

# Machining of AISI D2 Tool Steel with Multiple Hole Electrodes by EDM Process

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**Abstract.** In recent years, with the increasing of technology the demand for machining processes is increasing for the newly developed materials. The conventional machining processes are not adequate to meet the accuracy of the machining of these materials. The non-conventional machining processes of electrical discharge machining is one of the most efficient machining processes is being widely used to machining of high accuracy products of various industries. The optimum selection of process parameters is very important in machining processes as that of an electrical discharge machining as they determine surface quality and dimensional precision of the obtained parts, even though time consumption rate is higher for machining of large dimension features. In this work, D2 high carbon and chromium tool steel has been machined using electrical discharge machining with the multiple hole electrode technique. The D2 steel has several applications such as forming dies, extrusion dies and thread rolling. But the machining of this tool steel is very hard because of its hard alloyed elements of V, Cr and Mo which enhance its strength and wear properties. However, the machining is possible by using electrical discharge machining process and the present study implemented a new technique to reduce the machining time using a multiple hole copper electrode. In this technique, while machining with multiple holes electrode, fin like projections are obtained, which can be removed easily by chipping. Then the finishing is done by using solid electrode. The machining time is reduced to around 50% while using multiple hole electrode technique for electrical discharge machining.

## 1. Introduction

The demand for improving of surface quality of the products surface after machining are becoming more imperative to gratify the complex and intricate component reliability and performance. To make the precision fittings and reliable couplings it is highly necessary to meet the surface veracity requirements. The machined products surface integrity depends on the surface texture, which directs



the surface roughness and surface layer nature after machining, which concerns the surface metallurgy and property. The surface integrity of a machined products produced by metal removal process comprises a nature of both surface metallurgy and surface topography have effect on the physical and mechanical properties of the machined material in its service conditions [1]. The machining of products using conventional machining process are resulted in poor metallurgical and topography properties of the materials. However, to overcome these issues non-conventional machining processes are contemplated which lead to achieve required properties after material removal process. Among the non-conventional machining processes, electrical discharge machining (EDM) operation become a successful process for precision making and intricate shapes. In this process, material removes rapidly by means of electrically conductive material with the mechanism of insistent spark discharge releases from a its power supply source of pulsed direct current with the flow of dielectric between the tool and substrate [2]. During this process, the mechanism of each discharge associates with substrate material and helps to melts or vaporizes as a metal removal process. The extracted molten metal is mixed with the dielectric fluid to cool down its temperature and solidifies into as a scarp particles with a size of small diameter. These particles are easily carried out by dielectric fluid and flushed away by the sweep action of the fluid [3,4]. The EDM process is moderately advanced machining process and it has several advantages compared to the other conventional and other non-conventional machining processes, and its applications are becoming more and more distributed over a considerable products. One of the major benefit of this process is not involve in any direct contact among the substrate and electrode, thus the mechanical stresses and possibility of producing vibrations can be easily eliminated during EDM process. It can be possible to cut even high hardness materials as the material connected through electrical conductivity. Hence, in the present work the highly alloyed material with carbon and chromium hard material which is impossible to cut by using conventionally available machining processes has been chosen to cut using EDM process. Some of the other hard materials of titanium, steel and its combination of welded joints made by solid state welding process to remove the extra material of flash material is difficult to remove my conventional machining processes [5-12]. Whereas, some of the weldments needs a highly surface finish for soft materials of aluminum, steel and its alloys [13-19]. The weldments which are produced in butt joint are needed less vibration and high precision machining processes to get their proper applications in the production [20-23]. To deal with the such kind of materials and high precision application products a new approach has been implemented in this study of using a EDM electrode in the form of tubular electrode, which is vibrates during EDM process with the help of ultrasonic frequency thus it will makes rotation in axis synchrony [24]. This process can able to produce holes in circular shape with concentric axis using a tubular electrode. To release the removal of substrate material from the holes of tubular electrode a pressurised and high velocity gas is connected to the holes through internal connectors and it will flow over the discharging gap. This mechanism owing to improve to the material removal rate of the substrate and flushing of the extracted particles to send out from the electrode [25]. To enhance the machining process a magnetic force device was fixed to an EDM machine which can alleviate and to take out the machined particles of debris ejected from the machining area. Therefore the ware rate of the electrode, material removal rate (MRR) and surface roughness properties drastically improves [26]. In order to maintain the higher relative speeds with respect to at any point of the electrode to the substrate, the electrode shape is modified as a pipe [27].

The previous literature reports [28] analysed that the EDM machining of D2 steel material was examined by higher characterised atomic force microscopic analysis to reveal the machined surface roughness, its morphology and the presence of micro cracks. It is also studied that the machined surfaces of the substrate texture after EDM process is ascertained by the discharge energy [29]. The recent developments in EDM process revealed a versatile process of using magnetic force and its effects on machining process are explored deeply for various materials. Moreover, the gains of magnetic force based EDM machining process were studied thoroughly and confirmed that the discharged waveforms analysis and microstructural characterization of the surface integrity. The analyses of the EDM machined surfaces exhibited a considerably higher material removal rate and

electrode wear ration is lower [30]. In addition the other studies reported that, the study the experimental parameters a new empirical model was proposed for machining of tool steel. After machining, the substrate damage studies were conducted by using a new damage variable method. The substrate surface and diffused layers were characterised by a scanning electron microscopy. The structure studies revealed that the formation of tensile residual stresses due to the EDM machining operation over the substrate surfaces, hence these are resulted in deterioration of the strength [31]. Most of the studies were used  $L_{18}$  orthogonal array which is related to the Taguchi method in order to carry out a several experiments, and these are evaluated using statistical approach and variance analysis was used to study the experimental data.

In the present work, machining with multiple hole electrode technique was introduced to evaluate the EDM machining efficiency and which will effect on the reduction of contact region between the EDM tool and substrate owing to the presence of holes on the tool face. The removal of metal particles from the substrates are fleshing out from the tubular rod mechanism was studied by using Di-electric fluid which is passed through the electrode holes. A new approach of optimization technique was used to find the experimental conditions and its effect on materials removal rate. The comparison studies also conducted between solid and multiple hole electrodes in EDM machining process.

## 2. Experimental Procedure

Table 1 Machining parameters and their levels

Symbol	Machining parameter	Unit	Level 1	Level 2	Level 3
A	Peak Current	Amps	4	8	12
B	Pulse ON time	$\mu\text{s}$	200	400	600
C	Pulse OFF time	$\mu\text{s}$	10	20	40

Table 2 Experimental layout using an  $L_{18}$  orthogonal array

Exp No	Machining parameter level			
	A (Peak Current)	B (Pulse on Time)	C (Pulse off Time)	D (Error)
1	1	1	1	-
2	1	2	2	-
3	1	3	3	-
4	2	1	1	-
5	2	2	2	-
6	2	3	3	-
7	3	1	2	-
8	3	2	3	-
9	3	3	1	-
10	1	1	3	-
11	1	2	1	-
12	1	3	2	-
13	2	1	2	-
14	2	2	3	-
15	2	3	1	-
16	3	1	3	-
17	3	2	1	-
18	3	3	2	-

In the present study, the experimental procedure and machining parameters are selected based on the following of some of the necessary steps which are helpful for identifying the required factors that are used for determining the levels of factor. The main machining parameters are chosen that are having effect on the machining process are peak current (Amps), pulse on time ( $\mu$ s) and pulse off time ( $\mu$ s) on the responses viz. machining time, material removal rate and electrode wear rate. The selected levels of machining parameters are which are applied for experiments are listed in Table 1. The experiment was conducted based on  $L_{18}$  orthogonal array for three parameters at three different levels which is mentioned on Table 2. Experiment was conducted and the performances were measured, using orthogonal array and the parameters are selected for the experimental design having three conditions with three different levels.

## 2.1 Work Piece Material

To study the EDM process, AISI D2 tool steel has been chosen which is higher in hardness and alloyed with the higher carbon and chromium levels, and other elements of Mo, Cr, and V. This material is highly demanded in several application of cutters and dies for tool materials due to their high strength and resistance to wear rate at heat treatment condition. In heat treated condition its mechanical properties are very high and the hardness of 57 HRC, tensile strength of 1736 MPa and 1532 MPa yield strength. Among these steel grades, D grade tool steels are having Cr contains between 10-18% Cr as shown in Table 3. The hardness of these steels will not change with temperature and the critical value of above 425°C, its properties starts to degrade.

Table 3 The chemical elemental composition of the tool steel material

Elements	C	Si	Mn	Mo	Cr	Ni	V	Co	Fe
Wt.%	1.5	0.3	0.3	1.0	12.0	0.3	0.8	1.0	Balance

## 2.2 Electrode Material

Two types of electrodes were used for EDM machining tool steel by using electric discharge machine, normal electrode are made with dimensions of 12 mm diameter and 15 mm length and multiple through hole electrodes are prepared from copper rods of 12 mm diameter with 3 mm thickness. High precision drilling machine used for machining 1 mm diameter hole on the 3 mm thickness copper electrode material. Figure 1 shows the design of multiple hole electrode. Multiple hole electrode of 3 mm thickness is brazed to hollow copper rod by using the copper as filler metal is illustrated in Figure 2.

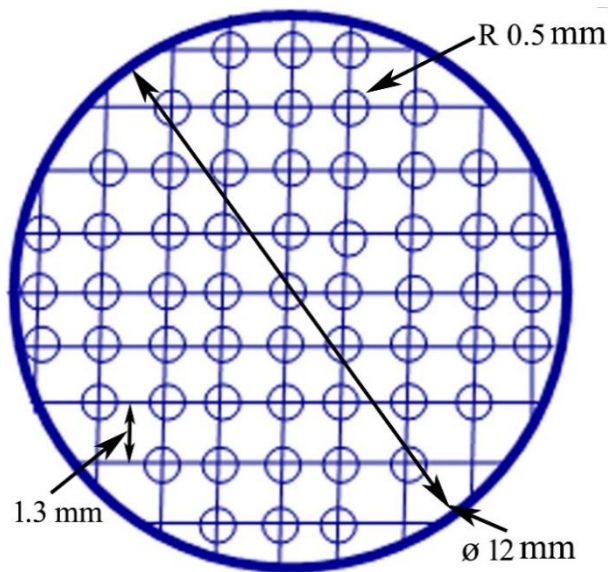


Figure 1 Design of electrode (array pattern)

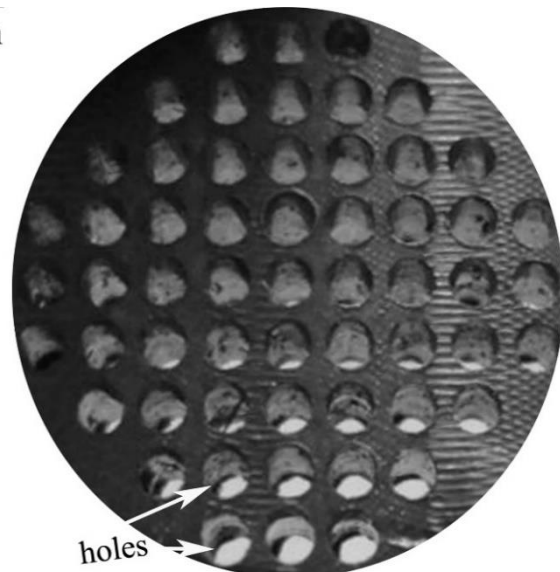


Figure 2 3 mm thickness multiple hole electrode

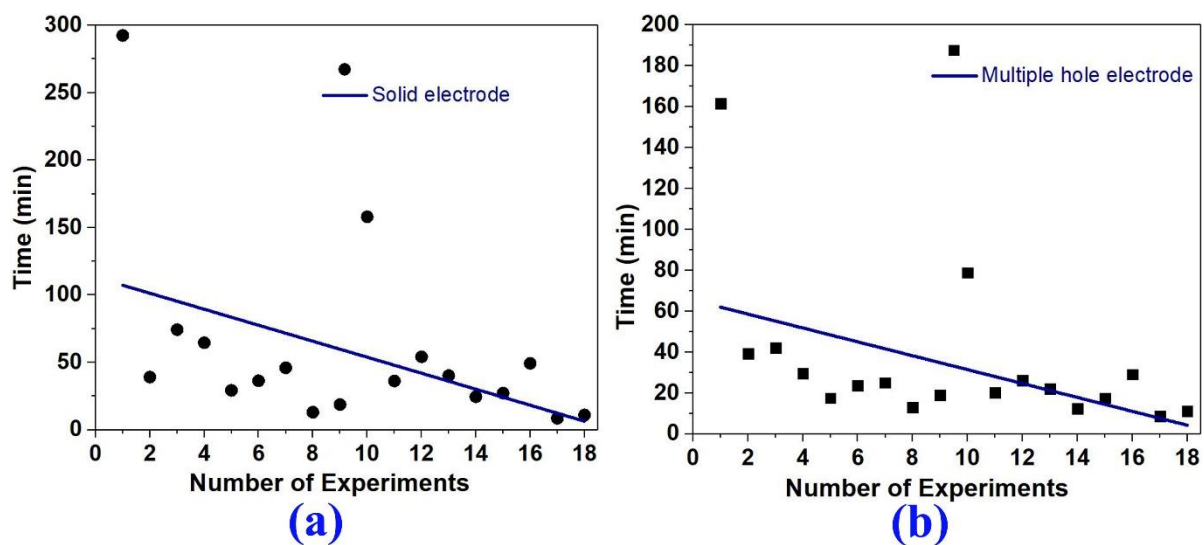


Figure 3 The relationship of the experiments and the time for (a) solid electrode and (b) multiple hole electrode.

### 2.3 Experimental Process

Machining was done on an EDM machine for tool steel using the copper electrodes. There are total 36 experiments contributing to make 5mm blind holes on the 10mm thick work piece has been carried out and machining time is noted down. Electrode wear, and material removal rate have been tabulated as shown in Table 4. First 18 experiments of machining were done by using solid electrode and remaining 18 experiments were done with multiple hole electrode. After machining, fin type projections appear which can be easily chipped out, since work piece material will become brittle. Brittleness is formed in fins because of recast layer. Surface finishing was done by using a solid electrode.

Table 4 Experimental results of EDM on solid electrode and multiple hole electrode

Exp no.	MRR, g/min( $\times 10^{-2}$ )	TWR, g/min( $\times 10^{-3}$ )	MRR, g/min( $\times 10^{-2}$ )	TWR, g/min( $\times 10^{-3}$ )
1	1.70	2.50	3.09	5.23
2	7.02	2.31	12.76	2.86
3	6.70	0.06	11.86	15.42
4	7.80	15.14	16.92	29.61
5	17.04	8.86	28.53	23.05
6	13.73	0.13	21.09	0.42
7	10.86	29.30	19.96	36.74
8	21.43	25.07	38.28	58.88
9	16.90	0.169	26.63	4.26
10	3.16	5.44	6.34	10.78
11	13.79	1.93	24.93	9.74
12	9.23	0.092	9.12	5.16
13	12.42	29.31	22.72	61.53
14	20.36	13.46	40.88	64.14
15	18.36	0.183	28.58	58.02
16	10.13	28.58	17.17	35.14
17	38.02	41.44	58.47	103.50
18	26.09	1.04	45.33	100.18

### 3. Results and Discussions

#### 3.1 Machining Time and Electrode wear rate Comparison

Machining time comparison for machining AISI D2 tool steel with solid electrode and multiple hole electrode are plotted in Figure 3, which results less time taken while machining with multiple hole electrode because of the area of contact is reduced due to presence of holes on the tool face and dielectric fluid is passes through the electrode holes that which allows easy to remove the machined debris. Electrode wear rate comparison for machining AISI D2 tool steel with solid electrode and multiple hole electrode are plotted in Figure 4, which results slightly increase in tool wear rate while machining with multiple hole electrode is used, arc gets struck between the holes which results in melting and evaporation of tool electrode material, thus increasing the TWR. When compared with the solid electrode, multiple hole electrode has more TWR.

#### 3.2 Signal to Noise Ratio

Using ANOVA technique for the experimental analysis, the ratio of S and N for the outputs of electrode wear rate and material removal rate are calculated. Also the Taguchi technique tables for all the experiments are analysed and tabulated in Table 5. The process parameters and its optimal combination can be done by finding the signal-to-noise ratio (S/N) for each performance variable. In general there are three types S/N ration performance characteristics are used for analysis such as the higher-the-better, lower-the-better and nominal-the-better. It is also worth to mention that the performance characteristics are independent and the larger S/N ratio always represents for better performance characteristics. Hence the highest S/N ratio is equal to the optimal level of the process parameters. The signal to noise ratio is being find out by calculating the loss function (Lij).

The loss function Lij of the higher the better performance characteristics can be expressed as:



$$(S/N) \text{ for MRR} = -10\log(L_{ij})$$

$$\text{Where } L_{ij} = 1/(Y_{ij})^2$$

The loss function  $L_{ij}$  of the lower the better performance characteristics can be expressed as:

$$(S/N) \text{ for TWR AND SR} = -10\log(L_{ij}), \quad \text{Where } L_{ij} = (Y_{ij})^2,$$

Where  $l_{ij}$  is the loss function of the  $i$ th performance characteristics in the  $j$ th experiment.

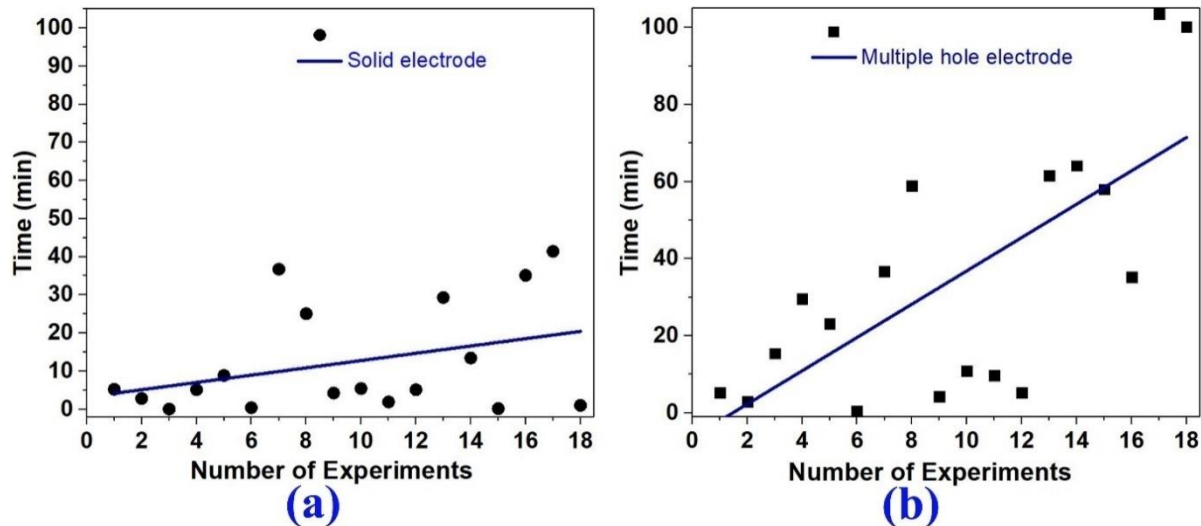


Figure 4 The relation between the number of experiments and the tool wear for (a) solid electrode and (b) multiple hole electrode.

Table 5 S/N ratio's for solid electrode and multiple hole electrode

Exp No.	Solid Electrode		Multiple Hole Electrode	
	S/N Ratios for MRR	S/N Ratios for TWR	S/N Ratios for MRR	S/N Ratios for TWR
1	-35.39	52.04	-30.20	45.62
2	-23.07	52.72	-17.88	50.87
3	-23.47	84.43	-18.51	36.23
4	-22.15	36.39	-15.43	30.57
5	-15.37	41.05	-10.89	32.74
6	-17.24	77.72	-13.51	67.53
7	-19.28	30.66	-13.99	28.69
8	-13.37	32.01	-8.34	24.60
9	-15.44	75.91	-11.49	47.41
10	-30.00	45.28	-23.95	39.34
11	-17.20	54.28	-12.06	31.83
12	-20.69	80.91	-20.80	35.05
13	-18.11	30.65	-12.87	48.65
14	-13.82	37.41	-7.76	23.85
15	-14.72	74.89	-10.87	42.48
16	-19.88	30.87	-15.30	46.23
17	-8.39	27.65	-4.66	44.97
18	-11.67	59.65	-6.87	46.89

### 3.3 Results of ANOVA

The optimum combination of parameters A3B3C1 is obtained for higher MRR, and lower TWR, by using response S/N ratio shown in Table 6 for solid electrode. ANOVA is performed using “Minitab 15” software to determine percentage contribution of machining parameters influencing MRR. The optimum combination of parameters A2B3C3 is obtained for higher MRR, and lower TWR, by using response S/N ratio given in Table 6 for multiple hole electrode. ANOVA is performed using “Minitab 15” software to determine percentage contribution of machining parameters influencing MRR.

Table 6 S/N Response Table for Solid electrode for MRR & TWR

Level	Solid electrode			multiple hole electrode		
	A	B	C	A	B	C
1	-27.03	-32.28	<b>-25.11</b>	-7.170	-6.274	-4.252
2	-25.64	-24.92	-25.31	<b>-1.995</b>	-3.088	-3.833
3	<b>-24.04</b>	<b>-19.50</b>	-26.29	-2.707	<b>-2.509</b>	<b>-3.786</b>
Delta	2.99	12.78	1.18	5.175	3.765	0.466
Rank	2	1	3	1	2	3

### 3.4 Analysis of variance

Analysis of variance in experiments can be considered as a portioning variability method into distinctive sources of variation and the associated degree of freedom. To analyse the effects of experimental conditions a frequency test was used which have considerable contribution on the quality characteristics. However, the Tables 7 and 8 clearly indicated the result of ANOVA analysis of S/N ratio for MRR and TWR. From the results of ANOVA, it can be found that discharge current is the most affecting MRR, the pulse on time is most affecting TWR and pulse off time is least affecting on MRR and TWR.

Table 7 Results of ANOVA for MRR and TWR of solid electrode

Symbol	Factor	MRR						TWR					
		Sum of squares	Degree Of Free dom	Mean square	F value	P Value	Contribution (%)	Sum of squares	Degree Of Free dom	Mean square	F value	P Value	Contribution (%)
A	Discharge current	352.25	2	176.13	21.06	0.000	49.23	1087.7	2	543.9	27.21	0.000	16.29
B	Pulse on time	263.61	2	131.81	15.76	0.001	36.84	5311.5	2	2655.8	132.87	0.000	79.59
C	Pulse off time	7.67	2	3.84	0.46	0.644	1.07	54.3	2	27.2	1.36	0.297	0.81
E	Error	91.98	11	8.36			12.85	219.9	11	20.0			3.29
T		715.52	17				100.00	6673.4	17				100.00



Table 8 Results of ANOVA for MRR and TWR of multiple hole electrode

S y m b o l	Facto r	MRR						TWR					
		Sum of squares	Degr ee Of Free dom	Mean square	F value	P Value	Contri bution (%)	Sum of squares	Degr ee Of Free dom	Mean square	F value	P Value	Contri bution (%)
A	Disch arge curre nt	375.717	2	187.859	21.26	0.000	54.75	5.4	2	2.7	0.02	0.982	0.26
B	Pulse on time	211.952	2	105.976	12.00	0.002	30.88	372.2	2	186.1	1.24	0.326	18.36
C	Pulse off time	1.424	2	0.712	0.08	0.923	0.20	2.9	2	1.4	0.01	0.990	0.14
E	Error	97.180	11	8.835			14.16	1646.8	11	149.7			81.23
T		686.273	17				100.00	2027.2	17				100.00

### 3.5 Conformation Experiment

It is important to conduct confirmation tests to verify the improvement in the machining process characteristics of tool steel, implying that the factors and levels chosen for the experiment provide the desired result are shown in Table 9. The optimal parameters are 12 Amps Peak current, 600  $\mu$ s pulse ON time and 9  $\mu$ s pulse OFF time and are 8 Amps Peak current, 600  $\mu$ s pulse ON time and 40  $\mu$ s pulse OFF time for solid electrode and multiple hole electrode respectively.

Table 9 Result of Conformation test of MRR &amp; TWR

Optimum level	Solid Electrode		Multiple Hole Electrode	
	IMP	OMP	IMP	OMP
	A <sub>1</sub> B <sub>1</sub> C <sub>1</sub>	A <sub>3</sub> B <sub>3</sub> C <sub>1</sub>	A <sub>1</sub> B <sub>1</sub> C <sub>1</sub>	A <sub>2</sub> B <sub>3</sub> C <sub>3</sub>
MRR, (gm/min) x 10 <sup>-2</sup>	1.70	16.90	3.09	21.09
TWR,(gm/min) x 10 <sup>-3</sup>	2.50	0.169	5.90	0.42

IMP – Initial Machining Parameters,

OMP- Optimal Machining Parameters

## 4. Conclusions

The experimental and statistical approach was conducted on machining process to reduce the machining time for the machining tool steel, by using multiple hole copper electrode on EDM. The major conclusions of the experimental work can be summarized as follows

- The machining time is reduced by 40% to 50% with multiple hole electrode when compared to normal machining with solid electrode. The time taken for machining and chipping the fin projections is less than the normal method.

- Therefore experiment no. 17... 12 Amps Peak current, 400µs pulse ON time and 10µs pulse OFF time is the optimal machining parameters setting for minimum machining time, maximum MRR among the eighteen experiments conducted for AISI D2 tool steel using solid and multiple hole electrodes.
- While experiment no.9... 12 Amps Peak current, 600µs pulse ON time and 10µs pulse OFF time is the optimal machining parameters setting for minimum machining time, maximum MRR and minimum EWR among the eighteen experiments conducted for AISI D2 tool steel using Solid electrodes.
- While experiment no.6... 12 Amps Peak current, 600µs pulse ON time and 40µs pulse OFF time is the optimal machining parameters setting for minimum machining time, maximum MRR and minimum EWR among the eighteen experiments conducted for AISI D2 tool steel using multiple hole electrodes.

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