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EDM Parametric Study of Composite Materials: A Review

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Abstract: This paper outlines the findings of the investigational studies performed to explore the impact of the electrical discharge machining method and input variables on the properties of the output parameters. EDM allows the machining of very hard and high temperature resistant metals and alloys such as super-alloys, carbides, ceramic, composites and heat-resistant alloy. However, these products are challenging to produce owing to the need for higher cutting strength and large machine usage costs. EDM offers a minimal machining force with an appropriate tooling expense is a promising non-conventional machining method for machining Composites. As electrical erosion method is commonly used for the manufacturing of composites with further uses in the construction, aircraft and automotive industries. Composites have desirable physical as well as mechanical properties such as light weight, high specific modulus, higher toughness and Strength and thermal resilience. Due to wide range of application of composites nowadays the present analysis addresses the EDM and its input and output parameters such as T_{on}, T_{off} and Discharge Current, etc. on the MRR and SR especially for the composites.

The goal of this paper is to examine past work and to establish a path forward for study.

Keywords: EDM, Composites, MRR, Process Parameters

1. Introduction

Electric Discharge Machining (EDM) is based on non-conventional process method, i.e. into which there is any mechanical interaction between the device and the workpiece[1]. In traditional machining methods, the machining of complex form as in the aircraft engine industry[2], the machining costs are high and the surface finish is not valued either. The job material is machined by EDM via spark erosion[3]. When spark is generated in between work material anode as well as the electrode Cathode, Die electric fluid is a source of liquid[4]; it does not conduct electrical current. Forms of the EDM include Micro-EDM, Die- Sinker EDM and Wire-Cut EDM[5]. The number of EDM-processed materials is very high. Several of the common components that are used in the engineering and medical industries[6] are the following below. Tool Steels[7], Duplex Steel[8], Tungsten Carbide[9], Stellite[10], Hastalloy[11], EN-31 Die steel[12], Nitralloy[13], SKD-11 alloy[14], Waspaloy[13], Inconel[15], Inconel 825[16] with nano powders, Aluminum alloys[17], Copper, Stainless Steel[18], Brass, Titanium[19], Gold, Silver, Spring Metal, Bronze, Super Alloy[20]. Quite hard and difficult to process metals, Tungsten carbide ceramic[21], Sintered carbides[22], Zirconia ceramic[23], Iron copper alloy[24], Insulating ceramics Si_3N_4, Aluminum-reinforced silicon carbide matrix, Aluminum composite Al_2O_3/6061[25], Al/SiCp composite[26], Gamma-titanium aluminum alloy, ceramics and composites, Al_2O_3 reinforced particulate alloy, Aluminum composites with fly ash, Aluminum composites with egg shells[27], Aluminum composites with ground nut shells[28], ABS and PLA based reinforced composite[29], Nanocomposites[30],[31],[32] E-Glass reinforced hybrid polypropylene composites[33], Nanocrystalline diamond amorphous carbon composite[34] and some other composites[35],[36].

Taguchi methodology is the simplest way to organize experiment design to draw up the orthogonal arrays and the approach is also very reliable, quick and systematic path to optimizing techniques[37]. While increasing the number of process parameters a large number of experimental works need to be accepted[38]. The Taguchi method approach utilizes a special arrangement for orthogonal arrays[39] to redesign the whole process parameters with only a limited number of experiments used to solve the issue above[40]. The best benefit of this approach is to reduce the effort involved in doing experiments[41]; saves lab time, minimize costs, and rapidly discover significant factors. The robust design method used by Taguchi is an important in designing a high consistently high quality device[42]. Several research studies that comprise been carried out to identify the affected process parameters for the EDM. Many research shows most important aspect of current and precision machining time on efficiency indicators of EDM[43].

2. Working

EDM is a thermal erosion method used to extract material through a number of small-duration, repetitive electrical discharges and higher current density[44] in between the workpiece and from the tool as shown in Fig.1. The removal of material in EDM is based on erosion of electric sparks taking place amid two electrodes[45]. There are numerous theories has in attempts to clarify the complicated phenomenon of "erosive spark"[23].

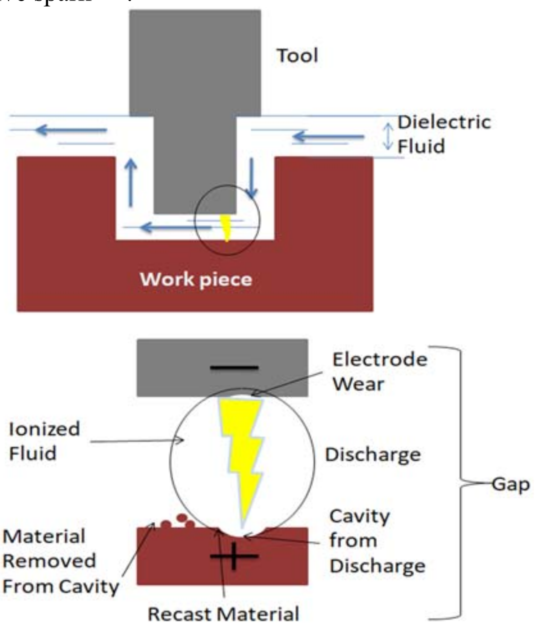

Fig.1: EDM Process Discharge and Material Removal

The EDM cycle runs in six stages for material removal operation[46].

1. The electrode reaches near a piece of work. The two systems are being energized.
2. Strength of the electric field about where the area in between both the electrode and the work is located closely.
3. Formation of an ionized stream here between work piece and an electrode between closest paths.
4. Spark breakdown occurs. The substance from the piece of work melts away locally and disintegrates then electrode just slightly wears out.
5. The current is then cut off which causes the spark to collapse.
6. Then Evacuation of the metallic particles by pressurized dielectric flushing.

3. Literature Review

Composites are well known over those of unreinforced alloys for their superior mechanical properties[25]. Nevertheless, the high cost of machining hinders a complete implementation of these advanced materials[47]. Unacceptable short life of the devices and the resultant sub-surface degradation[48] of the composites are the key problem to be addressed when the composites are machined by customary process. And this study paper discusses the viability for EDM use[49].

Also Composites are widely used as a electrode material nowadays[50], [51].

Table 1.Studies carried out on composite engineering materials

S.N	Ref.	Material	Technique	Particulars of Research
1.	[52]	Al–10 % SiCp Composite	Taguchi L27, ANOVA	Low flushing pressure allows the fibred reinforced particles to settle and assemble in the cutting zone resulting in regular breakage of the wire. The suggested flushing pressure set-value. It obtains the optimum combination of parameters for the above described response variables.
2.	[53]	15–35 % SiCp Al-359 MMC	4-Level Factorial Design, ANOVA	In the microstructure below the RLT, EDM sparking has been found to raise dramatically SR and causes insignificant softening of the subsurface. EDM processing greatly decreases fatigue strength, with greater deterioration resulting from higher levels of MRR.
3.	[49]	Cast MMC	2-Level Factorial experiment	The SiC particles had been identified to shield and defend from vaporization of the Al matrix, thereby reducing the rate of MRR. Along with nearby molten aluminum droplets, the un-melted particles SiC drop out of the MMC. Although the dielectric flushes

				away some aluminum droplets, others trap the loosen particles of SiC and then re-solidify them onto the face to structure a re-cast sheet. No crack was established in the RLT and the heat-affected zone softened region, beneath the RLT. The input power influence the MRR and depth of RLT but the Ip only controls an EDM surface finish.
4.	[54]	Al_2 O_3 Al-6061 Composite	Taguchi L9, ANOVA	The findings indicate that the applied Ip is the most important factor between Ip, pulse length and concentration of electrolytes for getting the highest MRR. This result is confirmed by experiments, and it is clarified in terms of matrix phase surface area and SG duration.
5.	[55]	Cast Al4 Cu -6Si Alloy10 % SiC	3-Level full Factorial Design, ANOVA	A second order, non-linear type mathematical model was established to define the relationship between process parameters of machining effect of Ip, Ton and air GV on MRR, TWR and radial over cut.
6.	[56]	Ceramic Composite TiB_2/SiC	Taguchi L9	Ton, Toff, and WT are considerable factors for CS. It increases with Ton increases, and decreases with Toff increases.
7.	[57]	Hybrid Al-SiC-B4C with Al-SiC-Glass MMCs	Taguchi L9	This study reports on the usage of EDM in machine cast silicon carbide boron carbide and cast aluminum silicon carbide glass hybrid MMC, and how MRR as well as surface finish vary in reaction to the different EDM parameters.
8.	[58], [59]	Al-6061/ Al_2O_3-20 % Composite	Taguchi L18 ANOVA, F-test, Lenth method	Experimentally it was found that the most significant parameters influencing on surface characteristics are abrasives size, abrasives concentration, and Ip.
9.	[60]	TiC/Fe MMC	Normalized Radial basis Function N/W with enhanced k-means Clustering	Four parameters of the input process such as Ton, Toff, WF rate including average GV were considered, whereas CS and KW were considered as the performance measures. The occurrence of non-conductive TiC particles and development of Fe_2O_3 make process quite unstable as well as stochastic while machining.
10.	[61]	Al 6063 SiCp MMC	RSM, ANOVA	The experimental findings and subsequent review showed that all parameters chosen for procedure were important. MRR increases upto an optimum level with rising Ip and Ton, and then decreases.

				Impact of Ip on MRR opposed to other parameters is predominant.
11.	[62]	Hybrid Composite (356/B4C /Fly Ash)	Taguchi L27, ANOVA	The five crucial process parameters like GV, Ton, Toff, WF and proportion reinforcement be taken as input parameters and MRR as output. The findings of the study of the S/N ratio reveal that GV is the mainly critical parameter for having high MRR, accompanied by Ton and Toff. Reinforcement parameters and WF are meaningless, since WEDM be capable to cut material for large hardness.
12.	[63]	Cast-Al/SiC Metal Matrix Nano-Composite	RSM	Ip, Ton and Toff are the most important factors influencing the MRR though voltage remains negligible. In both TWR and SR the Ip and Ton have statistically significant results. The larger Toff offset lower the TWR value. Conversely, for any voltage value, the TWR increases with increasing in Ip and Ton.
13.	[64]	Carbon–Carbon Composite	Taguchi L8, ANOVA	The TWR is observed to significantly reduce within the experimental region If parameters are chosen at their lowest values, and parameters at their maximum values raise the MRR drastically.
14.	[65]	Al-6082/ SiC MMC	Taguchi L9	It was observed that composites with Al-6082/SiC-92.5% /7.5 % are perfect fit after the comparative analysis. Therefore, using Taguchi's experiment design, it is used to refine EDM device parameters.
15.	[66]	Al-6351 5% SiC-10% B4C Hybrid	Grey Relational analysis, ANOVA	The goal is to reduce the machining feature, which is the wear ratio of electrodes, SR and power usage. This determines the optimum set of input parameters, and indicates the major change in process characteristics. The outcome reveals that the Ip adds most to the cumulative output responds (83.94%).
16.	[67], [22]	Si_3N_4-TiN Composite	Discharge Pulse by Power Spectral Density	The findings show that it's not the amount of ordinary pulses which lead to a greater discharge of energy, but instead its time-duration and development.
17.	[68], [69]	Al-6061 4 % B4C Composite	Taguchi L9, ANOVA	The discharge current is an important factor with a contribution of 85.81% then Ton with a contribution of 13.187% impacting MRR. The important parameter with Average RLT was defined as the length of discharge, Ton with 68.50%.
18.	[70], [71]	Al-7075/ B4C composite	Design of experiment, RSM, ANOVA	MRR's established mathematical model is compatible with experimental values at a confidence interval of 95%. Most important cycle parameters influencing MRR are Ip and Ton. Comparative analysis of SEM images showed improved surface finish due to lower RLT at medium setting of input method

				component.
19.	[72]	Al6061 Hybrid Nano-Composite	Taguchi L16, ANOVA, RSM	The projected RSM model for Ra demonstrates 96.32% model accuracy with an average 3.68% error. Analysis by ANOVA revealed that the most influential factor followed by Ip in predicting Ra is Ton.
20.	[73]	Al-4.5Cu-SiC Composite	Multiple Regression Analysis	The findings demonstrate that using the Multiple Regression Analysis is accurate way to estimate the achievement of minimal tool wear toward full metal removal with reasonable surface finishing.
21.	[74]	LM6-Alumina Stir casted	Grey Relational Analysis	The research showed that the discharge current is the most important parameter influencing surface finish and removal rate of material.
22.	[75]	SiC/6025 Al composite	Genetic Algorithm	The result of EDM drilling with the electrode rotating tube has provided a higher rate of content removal than the flat electrode that rotates. The depth of the electrode tube opening strongly impacts the MRR, EWR, and SR. The reduction in hole diameter has resulted in improved MRR, SR, and higher EWR. The rise in SiC volume percentage has contributed to a decline in MRR, SR and an improvement in EWR.
23.	[76]	SiC(5-15 %), Graphite (5-15 %) with Al alloy AC2B	Taguchi L27 , ANOVA, GRA	According to ANOVA, the combined equal weight % of SiC- Gr is the most important factor compared to other machining parameter.
24.	[77]	Al6061/ 10 % SiC Composite	Scanning electron microscopy, X-ray diffraction	Scanning electron microscopy study reveals SiC reinforcement clusters in the framework of the formulations. X-ray diffraction tests affirm compositional elements of 6061Al alloys along with silicon carbide reinforcement particles
25.	[78]	Al6061/ B4C/ Graphite composite	Taguchi L9	The graphite and boron carbide distribution on the matrix was relatively uniform, suggesting a decreased porosity and a strong bond between the matrix and the reinforcements. Compared with traditional heat treatment, microwave heat treatment has proven to be an easy and energy efficient method. Current and pulse on time were considered to be the most important criteria of both traditional and microwave heat treatments.

4. Conclusion

Process parameter influence on EDM process:
The key goal of EDM producers and consumers is to achieve improved process reliability and greater efficiency[79)] by monitoring the affecting parameters.

- **Pulse Parameter Impact[80)]:**

The Ton, Ip and capacitance dictate the series of steps to achieve the optimum value of GV. If the Ton and Ip are adequate and the capacitance is low enough, only one step can be taken by the GV to achieve the max.

- **Frequency Effect[81)]:**

Increased level of discharge cycles will increase surface finishes under limits by twice current and frequency; the MRR could double without altering the finish. The amperage is diminished at high frequencies due to inductance and therefore the MRR is diminished.

- **Work Piece Material Effect[82)]:**

EDM method is affected by physical, metallurgical including electrical properties of a work. A lower Material Melting Point improves MRR. Improper metal heat treatment results in distortion die punches breakage when being machined with EDM.

- **Wire Material Structure Effect and Wire Tension:**

It should have sufficient tensile strength for melting and vaporization with higher fracture toughness, large electrical conductivity, strong flushing capacity, small melting point and reduced energy requirement. Tension in wire improves speed and efficiency of cutting, and reduces strength of wire vibrations. Wire snaps if the strain of the wire crosses the tensile force.

- **Dielectric and flushing-pressure effect[83)]:**

Until a significant volume of energy is collected, the dielectric fluid insulates the electrodes and concentrates the discharge power to a small region, maintains a desirable gap state following discharge via cooling the gap and de-ionizing and flushing off the residue of the work piece generated by fire. Unless the flushing pressure is greater than that amount of pressure, otherwise no machining.

5. Parametric Optimization

The most efficient machining technique is calculated by defining different variables that influence the EDM mechanism and looking for the different ways to achieve the optimum machining state and response[84)].

- The inclusion of the strong reinforcing ceramics in the composites of the metal matrix causes them challenging for traditional machining[85)].
- W-EDM is known as an efficient as well as cost-effective technique for the machining of composite modern materials. Multiple contrasting researches on the control of MMC, carbon fiber and reinforced liquid-crystal polymer composites were performed among WEDM and laser cutting[86)]. Such experiments found that, with less work piece surface losses, WEDM has yields higher cutting edge efficiency and has greater control for process variables. It has smaller MRR for every composite materials tested.
- The time during two pulses was the most responsive variable that controls oxide layer[87)] formulation as opposed to pulse length, injection pressure, wire velocity and tension of the tube. A substantial decrease in the oxide forming is achieved with a lower time value among two pulses.
- It is evident from the above review that the bulk of MMC'S EDM machining research was limited to the machining of Aluminum MMC[88)].

Nomenclature

ABS	Acrylonitrile Butadiene Styrene
PLA	Polyactic Acid
CS	Cutting speed
MRR	Material Removal Rate
GV	Gap Voltage
Ip	Peak Current
TWR	Tool wear rate
KW	Kerf Width
RLT	Thickness of recast layer
SR	Surface Roughness
Toff	Pulse OFF Time
Ton	Pulse ON time
SG	Spark Gap
WF	Wire Feed
WT	Wire Tension
OGV	Open Gap Voltage
MMC	Metal Matrix Composite
ANOVA	Analysis of Variance
RSM	Response Surface Method
SiCp	Silicon Carbide Particle
B4C	Boron Carbide

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