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Experimental Investigation of EDM Process Parameters on Tungsten Carbide Using Copper Electrode

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ABSTRACT

Electro-Discharge Machining (EDM) is a non-conventional manufacturing process which used for machining complex shapes in all type of conducting materials irrespective of the hardness for applied in aerospace industries, tool and die making industries etc. Material removal rate and surface roughness are the important performance measures in the EDM process. A reactive force is generated in the EDM process, due to the low electrical permittivity, reduces the damage to the tool and the required shape can be cut on the work piece with better accuracy. Discharge current, pulse-on duration (Ton & Toff) and gap voltage were used as the various input process parameters and to investigate their effects on the material removal rate, surface roughness were analyzed. The experiments were designed using Taguchi L9 orthogonal array, and nine experiments were conducted accordingly. All the experiments were conducted randomly. The results were also analyzed using Grey Relational Analysis (GRA), and the most influential parameters over the response were identified. The experiments conducted in the tungsten carbide super alloy work pieces using Copper tool electrode (rectangular cross section) exhibited more material removal rate in the EDM process. The material removal rate increased and the surface roughness was decrease found in the EDM process. The experimental results were also analyzed using GRA, and the optimal combination of the parameters was found to achieve the better results. The results were also confirmed by conducting a confirmation experiment.

Keywords: Electro-Discharge Machining, Material removal rate, Surface Roughness, pulse-on duration, Grey Relational Analysis

I. INTRODUCTION

Electric discharge machining is employed in hard material and complex shapes could be create with high precision. Hard and brittle materials like tungsten carbide, high speed steels, stainless steels, ceramics etc., find a variety of applications in several industries. The tool and the work piece come into close touch during the traditional machining process and therefore, either the tool undergoes extreme wear or the machining part gets damaged. Also large cutting forces are involved in the traditional methods of machining and the stuff is taken out in the form of chips. How much heat is generated which induces the residual stresses that decrease the product structure's quality and life. The problems such as machining of complex shape, distortion and hardness of the materials were overcome in the non-conventional machining process. EDM removes the material from a workpiece by successive separate discharges occurred between the tool and the work item by a film of insulating liquid, called as dielectric liquid. In this process, the material is removed by the use of electrical energy and thermal energy. EDM is capable of metal processing regardless of its hardness, provided that the substance is a conductor of electricity. The metal is taken out using discharge machining by an electrical spark erosion process, in which the electric spark jumps involving electrodes placed subjected to a voltage and through a dielectric medium. De-ionized water is a very common type of dielectric liquid. The tool acts as the cathode and the work piece acts as the anode. These electrodes are segregated by a small gap of about 0.01 to 0.5 mm. The space is preserved with the help of a servo system as shown in Fig.1.

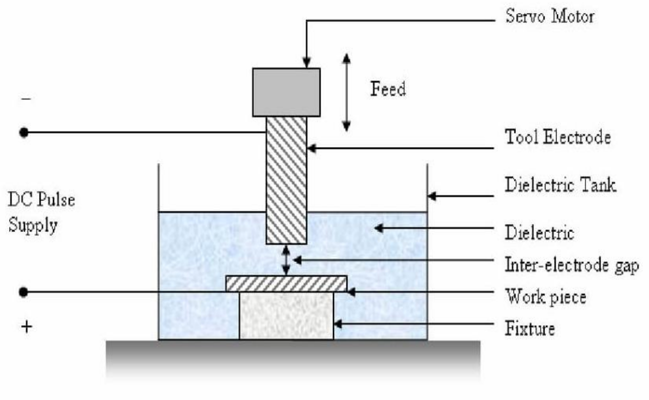

Fig. 1: Schematic Electric Discharge Machining Process

The metal is removed from the work piece, by involves passing a slightly elevated charged particles through an electrode onto the work item in a pulsed (on/off) manner. If the tool and work piece touch each other, arc would occur. Larger gap between the tool and the work piece will not support sparking. In order to maintain a constant gap between the tool and the work piece, a servo mechanism is applied.

Basic Component of EDM: The essential parts of discharge machining:

- Power supply
- Tool Material
- Dielectric medium
- Flushing
- Servo Mechanism

Power supply: It is given to the machining process i.e. Negative terminal is given to the tool and a Positive terminal is given to the workpiece. Electrical connections are made between the work item and the tool and a DC power source.

Tool Material: The tool material must be selected properly, to obviate experience of more wear when collided by the positive ions. In the machining process, the tool acts as the negatively charged electrode. The tool material must have the following characteristics:

- High thermal conductivity
- High electrical conductivity
- High melting point
- Must be easily workable
- High density

Dielectric medium: The tool and the work piece in this process are submerged in insulating oil known as dielectric fluid. The dielectric fluid initiates the discharge by serving as a conducting medium when ionized, and conveys the spark. The dielectric fluid helps to control the arc discharge.

Flushing: Flushing is the process of introducing the clean, filtered dielectric fluid in the spark gap. Flushing of the debris particles from the machining area is one of the most important tasks in the EDM process. Flushing must be carried out at optimal pressure. High pressure of the dielectric fluid flushes the debris before they assist in the cutting process, resulting in smaller material removal rate. Low pressure does not flush the debris particles effectively, and results in short circuiting.

Servo Mechanism: Electric discharge machining process is maintaining a constant gap between the tool and the work piece. If the tool and work piece touch each other, arcing would occur and the work piece will be damaged severely. Larger gap between the tool and the work piece will not support sparking. In order to maintain a constant gap between the tool and the work piece, a servo mechanism is applied.

Process Parameters:

Peak Discharge Current: The discharge energy is directly inversely correlated with the discharge current, and hence the material removal rate.

Voltage: It is the potential measured by volt. It also affects the material removal rate.

Arc Gap: This is the distance maintained between the tool and the work piece in the EDM process. The arc gap is maintained constant with the help of a servo system.

Pulse on Time: It is the duration of time in which current is allowed to flow per cycle. The pulse on time is also directly proportional to the discharge energy and material removal rate. **Pulse off Time:** It is the duration of time between two successive sparks. During the pulse off time, the removed molten material gets solidified.

Duty Cycle: It is the ratio of the pulse on time to the total cycle time (pulse on time + pulse off time).

II. LITERATURE REVIEW

Lighter weight, good strength, impact resistance, and thermal resistant materials have improved for a variety of applications due to advancement in new mechanization which include aerospace, medical, automobile and more. A good understanding on the phenomenon of achieving optimal responses in the EDM is possible through extensive research in this field. literature review is made on the process of discharge machining, various factors affecting the performance, need for the development of the process of discharge machining, research works on the improvement of the performance in the process of discharge machining and the optimization procedures adopted to determine the best values of factors. **Lonardo et. al. (1999)** deals with the effect of flushing and electrode material on MRR, electrode wear, Surface roughness that found with the use of copper electrode lower surface roughness can be obtained. **Mohan et. al., (2002)** deals with the machining of Al-SiC composite by EDM that found with positive polarity of work-piece. MRR rises with rise in peak current. Surface roughness decreases with decrease in peak current. **Tosun et. al. (2003)** studied the impact of the process parameters on the surface roughness of the work piece. Wire EDM process was analyzed by increase in surface roughness with increasing pulse duration, open circuit voltage and wire speed, and decrease in surface roughness with increase in dielectric fluid pressure was reported. **Tsai et. al. (2003)** conducted the EDM experiments AISI 1045 medium carbon steel tool produced by a new method due to the migration of chromium elements present in the tool. **Lee et. al. (2004)** investigated the surface characteristics in the process of discharge machining by electric the machined surface characteristics on the selection of the variable, apart from the dielectrics used in the discharge machining by electric process. **Luis et. al. (2005)** conducted the EDM experiments on silicon carbide to study the MRR and the rate of wear. Current, pulse on time, duty cycle, open-circuit voltage and dielectric flushing pressure were used as process parameters. **Sushant et. al. (2007)** investigated as discharge machining by electric of aluminium alloy–10 wt. % SiCp composites using cylindrical brass electrode of 30 mm diameter. **Sohani et. al. (2009)** studied the impact of tool forms such as triangular, square, rectangular, and circular with size factor consideration along with other process variables such as discharge current, on-time, off-time, and tool area on discharge machining by electro of medium carbon steel. **Jha et. al. (2010)** studied the impact of discharge machining by electro on stainless steel component fatigue performance. **Syed et. al. (2012)** studied the performance of electric discharge machining of water as the dielectric medium. Current, on time, polarity and percentage of aluminium powder were chosen as the different input process parameters. **Zhang et. al. (2014)** investigated the influence of the dielectrics on the material removal characteristics in EDM and their impact on the melting volume and removed material and removal efficiency in different dielectrics. **Younis et. al. (2015)** studied the effect of the electrode material in electrode discharge machining of tool steel to avoid the residual stresses and surface roughness. **Kulkarni et. al. (2018)** studied focuses on effects of different input parameters of discharge machining by wire electric on results of output like surface roughness and rate of material removal during machining of NiTi alloys. **M. R. Singh et. al., (2020)** has used varying parameter electric discharge machining on Ti–6Al–4 V alloy to estimate the two of the major performances i.e. the rate of material removal (MRR) and rate of tool wear (TWR). **A. Gupta et al., (2021)** focus on discharge machining parameters are usually evaluated on the based on surface abrasiveness (SR), Material removal rate (MRR), cutting speed (V), and rate of tool wear (TWR). The discharge machining by electrical parameter affecting to the characteristic measures of the course is Ip, arc gap, T_{on}, and T_{off}.

From the literature review, Electric discharge machining is a widely used industrial process for embossing and producing intricate shapes. It has been continuously observed that it is a very time consuming for effective material removal rate, its rate can be increased by increasing current, but the strength of shapes gets compromised and gets damaged before completing its life. Our objective is to provide such optimized process parameters to work on hard material such as Tungsten carbide using copper electrode by which we can get higher material removal rate with less time and constant strength.

The methodology adopted for conducting the experiments as shown in Fig.

III. Methodology

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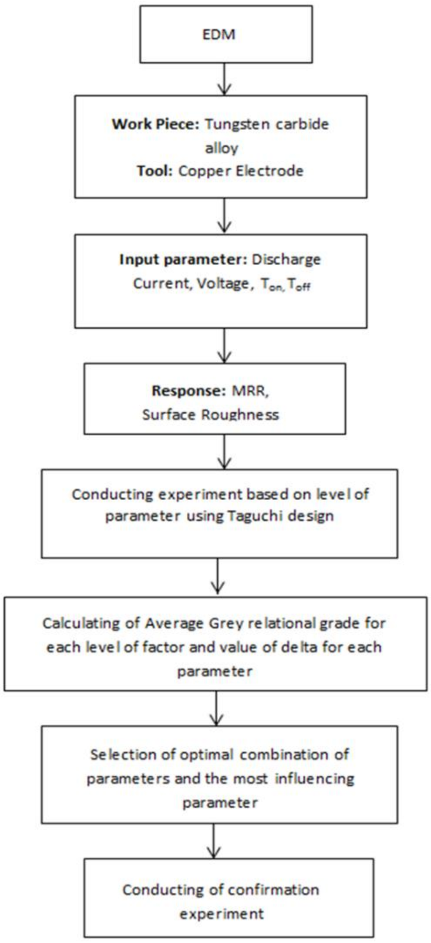

Fig.2: Methodology for conducting experiment

Workpiece and Tool material Selection: Tungsten carbide workpiece for our experiment which is extensively used for rolls in non-twisting rolling mills for its hardness and non-wear properties at very high temperature conditions. Electrolytic copper is used as tool for this experiment. It has low wear rate under both roughing and finishing operation and has the capacity to remove large amount of material. The material is advisable for spark eroding cavities in very hard materials. The properties of workpiece and tool are presented in Table 1:

Table 1: Properties of workpiece and tool

	Material	Composition	Melting Point	Thermal Conductivity	Hardness	Density
Workpiece	Tungsten Carbide	W = 93%, Co = 7%	2870°C	100 W/mK	93.7 HRA	12.7 g/cm³
Tool	**Material**	**Composition**	**Melting Point**	**Electric resistivity**	**Hardness**	**Density**
	Electrolytic copper	Cu = 99.9%	1083 °C	9μΩcm	------	8.9 g/cm³

Fig.3: Workpiece and Tool Material

Experimental Setup: The experiments are carried out on EDM model 500 X Sparknix as shown in Fig.4

Fig.4: Experimental Setup

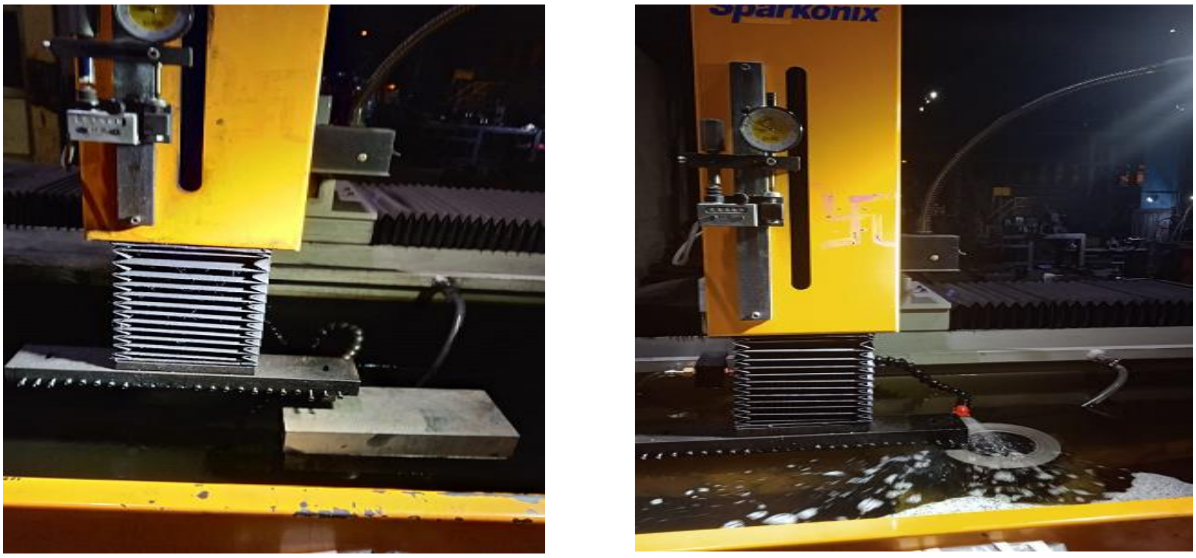

Fig.5: Machining process of Workpiece using EDM model 500 X Sparknix

The machine was equipped with a DC servo system for the three axes movement of the machine tool, and negative polarity used for the electrode to conduct the experiments. The discharge energy is directly proportional to the current, pulse-on duration (T_{on} & T_{off}) and the voltage. The selection of the values of the process parameters plays a critical role in the study of performance of the machining characteristics.

Process Parameters: The levels of the process parameters are chosen on a trial and error basis for machining of Tungsten Carbide in the electro discharge process with varying input process parameters are shown in Table 2:

Table 2: Input machining Parameters and level

Sr. No.	Input Parameter	Level			Observation
		1	2	3	
1	Discharge Current (I) in Amp	3	5	6	Material removal rate (MRR) and Surface roughness (R_a)
2	Voltage(V) in Volt	25	45	65	
3	Pulse on Time(T_{on}) in µs	100	200	400	
4	Pulse off Time(T_{off}) in µs	20	30	40	

Experiments were conducted on tungsten carbide super alloy using copper electrode in EDM process. The Experiments carried on the following two observations:

- Material removal rate
- Surface roughness

IV. RESULTS AND DISCUSSIONS

Performance characteristics of machining parameters: Optimization of the process parameters in EDM of tungsten carbide super alloy is carried out using Taguchi method and GRA. Experiments were conducted in the EDM process using Discharge current, voltage, pulse on time and pulse off time were used as the various process parameters. Material Removal Rate (MRR) and Surface Roughness (Ra) are the performance characteristics. Machining was conducted for a various machining time for tungsten carbide. The experiments were designed using Taguchi's L_9 orthogonal array. All the experiments were conducted in a random order. Taguchi's L_9 orthogonal array helps to choose the nine different combinations of the parameters to conduct the experiments. This method helps to reduce the cost and time by reducing the number of experiments. In the EDM process, the higher the better is used for the MRR, and the smaller the better is employed for surface roughness. The performance characteristics of machining parameters analysis used for minitab software which can represent as graph for main effects for means and S/N ratio as shown in figure.

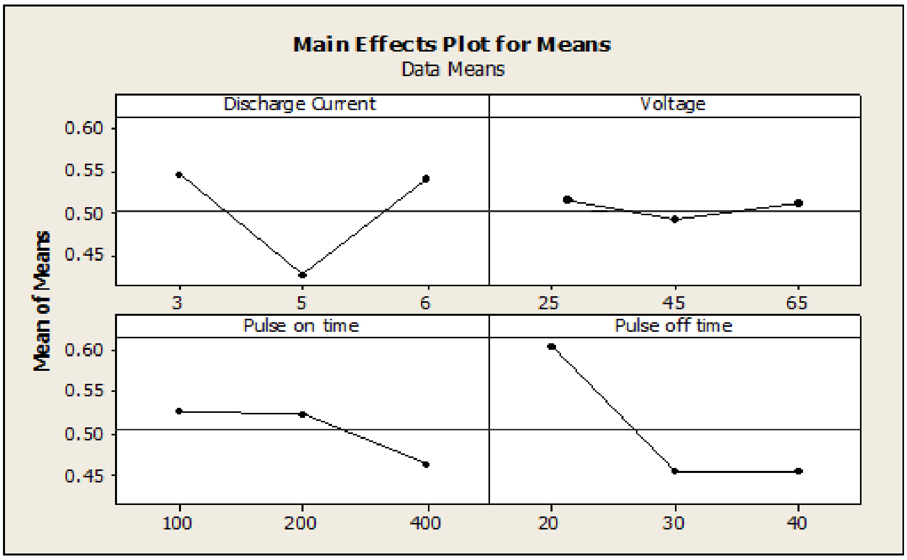

Fig. 6: Main Effects Plot for means of grey relational grade

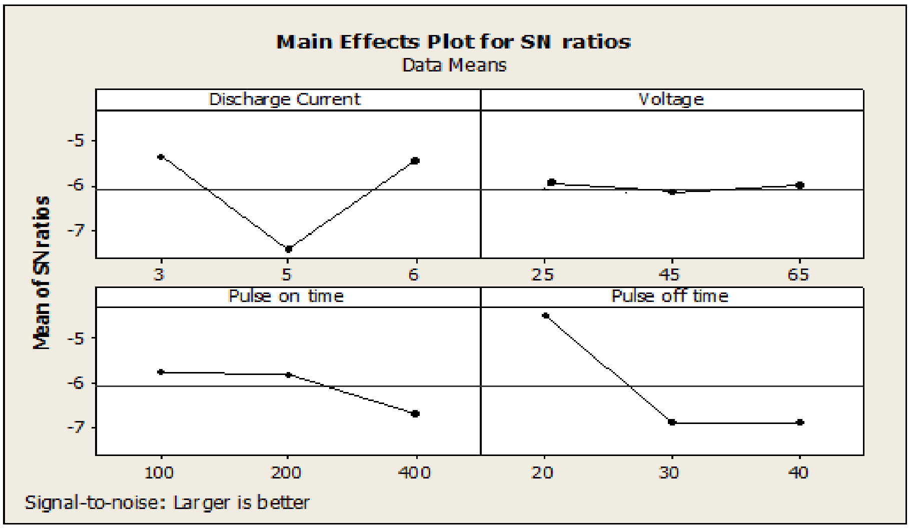

Fig.7: Main Effects Plot for S/N Ratio of grey relational grade

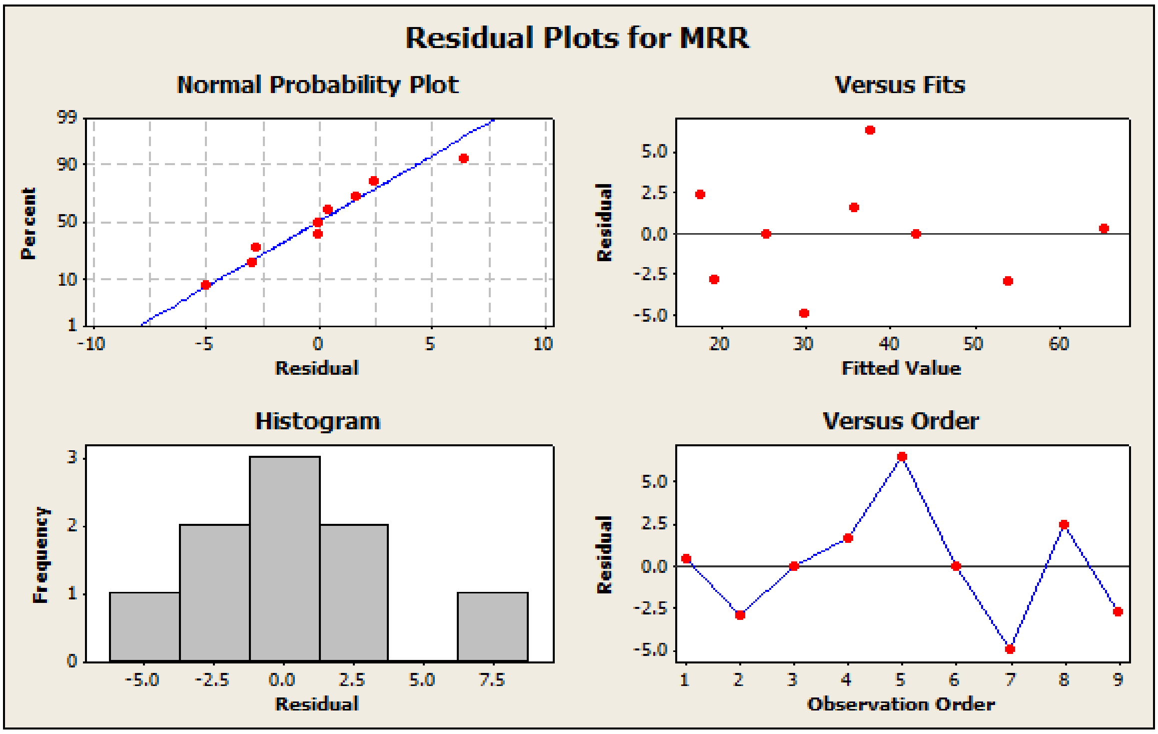

Fig.8: Residual Plots for MRR

Table 3: Anova for Material Removal Rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Current	2	20.797	20.797	10.3985	21.56	0.002
Voltage	2	2.437	2.437	1.2187	1.22	0.305
Pulse on Time	2	2.523	2.523	1.2616	0.03	0.458
Pulse off Time	2	104.243	104.243	52.121	0.39	0.554

From above table, it is also observed that, the Pulse off time (µs) is the most influencing factor followed by the Current (A), the Voltage (V) and Pulse on Time (µs), for obtaining the best multi response characteristic. Therefore, longer time will be available for flushing the debris particles, which results in effective flushing. The confirmation experiment was conducted by choosing the parameters having the highest relational grade (3A, 25V, 100µs and 20µs) obtained.

V. CONCLUSION

The following conclusions were reached after nine experiments with varied process variables.

- To enhancing the combination for machining tungsten carbide over the give range using analysis of grey relational which show the study is at its best value discharge current (3A), Voltage (25V), T_{on} (100µs) and T_{off} (20µs).
- In the EDM process, surface roughness values and the rate of material removal are measured to produce better results due to the difficulty in machining alloying elements.
- The rate of material removal increased and the roughness was decrease in the discharge machining by electrical process.
- For rate of material removal, T_{off} is most influencing factor and then discharge current and after that T_{on} and last is voltage.

VI.FUTURE SCOPE

We could be taken further by making some modifications in the design of the tool for achievement of better machining, particularly for the alloy materials and composite materials, which has the combination of the hard and the soft particles. Experiments also can be carried out other process parameter by using genetic algorithms.

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