THE EFFECT OF PROCESS PARAMETERS ON THE ELECTRICAL DISCHARGE MACHINING OF ADDITIVE MANUFACTURED TI6AL4V

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Abstract

Electrical discharge machining process can be regulated using parameters such as pulse on time, voltage and current. One of the most important parameter that measures the machining efficiency is the material removal rate. Heat generated during Electrical discharge machining is determined upon by the spark energy, which in turn influences the material removal rate. Essential process parameters of EDM are current, voltage and pulse on time. This research work manipulates these parameters of current, voltage and pulse on time to study the consequence [redacted] *of variation in these parameters on material removal rate. It was observed that MRR increases indirectly with the increases in voltage. MRR have direct proportional relationship with pulse on time up to a certain limit then decreases. MRR increases with an equal increase in current. However, further increase in current results in decrease MRR.*

KEYWORDS:
machining, process, parameters, metal, current, voltage.

Introduction

Electrical Discharge Machining (EDM) is a process that concerns material removal by thermal medium in which material removal is done by local melting or vaporization of small areas at the surface of work piece Yoo, Kwon and Kang (2104) Material removal is achieved by erosion of the material by continuous sparks between the tool referred to as electrode and the work piece while submerged in a bath of a dielectric medium. The electrode is moved in the direction toward the work piece until the distance apart is small enough so that the applied voltage is excessive enough to ionize the dielectric. According to Yan (2010) and Davim (2010) EDM is not based on direct contact between work piece and tool, thereby eliminates mechanical stresses and vibration during the process. Engineering material of any hardness, high strength and high temperature resistant can be machined as long as it is a good conductor of electricity. The conventional machining methods are often not suitable to machine titanium alloys mainly due to its extreme hardness. However, this process is usually applied to such high precision machining of extremely hard and exotic materials used in aerospace, marine, nuclear and bio-engineering economically. The temperatures of the electrodes can be raised more than their normal boiling points (Debrov and Chakraboty 2013).

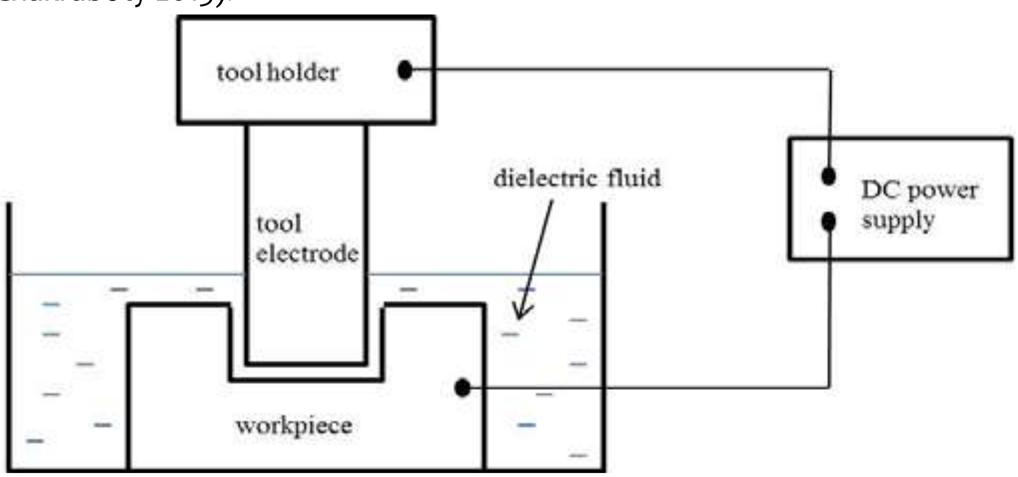

Figure 1: working diagram of EDM

As opined by Aspnwall et al (2008) Accompanying the development of mechanical industry, the demands for alloy materials having high hardness, toughness and impact resistance are increasing. Wire EDM machines are used to cut conductive metals of any hardness or that are difficult or impossible to cut with traditional methods. The consistent quality of parts being machined in wire electrical discharge machining is difficult because the process parameters cannot be controlled effectively. These are the biggest challenges for the researchers and practicing engineers as observed by Hoang and Yang (2013) Keeping in view the applications of material titanium alloys, it has been selected and has been machined on wire-cut EDM. Wire cut electrical discharge machining (WEDM) or Electrical discharge wire cutting is a spark erosion process used to produce two and three dimensional complex shapes through electrically conductive work pieces. The aim of this paper is to study the influence of pulse on time, pulse off time, gap voltage, peak current and duty factor on output responses on material removal rate (MRR)

Literature Review

EDM performance measures such as material removal rate, tool wear rate, and surface roughness (Ra) are influenced by different process parameters (Amitabha Ans, 2009). The different process parameters of EDM are shown in the fishbone diagram (figure 2) with output parameters MRR, TWR and Ra.

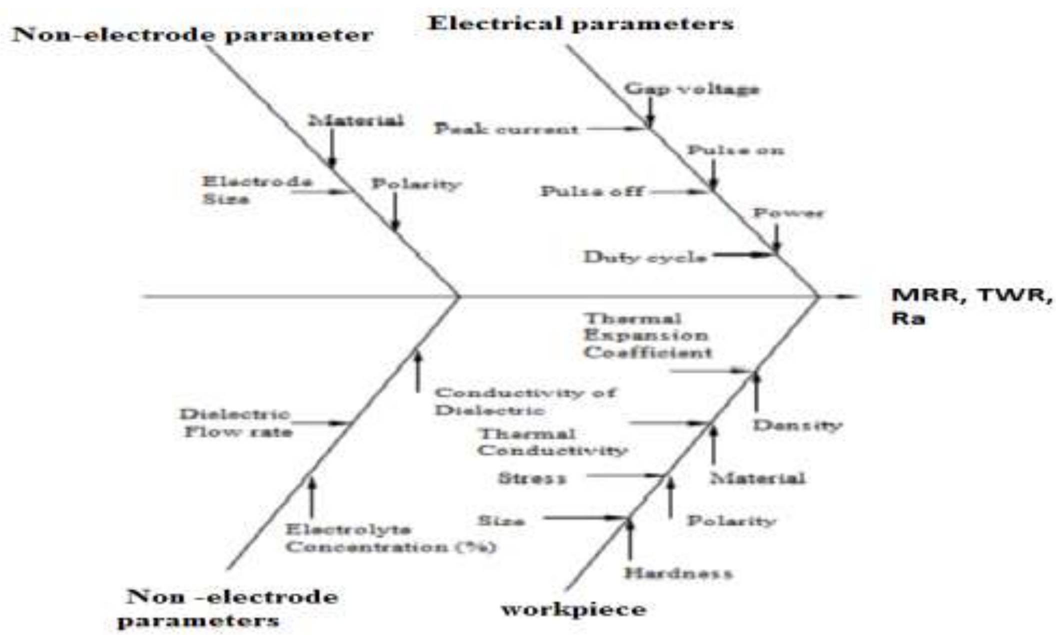

Figure 2:process parameters of EDM(Pour, Pour and Ghoreshi 2014)

Liao, Chen and Lin (2005) have studied the effect of process parameters on Ra. The work piece material was alloy steel (EN-31). They prepared mathematical models using the response surface methodology (RSM) to correlate dominant machining parameters, including the discharge current, pulse on time, duty factor and open discharge voltage in the EDM process of alloy steel. They observed that, the value of Ra first decreases with an increase of pulse on time and then increases with further increase in pulse on time. The value of Ra increases with an increase of discharge current and open discharge voltage but decreases with an increase

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of duty factor. Ra value reduces with decreasing peak current and reduces with increasing of gap voltage (Jain, Belokar, & Chakaraboti, 2002).
Hoang and Yang (2015) investigated influence of process parameters on MRR, TWR and Ra during the manufacture of SKD61 by EDM. A hybrid method including a back-propagation neural network (BPNN), a genetic algorithm (GA) and RSM were used. Specimens were prepared under different EDM processing conditions according to a Taguchi orthogonal array table. The conclusion was that the cutting parameter of discharge current is the most significant factor for MRR and the cutting parameter pulse on time is the most significant factors for surface roughness as observed by Chow et al (2000).

Methodology

Fabrication stage of Selective Laser Melting (SLM) Specimen used for this Work
Two set of SLM specimen build on a single base plate have been provided by our research collaborator, the Net Shape Centre Birmingham University. Even though the fabrication aspect of the specimen is not within the scope of this work, it is pertinent to highlight some important aspect of it so as to have a clear overview of the specimen under investigation.
The material used for the purpose of this investigation was Ti-6Al-4V powder of size range within 20-50 **µm,** the SLM system used is the Concept Laser M2 Cusing that utilises an Nd: YAG laser and having a 1075nm wavelength. The specimen was built with maximum laser power is 400W as the maximum laser scan velocity is up to 2300mm/s. All the specimens studied in this work were built on wrought Titanium Base plate

Sample Workpiece

The specimens that were studied with some basic parameters are tabulated in table (1) there are four specimen made of different scanning strategies, built at same scan speed, power and building orientation. The detail of the layer thickness is not certain to the author but the building height of all specimens are measured to be 50mm. further details are given in the table below.

Table 6:description of the specimen under studies

Specimen	SLM Machine Used	Scanning strategy	Building direction	Power (W)	Scan velocity (mm/s)	Building Height (mm)
Specimen 1	Concept Laser	Continuous Unidirectional	Horizontal XY	400	2300	50

Specimen 2	Concept Laser	Continuous Bidirectional	Horizontal XY	400	2300	50
Specimen 3	Concept Laser	Island Scan Bidirectional	Horizontal XY	400	2300	50
Specimen 4	Concept Laser	Chess Scan Bidirectional	Horizontal XY	400	2300	50

Physical Observation of the Specimen

The four specimen were physically scrutinized via careful observation one after the other to find out the deformations and defects that can be detected by naked eye before subjected to the designed experiments. Some of the common observations as depicted in following pictorial views of the specimen suggest that there is a serious cause for concern with respect to structural integrity of components produced via the SLM processes. All areas of concern are outlined using red circle or arrow to show emphasis in Figure 5-44) However, irregularities are observed to be lesser with the island scan specimens while the continuous scan unidirectional specimen exhibits higher tendencies of deformation including cracks in vertical and somewhat horizontal.
The following are summary of physical observations carried out on the specimen before EDM.

Physical Observations

- Cracks both horizontal and vertical.
- Delamination
- Surface roughness
- Unequal lift from the substrate
- Inconsistent top edge profile
- Sharp side and top edge profile
- Ridges at the top surface

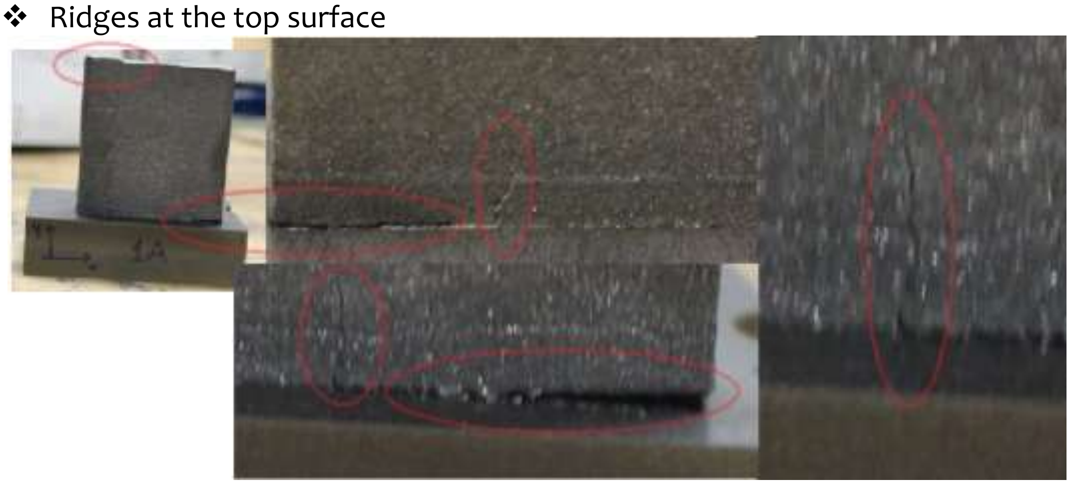

Figure 3: physical observation on specimen

Tools

There are several different methods to cut the specimen from base plate to conduct the residual stress characterization of the specimen after cutting or to cut a part out of specimen for microstructural evolution. Some methods are simpler to handle as compared to others, and some have consequences on the measurements. However, the wire EDM cutting was adopted for this research work because of it numerous advantages, one it provides much finer surface after cut and secondly EDM can provide a gentle cut as compared to traditional machining and as such not inducing significant internal stresses. EDM is known for its ability in providing cutting of renowned hard materials that are proven difficult in the conventional machining very easily. The ability to provide continuous cutting as against the incremental type is also considered to be another milestone of this process of cutting. (Prime, 1999)

(a) (b)

Figure 4:(a) workpiece clamped in a deionized water ready for cutting and (b) cutting process showing the tiny brass wire

Description of the Specimens

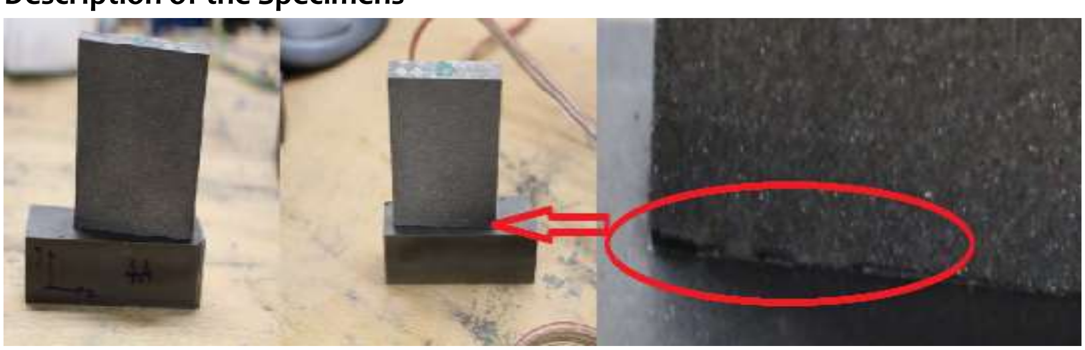

Figure 5: specimen 4 showing lifting of the specimen from the base plate at one side

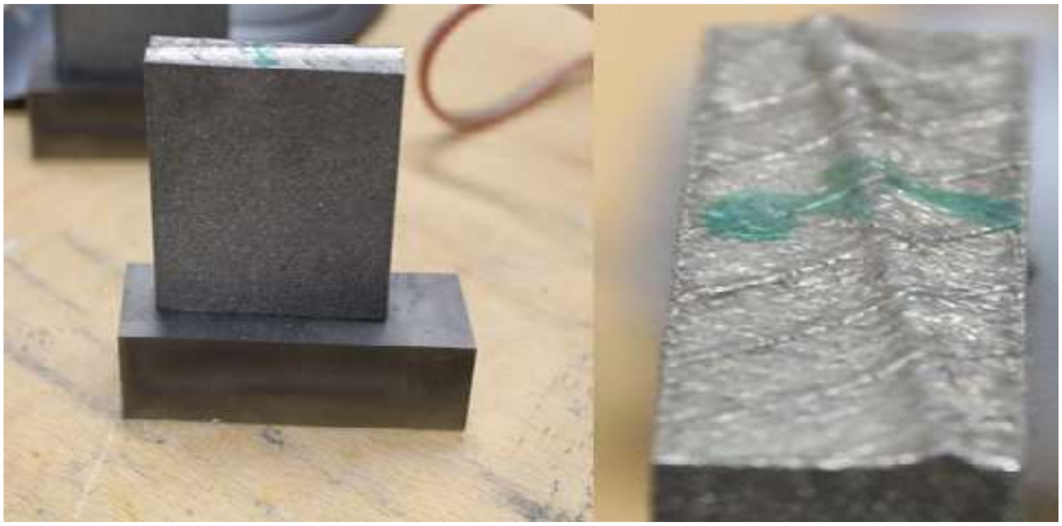

Figure 6: Specimen 3 showing irregular top surface with ridges

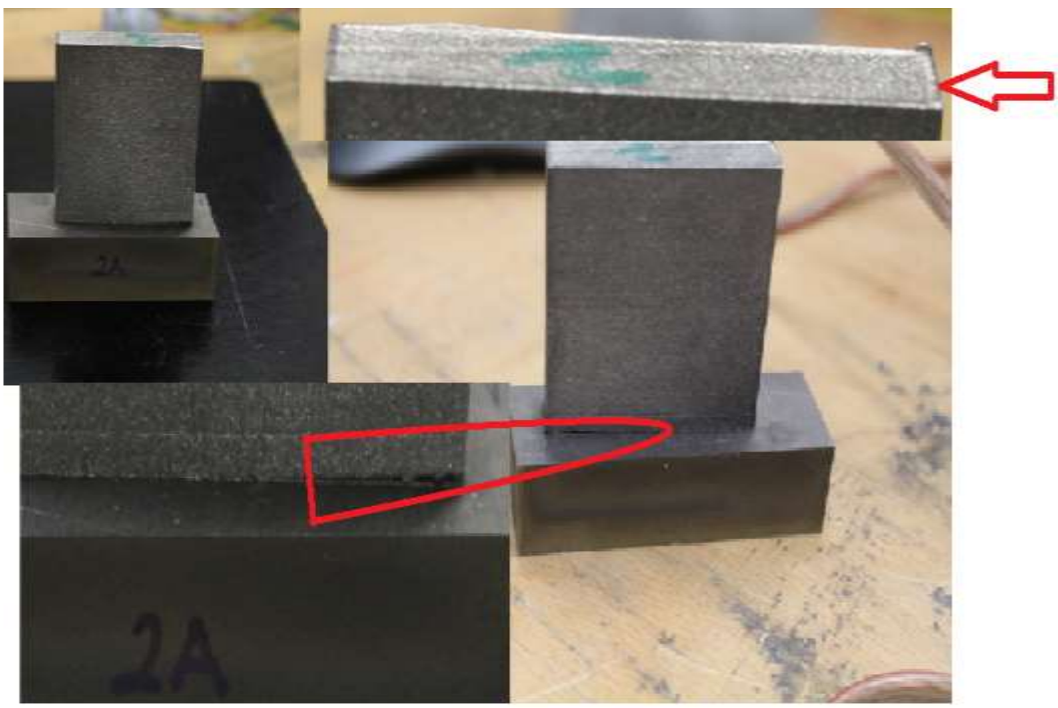

Figure 7: Specimen 2 showing a lift from the base plate and a poor surface finish at one end of the top edge

Material Removal Rate Calculations

MRR is the rate at which the material is removed from the work piece. Its unit is mm^3/s. The material is removed from the work piece because of series of recurring spark between the two electrodes.

Mathematically: $MRR = (W_i - W_f) / t \times \rho$
Where, W_i = initial weight of material.
W_f = final weight of material after experiment.
t = machining time = 10 min
ρ = density of material = 4.43 gm/cm^3
The MRR can be defined as the rate of material removed per second or the ratio of change in volume of workpiece during machining divided by duration of machining. Since for each and every experiment, t and ρ have been kept constant and weight loss is only varying quantity with respect to various EDM process parameters. That's why MRR has been expressed in terms of weight loss in gram.

Spark Energy Calculation

Evaluation of spark energy is important due to melting and evaporation of workpiece material and outcome of machining on surface roughness, microstructure, microhardness, and heat affected zone (HAZ) Following equation was used for calculating the spark energy;
Spark Energy (joule)= Id x Vg x Ton

Machine Tool

The wire EDM cutting for this research work was conducted at the Institute for Advance Manufacturing and Engineering (AME) Coventry UK, using the Fanuc Robocut α-600iA wire EDM machine. A hard brass wire of 0.1mm and a speed of 7mm/hr and suitable feed rate that ensure appropriate tension in the wire were applied. These parameters were adopted for operation with view of accomplishing a skim cut surface finish with less tendencies of wire cut failure. In this process, an electrical spark is generated between the electrically charged wire and the specimen (workpiece). Flow of electricity is evident by the visible spark, as the moving wire approaches the specimen the cautiously controlled and localised spark jumps the space and melt and removes part from the specimen. Material removal continuous as the wire advances. This whole process is happening in a dielectric fluid, mostly deionised water and practically there is no mechanical contact between the wire and the work piece. The work piece was clamped using angle plate and G-clamps for ease of work while ensuring perpendicularity with the wire.

Figure 8: Fanuc Robocut Machine with control panel

Weighing of specimen

Electronic balance was used for weighing the workpiece and tool, before and after machining. It had a weighting capacity of 500 grams and can accurately measure the weight of 0.001 gram.

Figure 9: Electronic weighing machine

Condition of EDM Process

Table 2 shows the details of experimental conditions used in the present study.

Table 7: Experimental conditions

S/N	Parameters / Units	Details
1	T_{on} (Micro seconds)	10, 50, 100, 200
2	Discharge Current (amp)	4, 5. 6, 7
3	Voltage (V)	5, 10, 15, 20
4	Dielectric	Ionized water
5	Machining time (minutes)	10
6	Polarity	Straight

Results and Discussion

This work dwelled on the effect of different EDM parameters on MRR and spark energy. There are three important process parameters associated to EDM that are considered at four different selected levels these parameters include I_{on} I_p and $V_{g.}$ this is to study the consequences of such variation of parameters to MRR and spark energy. It has been discovered that flushing serves to remove the eroded sloid debris and entrapped gases from the spark gap area while the machining operation is taking place and that serves to maintain the dielectric temperature very well below the flash point. the loss in weight of the specimen material as a result undergoing EDM is tabulated below.

Table 8:Weight loss result*Error! Reference source not found.*

Parameters		Initial weight	Final weight	Weight loss
T_{on} (Micro seconds)	10	440.322	439.399	0.923
	50	439.399	436.107	3.292
	100	436.107	431.983	4.124
	200	431.983	427.983	4.000
Discharge Current (Amp)	4	457.076	455.790	1,286
	5	455.790	454.399	1.391
	6	454.399	453.052	1.346
	7	453.052	452.167	0.885
Voltage (V)	5	448.303	447.154	1.149
	10	447.154	445.985	1.168
	15	445.985	444.771	1.214
	20	444.771	443.487	1.284

Effect of Pulse on Time on MRR

An indirect relationship has been observed on time and MRR as indicated in figure …… there is significant rate of increase in MRR within the range of (10-50 ms) as compared to the range of 50-100ms which signified a short increase. There is a slight drop of MRR as a result of further increase of pulse on time.

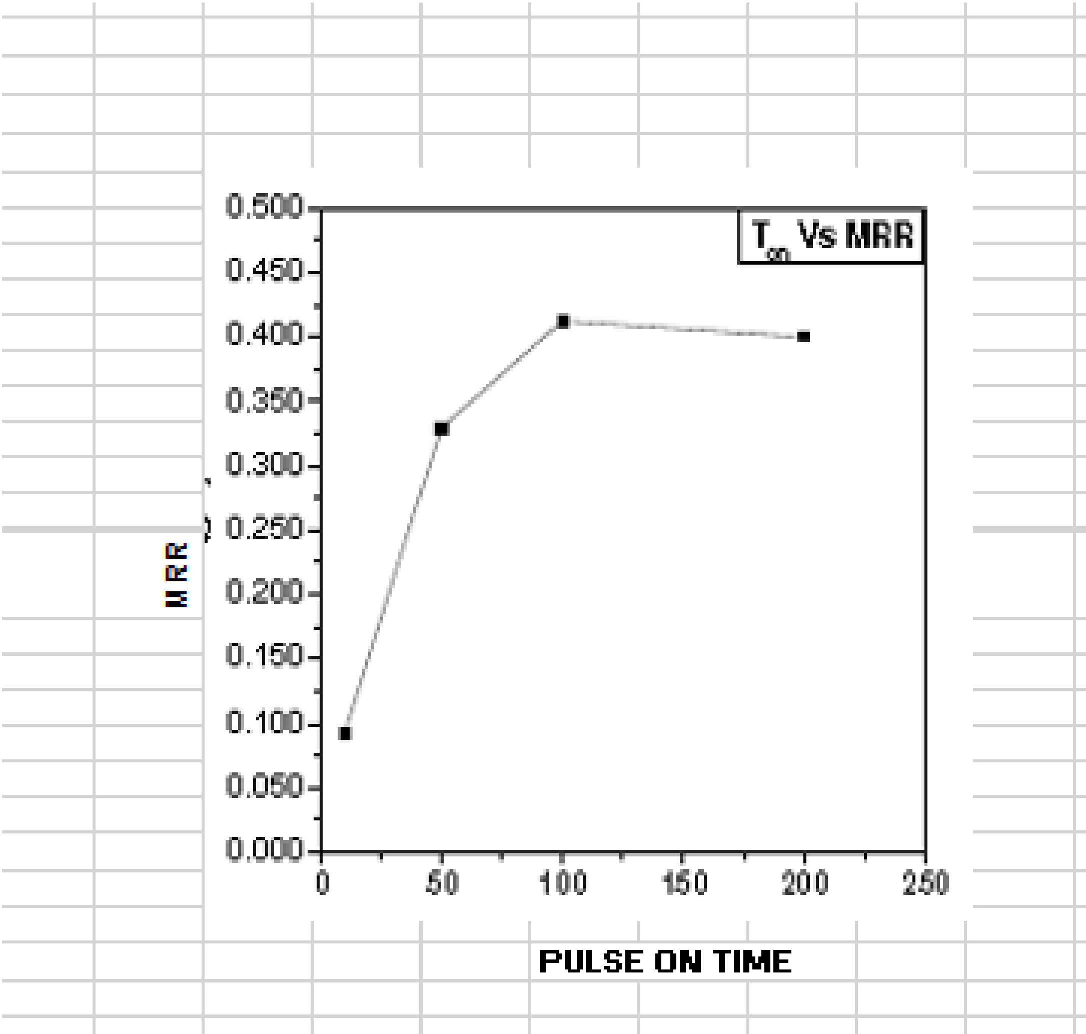

Figure 10: MRR against PULSE ON TIME

Effect of Current on MRR

It was observed that MRR relates linearly with current as indicated in Fig…… In the range (4 amp-5 amp), MRR then decreases slightly between (5amp-6 amp) and finally MRR decreases sharply in the range (6amp-7 amp). Decrease in MRR may be connected to the contamination of plasma column in gap, which is mainly due to debris resulting from the electrodes.

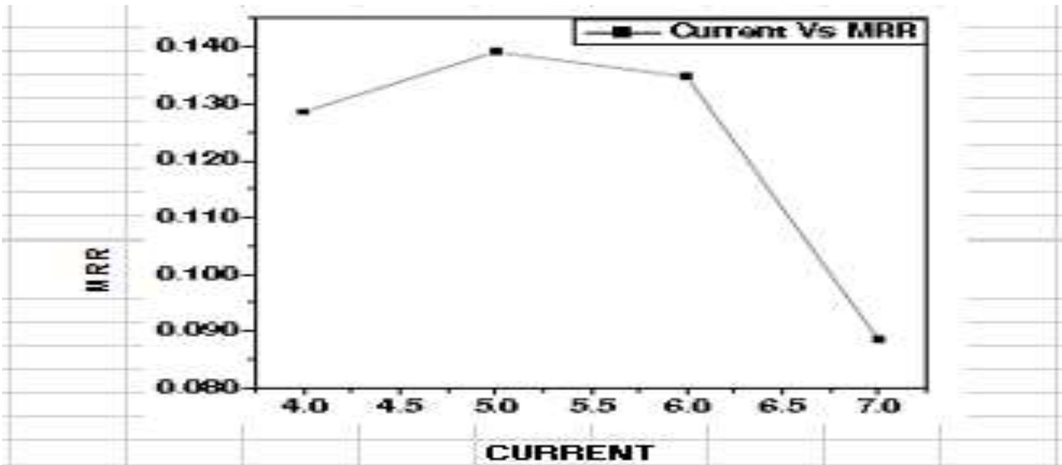

Figure 11:MRR against Current

Effect of Voltage on MRR

Figure … characterizes the relation of MRR as compared to voltage. There is small increase of MRR from 5 V to 10 V and sudden rise from 15 V to 20 V. Rise in MRR with increase in voltage lies above two in range of (10 V- 15 V). Increase in voltage in turn leads to increase in spark energy. More spark energy means more material removal in the presence of suitable values of remaining process parameters.

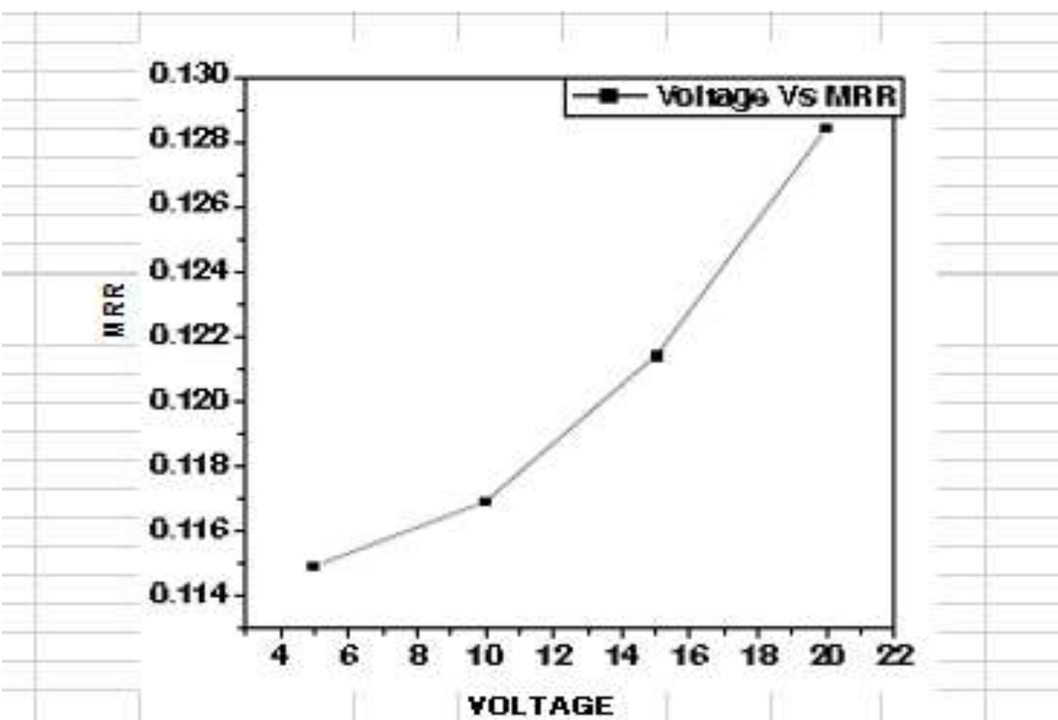

Figure 12:MRR against Voltage

CONCLUSIONS

This research work can be concluded with the following major findings;

1. EDM Process parameters namely pulse on time, current and voltage affect the material removal rate.
2. MRR increases with increase in pulse on time up to a certain then decreases.
3. Increase in current provide an initial increase in MRR but further increase in current results in decrease in MRR.
4. MRR increases with increase in voltage.

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