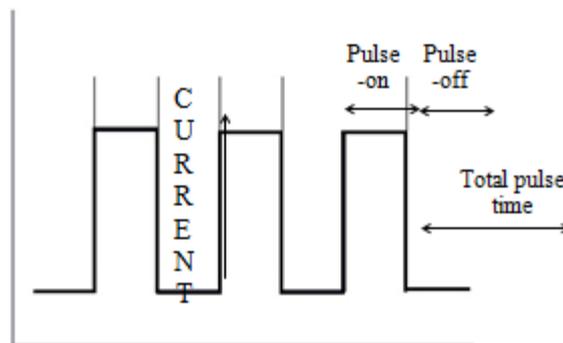
Higher amperage is used in roughing operations and in cavities or details with large surface areas. Machined cavity is a replica of tool electrode and excessive wear will affect the accuracy of machining.

c) Pulse Duration and Pulse Interval

Each cycle has an on-time and off-time that is expressed in units of microseconds. Since all the work is done during on-time, the duration of these pulses and the number of cycles per second (frequency) are important. Pulse on-time is commonly referred to as pulse duration and pulse off-time is called pulse interval. When the optimum pulse duration for each electrode—work material combination is exceeded, material removal rate starts to decrease.

d) Polarity

Polarity determines the direction of current flow relative to electrode; it can be either positive or negative depending on applications. In positive or normal polarity workpiece is positive and tool is negative and in reverse or negative polarity workpiece is negative and tool is positive.



Pulse waveform of controlled pulse generator

e) Dielectric

Basic characteristics necessary for a dielectric in EDM are high dielectric strength and quick recovery after breakdown, effective quenching and flushing ability. TWR and MRR are affected by the type of dielectric and the method of its flushing. Generally kerosene and deionized water is used as dielectric fluid in EDM. Tap water cannot be used as it ionizes too early and thus breakdown due to presence of salts as impurities occur. Dielectric medium is generally flushed around the spark zone. It is also applied through the tool to achieve efficient removal of molten material.

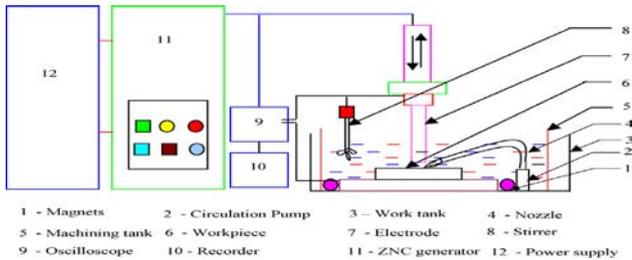
f) Pulse-on Time

This is time period during which machining is performed. As the 'pulse on' time increases, machining will perform at faster rate and craters will be broader and deeper thereby resulting in poor surface finish and high MRR. Larger the pulse on times means larger is the recast layer and more are the heat affected zones.

g) Pulse-off Time

The 'pulse off' is the time during which re-ionization of the dielectric takes place. The more is the off time, the greater will be the machining time. The off

time governs the stability of the process. An insufficient off time can lead to erratic cycling and retraction of the advancing servo thereby slowing down the operation cycle.



The experimental set up consists of transparent container in which machining is performed called machining tank, placed in the work tank of EDM. Fixture assembly is used to hold the work piece. Dielectric (kerosene oil) fluid is filled in machining tank. A stirrer system is used to avoid particle setting. Small dielectric circulation pump is used. Pump and stirrer assembly are placed in same tank in which machining is performed. Magnetic forces were used to separate the debris from the dielectric fluid, for these two permanent magnets are placed at the bottom of machining tank.

The spark gap is filled with powder particles. When voltage was applied an electric field was created. The powder particles get charged and act as conductors behaving in zigzag manner.

III. EXPERIMENTAL DESIGN

Designing an experiment is the principle need of any experimentation plan. In present study Taguchi Method is used for preparing experimental design. Main steps of experiment plan are listed below.

- Defining objective function
- Selecting an appropriate OA
 - Selection of factors
 - Pilot Experimentation
 - Finalizing the factors and their levels

a) Defining Objective Function

The main objective of this experimentation is to study the effect of current, powder concentration, type of powder and magnetic strength on tool behavior during macro and micro EDM, PMEDM during slot cutting to analyze output parameters dimensional and profile accuracy of tool.

b) Selecting an Appropriate OA

The Taguchi method involves reducing the variation in a process through robust design of experiments by using a selected set of experimentation plan. Each factor is assigned column(s) depending on its DOF. Each level of a factor has an equal number of occurrences within each column; and for each level within one column, each level within any other column will occur an equal number of times as well.

c) Selection of Factors

Selection of factors is an important task which is to be done carefully to prepare the most effective design of experiment. Brainstorming and pilot experimentations are conducted to decide factors and their levels.

d) Calculation of DOF

DOF denotes the number of the independent comparisons that can be made in any experiment. The number of factors considered for experimentation, their respective levels determine the total degree of freedom required for designing OA. Mathematically, DOF for each factor is calculated as, $DOF = n - 1$, where n is the level of each factor

e) Selection of OA for PMEDM

Different factors considered for PEDM experiments and their levels are listed in Table 3.2.

Factors (unit)	Levels		
	Level 1	Level 2	Level 3
Current (A)	2	4	6
Magnetic field (T)	0.1	No	-
Tool material	Copper	C18000	Tungsten
Powder type	Tungsten	Copper	Titanium
Concentration (g/L)	2	4	6
Pulse-on time (μs)	50	100	200

Factors and their levels for magnetic assisted PMEDM

IV. EXPERIMENTAL SET UP

The experimentation work is performed on T-3822 M Electric Discharge Machine of Victory Electromech placed in non-traditional machining lab at Thapar University, Patiala. A separate arrangement is added for performing powder mixed EDM, a mild steel tank with inside dimensions as length 330 mm, breadth 180 mm, height 187 mm and plate thickness 3 mm. Capacity of the used tank is 9 L. A stirrer with the maximum speed of 1400 rpm is used to properly mix the powder in the dielectric medium.

V. WORKPIECE AND TOOL ELECTRODE DETAILS

For experimentation, die steel material is used as workpiece. Before machining, workpiece is properly grinded from both the sides for maintain perfect alignment of workpiece with the tool electrode during machining. Three electrode materials used for machining purpose, namely copper, tungsten and C18000 (alloy (Copper, Chromium, Nickel, Silicon (beryllium free))), all with diameter 2.4mm and 30mm length.

Selection of workpiece

S. No	Parameter	Value
1	Voltage	135±5% V
2	Polarity	Positive
3	Machining time	8min
4	Pulse-off time	57µs
5	Dielectric medium	EDM oil

EN-19 tool steel is very hard having the following Mechanical properties.

Mechanical properties of EN-19 steel

Tensile strength	1150N/mm2
Yield stress	850N/mm2
Elongation	14-17%
Modulus of elasticity	210000N/mm2
Density	7.8Kg/m3

Exp. No	Magnetic strength	Powder	Concentration (g/L)	Current (A)	Tool material	Pulse-on (µs)	MRR (g/min)
1	With	W	2	2	Cu	50	0.05200
2	With	W	4	4	W	100	0.00533
3	With	W	6	6	C18000	200	0.01333
4	With	Ti	2	2	W	100	0.01200
5	With	Ti	4	4	C18000	200	0.02733
6	With	Ti	6	6	Cu	50	0.02000
7	With	Gr	2	4	Cu	200	0.06000
8	With	Gr	4	6	W	50	0.00800
9	With	Gr	6	2	C18000	100	0.01000
10	Without	W	2	6	C18000	100	0.01733
11	Without	W	4	2	Cu	200	0.02533
12	Without	W	6	4	W	50	0.00666
13	Without	Ti	2	4	C18000	50	0.03133
14	Without	Ti	4	6	Cu	100	0.02733
15	Without	Ti	6	2	W	200	0.01200
16	Without	Gr	2	6	W	200	0.00533
17	Without	Gr	4	2	C18000	50	0.02466
18	Without	Gr	6	4	Cu	100	0.05866

VI. RESULTS

The effect of powder mixed in dielectric, concentration of powder, current, tool material and pulse-on duration is analyzed on MRR and TWR with and without using external magnetic field. Using Taguchi experimental design, L18 orthogonal array is used for the experiments using bar magnets of 0.1 T. Schematic representation of the tool and the workpiece Tool is made in contact with the workpiece up to 10 mm in length and machining duration is kept 10 minutes.

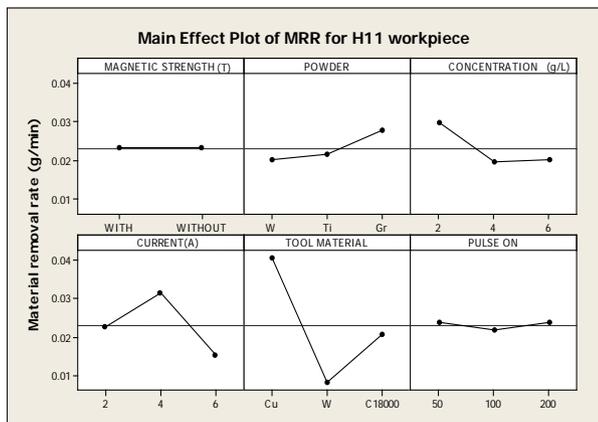
The results are analyzed using ANOVA. It helps in identifying the important process parameters affecting the response. Results for mean of MRR calculated at 90% confidence level ANOVA table for MRR of EN-19 workpiece (Note: For 90% CI, $F_{critical}(2,6) = 3.46$, $F_{critical}(1,6) = 3.78$, PC= percentage contribution)

Parameter	Symbol	DOF	SS	Variance	F value	p-value	PC
Magnetic strength (T)	A	1	0.00000	0.00000	0.0	0.989	0
Powder	B	2	0.000201	0.000101	0.91	0.452	3.822
Concentration (g/L)	C	2	0.000383	0.000192	1.73	0.255	7.284
Current (A)	D	2	0.000802	0.000401	3.63	0.093	15.252
Tool material	E	2	0.003192	0.001596	14.44	0.005	60.707
Pulse-on time (μs)	F	2	0.000017	0.000008	0.08	0.927	0.323
Residual error		6	0.000663	0.000111			12.60
Total		17	0.005258				

The principle followed by F-test is that, greater is the F value for an input parameter the larger is its effect on output parameter. ANOVA shows the results of MRR of PMEDM with and without the use of magnetic strength. Under such experimental conditions the two factors i.e. tool material (F value 15.56) and current (F value 4.27) are found to be significant. The value of F is for the concentration 1.58 g/L. MRR is found to decrease with concentration because as the amount of powder suspended in the dielectric increases, the circulation of the powder particles is not enough also with increase in concentration above a certain level arcing occurs as the effective gap between the tool and the workpiece decreases with increase in concentration.

The highest MRR is achieved on suspension of graphite powder as its density and electrical resistivity is least among the all three. The MRR obtained by titanium is slightly higher as compared to tungsten but less than graphite as the electrical resistivity and density of titanium is less than tungsten but higher than graphite. Thus less is the density and electrical resistivity of a powder more is the MRR achieved by it till the concentration reaches an optimum level. The effect of pulse on duration and magnetic strength have not been found to be very significant and have been ranked as 5th and 6th respectively based on their F values. The MRR is found to increase on increasing the pulse on duration as more melting and vaporization of workpiece will take place when time for which the energy supplied increases.

Magnetic strength has least effect on the MRR. The MRR obtained under the influence of magnetic field is slightly less than that obtained without the use of magnets but overall the effect of this factor is negligible.



Main effects plot of MRR for EN-19 work piece

Level	Magnetic strength (T)	Powder	Concentration (g/L)	Current (A)	Tool material	Pulse-on time (μs)
1	0.023110	0.01997	0.029665	0.022665	0.040553	0.023775
2	0.023181	0.021665	0.019663	0.031552	0.008220	0.021775
3		0.027775	0.020108	0.015220	0.020663	0.023887
Delta	0.000071	0.007778	0.010002	0.016332	0.032333	0.002112
Rank	6	4	3	2	1	5

Response table for MRR of EN-19 workpiece

Optimal design

In the experimental study, the mean effect plots is used to evaluate the mean MRR at optimal trial conditions considering higher F-value and corresponding percentage contribution two parameters are found to be significant tool material and current. The level of these factors which gives the maximum MRR are noted from main effect plot and the corresponding MRR for D₂, [E]₁ is directly obtained from Maximum value of these parameters is selected because MRR is the higher the better type of response variable. Desired mean in this case is estimated as:

$$\mu_{D_2, E_1} = \bar{D}_2 + \bar{E}_1 - \bar{T} = 0.031552 + 0.040553 - 0.0231456 = 0.0489594 \text{ g/min}$$

Confidence interval

$$CI = \sqrt{\frac{F_{\alpha, v_1, v_2} V_e}{n_{eff}}}$$

Where $F_{\alpha, v_1, v_2} = F$ ratio

$\alpha = 0.1$ (risk)

Confidence = $1 - \alpha$

$v_1 = \text{DOF for mean (always 1)}$

$v_2 = \text{Total DOF (=17)}$

$\bar{T} = \text{Average of all experimental trials}$

trials

$n_{eff} = \text{Number of tests under that condition}$

using the participating factors

$$n_{eff} = \frac{N}{1 + DOF_{D,E}} = \frac{18}{1 + 4} = 3.6$$

N is the number of trial in the experiment

$V_e = \text{Variance of error}$

$$CI = \sqrt{\frac{3.03 \times 0.000111}{3.6}} = \pm 0.00966$$

Thus the optimum value of MRR is given by

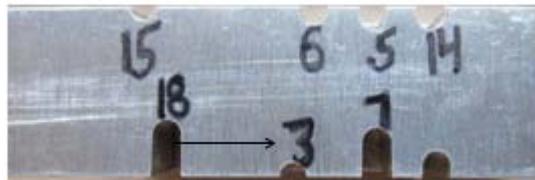
$(0.0489594 \pm 0.00966) \text{ g/min.}$

The workpiece samples from different views of H11 after each cut is shown in Figures shows top view

which indicates the length of cut shows the side views where depth till which machining has been completed can be seen.



(a)



(b)

a) Results and Analysis of TWR

The effect of powder mixed in dielectric, concentration of powder, current, tool material and pulse on duration on tool wear rate is analyzed with and without using external magnetic field on tool wear rate, using Taguchi experimental design. L18 orthogonal array is used for the experiments using bar magnets of

0.1 T. It is smaller the better type of response variable. TWR is calculated by measuring the initial and final weight of the tool using a weighing machine with least count of 0.001 g

Where W_i = Initial weight of the workpiece (g)
 W_f = Final weight of the workpiece after the experimentation (g)
 t = Machining time (min)

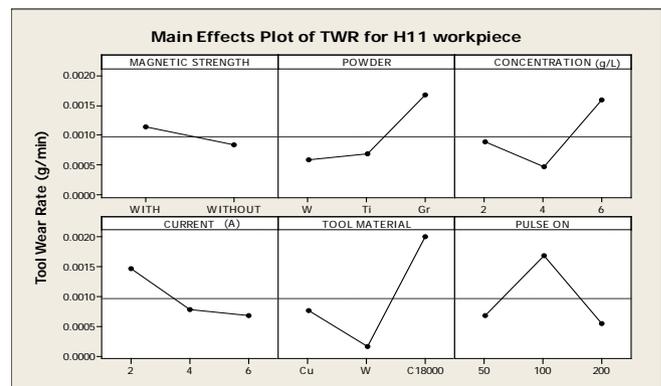
$$TWR = \frac{W_i - W_f}{t} \text{ g/min}$$

Expt. No	Magnetic strength (T)	Powder	Concentration (g/L)	Current (A)	Tool material	Pulse-on (μ s)	TWR (g/min)
1	With	W	2	2	Cu	50	0.00067
2	With	W	4	4	W	100	0.00006
3	With	W	6	6	C18000	200	0.00066
4	With	Ti	2	2	W	100	0.00006
5	With	Ti	4	4	C18000	200	0.00067
6	With	Ti	6	6	Cu	50	0.00067
7	With	Gr	2	4	Cu	200	0.00060
8	With	Gr	4	6	W	50	0.00067
9	With	Gr	6	2	C18000	100	0.00670
10	Without	W	2	6	C18000	100	0.00133
11	Without	W	4	2	Cu	200	0.00067
12	Without	W	6	4	W	50	0.00006
13	Without	Ti	2	4	C18000	50	0.00200
14	Without	Ti	4	6	Cu	100	0.00067
15	Without	Ti	6	2	W	200	0.00006
16	Without	Gr	2	6	W	200	0.00067
17	Without	Gr	4	2	C18000	50	0.00067
18	Without	Gr	6	4	Cu	100	0.00133

Parameter	Symbol	DOF	SS	Variance	F-value	PC
Magnetic strength (T)	A	1	0.00000036	0.00000036	0.18	0.914
Powder	B	2	0.000004	0.000002	1	10.162
Concentration (g/L)	C	2	0.000004	0.000002	0.87	10.162
Current (A)	D	2	0.000002	0.000001	0.51	5.081
Tool material	E	2	0.000011	0.000005	2.42	27.947
Pulse-on time (μ s)	F	2	0.000005	0.000002	1.06	12.703
Residual error		6	0.000013	0.000002		33.028
Total		17	0.00003936			

b) Results and analysis of TWR for EN-19 workpiece

Based on this analysis conducted, most significant factor is tool material. The highest tool wear is observed with C18000 alloy followed by copper tool. Tungsten tool has been found to give the least tool wear. This is because of difference in the melting points of the tool materials. Thermal conductivity of copper at 100 °C is about 400 W/m-K and of alloy C18000 is 208 W/m K and that of tungsten is 173 W/m-K although tool wear is found to decrease with increase in thermal conductivity but in this case it is not a dominating factor. Pulse on duration is the second factor affecting the tool wear rate after the tool material. The center line represents mean value of the levels.



Main effect plots of TWR for EN-19 workpiece

Optimal Design

In the experimental study, the mean effect plots. are used to evaluate the mean TWR at optimal trial conditions. From Table considering higher F-value and corresponding percentage contribution three parameters are found to be significant tool material followed by current and type of powder. The level of these factors which gives the minimum TWR are noted from main effect and the corresponding TWR for E_2 and F_3 is directly obtained. Minimum value of these parameters is selected because TWR is the lower the better type of response variable. Desired mean in this case is estimated as:

$$\mu_{E_2} = \bar{E}_2 + \bar{F}_3 - \bar{T} = 0.000162 + 0.000555 - 0.0010122 = -0.0002952 \equiv 0$$

The optimal calculation for population mean (μ) gives negative value. This situation may appear for responses which are lower the better type and where the optimum/target value is zero. For such case negative value of μ may not have any physical significance and is to be considered as zero.

Confidence interval

$$CI = \sqrt{\frac{F_{\alpha, v_1, v_2} V_e}{n_{eff}}} \quad (\mu s)$$

Where $F_{\alpha, v_1, v_2} = F$ ratio

$$\alpha = 0.1 \text{ (risk)}$$

$$\text{Confidence} = 1 - \alpha$$

$$v_1 = \text{DF for mean (always 1)}$$

$$v_2 = \text{Total DOF (=17)}$$

$$\bar{T} = \text{Average of all experimental trials}$$

trials

n_{eff} = Number of tests under that condition using the participating factors

$$n_{eff} = \frac{N}{1+DOF_{E,F}} = \frac{18}{1+4} = 3.6$$

N is the number of trial in the experiment

V_e = Variance of error

$$CI = \sqrt{\frac{3.03 \times 0.000002}{3.6}} = \pm 0.001297$$

This experimental investigation was mainly aimed at comparing the tool wear behavior of the three tool material copper, C18000 and tungsten with and without using the external magnetic field. Different process parameters like current, pulse-on time, powder suspended in dielectric (tungsten, titanium and graphite) was varied at three levels with and without using magnetic field. Different output parameters measured are MRR, TWR, geometrical tool wear characteristics (corner wear, side wear), overcut. Some significant conclusions drawn on the basis of analysis of results

- Tool material is found to be the most significant factor in case of all the response variables measured with copper giving the highest MRR and TWR followed by C18000 alloy and tungsten.
- Besides tool material current is found to be the significant factor in affecting MRR for EN-19 workpiece materials, type of powder suspended in dielectric is found to affect the MRR for EN-19 workpiece materials.
- Including the tool material factor TWR is affected by pulse-on duration for EN-19 workpiece, by magnetic strength for EN-19 workpiece.
- EN-19 workpiece material is found to have maximum MRR and Graphite powder has reported better MRR compared to the two other powders used.
- Trials conducted in the presence of external magnetic field have reported to show better MRR and less TWR.
- Maximum MRR is achieved at the powder concentration of 2g/L.
- Maximum corner wear is reported in tool material C18000 alloy while maximum side wear is shown in tungsten tool.
- Overcut is found to decrease with increase in pulse-on duration, presence of magnetic strength is also found to decrease the overcut.
- Maximum depth of cuts is achieved using copper as a tool material and using 4 A of current setting.

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