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A Review on Performance of Process Parameters of Electric Discharge Machining with Ti6AL4V

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Abstract:

Electrical Discharge Machining (EDM) is a specialized thermal machining process stands out as a versatile and indispensable manufacturing process, offering unique capabilities for machining complex shapes and hard materials with exceptional precision. Spark erosion Electrical Discharge Machining (EDM) has emerged as a pivotal technology in modern manufacturing, enabling precise machining of complex geometries in electrically conductive materials. In the aerospace industry, EDM is extensively used for machining turbine components, such as blades and vanes, with intricate cooling features that optimize performance and fuel efficiency. In the automotive sector, EDM finds application in the fabrication of precision components for engines, transmissions, and fuel systems. Furthermore, EDM plays a crucial role in mould making for the plastics, rubber, and packaging industries. By accurately machining intricate cavities, cores, and inserts, EDM enables the production of moulds capable of replicating complex part geometries with consistent quality and minimal cycle times. This paper reviews the vast array of research work carried out from the EDM process to parameters surveying the influence of the various factors affecting performance, part quality and productivity on the titanium alloy (Ti6AL4V). This paper reviews the effect of various EDM process parameters such as peak current, pulse on time, pulse off time, gap voltage and dielectric medium on different process response parameters such as material removal rate (MRR), surface roughness (Ra), electrode wear rate (EWR) and surface topography.

Keywords **— EDM, Titanium alloy, MRR, Ra and EWR**

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I. INTRODUCTION

Titanium and its alloys have good electrical conductivity and thermal conductivity. Ti-6AL-4V is the most widely used titanium alloy. It features good machinability and excellent mechanical properties. The Ti-6AL4-V alloy offers the best all-round performance for a variety of weight reduction applications in aerospace, automotive and marine equipment. Ti-6AL-4V also has numerous applications in the medical industry. Biocompatibility of Ti-6AL-4V is excellent, especially when direct contact with tissue or bone is required. Ti-6AL-4V is used in applications up to 400 degrees Celsius. The use of titanium alloy in various engineering field is due to its high specific strength and high temperature strength within a broad temperature range, and also high corrosion resistance with Comparing to other metals. In late years, titanium has become an important material which has widely applied in the aerospace industries. Basically, titanium has a high melting temperature and low thermal conductivity where it belongs, to the group of difficult-to-cut materials which is not suited for traditional machining Titanium has lower values of thermal conductivity. Electrical resistance and thermal expansion (Rao 2020).The erosive effect of electrical discharges was first noted in 1770 by English physicist Joseph Priestley. Generally, EDM produces complex shapes and permits high precision machining of any strong, difficult-to machine, breakable or thin materials.

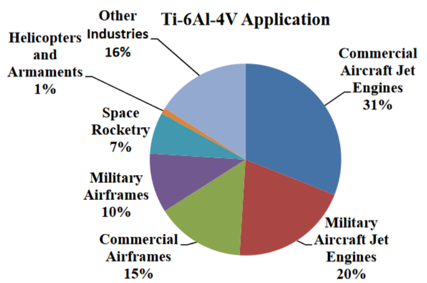

Figure 1 Application of Ti-6AL-4V

Electrical discharge machining (EDM) is unitary of the well-known modern machining process used in machining materials that are mainly hard to be machined. EDM is widely being used in innovative manufacturing industry purposely used to transfer material from the work piece by controlling erosion through a series of electric sparks occurring between the electrode and the work piece immersed in dielectric fluid. (Nurezayana Zainal 2016) The performance of the EDM depends upon several parameters and these mainly include pulse-on time and current, voltage, polarity, duty factor, the flushing pressure, and the gap in electrode and work piece. (. Ou SF 2017). Over the last few years, several researchers have evaluated the performance of the EDM process for various parameters such as material removal rate (MRR) and tool wear ratio (TWR), and this resulted in machined surface quality. The work piece and electrode material are the most important factors in determining the performance of EDM parameters. As a result, alternative EDM parameters and electrode materials must be investigated for the microstructure and surface roughness of the machined surface. (Rathod 2022) This paper focuses on different input parameters and various output parameters like MRR, TWR and influencing the surface characteristics of titanium alloy (Ti6AL4V) during the EDM process.

II. WORKING PRINCIPLE OF EDM

Material is removed by means of rapid and repetitive spark discharges across the gap between electrode and work piece. In addition, mechanical and physical properties of titanium such as excellent corrosion resistance, a high strength to weight & good high temperature properties has made it an important material for engineering components particularly in aerospace and automotive industries, and also used as medical implant material in wide range of application. EDM consists of the following components, Power supply Unit- Used to provide the Direct Current to produce spark between the tool and workpiece. Dielectric fluid reservoir, pumps, filters and control valve Used to supply dielectric to the tool and workpiece. The tool and workpiece are immersed in dielectric fluid. Workpiece holder, Tool holder and table – Used to hold tool and workpiece firmly so that the vibrations are reduced. Servo control Mechanism - Used to provide a constant gap between tool and workpiece. The tool and workpiece are directly connected with DC power supply. The workpiece is connected into positive terminal and tool is connected into negative terminal of DC supply. The tool and workpiece are submerged in the dielectric medium.

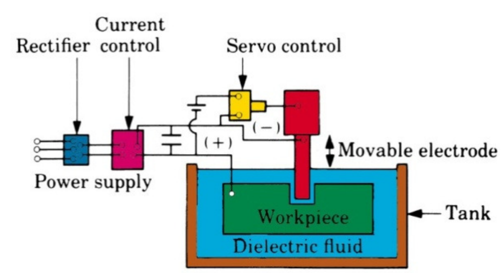

Figure 2 Working Principle of EDM

The servo feed mechanism is used to give a constant gap (spark gap) between the tool and workpiece. Figure 2 shows the schematic diagram of EDM. When the DC supply is given to the circuit, the voltage across at 250V and high spark is produced at the spark gap. So that the dielectric breaks down and electrons are emitted from cathode, the gap is ionized and thousands of sparks/sec occurred at the gap. This high spark produces high temperature. Due to that high temperature and high pressure the metal is removed and flushed away by the dielectric fluid. When the voltage drops, the dielectric fluid got deionised dielectric fluid got deionised (J. Jeevamalar 2014)

III. Process variables of EDM

The selection of optimum levels of process parameters is playing an important role to enhance EDM efficiency. Required surface qualities can be obtained only when the process performed with optimum levels of parameters. Important process parameters and its effects on process performance are mentioned below:

a) Peak Current (Ip): It is one of the important process parameters to govern the machining process. At initial stage-discharge current is zero and voltage start to increase continuously which leads to ionization of dielectric. Spark is initiated once the voltage is reaching its break down level with enough potential between electrode and work material. With the beginning of spark, the voltage starts reducing and became zero while current increases continuously during spark on time, which is considered as peak current. Values of peak current to be selected for machining is mainly depends on different factors such as the cross-sectional area and material of the electrode, work material, etc. The high value of peak currents lead to maximize material removal rate but at the cost of poor surface finish with high electrode wear. Large values of peak current also produce adverse effects on dimensional accuracy.

b) Pulse on Time (Ton): It is the duration of spark for one complete cycle. EDM cycle comprises a span of pulse on-time and pulse off time in microseconds. The thermal energy is (heat) released during spark on time only. The material removal rate is always proportional to the amount of heat energy generated during spark on time. Total heat 22 energy obtains during a cycle is the product of peak current and pulse on time. Longer pulse duration means energy applied for a longer span and hence wide and deeper crater produce with extended on time. The further high value of energy is creating thick recast layer and deeper heat affected zone. Hence selection of the optimum value of pulse on time is important for EDM operation. The appropriate value of pulse on time is able alloy the work surface, which the desired condition for surface modification.

c) Pulse off Time (Toff): Timespan between the end of previous spark and beginning of next spark is considered as pulse off time. Optimal duration of pulse off time able to provides stable cutting operation. The lower value of off-time will increase the speed of the EDM operation. However, if the pulse off time is too short than eroded material not flush away properly and hence unstable machining. Further too short off-time unable to ionization of dielectric properly, which affects the efficiency of EDM. The total duration of pulse off time must be greater than the ionization-time of the dielectric to attain ideal machining condition. In modern EDM setup, one can select values of pulse off time independently ranging from 2 to 1000 µs. Sometimes EDM pulses fail to generate spark because of not selecting required levels of pulse on-time and pulse off-time.

d) Gap Voltage (V): The level of gap voltage is selected based on the inter electrode gap required and breaking strength of dielectric. When the electrode is set very near to work material (0.01 to 0.02 mm) voltage is increasing continuously until it will reach up to the present level. When voltage is attained break down level ionization of dielectric able to initiate sparking action. During sparking action peak currents are increased and voltage drop till the spark is stabilized. The large inter-electrode gap is required with the setting of maximum discharge voltage, which is a favourable condition to flush away debris and hence less possibility of arcing.

e) Dielectric Fluid: Types of dielectric used during EDM operation is play an important role in performance. EDM is used thermal energy for melting and evaporate the work material. The EDM operations must be performed under the absence of oxygen to prevent oxidation and govern the process well. The dielectric helps to concentrate the generated discharge energy in a very small area. In EDM different types of hydrocarbon oil such as mineral oil, kerosene, transformer oil, lubricating oil, paraffin oil, and deionized water are used as the dielectric. Dielectric must possess very high dielectric strength means it will remain insulator until the levels of break down voltage attained. Further, it helps to cool down electrode and work material. Dielectric also helps to flush away the debris from the inter-electrode gap which is necessary to avoid arcing during operation.

IV. Response variable of EDM

Various response variables such as material removal rate (MRR), tool wear rate (TWR), surface roughness (SR) are summarized below:

a) Material removal rate (MRR)

Before and after machining (g), ρ density of work material (g/mm³) and t is machining time in minutes. Electrode must be capable to machining the work material. If the electrode is not capable to erode the work material, then no molten pool created, results in no transfer of electrode material.

MRR = ΔW / ρ × t(100) mm3/min

MRR – Material removal rate
ΔW - weight difference of work piece before machining and after machining.
ρ – density of the material
t – machining time in minutes

b) Tool wear rate (TWR)

Tool wear rate is very important parameters for EDM operation performed as an aspects of surface modification. Dimensional accuracy and surface quality of the EDMed product is mainly depends on electrode wear. Very high electrode wear is deteriorate the EDM performance because of arcing. Optimum tool wear rate is desirable for surface modification. Where ΔW is the weight of electrode before machining and weight after machining in grams, t is the machining time in minutes and ρ is the density of electrode material.

EWR = ΔW / ρ × t(100) mm3/min

c) Surface roughness (SR)

The rough surface of engineering component is always work as stress raiser, which results in development of crack and corrosion, will lead to early failure of component. Irregularities in surface obtained during machining are considered as rough surface. In other words, surface roughness is defined as the deviation of a surface from its geometrical mean. If the deviation is higher than it is considered as rough surface and surface with lower deviation is finish surface. Ra value of machined sample was measured using surface tester also known as profilometer. Roughness measurements were carried out in the transverse direction on machined surface with cut-off length or sampling length of 10 mm and were repeated three times and average values are calculated.

Figure 3 Surface Tester

V. Chemical composition of Ti6-AL-4V

Fe	0.25
C	0.08
N2	0.05
O2	0.2
AL	5.5-6.7
V	3.5-4.5
H2	0.0125
Ti	Balance

Table 1 Chemical composition of Ti6AL4v

VI. Mechanical and physical Properties of Ti-6Al-4V

Properties	**Quantity**
Hardness (HRC)	36
Melting Point (^{0}C)	1649
Density (g/cm^3)	4.5
Ultimate tensile strength (MPa)	897-1000
Thermal Conductivity (W/m^{0}K)	7.2
Specific heat (J/kg^{0}K)	560
Mean coefficient of thermal expansion 100^{0}C/^{0}C	0-8.6x10-6
Volume electrical resistivity (ohm-cm)	170
Elastic Modulus (GPa)	114
Yield strength (MPa)	955
Shear Modulus (GPa)	41-45
Elongation at break (%)	≥ 10

Table 2 Mechanical and physical Properties of Ti-6Al-4V

VII. LITERATURE SURVEY

(Shoufa Liu 2022) in this research paper the selected input parameters are gap voltage, discharge current and duty cycle to measure the surface roughness of the Ti-6AL-4V and utilized tools for experimental plan are brass, copper and tungsten carbide. With this plan they conclude the proposed approach on an air gap can produce better surface morphology of the machined specimens. The tungsten carbide electrode creates tiny and uniform craters for making a better smooth surface in the EDM process.

(M.S. Zam 2023) this paper was designed to study the tool wear rate (TWR) using graphite tool on Ti-5Al-2.5Sn alloy with input parameters peak current, pulse on time, pulse off time and servo voltage to conclude the Negative tool wear is found at the combination of peak current, pulse-on time, pulse-off time and servo voltage. In addition, of peak current, pulse-on time, pulse-off time and servo voltage the combination of yields maximum negative electrode wear rate.

(Bhiksha Gugulothu 2015) In this research paper taguchi approach is used for optimization technique. The selected input parameters are peak current, pulse on time and pulse off time with graphite concentrated powder to optimize the material removal rate (MRR) and surface roughness (SR). Machining characteristics namely MRR, SR increase with increase of peak current. MRR and SR decreases less significantly with increase of powder concentration. Based on the results of ANOVA analysis, peak current is most significant parameter affecting MRR and SR. However powder concentration has less significant effect on all response characteristics namely MRR and SR. Empirical models were developed by performing nonlinear regression analysis to predict all response characteristics such as MRR, SR.

(K. M. Sivakumar 2013) in this research paper different kinds of electrodes are used to establishing optimum Process Parameters for titanium alloy grade 5. Electrolytic copper, beryllium copper, tungsten copper, graphite, aluminium, steel(EN24) and copper impregnated graphite, were conducted to find the suitable electrode material. It is found that material removal rate is mainly influenced by discharge on time (Ton) and discharge current (I), whereas discharge off time (Toff) has least effect on material removal rate. Electrode wear is mainly influenced by discharge on time (Ton) and discharge off time (Toff), whereas discharges current (I) has least effect on electrode wear. Over cut is mainly influenced by discharge current (I) and discharge on time (Ton), whereas discharge off time have a very least effect on over cut. The output parameters are over cut, MRR and EWR.

(Muttamara 2015) in this research paper the experiments were carried out on Ti6Al4V. Performance in respect to MRR and electrode wear is compared for two graphite qualities. The MRR is larger when using graphite and the EWR is smaller compared to in infiltrated-graphite. Infiltrated-graphite gives better surface roughness of work piece than produced by infiltrated-graphite. EDM process gives value in hardness of the white layer up to 3 to 4 times (720- 800 HV) compared to Ti6Al4V substrate.

(Dignesh Thesiya 2023) in this research paper the influence of various on process parameters on material removal rate (MRR), electrodes wear rate (EWR) and surface roughness (SR) of Ti-6Al-4V. The process parameters considered in the research were voltage (V), current (Ip), pulse ON time (Ton), pulse OFF time (Toff) while copper and graphite electrode was used as a tool. From MRR and EWR point of view, graphite has demonstrated competitive performance, significant decline in surface quality is found. Material removal rates were observed between 0.000903 to 0.002612 mm3 /min for copper and 0.000440 to 0.001663 mm 3 /min for graphite electrodes. Electrode wear rates were observed between 0.000010 to 0.000500 mm3/min for copper and 0.000034 to 0.430660 mm3 /min for graphite electrodes. Surface quality observed was between 2.23 to 3.37 µm for copper and 2.32 to 3.92 µm for graphite electrode respectively.

(Jush Kumar Siddania 2021) in this research paper investigates brass tubular electrode, copper tubular electrode and zinc electroplated brass electrode are compared at different process variables on drilling of Ti-6AL-4V. The selected process parameters are T_{on} time and T_{off} time and peak current.

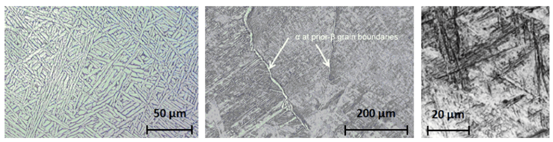

Figure 4 Microstructure of Ti-6AL-4V

Increase process capabilities such as MRR, EWR and geometrical precision. This method may be highly useful in achieving greater machining efficiency when fabricating complicated micro-parts on difficult-to-machine and multi-materials. It has been discovered that a little Zinc coating over plain brass greatly enhances EWR & HOC. It was also identified that, for improved machining quality, discharge energy should be maintained to a minimum. High machining rates are achieved by the CTE due to high thermal conductivity. The greater amount of zinc particles are flush out from the electrode and adhere to the hole surface.

(Kumanan 2018) in this research paper three different electrodes used such as Copper, Brass and Aluminium is most suitable for
Use as the tool electrode in EDM of Ti-6Al-4V alloy and study of Response surface methodology (RSM) is used to investigate the relationships and parametric interactions between the four controllable variables on the MRR and Ra. The response was modeled using a response surface model based on experimental results. RSM revealed that the all four input parameters such as peak current(I), pulse on time(Ton), electrode rotational speed(S) and flushing Pressure(P) are the most influential parameters for MRR and Ra. Increase the flushing pressure to the dielectric fluid, the surface roughness deteriorated with an increase in peak current. Since an increase in the peak current increased the discharge energy and the impulsive force, removing more molten material and generating deeper and larger discharge craters. Hence, the surface roughness became coarser. The material removal rate and surface roughness are increasing with peak current and pulse duration for each electrode material. Copper electrode gives the higher material removal rate, followed by brass and aluminium. Brass and aluminium electrodes exhibit the best performance with regard to surface roughness.

(Shetiye 2024) This paper emphasizes identifying the combination of parameters that lead to arcing in the machining of titanium alloy Ti-6Al-4V using copper C100 electrode on Die Sinking EDM. Graphite powder concentration of 0%, 5% and 10% in EDM oil is used for the investigation. To identify arcing parameters, Taguchi parameter Design approach is used. Three stage process parameters are selected for finishing, intermediate and roughing stages to study arcing. Discharge current, duty cycle and graphite powder concentration are the variables and effect of arcing on Material removal rate, Electrode wear rate and Surface roughness of Ti-6Al-4V is analyzed. Arcing parameters contribute significantly to decreasing machining characteristics namely material removal rate, electrode wear rate. Surface of the electrode is fractured due to arcing which ultimately results in high electrode wear. Arcing results in a poor surface finish and damages the electrode and workpiece during EDM operation. Arcing has been observed when the duty cycle is kept at max value. The controlled strategy of adjusting duty cycle input current might minimize the arcing related issue and ensure the efficiency in EDM manufacturing process.

(Chi 2024) In this article, the influence of technological parameters in micro-EDM with coated electrodes on quality indicators is investigated. The experiments were performed on titanium alloy strip (Ti-6Al-4V) and AlCrN coated tungsten carbide rod served as electrode rod. The technology parameters used in the study include Voltage (V), Capacitance (C) and Spindle Rotation (RPM), and tool wear rate (TWR), overcut (OVC) and depth (Z co-ordinate) are the quality indicators in research results. Taguchi method is used to design experiments, and ANOVA is used to analyze the results of quality indicators. They conclude that Capacitance has greater effect on multi- performance characteristics than U and RPM. Depth, overcut and TWR were increased with the increase in U, and Capacitance increases have resulted in Z co-ordinate and TWR both increasing. The influence of RPM on OVC and TWR is similar.

VIII. Conclusion

- Required more focus to adopt different kinds of electrodes with unique shapes and different materials for effective for practical implication and also as a cost effective for industrial application. Include a broader range of materials could enhance its applicability and relevance to a wider range of industrial applications.

- More comprehensive study of EDM process parameters required depth investigation for tool life and internal micro structure by analyzing different defects appear after machining in the tool structure process parameters on surface integrity aspects such as surface roughness, microstructure alterations, or residual stresses. Understanding the influence of process parameters and electrode materials on surface integrity is crucial for ensuring the quality and functionality of EDMed components.

- Taguchi and genetic algorithms techniques are commonly employed for optimization of parameters for EDM. Required to investigate more on process parameters by any other optimization techniques for optimum values.

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