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Parametric Study and Experimental Investigation of Material Removal Capability with Ultrasonic Assisted Electric Discharge Machining

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Abstract

The development of modern materials has caused the exposure of metal matrix composites (MMCS). A metal matrix composite (MMC) is a composite material with at least two constituent parts, one necessarily metal, and the other may be a different metal or another material, such as a ceramic or organic compound. Carbon fibers are commonly used in the aluminum matrix to integrate composites showing high strength and low density.Non-conventional machining process Electrical discharge machining (EDM) is for machining electrically conductive materials.This research illustrates the effect of input variables (voltage, peak current, pulse on time, pulse off time) on output parameters like material removal rate, surface roughness, and electrode/Tool wear ratio (TWR).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, Material Removal Rate (MRR)

1. Introduction

In recent times, Manufacturing industries have had challenges satisfying the requirements of customers to increase their global market within stipulated periods. Customers of the global market have competition and continuously increasing standards of satisfaction for innovation of new emerging materials, which is very complex and difficult to be a machine by use of traditional machining process [1-3].

Most research in EDM is directed toward improving the major performance indices, such as machining rate, tool wear, and surface roughness. Other factors in EDM systems, e.g., metallurgical and tribological properties and accuracy of the machined surfaces, are not governing factors, although improvements are appreciated. In this investigation, therefore, the response variables considered for the performance evaluation of ultrasonic-assisted EDM are 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

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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].

1.1Wire 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).

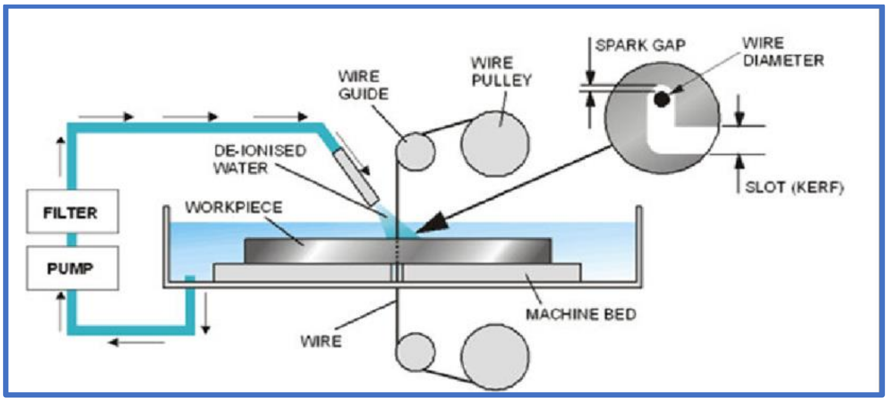

Fig. 1Wire electric discharge machining

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.

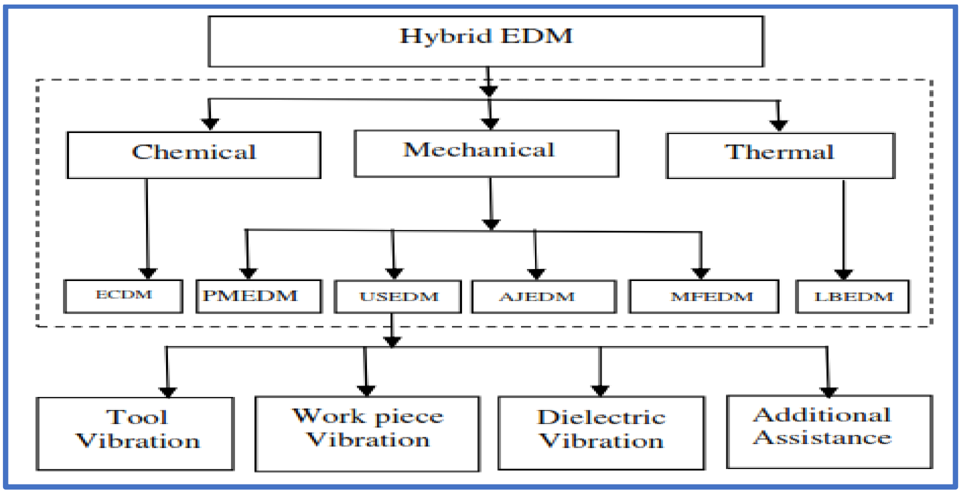

Fig. 2Hybrid Electric Discharge Machining

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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

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).

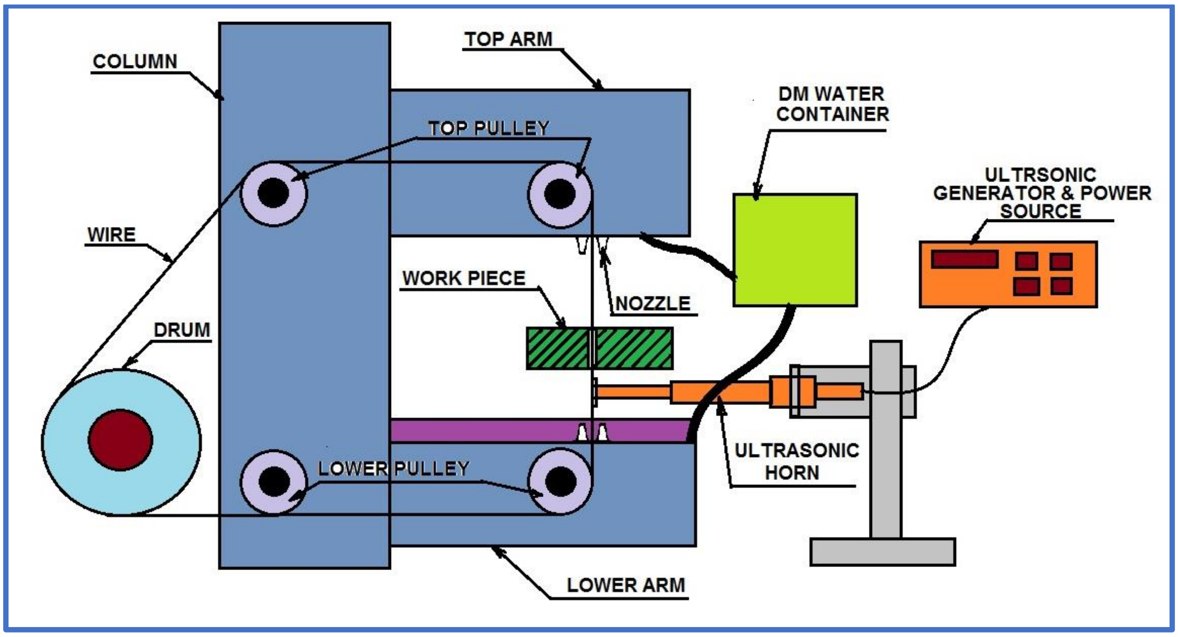


Fig. 3Ultrasonic-Assisted Electric Discharge Machining

UAEDM process has electrical parameters like polarity, voltage, current; pulse on time, pulse off time, etc., nonelectrical parameters like flushing pressure and dielectric medium, electrode base parameters like electrode size, electrode shape, and electrode material, etc., and ultrasonic base parameters like frequency, ultrasonic power, amplitude, capacitance, etc. are affected directly to machining process and the surface of machining. Machining process parameters of UAEDM [12-15].

2. Experiment Details

All experiments were conducted on a developed WEDT using ultrasonic vibration. The workpiece is fixed and the wire is moving up, down, and rotating. (Fig.4). A round stainless-steel bar with a WC head (wire holder) transmitting the ultrasonic vibration from the ultrasonic transducer to the wire is installed between the two wire guides (Fig.5).

Fig. 4 Ultrasonic machine.

During machining, the wire electrode is traveling through the groove in the wire holder. The vibration of the wire is amplified by the concentrator. The output power of the Ultrasonic power is adjusted by the wire vibration amplitude. When the wire is being driven, the transducer and the wire holder vibrate under the resonance condition in a longitudinal direction. These experiments were focused on the effects of several manageable factors on the MRR and the surface roughness and roundness. The mean cutting feed rate (v_f) was observed directly from the computer monitor attached to the machine tool. Equation 1 can be obtained to describe MRR.

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

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

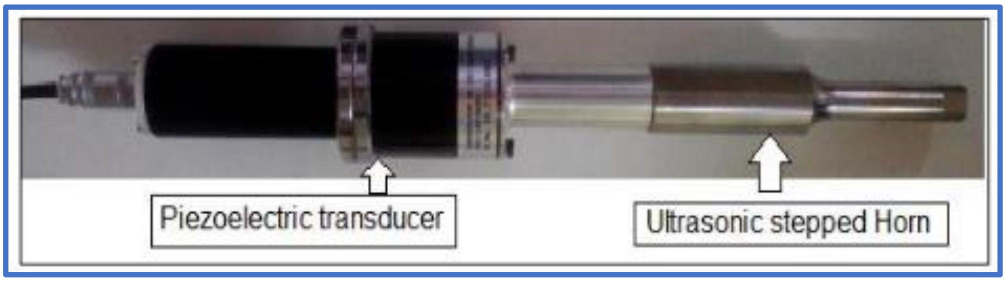


Fig. 5 Ultrasonic transducer

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].

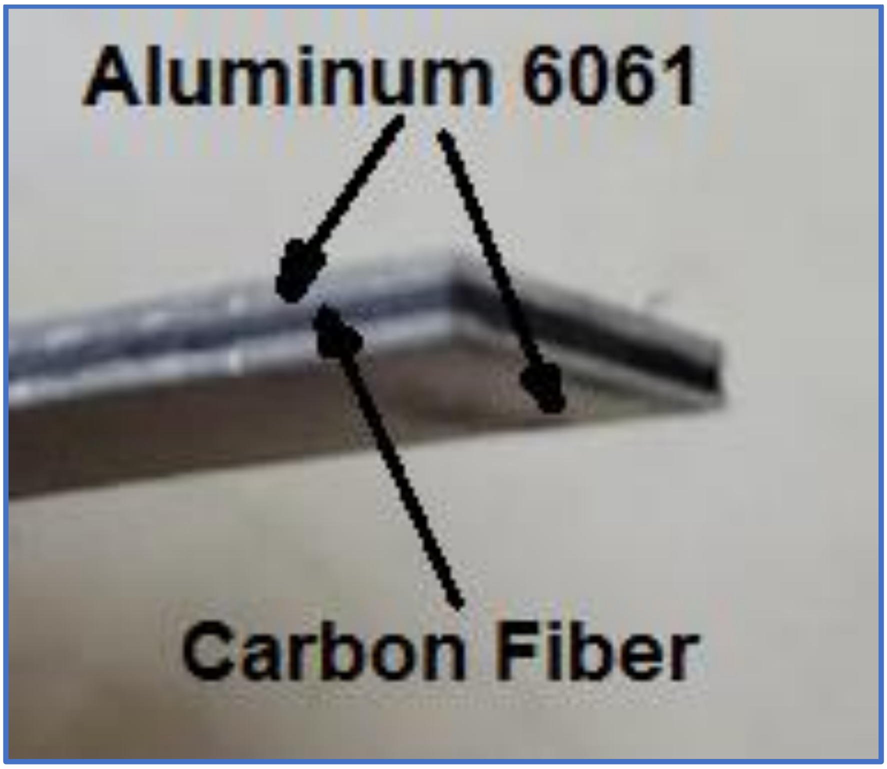


Fig. 6Al-CFRP Stack Material

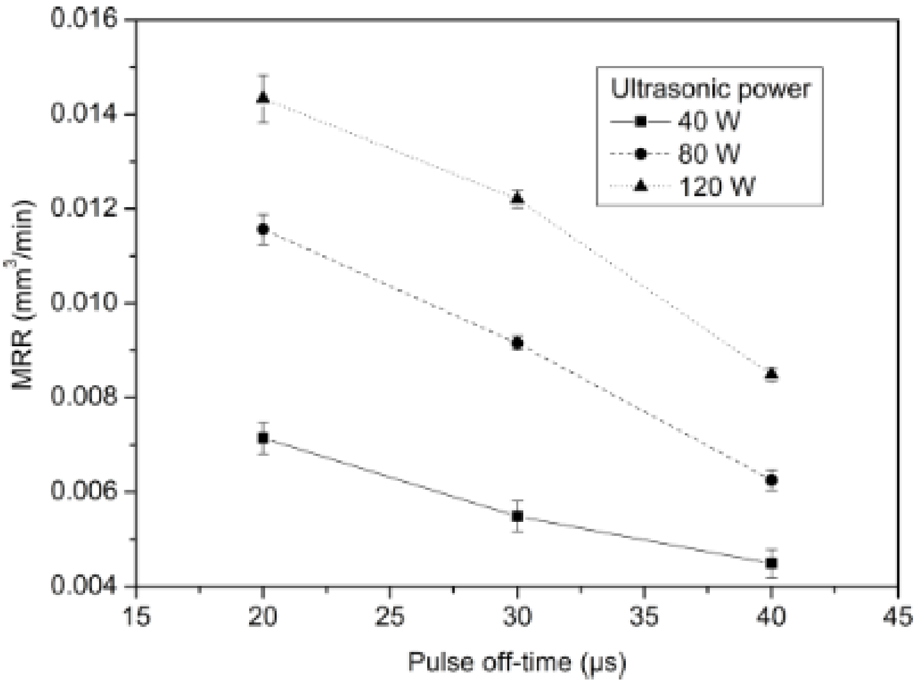
Composite materials are classified as metal matrix composite, ceramic matrix composite, polymer matrix composite, and stack materials. Carbon fibers used in the aluminum 6061 to integrate composites showing high strength and low density. Though, carbon reacts with aluminum to cause a brittle and al4c3(water-soluble 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 cavitations, 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



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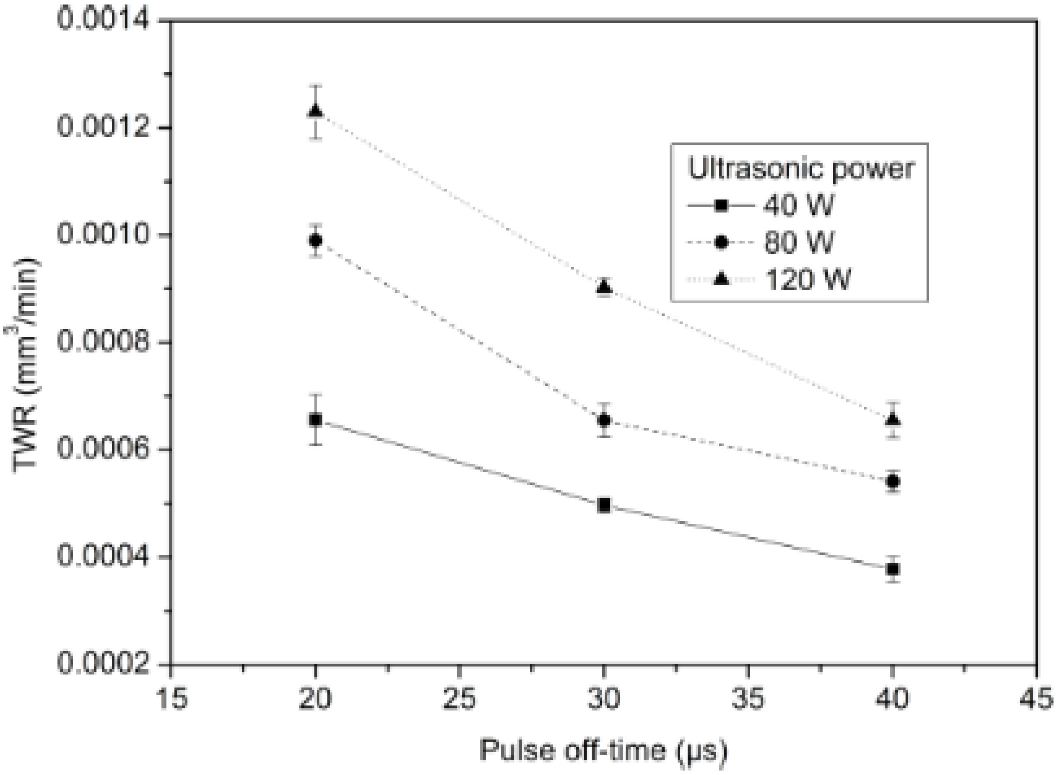
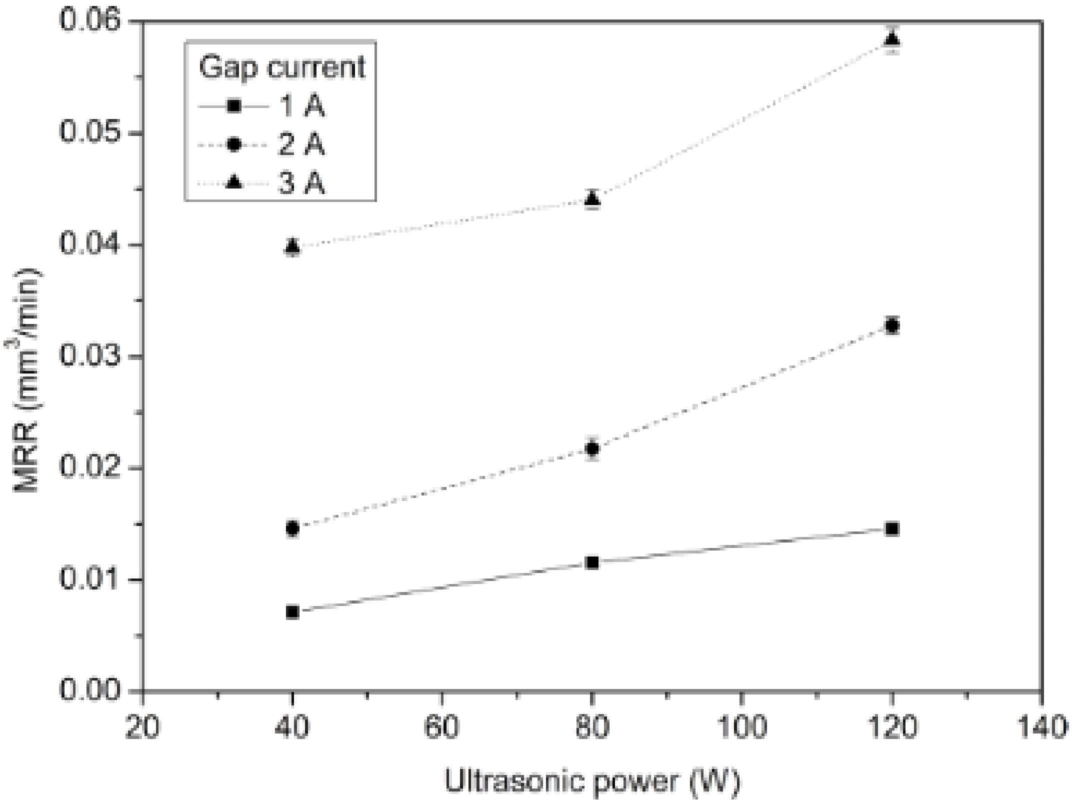


Fig.7 Effect of Pulse off Time on MRR and TWR at I_g=4A and T_{on}=6 μs for different values of ultrasonic power [23]



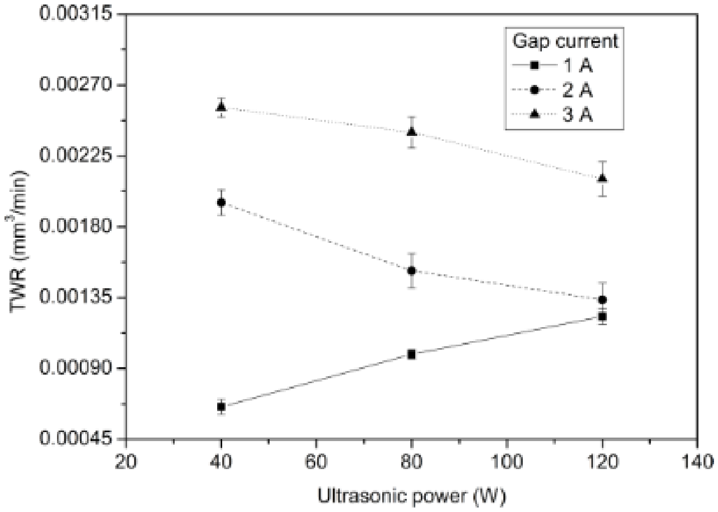


Fig.8 Effect of Ultrasonic Power on MRR and TWR at T_{off}=20 µs and T_{on}=6 µs for different values of ultrasonic power [23]

The plot of the MRR vs. the time-off and the ultrasonic power is shown (Fig-7,Fig.8). Increasing the time between two cycles results in a decrease in the MRR, and increasing the ultrasonic power results in the formation of cavitations and an increase in the MRR [21]. The result clearly shows that the tool wear rate is significantly influenced by ultrasonic. The better sparking efficiency associated with ultrasonic results in greater tool wear. The occasional case of lower tool wear rate with ultrasonic may beat tribute to the reduced incidence of arcing [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).

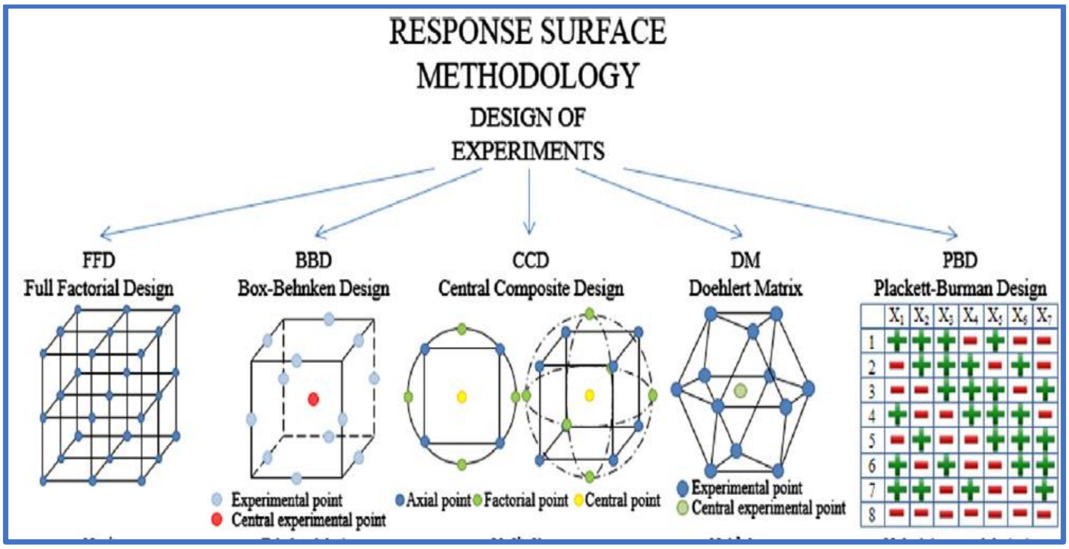


Fig. 9 Response Surface Methodology

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. Different factor values are called levels. Special 3-level design because it does not contain any points at the vertices of the experiment region Points on the corners of the cube represent level combinations that are prohibitively expensive or impossible to test because of physical process constraints (Fig.10).

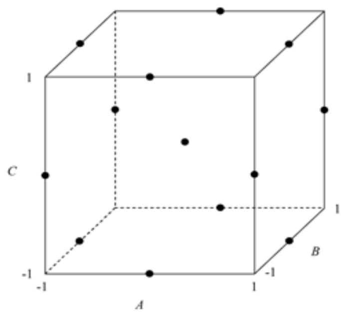


Fig. 10Box-Behnken

Table 2: Vertices of the experiment regionPoints.

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 point lies on corners of the experimental range. There are fewer design points than CCD, which results in less expensive to run with the same number of factors. BBD never include runs where all factors are at their extreme setting or such as all of the low settings, unlike CCD.FFD will have more no. of experiments and performing that many experiments will result in excess loss of resources. From the literature it has been found that the percentage deviation is high in Taguchi, hence RSM was selected. It restricts the potential data loss. As it does not contain corner points data and avoids the combined factor factors 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

The test result shows that the material removal rate slightly decreases in the initial phase but increases with the average surface roughness (Fig.11). Maximum MRR value is 10 and after that its value is stable. The surface roughness is not found to affected by the amplitude of ultrasonic vibration clearly. The surface roughness, Ra, stabilizes at about 0.08 mm.

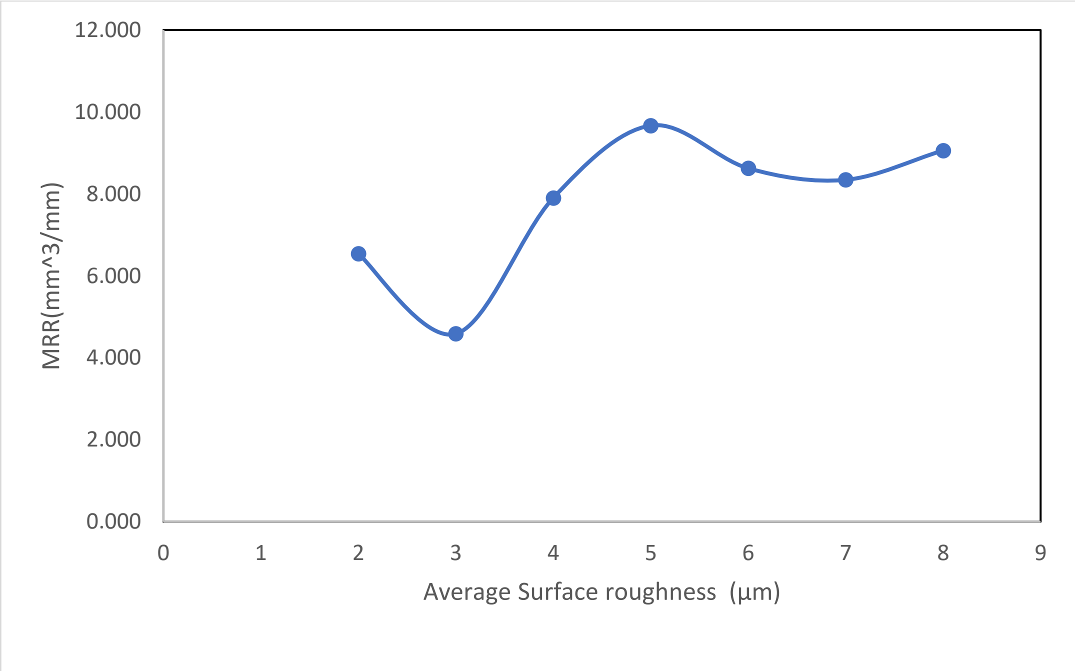


Fig.11 The effect of amplitude of average surface roughness on MRR

4.2 The effect of average cutting time on MRR

The experiment took on the 10mm length and the resulting graph (Fig.12) is shown below. It is clearly visualized that the MRR increases with the Average cutting time. The maximum value of cutting time is 120 at the MRR value 8, after that cutting time is decreased.

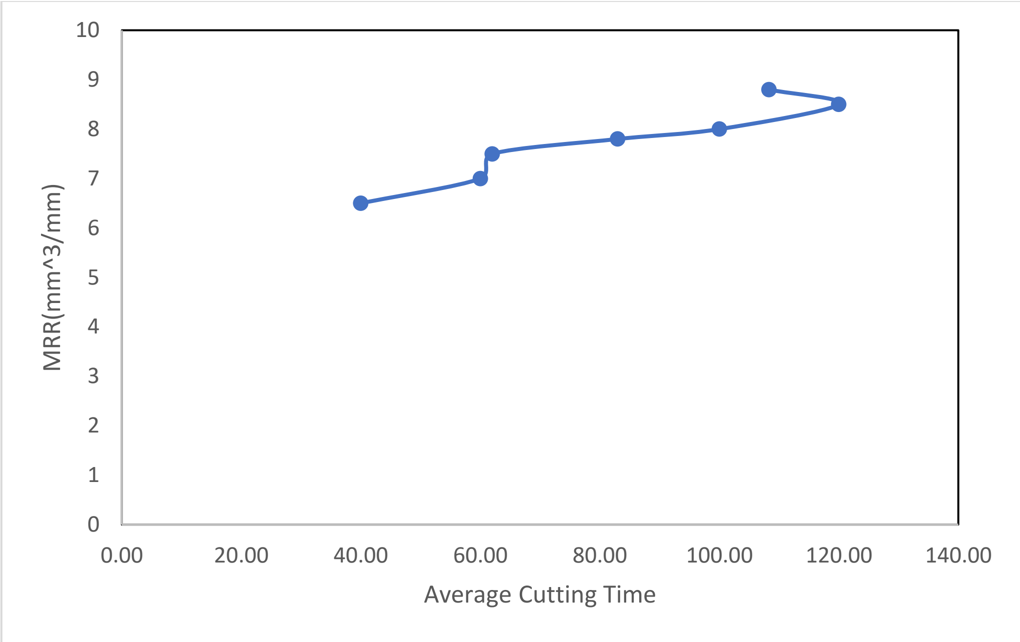


Fig.12 The effect of amplitude of average cutting time on MRR

4.3 The effect of amplitude of ultrasonic vibration on MRR

Test results show that the material removal rate tends to increase with the increase of the amplitude of ultrasonic vibration (Fig.13). It is considered that a workpiece vibrating with ultrasonic frequency can have the molten workpiece material ejected out from the base body of the workpiece without being reattached to the tool-workpiece again, it is beneficial to MRR improve.

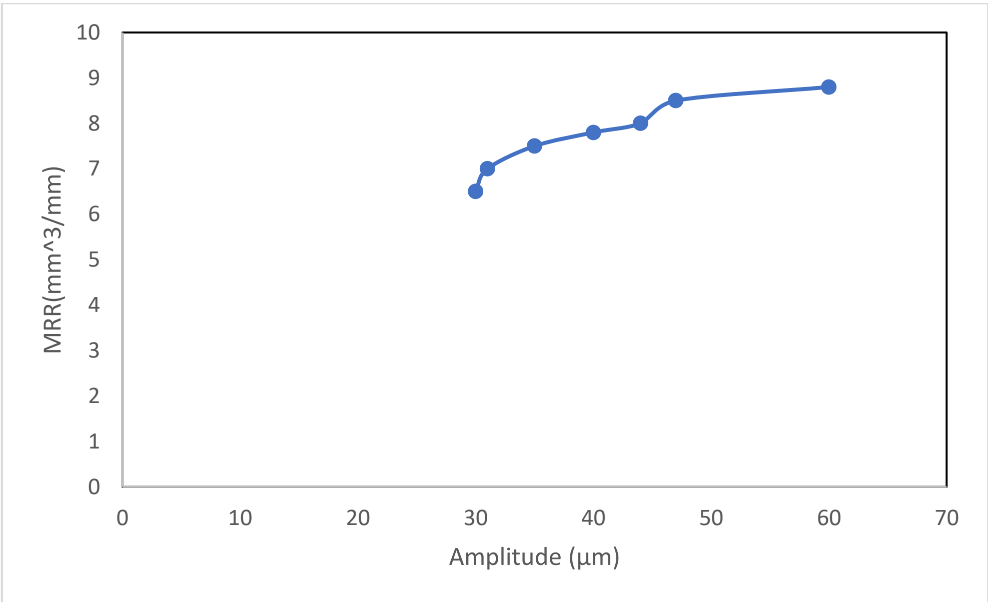


Fig.13 The effect of amplitude of average cutting time on MRR

5. Conclusions

It can be shown from the above result that the use of Hybrid electric discharge machining is a promising and the most reliable nonconventional machining process for MMCs. Ultrasonic vibration assistance increases the MRR, surface roughness, and amplitude due to the reduced arcing, inactive pulses, cavitations effect, and stable discharge. Cracks in traditional EDM processes are developed larger and bigger on the surface of the workpiece than Ultrasonic assisted EDM processes. The smaller crack depends not just on electrical discharge parameters, discharge voltage, peak current, and pulse on time.

7.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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