Experimental Investigation For Process Parameters In Electric Discharge Machining Of M2 Die Steel Using Different Electrode By Taguchi Method

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Abstract
Electric Discharge Machining (EDM) is one of the most efficient employed non-traditional machining processes for cutting hard-to-cut materials. Modern ED machinery is capable of machining geometrically complex or hard material components. Heat treated tool steel, composites, super alloys, ceramics, etc. but the major problem is tool wear rate and low material removal rate. In the present work, an experimental investigation has been carried out to study the effect of cryogenic treatment on copper electrode in terms of Material Removal Rate, Electrode Wear Rate on M2 tool steel. The present material used for the work were having hardness up to 62 HRC and then machined with electrode materials of normal copper and cryogenic treated copper and cryogenic treated tempered copper with 12 mm diameter and 100 mm in length using different process parameters like Discharge current [A], Pulse on time [µs], pulse off time [µs] at three levels using L9 orthogonal array. Then in second part of present work optimization of output parameters such as Material Removal Rate (MRR) and electrode wear rate (EWR) during electric discharge machining of M2 tool steel using Grey-Taguchi analysis .After the comparative study the Result includes the selection of best electrode under optimal process parameters to get the High Material Removal Rate and Depth of cut and Low Tool Wear Rate.

Keywords: EDM Process, Microstructure, Hardness, MRR and TWR.

1. Introduction

In present days, there has been an expanded enthusiasm in newer and advanced materials with high strength, hardness, thermal stability and high wear resistance used in tool and die making, automotive, aircraft, aerospace, medical appliances etc [1]. More and more challenging problems are faced in producing complex geometries in such hard and difficult to machine materials by conventional machining processes [2]. To overcome such challenges several of unconventional machining processes have been developed. Electric discharge machining (EDM) [3], also name as spark erosion, electro-erosion or spark machining is one of the essential unconventional machining processes, broadly utilized for producing complex dies, tools and other components in hard and electrically conductive materials such as tool steel, die steel, composites, ceramics etc [4,5]. The present work aims to investigate the feasibility of copper electrode and cryogenic treated copper electrode while machining M2 tool steel in first section [6]. M2 is the & quot; standard & quot; and most widely used industrial HSS. It has small and evenly distributed carbides giving high wear resistance, though its decarburization sensitivity is a little bit high [7]. After heat treatment, its hardness is the same as T1, but its bending strength can reach 4700 MPa, and its toughness and thermo-plasticity are higher than T1 by 50% [8]. It is usually used to manufacture a variety of tools, such as drill bits, taps and reamers. 1.3343 is the equivalent numeric designation for M2 material identified in ISO 4957 [9]. In this first section of EDM experimentation effect of process parameters at three levels on M2 tool steel taking response as MRR, TWR has studied [10]. Experimentation was performed on this condition with machining time 15 min. taken for each experiment and measures the performance [11]. To concluded that cryogenic treated copper feasibility rate for existing experimental conditions. It has to be observed that the output parameters such as material removal rate [12], depth and EWR of EDM whether increase with increase in pulsed current or not. Levels of process parameters are different depending on desired performance parameters [13]. Investigated work finds applications in industry for requirements such as; higher metal removal rate and depth of M2 tool steel and medium surface roughness

for M2 tool steel [14]. In case higher metal removal rate, higher depth and medium surface roughness simultaneously for M2 tool steel. According to requirements these conditions are useful to the user [15].
The machining M2 grade high speed steel (62 HRC) it is difficult get higher MRR without choosing best process parameters and electrode. In EDM hard material cause the tool or cathode also erodes which is not desirable [16]. It is unavoidable but remains in tolerable limit as the wear of the cathode is much less than the anode. This occurs because Positive ions from the dielectric fluid hit the cathode but electrons strike the anode. Though electrons are much lighter than the positive ions it possesses more energy as it moves it greater velocity [17]. So, anode gets more eroded. At the time of spark a compressive force is created at the cathode which reduces the cathode erosion [18]. Fluid medium is generally hydrocarbon. Due to pyrolysis gases are produced which produces carbon particle and these particles create a thin layer [19] of protection on the cathode. Thus, the cathode is much safer than anode [20]. Proper method to carry out cryogenic treatment and tempering Low TWR only possible if the copper electrode become harder by some special treatment like cryogenic treatment and tempering (temperature, soaking period, cycles etc) [22,22].

2. Materials and Methods

2.1 Material

The many factors are needed to be taken into consideration while selecting the tool material. The material has low erosion rate, good electrical conductivity, good machinability, low electrical resistance, high melting point and high rate of electron emission. The EDM has one major drawback and it is the wear ratio of the tool as shown in the Table 1. Different material has different wear ratio. Copper electrode is used as electrode due to its high conductivity and low cost.

Table 1: Physical properties of copper

Properties	**Values**
Density g/cm3	8.96 g/cm3
Melting range 0c	1,085 °C
Specific heat J/gm. C	0.386
Resistivity ohm.m	1.724 x 10-8
Thermal conductivity(w/mk)	388
Thermal expansion coefficient((1/0C))	16.7*10^-6

2.2 Method

Once when the required parameters are chosen and set, the machining starts. Either the machining time or the depth of cut is made as a fixed parameter and accordingly the machining time 15min is made fixed. EDM 30 oil is used. As the electrode moves up and down, due to the contact of the work piece and electrode, the current flows and material is removed this is called pulse on time. When the electrode moves away from metal, the current doesn’t flow and the removed material is washed away with the help of dielectric fluid, this stage is called pulse off time. In this way the metal removal takes places. The application of design-of-experiments (DoE) requires careful planning, prudent layout of the experiment, and ex-pert analysis of results. The experiment is conducted using different process parameters like peak current, pulse on time, pulse off time and different electrodes. Machining experiments for determining the metal removal rate will be carried out by setting the discharge current in the range of 15 to 60A, the pulse duration in the range of (0.5-3000µs ON) (0.25-500µs OFF), and the gap between the electrode and work piece in the range of 1-20mm as shown in the Figure 1.

Figure 1: Electric discharge machining.

Many factors are needed to be taken into consideration while selecting the tool material. The low erosion rate, good electrical conductivity, good machinability, low electrical resistance, high melting point and high rate of electron emission. The EDM has one major drawback and it is the wear ratio of the tool. Different material has different wear ratio. Copper electrode is used as electrode due to its high conductivity and low cost. Tool Material Selection In this experiment, copper and Cryogenic treated copper, Cryogenic treated and tempering with a length of 120mm and a diameter of 10 mm will be used. Because of their tool-making tradition, many firms in the current scenario prefer to employ copper as a primary electrode. Copper's structural strength allows it to create exquisite surface finish even without the use of elaborate polishing circuits. Copper electrodes have the same structural strength that makes them very resistant to DC arching in poor flushing circumstances. And one more way to get best electrode is Cryo-tempering treatment, it relieves residual stresses and reduce tool wear rate. This tool wear is not desired as it changes the tool geometry. To overcome this hurdle, cryogenic treatment is carried out for tool material before machining. Cryogenic treatment relieves the stress when subjected for a period of time as the cryogenic treatment eliminates austenite via isothermal marten site phase transformation at low temperature. In addition to this, during the cryogenic treatment austenite and marten site endures high amount of contraction due to low temperature. The high degree of stress decomposes marten site. The defect generated acts as a preferential site for wandering carbon atom. The EDM process parameters of L9 OA as shown in the Table 2 & Table 3.

Table 2: Design level for Thguchi L9 OA.

Symbol	**Machining parameter**	**Level 1**	**Level 2**	**Level 3**
C	Current (A)	5	10	15
P(ON)	Pulse on-time (micro sec)	100	200	300
P(OFF)	Pulse off time (Micro sec)	50	70	90

Table 3: Design level for Thguchi L9 OA with process parameter.

NO	**I (A)**	**T [on](μs)**	**T[off](μs)**
1	5	100	50
2	5	200	70
3	5	300	90
4	10	200	90
5	10	300	50
6	10	100	70
7	15	300	70
8	15	100	90
9	15	200	50

3. Results and Discussion

The experiment will be carried out on AISI type tool steel M2 grade molybdenum-based high-speed steel. It has a hardness of 62 HRC making it a perfect work piece material for EDM. Experiments were performed using CNC EDM Machine (model: CREATOR CR-6C).

3.1 Microstructure Evolution

The examination of the microstructure of a material provides information used to determine if the structural parameters are within certain specifications. The analysis results are used as a criterion for acceptance or rejection. Microstructural examination is generally performed using optical or scanning electron microscopes to magnify features of the material under analysis. The amount or size of these features can be measured and quantified, and compared to acceptance criteria. These examinations are often used in failure analysis to help identify the type of material in question and determine if the material received the proper processing treatments. The Equipment used to take pictures of microstructure of all the samples is shown in Figure 2.

Figure 2: Microstructure Equipment.

This step reveals features such as grain boundaries, twins and second phase particles not seen in the unetched sample as shown in the Figure 3.

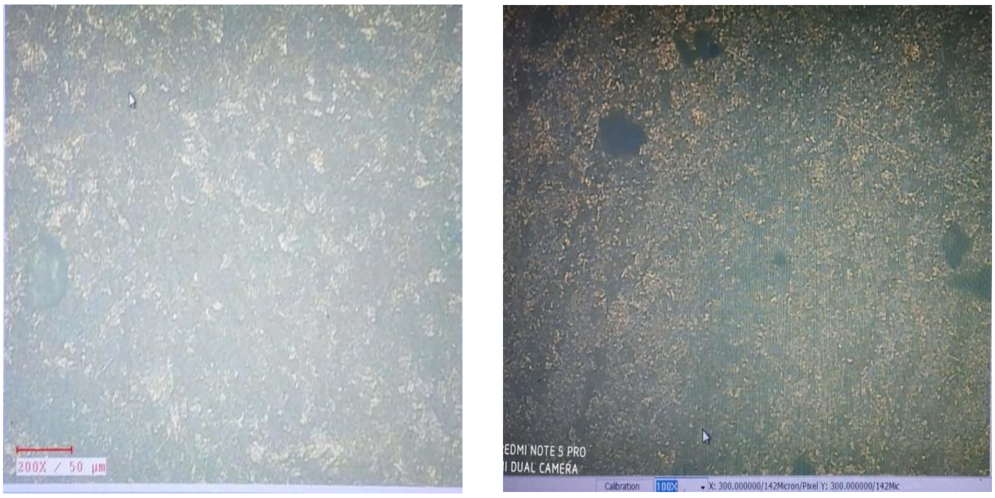

Figure 3: copper electrode (microstructure) and cryogenic treated copper electrode (microstructure).

This microstructure is uniform but large and non-uniform carbides are produced with residual stresses and brittle structure. Cryogenically treated electrode provides lesser crack on the surface of workpiece than the other conditions. This happens as, cryogenically treated electrode provides average temperature around crater and uniform stresses in the machined surface as shown in the Figure 4.

Figure 4: cryogenic treated and tempered copper electrode (microstructure).

3.2 Vickers Hardness Test

The Vickers hardness test: applying a force on the test material using a diamond indentor (136 degrees between opposite faces). From the test cryogenic tempered copper has high hardness as compared normal copper electrode as shown in the Table 4.

Table 4: Vickers hardness results of copper electrode

Type of electrode	copper electrode	Cryogenic treated copper	cryogenic tempered copper
Vicker hardness number	115	128.5	140

3.3 Metal Removal Rate (MRR) and Tool Wear Rate (TWR)

The metal removal rate is usually expressed as cubic millimeter per minute (mm3/min), but in fact could just as realistically be expressed as gm/minute direct energy dissipated in the EDM process.

$$MRR = \frac{\text{WEIGHT BEFORE MACHINING} - \text{WEIGHT AFTER MACHINING}}{\text{TIME TAKEN FOR MACHINING}};$$

Achieving an efficient MRR is not simply a matter of the right machine settings. It also involves this energy can be dissipated in three ways: from the work piece MRR is influenced by the physical properties of the work piece material. The melting point and the thermal conductivity of the work piece are important. From the Copper electrode, as an example, has a low melting point, but the metal removal is still generally low. This is due to copper being a good thermal conductor. This means heat is dissipated too quickly and therefore interferes with efficient metal removal. From the gap, Particles of the electrode material in the work gap will contribute to instability and energy could be dissipated in the gap. This will slow down the metal removal process. There four different types of wear volumetric, corner, end, and side. Corner wear is usually the most important since it will determine the degree of accuracy of the final cut. If an electrode can successfully resist erosion at its most vulnerable points, then overall wear will be minimized and maximum electrode life achieved. The ability of an electrode material to produce and maintain detail is directly related to its resistance to wear and its machinability as shown in the Figure 5 and Table 5.

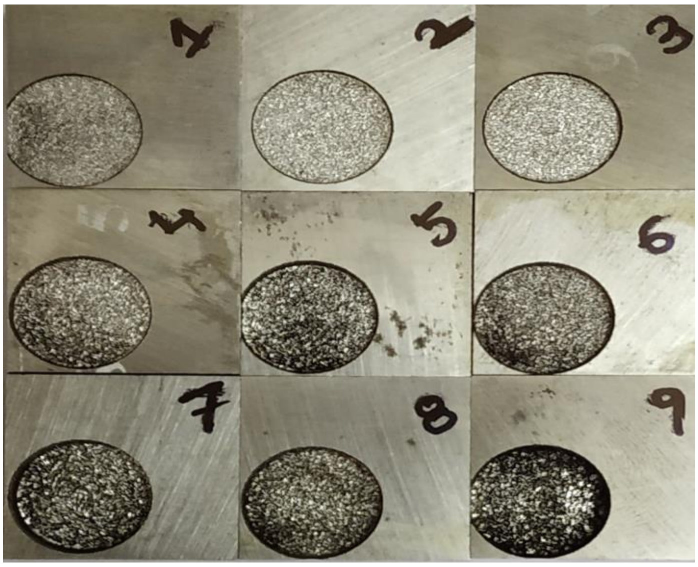

Figure 5: L9 OA EDM process parameters experimental results.

Table 5: Design level for Taguchi L9 OA with process parameter.

NO	I (A)	T [on] (µs)	T[off] (µs)	TOOL (NC-1 C-2, CT-3)	MRR (gm/ min)	TWR (milligm/min)
1	5	100	50	1	0.03078	0.330
2	5	200	70	2	0.02332	0.146
3	5	300	90	3	0.01916	0.013
4	10	200	90	1	0.08759	0.193
5	10	300	50	2	0.11922	0.293
6	10	100	70	3	0.08792	0.253
7	15	300	70	1	0.19198	0.886
8	15	100	90	2	0.14776	0.016
9	15	200	50	3	0.22760	0.013

3.4 Taguchi Method

The product optimization method based on 8-steps of planning, conducting and evaluating results of matrix experiments to determine the best levels of control factors. The primary goal is to keep the variance in the output very low as shown in the Table 6 and Figure 6.

Table 6: Response table by ANOVA.

Response Table for Means

Level	A	B	C	D
1	0.02442	0.10345	0.08882	0.12587
2	0.09824	0.09677	0.11284	0.10107
3	0.18911	0.11156	0.11012	0.08484
Delta	0.16469	0.01479	0.02402	0.04103
Rank	1	4	3	2

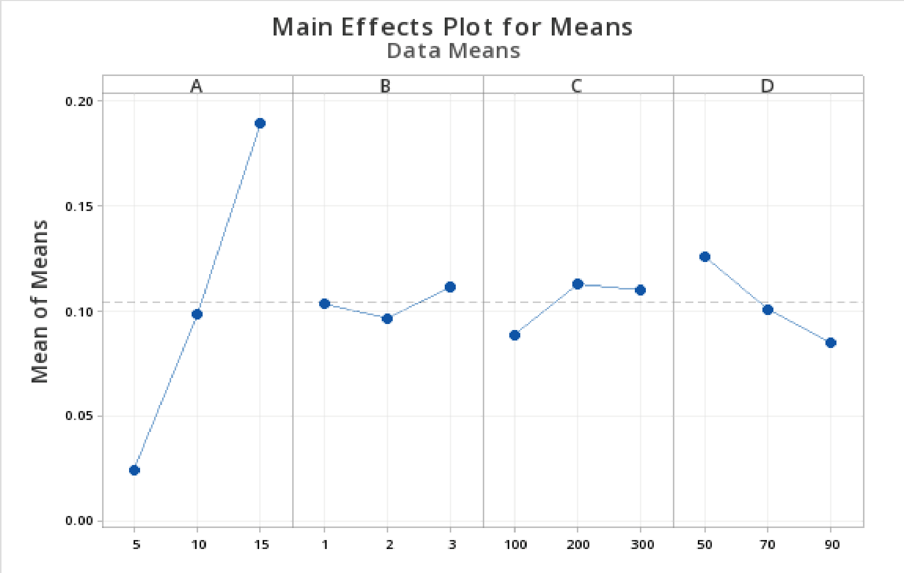

Figure6: Line plot for mean MRR verses all input process parameters.

A-CURRENT
B-TOOL MATERIAL
C-PULSE ON TIME
D-PULSE OFF TIME

4. Conclusion

In present work, experimental study of electrical discharge machining (EDM) process is performed on M2 grade High speed steel(tool and die steel)material with copper tool electrode with cryogenic treatment.: i. Electrical discharge machining (EDM) is a feasible advanced machining process for machining ofhard material like M2 High speed steel.

- After comparison of performance parameters MRR, TWR and SR using copper and cryogenic treated cryogenic tempered (CT) copper as electrode and M2 tool steel as work material. the best electrode for existing condition is cryogenic tempered(CT) copper electrode.
- Optimized process parameters like pulse on (300), pulse off (50), peak current(15), to obtain high MRR and high depth of cut.
- Optimized process parameters like pulse on (200), pulse off (90), peak current(5), cryogenic tempered(CT) copper electrode to obtain low tool wear rate .
- For better machining surface i.e. machined surface free from micro cracks and delamination, use of shorter pulse current (IP) is suitable. iii. Pulse-on-time (TON) should be kept at medium level for improved process performance in terms of MRR and TWR. iv. Medium pulse-off-time (TOFF) and higher rpm is found best suitable in order to obtain higher MRR and lower TWR.

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