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A PARAMETRIC RESEARCH AND EXPERIMENTAL INVESTIGATION OF THE MATERIAL REMOVAL CAPABILITIES OF ULTRASONIC ASSISTED ELECTRIC DISCHARGE MACHINING

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Abstract

Metal matrix composites (MMCS) have been exposed due to the advancement of contemporary materials. A metal matrix composite (MMC) is a composite material made up of at least two constituent pieces, one of which must be metal and the other of which can be another metal or another material, such as a ceramic or organic compound. Carbon fibers are extensively employed in aluminum matrix composites with high strength and low density. Non-traditional machining procedure Electrical discharge machining (EDM) is a technique used to machine electrically conductive materials. The influence of input factors (voltage, peak current, pulse on time, pulse off time) on output parameters including material removal rate, surface roughness, and electrode/Tool wear ratio (TWR) is demonstrated in this study. The results will show the relationship between input variables with responses which is obtained from Design of Experiments (DOE).

Keywords: Metal matrix composites (MMCs), Electric Discharge machining (EDM), Ultrasonic Assisted Electric Discharge Machining (UAEDM), Material Removal Rate (MRR)

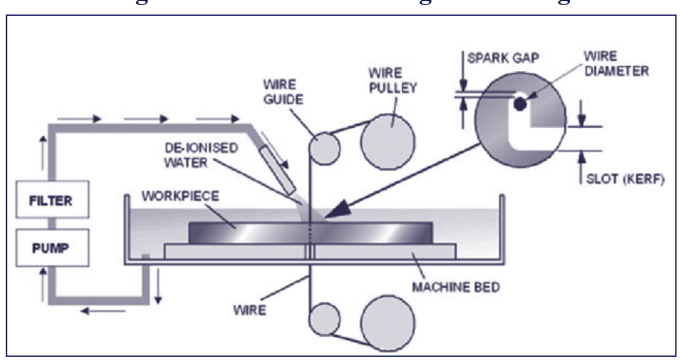
INTRODUCTION

Manufacturing sectors have recently faced hurdles in meeting client demands to expand their worldwide market within specified time frames. Customers in the worldwide market face competition and ever-increasing expectations for innovation of new developing materials, which are extremely complex and difficult to produce using classic machining processes. [1-3]. The majority of EDM research is focused on increasing key performance indicators such as machining rate, tool wear, and surface roughness. Other aspects in EDM systems, such as metallurgical and tribological characteristics and machined surface precision, are not controlling considerations, though advancements are welcomed. In this study, the response factors evaluated for evaluating the performance of ultrasonic-assisted EDM include machining rates, tool wear, and surface roughness [4]. Non-traditional machining processes can provide a solution, in which no contact of material and tool and thermal, mechanical, or chemical type of energy is used for the machining process to set the desired standard of customer satisfaction. EDM is a Thermoelectric base non-traditional machining process used to produce complex, geometrical, and dimensional accurate profiles, etc. Machining of parts in aerospace, automotive industries, medical, tool and die, etc. are preferable by EDM [5].

1.1 Wire electric discharge machining

The electrode wire is connected to the cathode of the impulse power source, and the workpiece is connected to the anode of the impulse power source. When the workpiece is approaching the electrode wire in the insulating liquid and the gap between them getting small to a certain value, the insulating liquid was broken through very quickly, discharging channel forms, and electrical discharging happens [6-8]. And release high temperatures immediately, up to over 10000 degrees centigrade, the workpiece (eroded) cooling down swiftly in working liquid and flushed away (Fig.1).

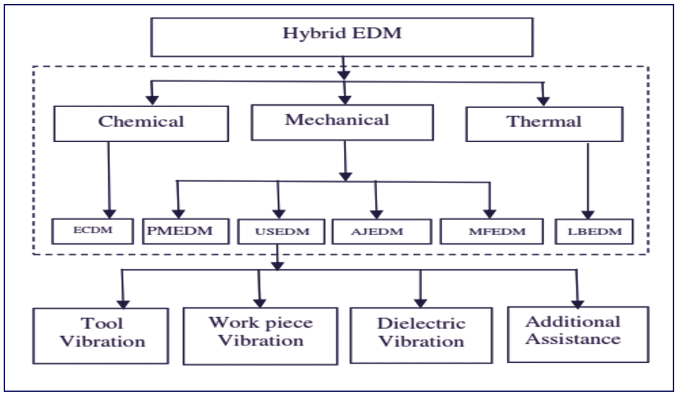
Fig. 1 Wire electric discharge machining



1.2 Hybrid Electric Discharge Machining

A hybrid advanced machining process merges two or more processes for a more efficient material removal (Fig.2). The present paper discussed Ultrasonic Assisted Electric Discharge Machining in detail.

Fig. 2 Hybrid Electric Discharge Machining

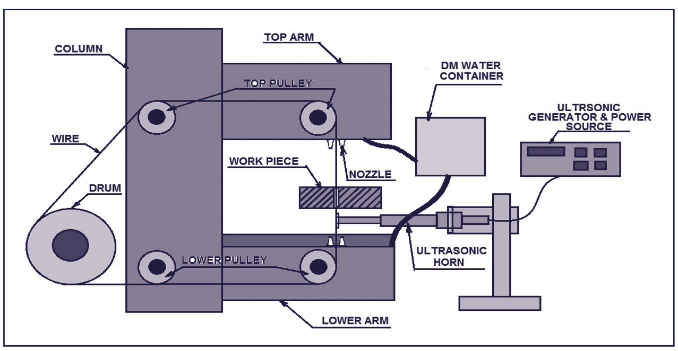


These hybridizations in EDM not only improve the speed but also make the machining of advanced materials possible, which cannot be machined efficiently [9-11]. The hybrid USEDM process has been proposed to machine high-strength materials i.e., composites and super alloys with complex geometries successfully.

1.3 Ultrasonic-Assisted Electric Discharge Machining (UAEDM)

In the USEDM, the stationary discharge gap is replaced by the relative reciprocating motion of the sub-system (tool, workpiece) to test various strategies to enhance the better circulation of dielectric fluid and process stability (Fig.3).

Fig. 3 Ultrasonic-Assisted Electric Discharge Machining Schematic Diagram



Electrical parameters such as polarity, voltage, current, pulse on time, pulse off time, and so on are affected directly by the UAEDM process, as are nonelectrical parameters such as flushing pressure and dielectric medium, electrode base parameters such as electrode size, electrode shape, and electrode material, and ultrasonic base parameters such as frequency, ultrasonic power, amplitude, capacitance, and so on. [12-15].

2. EXPERIMENT DETAILS

All investigations were carried out on a developed WEDM employing ultrasonic vibration. The workpiece is stationary, and the wire moves up, down, and rotates (Fig.4). A circular Tungustan bar with a WC head (wire holder) fitted between the two wire guides transmits the ultrasonic vibration from the ultrasonic transducer to the wire (Fig.5).

Fig. 4 Ultrasonic-Assisted Electric Discharge Machining.

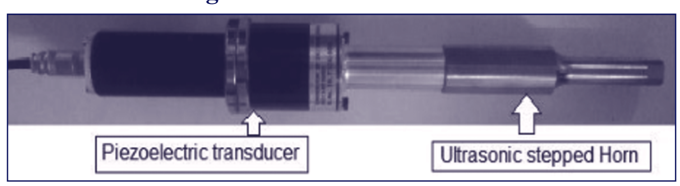
During the machining process, the wire electrode passes through the groove in the wire holder. The concentrator amplifies the vibration of the wire. The amplitude of the wire vibration affects the output power of the ultrasonic power. When the wire is driven, the transducer and wire holder vibrate in a longitudinal direction due to the resonance condition. These investigations concentrated on the impact of many controllable parameters on the MRR, as well as surface roughness and roundness. The mean cutting feed rate () was observed directly from the computer monitor attached to the machine tool. Equation 1 can be obtained to describe MRR.

$$\mathrm{MRR} = \pi(R^2\text{-}r^2)\,.\,v_f$$

----- Equation-1

where r is the new reduced radius of the workpiece after machining and R is the original radius of the workpiece.

Fig. 5 Ultrasonic transducer



Composite material is made by merging two or more materials frequently that have many different properties. Composite unique properties are given by these two materials working together. It has better strength, hardness, and toughness than ordinary materials [16].

Fig. 6 Al-CFRP Stack Material

Composite materials are classified as metal matrix composite, ceramic matrix composite, polymer matrix composite, and stack materials. carbon fibers used in the aluminum 6061 to integrate composites showing high strength and low density. Though, carbon reacts with aluminum to cause a brittle and al4c3 (water-soluble compound) on the surface of the fiber (Fig.6). The carbon fibers are coated with nickel or titanium boride to prevent this reaction [16].

The effect of the amplitude of ultrasonic vibration on the Current, Pulse off Time, Pulse on Time, and Amplitude was investigated [17-19]. The power parameter specifies the average electrical discharge current to the gap. The power and voltage indicate discharge energy. voltage increases the MRR as an increase in power (Table 1).

As shown, higher values of MRR can be obtained by selecting a greater power and higher values of the ultrasonic vibration amplitude [20]. It was indicated that increasing the ultrasonic vibration amplitude led to an MRR increase. The higher MRR gained by the employment of ultrasonic vibration is mainly attributed to the improvement in flushing, the creation of cavitation, and the cause of easier discharge breakdown.

Table 1: Test results for model parameters.

Sr No	Current	Pulse off Time	Pulse on Time	Amplitude
1	4	3	34	50
2	4	5	34	50
3	4	7	34	50
4	4	9	34	50
5	4	11	34	50
6	2	7	34	50
7	3	7	34	50
8	4	7	34	50
9	5	7	34	50
10	6	7	34	50
11	4	7	16	50
12	4	7	25	50
13	4	7	34	50
14	4	7	43	50
15	4	7	52	50
16	4	7	34	30
17	4	7	34	40
18	4	7	34	50
19	4	7	34	60
20	4	7	34	70

Fig.7 Effect of Pulse off Time on MRR and TWR at I_g=4A and T_{on}=6 µs for different values of ultrasonic power [23]

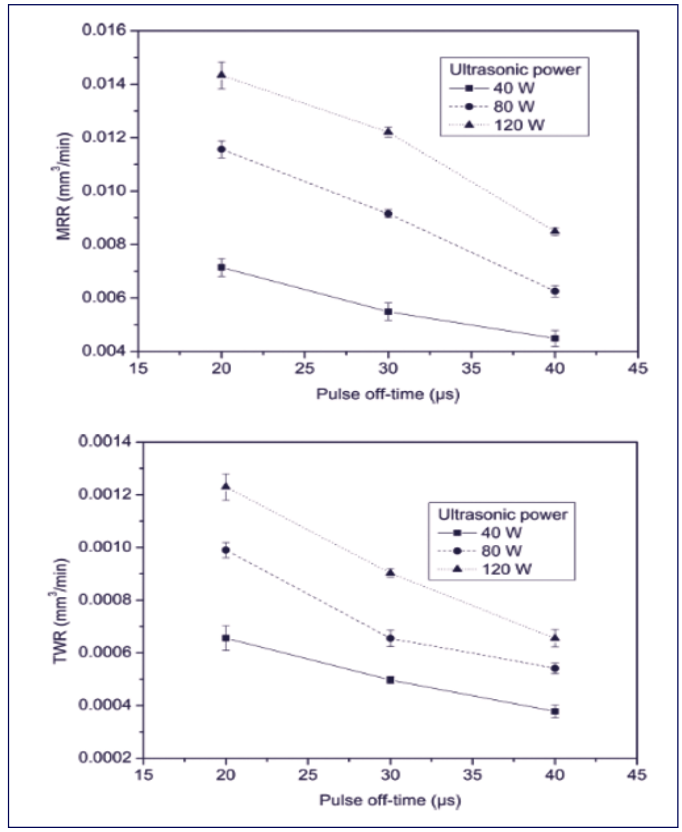
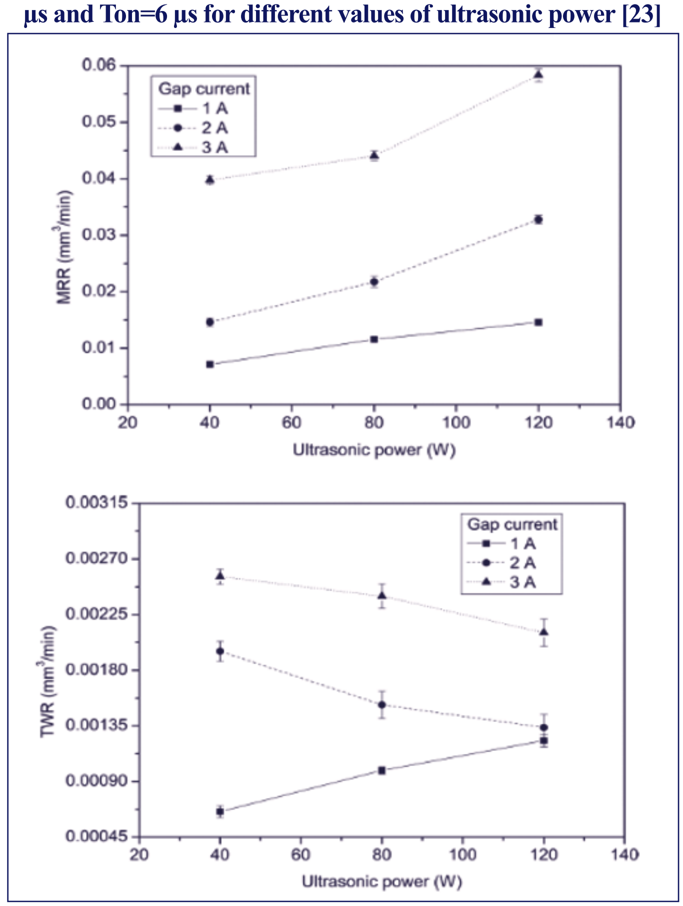


Fig.8 Effect of Ultrasonic Power on MRR and TWR at Toff=20 µs and Ton=6 µs for different values of ultrasonic power [23]

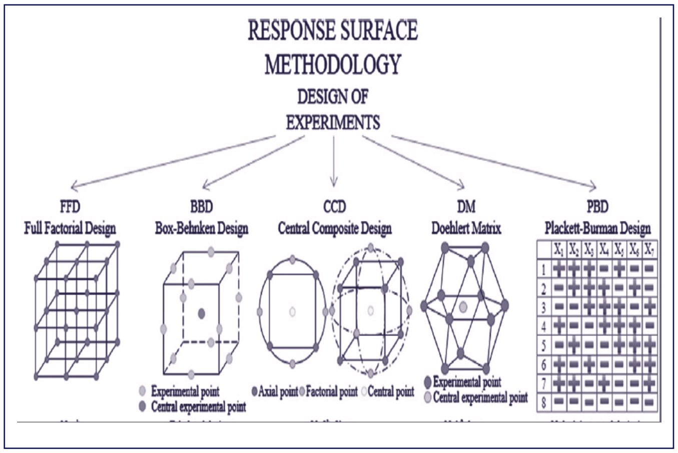


The plot of the MRR vs. the time-off and the ultrasonic power is shown (Fig-7,Fig.8). The MRR decreases as the duration between two cycles increases, whereas increasing the ultrasonic power causes cavitation and a rise in the MRR [21]. The results clearly reveal that ultrasonic has a major impact on tool wear rate. The increased tool wear related with ultrasonic sparking efficiency. The reduced occurrence of arcing may account for the occasional example of lower tool wear rate with ultrasonic [22].

3. RESPONSE SURFACE METHODOLOGY

The design of experiments is interpreted as a division of applied statistics that assigns analyzing, planning, and conducting controlled tests to evaluate the factors that control the value of a parameter or group of parameters (Fig.9).

Fig. 9 Response Surface Methodology



It is a Data Collection and Analysis tool. All possible combinations can be investigated (full factorial) or only a portion of the possible combinations (fractional factorial). Box-Behnken design is a response surface methodology (RSM) design. The different factor values are referred to as “levels”. Special 3 level design because there are no points at the edges of the experiment area. The points on the corners represent level combinations which are either too expensive or too difficult to test due to physical process limitations (Fig. 10).

Fig. 10 Box-Behnken

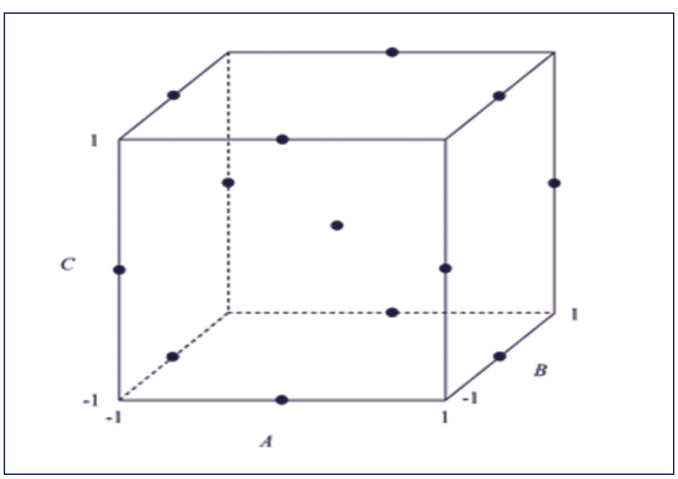


Table 2: Vertices of the experiment region Points.

Runs	Factors		
	A	B	C
1	-1	-1	0
2	-1	1	0
3	1	-1	0
4	1	1	0
5	-1	0	-1
6	-1	0	1
7	1	0	-1
8	1	0	1
9	0	-1	-1
10	0	-1	1
11	0	1	-1
12	0	1	1
13	0	0	0

There are no corners in the experimental range. There are fewer design points in BBD than in CCD. This makes it less expensive to run the same number of factors. BBD never includes runs with all factors at their extreme settings or all factors at their low settings. Unlike CCD, FCD will have more ‘no’ experiments. Performing that many experiments will lead to excessive loss of resources. Based on literature, the percentage deviation is very high in Taguchi. This is why RSM was chosen. It limits the data loss. It does not include corner points data. It avoids the combined factor effect (Table 2).

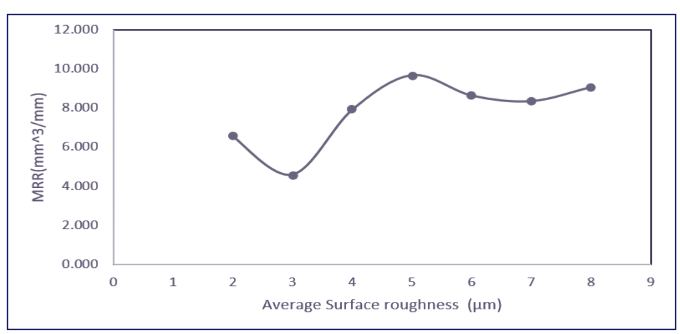
4. RESEARCH AND DISCUSSION

Five sets of experiments were carried out with the composite material of aluminum and Carbon fiber to show the effects of discharge current, pulse duration, the wall thickness of the pipe electrode, the amplitude of ultrasonic vibration, and gas medium on the MRR. Some observations of the roughness of the machined surface were also made.

4.1 The effect of amplitude of average surface roughness on MRR

According to the test results, the material removal rate initially slightly decreases but then gradually increases with average surface roughness (Fig. 11). After reaching a maximum of 10, the MRR’s value becomes stable. It is discovered that the amplitude of ultrasonic vibration has no discernible effect on surface roughness. Ra, the measure of surface roughness, stabilizes at 0.08 mm.

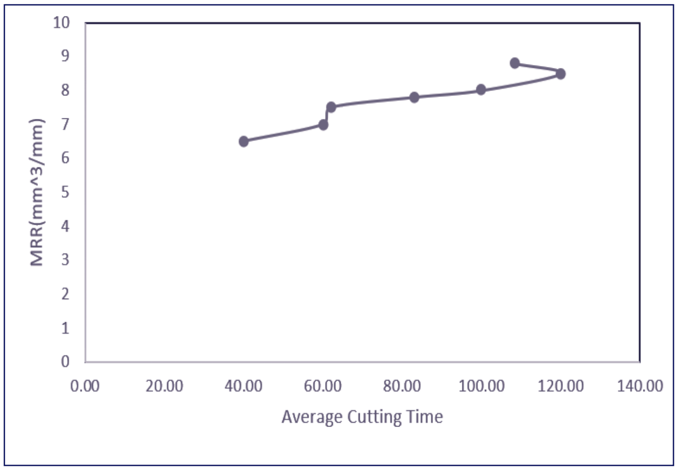
Fig.11 The effect of amplitude of average surface roughness on MRR



4.2 The effect of average cutting time on MRR

The experiment used a 10mm length, and the graph that resulted is shown below (Fig. 12). The relationship between the MRR and the average cutting time is easily seen. At an MRR value of 8, the maximum value of cutting time is 120; after that, cutting time decreases.

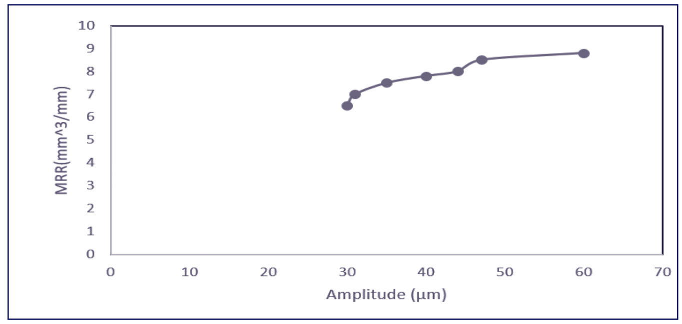
Fig.12 The effect of amplitude of average cutting time on MRR



4.3 The effect of amplitude of ultrasonic vibration on MRR

The results of the tests demonstrate that the rate of material removal increases as the amplitude of the ultrasonic vibration increases (Fig.13). It is thought that if a workpiece vibrates at an ultrasonic frequency, the molten workpiece material may be expelled from the base body of the workpiece without having to be reattached to the tool-workpiece, MRR would improve.

Fig.13 The effect of amplitude of average cutting time on MRR



4.4 The effect of Current & Pulse Off on Cutting time & Surface Roughness

According to the test's results and the graph that is displayed below (fig. 13). Cutting time increases and surface roughness progressively reduces as pulse off time increases. Additionally, cutting time decreases and surface roughness rises as current increases.

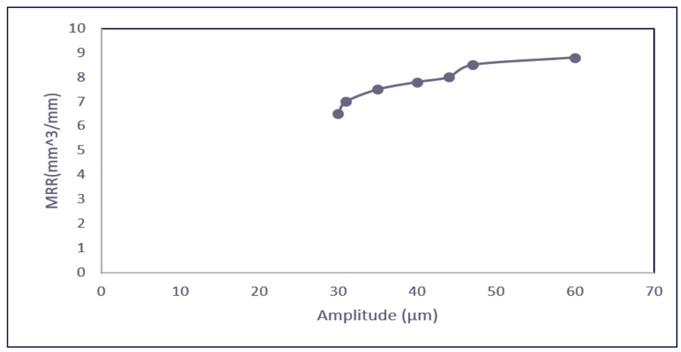
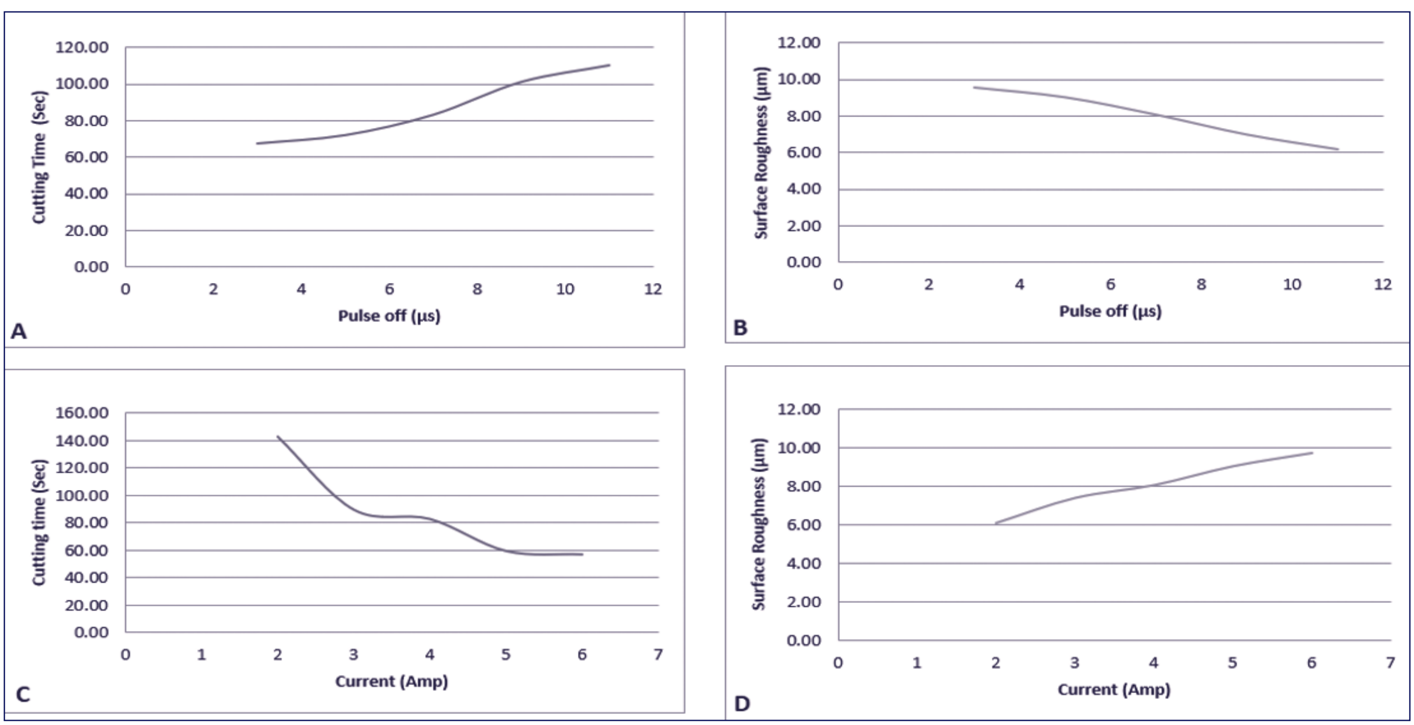


Fig.13 (A) The effect of Pulse off on Cutting Time (B) The effect of Pulse off on Surface Roughness (C) The effect of Current on Cutting Time (D) The effect of Current on Surface Roughness



5. CONCLUSIONS

Hybrid electric discharge machining shows that it's a great option for MMCs and the most dependable nonconventional process. Ultrasonic vibration helps improve the MRR, roughness, and size of the cracks because of the low arcing, slow pulses, cavitation, and steady discharge. In traditional EDM processes, the cracks tend to be bigger and deeper on the workpiece than in Ultrasonic-assisted EDM processes. The size of the crack doesn't just depend on the electrical discharge parameters, voltage, top current, and pulse on time.

6. FUTURE SCOPE

Future research has been identified to improve productivity and machinability by strengthening the UAEDM process. Machining Characteristics can be improved by the use of the UAEDM process and also found optimum machining process parameters by use of different optimization techniques.

In high pulse energies, the recast layer's thickness and the length and thickness of splits in US- EDM is more than in traditional EDM.

MRR is increased four times in the USEDM process than in the EDM process at short pulse on-times and MRR is reduced at long pulse on time.

MMC Aluminium and carbon fiber result show increasing discharge current and pulse duration, and MRR rate is increased as the workpiece.

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