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A RESEARCH ON MACHINING PARAMETERS ON SURFACE ROUGHNESS AND MRR OF TITANIUM (Ti-6AL-4V) ALLOY BY WEDM USING BRASS & MOLYBDENUM ELECTRODE

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ABSTRACT: ***Wire electrical discharge machining (WEDM) process is a highly complex, time varying & stochastic process. WEDM is extensively used in machining of conductive materials where precision is of major factor. The process output is affected by large number of input variables. Therefore suitable input variables for the wire electrical discharge machining process should be selected. In this work the objective is to investigate the effect of process parameters such as peak current, pulse on time and pulse off time on process performance such as material removal rate and surface roughness were studied while machining titanium alloy using brass and molybdenum wires in wire cut EDM. The Experimentation has been done by using Taguchi's L9 orthogonal array (OA). The experimental result analysis showed that the combination of higher levels of pulse on time, pulse off time and peak current is essential to achieve simultaneous maximization of material removal rate and minimization of surface roughness. Surface roughness tester is used for examination of machined surfaces was performed to understand the effect of two different wires on work piece material surface characteristics.***

Keywords: ***EDM,WEDM,OA,SEM***

INTRODUCTION

Electrical discharge machining (EDM) is a non-conventional machining concept which has been widely used to produce dies, molds and metalworking industries. This technique has been developed in the late 1940s and has been one of the fast increasing methods in developed area during 1980s and 1990s. This machining method is commonly used for very hard metals that would be impossible to machine with conventional machine. It has been widely used, especially for cutting complicated contours or delicate cavities that also would be tough to produce with conventional machining methods. However, one critical limitation is that EDM is only works with electrically conductive materials. Metal that can be machined by using EDM include nickel-based alloy (such as aerospace material), very hard tool steels etc. The different types of EDM process are shown in Figure 1.1

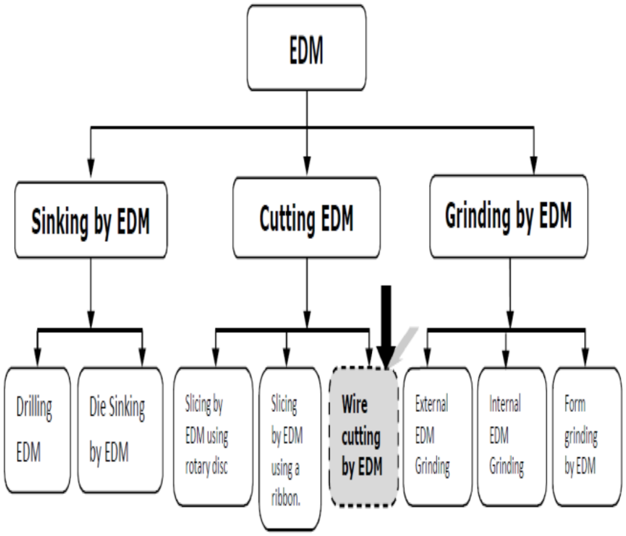

Figure 1.1: Types of EDM Process

1.2 TYPES OF EDM

Electric discharge machining enables the machining operation in several ways. Some of these operations are similar to conventional operations such as milling and die sinking others have its own characteristic. Different classifications are possible and also it should be keep in mind that, current developments in its technology gives different types of operations. General classification can done by considering applications such as,

i. Die Sinking EDM
ii. Wire EDM
iii. EDM Milling

iv. Wire Electric Discharge Grinding

1.2.1 Die Sinking EDM

The tool electrode has the complementary form of finished work piece and literally sinks into the rough material. Complex shapes are possible, but needs more machining time but dimensional accuracy is high when compared with wire EDM.

1.2.2 Wire EDM

The electrode is a wire that cuts through the work piece and renewed constantly to avoid rapture. The wire is cheaper than the complex electrodes used in die sinking electric discharge machining. Less material should be removed, which leads short machining time and electrode wear. But, the operation is possible only for ruled surfaces and the wire may bend during machining, cause substantial shape errors.

1.2.3 EDM Milling

Usually a rotating cylindrical electrode follows a path through the work piece, yielding the desired final geometry. It is advantageous when large holes or complex geometries are required.

1.2.4 Wire Electric Discharge Grinding

In the case where small holes are needed, a relatively large electrode may be reversibly eroded against a sacrificial work piece. In this case the polarity between the electrode and the work piece is reversed, so that the material removal predominantly takes place on the electrode.

1.3 WIRE ELECTRICAL DISCHARGE MACHINING (WEDM)

WEDM was first introduced to the manufacturing industry in the late 1960s. The development of the process was the result of seeking a technique to replace the machined electrode used in EDM.

Wire electrical discharge machining (WEDM) is a widely accepted non-traditional material removal process used to manufacture components with intricate shapes and profiles. It is considered as a unique adaptation of the conventional EDM process, which uses an electrode to initialize the sparking process. However, WEDM utilizes a continuously travelling wire electrode made of thin copper, brass or tungsten of diameter 0.05–0.3 mm, which is capable of achieving very small corner radii. The wire is kept in tension using a mechanical tensioning device reducing the tendency of producing inaccurate parts. During the WEDM process, the material is eroded ahead of the wire and there is no direct contact between the workpiece and the wire, eliminating the mechanical stresses during machining.

WEDM is a thermo-electrical process in which material is eroded from the work material by a series of separate sparks between the work material and the wire electrode i.e. tool (wire) and workpiece material, separated by a thin film of dielectric fluid (Distilled water oil) that is continuously fed to the machining zone to flushing away the evaporated particles. The movement of wire is controlled numerically to achieve the desired 3D (3-dimensional) shape and accuracy of the work piece. In addition, the WEDM process is able to machine exotic and high strength and temperature resistive (HSTR) materials and eliminate the geometrical changes occurring in the machining of heat-treated steels.

After computer numerical control (CNC) system was initiated into WEDM that brought about a major evolution of the machining process. As a result, the broad capabilities of the WEDM process were extensively exploited for any through-hole machining owing to the wire, which has to pass through the part to be machined. The common applications of WEDM include the fabrication of the stamping and extrusion tools and dies, fixtures and gauges, prototypes, aircraft and medical parts, and grinding wheel form tools.

Wire EDM often uses a steel wire that has been coated with brass, tungsten wire and other materials of good conductivity, with high strength and high melting temperature. The electrode material (wire) has to be matched to the work material so that in-process variations are controlled accurately. WEDM process is commonly conducted on underwater condition in a tank fully filled with dielectric fluid. While both conditions (submerged or dry machining) can be accomplished, very important is to produce a good quality of surface roughness and dimensional accuracy.

1.3.1 .Cutting Mechanism in Wire EDM

The main concept of WEDM is shown in Figure 1.2. In this process, a gently moving wire passes through a recommended path and removes material from the work piece. WEDM uses electro-thermal mechanisms to cut electrically conductive materials. The material is removed by a continuous of sparks between the wire electrode and the work material in the presence of dielectric (distilled water), which creates a path for each discharge as the fluid becomes ionized in the gap between tool (wire) work material. The area where discharge takes place is heated to extremely high temperature, so that the surface is evaporated and removed. The removed particles are flushed away by the flowing dielectric which shown in Figure 1.2. The wires materials for WEDM are made of brass, copper, tungsten, etc. (0.02 – 0.3mm in diameter) which capable to achieve very small corner radii. The wire used in WEDM process should be high tensile strength and very good electrical conductivity.

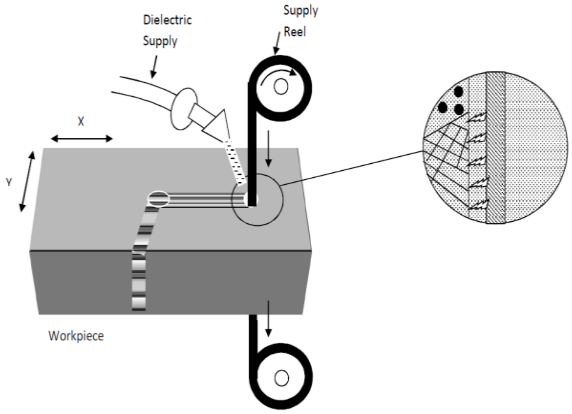

Figure 1.2: Schematic of the Thermal Removal

Process of WEDM

The melting temperature of the parts to be machined is an important factor for this process rather than strength or hardness. The WEDM process makes use of electrical energy generating a channel of plasma between the cathode and anode, and turns it into thermal energy at a temperature in the range of 8000–12,000°C or as high as 20,000°C initializing a substantial amount of heating and melting of material on the surface of each pole. When the pulsating direct current power supply occurring between 20,000 and 30,000 Hz is turned off, the plasma channel breaks down. This causes a sudden reduction in the temperature allowing the circulating dielectric fluid to implore the plasma channel and flush the molten particles from the pole surfaces in the form of microscopic debris.

1.3.2 Advantages of Wire EDM Process

1. Very small work pieces where conventional cutting tools may damage the part from excess cutting tool pressure.
2. Delicate sections and weak materials can be machined without any distortion because there is no direct contact between tool and work piece.
3. No electrode fabrication required.
4. No cutting forces.
5. Unmanned machining.
6. Die cost reduced by 30-70%.
7. Cuts extremely hard material to very close tolerances.
8. Intricate shapes can be cut with ease.
9. Very small kerf width
10. A good surface finish can be obtained.

1.3.3 Disadvantages of Wire EDM Process

1. The slow rate of material removal.
2. The additional time and cost used for creating electrodes for ram/sinker EDM.
3. Reproducing sharp corners on the work piece is difficult due to electrode wear.
4. Specific power consumption is very high.
5. "Overcut" is formed.
6. Excessive tool wear occurs during machining.
7. Electrically non-conductive materials can be machined only with specific set-up of the process.
8. Higher capital cost.
9. Electrolysis can occur in some materials.
10. Not applicable to very large work pieces.

1.3.4 Applications of Wire EDM Process

1. Ideal for stamping die components since kerf is so narrow, it is often possible to fabricate punch and die in a same cut.
2. Tools and parts with intricate outline shapes, such as lathe form tools, extrusion dies, flat templates and almost any complicated shapes.
3. It has been extensively used for machining of exotic materials used in aero-space industries, refractory metals, hard carbide and hardenable steel.
4. Prototype production.
5. Coinage dies making.

1.4.WIRE ELECTRODE

Wires used in this machine as the cutting tool. The wire is usually made of brass, molybdenum, copper, or tungsten; zinc or brass coated and multi-coated wires are also used. Pure copper or brass is extensively used as an electrode material. It is used when fine finishes are required in the work piece. It exhibits a very small wear ratio. A major problem with copper is its poor mach inability.

The properties required for the wire electrode are; (a) electrical properties, (b) geometrical properties,(c) physical properties and (d) mechanical properties. Electrical discharge performance is desired for steady and elevated energy discharge for high-speed cutting. The electrical properties are articulated by its electrical resistance. Energy losses are minimized by using two current contacts and selecting high-conductivity electrode materials, such as copper, brass, aluminum and its alloys, with optimized settings. Conductivity determines how readily the energy is transferred from power feed to the actual point of cutting. Improving the surface area of the wire will allow faster cutting. Ultra-fine wires (less than 30mm diameter) are used for micro WEDM, where small pulse energies are predominant. The coated layer structure is affected by the thermo physical properties of the electrodes, which are associated with its thermal conductivity, melting and evaporation temperature. Coating on the wire electrode initiates cooling of the wire electrode core and yields a good cutting performance. The imperative mechanical properties of the wire electrode are its tensile strength, elongation and straightness. High tensile signifies the ability of the wire electrode to endure tension during machining. Elongation describes how much the wire gives during cutting before it breaks. Straightness is important for successful auto threading. Soft wires are used for taper cutting and high tensile wires are used for high precision cutting. Non wire-related factors, such as mechanical machine concept, use of improved impulse generator and the dielectric flushing techniques, also play an important role for enhancing machinability of the WEDM process.

The wires diameter is typically about 0.3mm for rough cut and 0.20mm for finish cuts. The wire should have sufficient tensile strength and fracture toughness. As well as high electrical conductivity and capacity to flush away the debris produced during cutting. The wire is generally used only once, as is relatively inexpensive.

1.5 DIELECTRIC LIQUID

Dielectric fluid is a nonconductive liquid that fills between the work piece and electrode and act as an electrical insulator until needed space and voltage reaches. At that point dielectric fluid ionizes, becoming an electrical conductor and cause the current or spark to flow to the work piece.

The WEDM setup consists of a power supply whose one lead is connected to the work piece immersed in a tank having dielectric coil. The tank is connected to a pump, oil reservoir, and a filter system. The pump provides pressure for flushing the work area and moving the oil while the filter system removes and traps the debris in the oil. The oil reservoir restores the surplus oil and provides a container for draining the oil between the operations.

The main functions of the dielectric fluid are:

- ➢ To flush the eroded particles produced during machining, from the discharge gap and remove the particles from the oil to pass through a filter system.
- ➢ To provide insulation in the gap between the electrode and the workpiece.
- ➢ To cool the section that was heated by the discharge machining.

The two most commonly used fluids are petroleum based hydrocarbon mineral oils and deionized water. The oils should have a high density and a high viscosity. These oils have the proper effects of concentrating the discharge channel and discharge energy but they might have a difficulty in flushing the discharge products. De ionized water generally has the advantage that faster metal removal rates can be realized. However the surface finish of the material is generally poorer than that which can be achieved when using oil.

1.6 EQUIPMENT

The equipment used for machining is EZEECUT PLUS Wire cut EDM is as shown in Figure 1.4 and the specifications are presented in Table 1.1

Figure 1.3: EZEECUT PLUS Wire cut EDM

The Main Features of EZEECUT PLUS CNC Wire cut EDM are

- The highly precise machine tool includes high precision ball screw, wire rolling guide, high speed wire feed mechanism.
- Tension controllable wire driving system keeps constant wire tension.
- Simple to use software PRAPT. Features include DXF file interface, built-in utility packages for gears and curves, Built-in function like move, rotate, copy, mirror, scale reverse mirror, multi cavity program generation.
- Automatic center-find, edge find, pause at wire breaks, pause at short circuit and gap short recovery, program can be restarted after power failure from the same point where power was interrupted.
- X, Y, U, V table displacement and profile displayed on CRT screen.
- Automatic wire radius compensation ensures work-pieces accuracy.
- Back to origin through shortest path as well as along programmed profile.
- Program can be reversed.
- Multi pass feature gives the better finish for job.
- Unique feature: Wire is reused which drastically reduces machining cost.

Table 1.1: Technical Specifications for Wirecut EDM

Machine Tool	**Ezeecut Plus**
Max. work piece size	360 x 600 mm
Max. Z height	400 mm
Max. work piece weight	300 kg
Main table traverse (X, Y)	320, 400 mm
Auxiliary table traverse (u, v)	25, 25 mm
Machine Tool Size(L*W*H)	1500*1250*1700
Max. taper cutting angle	± 3°/100 mm
Machine Tool Weight	1400kg.
Max dry run speed	25mm/min.
Best surface Finish (Ra)	1-1.5µm.
Wire diameter	0.2 to 0.25 mm (Brass) 0.12 to 0.25 mm (Molybdenum)

1.8 OBJECTIVES OF THE PROJECT

The objectives of the project are:

- To determine the significant parameters that influences the machining responses during Wire Electrical Discharge Machining of work piece material.
- To evaluate the performance of Wire Electrical Discharge Machining on work piece material with respect to various responses such as material removal rate and surface roughness.
- Achieving the shortest machining time, satisfying the accuracy and surface roughness requirements.

1.9 NEED OF THE PROJECT

The scope of this project is conducting a machining operation using wire EDM to analyze the machining performance. The process of machining titanium and its alloys by conventional machining methods has some difficulties such as high cutting temperature and high tool wear ratio. Therefore, unconventional machining processes (Wire Electrical Discharge machining) are introduced for machining titanium and its alloys.

Selection of optimum machining parameter combinations for obtaining higher accuracy, higher cutting speed, lower dimensional deviation, better material removal rate and higher surface finish is a challenging task in WEDM. Improperly

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selected parameters may result in serious consequences like short-circuiting of wire and wire breakage. Hence, the best combination of machining parameters should be chosen properly according to work piece properties so that better performance can be obtained.

2. METHODOLOGY

In this chapter, the need and scope of the project, selection of material and wire and design of experiment using Taguchi method. The methodology of the project is represented as a flow diagram in Figure

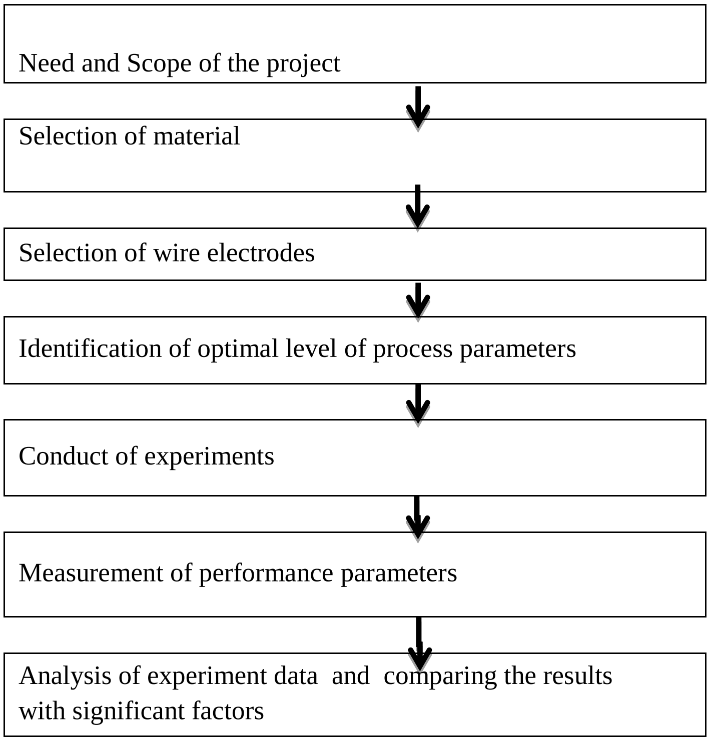

Figure 3.1: Methodology of the Project

2.1 SELECTION OF MATERIAL

Titanium is alloyed with aluminum, manganese, iron, molybdenum and other metals to increase strength, to withstand high temperatures and to lighten the resultant alloy. Titanium is a metal with excellent corrosion resistance, fatigue resistance, a high strength-to-weight ratio that is maintained at elevated temperature. Titanium and its alloys are attractive and important materials in modern industry due to their unique properties that are mentioned. Titanium is a very strong and light metal. Machining titanium and its alloys by conventional machining methods has some difficulties such as high cutting temperature and high tool wear ratio. Titanium and its alloys are classified as difficult-to-machine materials. Titanium and its alloys are used in different industries such as biomedical applications, automobile, aerospace, chemical field, electronic, gas and food industry. Titanium is used in different medical applications such as dental implants, hip and knee replacement surgeries, external prostheses and surgical instruments. On the other hand, there is some limitation for titanium use because of its initial high cost, availability, inherent properties and manufacturability.

The type of material selected is Titanium alloy (Ti-6Al-4Al) which has very high tensile strength, toughness, light in weight, corrosion resistance and the ability to withstand extreme temperatures. The Chemical composition are shown in 2.1, Mechanical properties are shown in 2.2 and Material properties are represented in Table 2.3

Table 2.1: Chemical Composition of Titanium Alloy

C	Fe	Al	O	N	V	H	Ti
0.056	0.065	5.75	0.2	0.05	3.68	0.15	90.049

Table 2.2: Mechanical Properties of Titanium Alloy

Density	4420 kg/m3
Melting point	1650^{o}C
Coefficient of expansion	9.0 µm/m^{o}C (21^{o}C–93^{o}C)
Hardness (HV20)	600
Modulus of elasticity	116 GPa

Table 2.3: Material Properties of Titanium Alloy

Ultimate Strength (MPa)	Yield strength (MPa)	Elastic modulus (GPa)	Hardness (HRC)	Elongation (%)
1026	939	115	32	14

2.2 SELECTION OF WIRE ELECTRODES

Brass wires are the combination of copper and zinc, alloyed in the range 63%–65% copper and 35%–37% zinc. Machining speed increases with the presence of zinc in the EDM wire electrode owing to stable discharge during machining. The zinc in the brass wire actually boils off, or vaporizes, which helps cool the wire and delivers more usable energy to the work zone. The addition of zinc in the wire provides a higher tensile strength, lower melting point, higher vapor pressure rating and improved flushability, but its conductivity is significantly reduced. Machining speed can be further enhanced with the addition of more zinc (more than 40%) to the wire, but in that case the drawing process to form a wire becomes difficult because of the presence of a brittle phase in the alloy.

Molybdenum wire electrode or tungsten wire electrodes are used because of their high tensile strength and load-carrying capability. The tensile strength of the pure molybdenum is approximately 1.6 times and tungsten is 3 times that of a plain brass wire electrode. Their use is limited because of low electrical conductivity and flushing. Tungsten and molybdenum wires also have poor discharge, low tensile strength at high temperature, which leads to poor surface finish, and wire failure. This drawback was removed by using the molybdenum alloy containing one or more of the oxides of Al, Si and K, and tungsten alloyed with rare earth elements like Y, La, Ce, and their oxides. The tensile strength and strains in the wire of molybdenum alloy was improved as the fine particles of the oxides are uniformly dispersed in the molybdenum, so that the recrystallization temperature of the molybdenum alloy becomes higher and accordingly the tensile strength of the molybdenum alloy at high temperatures is improved. The molybdenum wire electrode is also abrasive to power feed and wire guides, moreover they are very expensive. The diameter of the molybdenum and tungsten cutting wires can be reduced for more precise processing. The accuracy of the cut surface of the work piece can also be improved. Several authors have also suggested that the molybdenum alloy, used to make the cutting wire electrode, has a characteristic called an emission effect, whereby the emission of electrons is facilitated for an improved current flow through the cutting wire. This increases the discharging capability, which subsequently produces the effective spark. The processing speed and the accuracy of the cut surface of the work piece are improved, and the number of failures owing to breaking of the cutting wire is reduced. These wires are particularly suited for making small parts with very tight tolerances and good surface finishes.

2.3 DESIGN OF EXPERIMENT USING TAGUCHI METHOD

Number of experiments was determined using the Taguchi method. The Taguchi method is a powerful and efficient design of experiment technique, which can improves process performance with a minimum number of experiments. It reduces, rework costs, manufacturing and cycle time costs in processes. The Taguchi design is to find optimal values of the objective function in manufacturing processes. Compared to traditional experimental designs, the Taguchi method makes use of a special design of orthogonal array to examine the quality characteristics through a minimal number of experiments. The experimental results are then transformed into S/N ratios to evaluate the performance characteristics. Therefore, the Taguchi method concentrates on the effects of variations on quality characteristics, rather than on the averages. That is, the Taguchi method makes the process performance insensitive to the variations of uncontrollable noise factors. The optimum parameter conditions are then determined by performing the parameter design.

2.3.1 Summary of Taguchi Method

Genichi Taguchi, a Japanese scientist, developed a technique based on Orthogonal Array of experiments. This technique has been widely used in different fields of engineering to optimize the process parameters. The integration of Design of experiments with parametric optimization of process can be achieved in the Taguchi method. An Orthogonal Array provides a set of well-balanced experiments, and Taguchi's signal-to-noise. (S/N) ratios, which are logarithmic functions of the desired output, serve as objective functions for optimization. S/N ratio is the ratio of the mean to standard deviation. Here mean refers to signal and standard deviation refers to noise. The ratio depends on the quality characteristic of the product/process to be optimized. It helps to learn the whole parameter space with a small number (minimum experimental runs) of experiments.

A three stage design operation is done in taguchi's method to determine the target value and tolerances for relevant parameters in the product, the three stage designs are-

1. System design
2. Parameter design
3. Tolerance design

System design: A prototype of the product is created using scientific and engineering principle and experience. This is done having an eye on the functional requirement.

Parameter design: Taguchi defines a performance measure known as the signal to noise ratio(S/N).The target of the parameter design is to find the optimal setting of the product and the process parameters so that the performance variability is minimized. Selection of parameters is done to maximize the S/N ratio. Signal represents the square of the mean value of the quality characteristic while noise is the measure of the variability of the characteristics.

Tolerance Design: After the system design and the parameter design tolerance design are done in the third stage in this step we set tolerances in the range of admissible values around the target value of the control parameters.

The general steps involved in the Taguchi Method are as follows:

1. Define the process objective, or more specifically, a target value for a performance measure of the process. The target of a process may also be a minimum or maximum.
2. Determine the design parameters affecting the process. Parameters are variables within the process that affect the performance measure such as temperatures, pressures, etc. that can be easily controlled. The number of levels that the parameters should be varied at must be specified. Increasing the number of levels to vary a parameter at increases the number of experiments to be conducted.
3. Create orthogonal arrays for the parameter design indicating the number of and conditions for each experiment.
4. Conduct the experiments indicated in the completed array to collect data on the effect on the performance measure.
5. Complete data analysis to determine the effect of the different parameters on the performance measure.

2.3.2 Selection of Orthogonal Array

The effect of many different parameters on the performance characteristic in a condensed set of experiments can be examined by using the orthogonal array experimental design proposed by Taguchi. Once the parameters affecting a process that can be controlled have been determined, the levels at which these parameters should be varied must be determined. Determining what levels of a variable to test requires an in-depth understanding of the process, including the minimum, maximum, and current value of the parameter. If the difference between the minimum and maximum value of a parameter is large, the values being tested can be further apart or more values can be tested. If the range of a parameter is small, then less value can be tested or the values tested can be closer together. Knowing the number of parameters and the number of levels, the proper orthogonal array can be selected.

Table 2.4: Structure of L9 Orthogonal Array

EXPERIMENTS	P1	P2	P3	P4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

2.4 PROCESS PARAMETERS AND DESIGN

Parameters which are controlling the pulse energy and ultimately the machining speed and conditions are given below

(A) T_{ON}: Pulse on Time

During this period the voltage is applied across the electrodes. Higher the T_{ON} setting the larger is the pulse on period. The single pulse discharge energy increases with increasing T_{ON} period, resulting in higher cutting rate.

(B) T_{OFF}: Pulse off Time

During this period voltage for the gap is absent during this period.

With a lower value of T_{OFF}, there is more number of discharges in a given time, resulting in increase in the sparking efficiency. As a result cutting rate also increases. Using very low values of T_{OFF} period however may cause wire breakage which in turn reduces the cutting efficiency.

Table 2.7: List of Experiments Conducted

(C) I_P: Peak Current

This is for selection of pulse peak current.

Table 3.5: Range of Parameters

Higher the I_P setting larger is the peak current value. Increase in the I_p value will increase the pulse discharge energy which in turn can improve the cutting rate further.

(D) W_P: Flushing Pressure of Water Dielectric

This is for the selection of flushing input pressure.

High input pressure of water dielectric is necessary for cutting with higher values of pulse and power and also while cutting the jobs of higher thickness.

(E) W_F: Wire Feed Rate Setting

This is a feed rate at which the fresh wire is fed continuously for sparking.

Higher values of wire feed rate are required for working with higher pulse power

(F) W_T: Wire Tension Setting

This is a gram-equivalent load with which the continuously fed wire is kept under tension so that it remains straight between the wire guides. While the wire is being feed continuously, appropriate wire tension avoids the unintentional wire deflection from its straight path (between the wire guides). The wire deflection is caused due to spark induced reaction forces and water pressure.

(G) S_V: Spark Gap Set Voltage

This is a reference voltage for the actual gap voltage.

The experiment is conducted with three controllable 3-level parameters and material removal rate and surface finish as response variables. Each factor is investigated at three levels to determine the optimum settings for the WEDM process. These parameters and their levels were chosen based on the review of literature. Nine experimental runs based on the orthogonal array L9. Table 3.5 gives the range of parameters. Table 3.6 presents the level of the three controlled parameters of Current, Pulse ON and Pulse OFF

Table2.5: Range of parameters

Parameters	Range of parameters
Peak current	1-3 A
Pulse ON	32-36 µs
Pulse OFF	6-8 µs

Table 2.6: Level of Experimental Parameters

Factors	Level-1	Level-2	Level-3	Units
I_p	1	2	3	A
T_{on}	32	34	36	µs
T_{off}	6	7	8	µs

2.7 EXPERIMENTAL WORK

The EZEECUT PLUS Wire cut EDM was used to carry out the experiments. The Ti6Al4V has been applied as work piece material for the present experiments. The shape was machined by WEDM with 39mmx10 mmx5 mm size. Two types of wire electrode were used namely Brass wire and Molybdenum wire. De-ionized water was selected as the dielectric for experiments, as that is the standard for Wire EDM. The number of experiments to be conducted is shown in Table 2.7 and the machining of work piece is shown in Figure 2.2.

Experiment no	Current(a)	Pulse ON(µs)	Pulse OFF(µs)
1	1	32	6
2	1	34	7
3	1	36	8
4	2	32	7
5	2	34	8
6	2	36	6
7	3	32	8
8	3	34	6
9	3	36	7

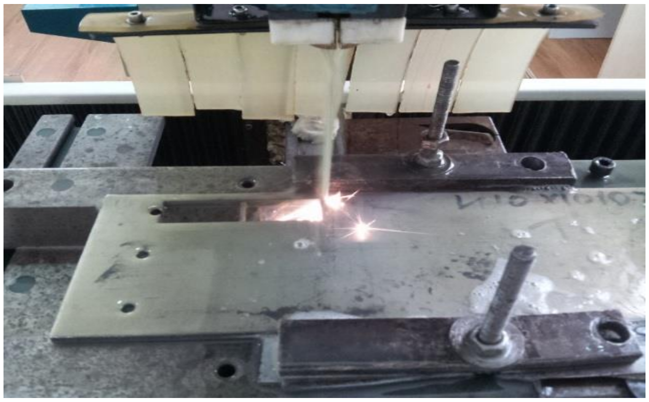

Figure 2.2: WEDM Machining of Work piece

2.6MEASUREMENT OF SURFACE ROUGHNESS (R_a)

Surface roughness commonly shortened to roughness, is a measure of the finely spaced surface irregularities. Surface finish may be measured in two ways: contact and non-contact methods.

Contact methods involve dragging a measurement stylus across the surface; these instruments are called

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profilometers. Non-contact methods include: interferometer, nonlocal microscopy, focus variation, structured light, electrical capacitance, electron microscopy, and photogrammetry.

The TR200 contact surface roughness tester (Figure 3.3) is used for measuring the surface roughness of the work piece. The TR200 Surface Roughness Tester is a portable instrument for measuring surface finish and offers comprehensive analysis with 13 different roughness parameters. The TR200 roughness gauge can operate on various surfaces including outer cylinder, outer cones, grooves and recesses and holes. The piezo-electric operated diamond stylus insures very reliable measurement which conforms to US and international standards.

Surface roughness parameters that are considered in the experiment is Roughness Average (Ra).

Ra is the arithmetic average of the absolute values of the roughness profile ordinates.

Figure 2.3: Surface Roughness Tester TR-200 Used for the

RESULTS AND DISCUSSION

The experimental results were collected for material removal rate and surface roughness.9 experiments were conducted using Taguchi (L9) experimental design methodology and there are two replicates for each experiment to obtain S/N values. In the present study all the designs, plots and analysis have been carried out using Minitab statistical software. Larger material removal rate and lower amount of surface roughness show the high productivity of Wire EDM. Therefore, large the better and small the better are applied to calculate the S/N ratio of material removal rate and surface roughness respectively by using the given equations (1) and (2).

1. Larger the Better:

$(S/N)_{HB}$=-10Log(MSD_{HB}) …….. (1)

Where: $MSD_{HB} = 1/n \sum_{i=1}^{n} \left(\frac{1}{yMRR^2}\right)$

2. Smaller the Better:

$(S/N)_L$=-10Log(MSD_{LB}) …………………………….. (2)

Where: $MSD_{LB} = MSD_{LB} = 1/n \sum_{i=1}^{n} \left(yRa^2 \right)$

Here $y_{MRR,}$ and y_{Ra} represents response for metal removal rate and surface finish respectively and n denotes the number of experiments.

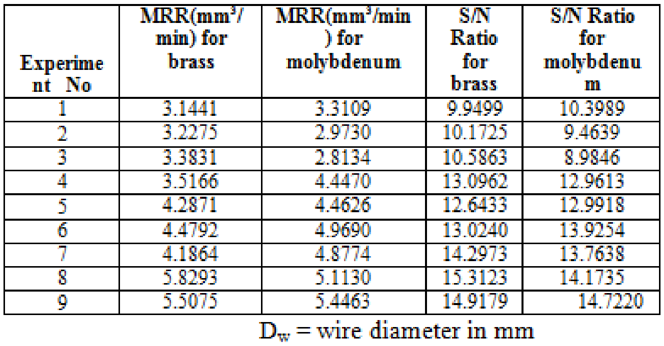
Experiments were conducted using L9 OA to find the effect of process parameters on the material removal rate and surface roughness. ANOVA analysis is carried out for all process parameters to determine the significant ones and response curves were plotted in order to detect the influence of significant parameters on response.

4.1EFFECT ON PROCESS PARAMETER ON MRR

The effect of the process variables on the MRR has been determined by using equation (3)

MRR = F×D_w×H mm^3/min ……………………..… (3)

Where F = Machine feed rate in mm/min
F = (60×l)/t
l = cutting length in mm
t = cutting time in sec
D_w = wire diameter in mm



Experiment No	MRR(mm^3/min) for brass	MRR(mm^3/min) for molybdenum	S/N Ratio for brass	S/N Ratio for molybdenum
1	3.1441	3.3109	9.9499	10.3989
2	3.2275	2.9730	10.1725	9.4639
3	3.3831	2.8134	10.5863	8.9846
4	3.5166	4.4470	13.0962	12.9613
5	4.2871	4.4626	12.6433	12.9918
6	4.4792	4.9690	13.0240	13.9254
7	4.1864	4.8774	14.2973	13.7638
8	5.8293	5.1130	15.3123	14.1735
9	5.5075	5.4463	14.9179	14.7220

D_w = wire diameter in mm

Table 4.1: Result of Material Removal Rate

Figure 4.1 is plotted based on the results are achieved from machining of titanium by brass wire. The Figure 4.1 shows that when pulse on and peak current increase the MRR increases, and MRR increase up to some level and decrease in the period of pulse off time. This is because of increase in discharge energy and enhancement in pulse on and peak current that lead to a faster MRR. The number of discharges within a given period becomes less because the off time between the pulses increase which leads to a lower MRR.

Figure 4.2 is plotted based on the results are achieved from machining of titanium by brass wire. The Figure 4.2 shows that when pulse peak current increase the MRR increases and pulse on also increases but some variation and MRR decrease in the period of pulse off time. This is because of increase in discharge energy and enhancement in pulse on and peak current that lead to a faster MRR. The number of discharges within a given period becomes less because the off time between the pulses increase which leads to a lower MRR. The optimal values for both wire material types are the third level of peak current, third level of pulse on, and first level of pulse off provide maximum value of MRR. The range of MRR with brass wire is higher than high molybdenum brass wire.

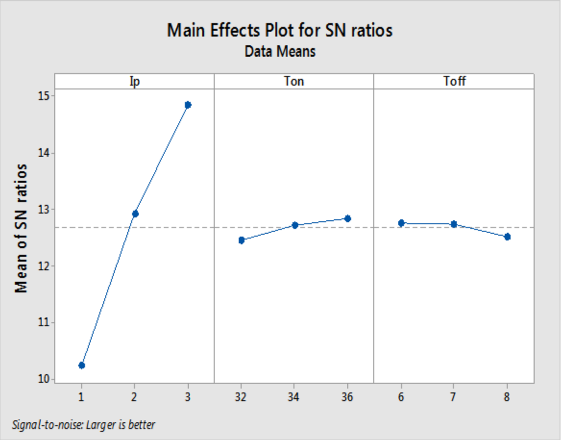


figure 4.1: Effects of Significant Parameters on MRR (brass wire)

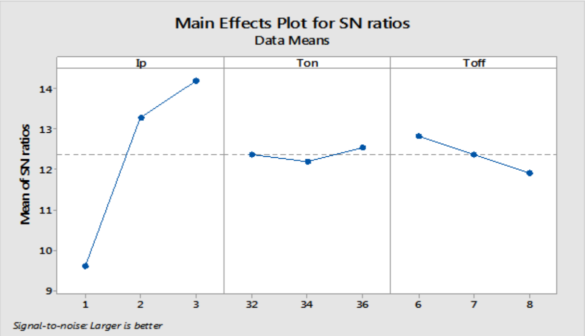


Figure 4.2: Effects of Significant Parameters on MRR (Molybdenum wire)

4.2 EFFECT ON SURFACE ROUGHNESS

Table 4.2 results revealed that in WEDM of titanium with both wire types, pulse off do not have any influence on surface roughness. Other parameters such as pulse on and peak current are the significant parameters for surface roughness.

Experiment No	R_a (μm) for Brass	R_a (μm) for molybdenum	S/N ratio for Brass	S/N ratio for Molybdenum
1	5.632	3.754	-15.0133	-11.489
2	5.489	4.262	-14.7899	-12.592
3	5.695	4.134	-15.1099	-12.327
4	6.638	4.356	-16.4407	-12.781
5	6.979	5.441	-16.8759	-14.713
6	7.517	5.772	-17.5209	-15.226
7	7.447	6.244	-17.4396	-15.909
8	6.754	6.413	-16.5912	-16.141
9	7.012	6.809	-16.9168	-16.661

The Figures 4.3 and 4.4 plotted to show the effect of significant parameters on surface roughness for machining of titanium using brass wire and molybdenum wire respectively. It is observed from Figure 4.3 and 4.4 surface roughness value increases when pulse on and peak current increase. The discharge energy increases with the pulse on time and peak current and larger discharge energy produces a larger crater, causing a larger surface roughness value on the work piece.

No difference between the optimal values obtained for machining of titanium with brass wire and molybdenum wire was found. Analysis of the results of S/N ratio and raw data leads to conclusion that factors peak current at first level, pulse on at first level and pulse off at second level can be set for minimization of surface roughness.

The molybdenum wire can produce smoother surface in comparison with brass wire. The wire with high tensile strength is a good heat resistance in high temperature and maintains straight under vibration and tension. Also, molybdenum wire provides good discharge characteristics. A finer discharge can be created with good discharge characteristics and higher tensile strength. As a result, the quality of work piece surface will improve.

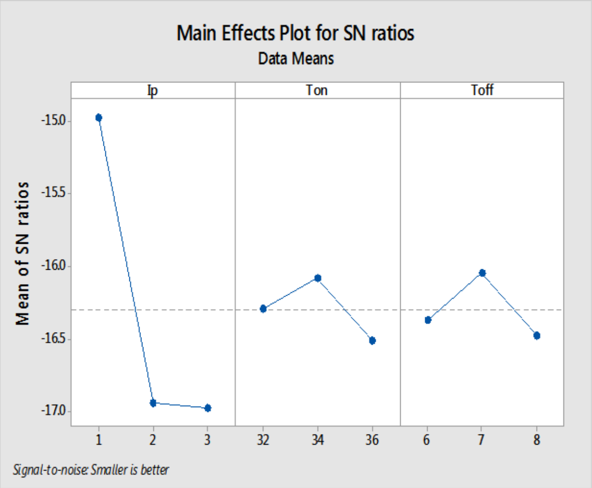


Figure 4.3: Effects of Significant Parameters on Surface Roughness (Brass wire)

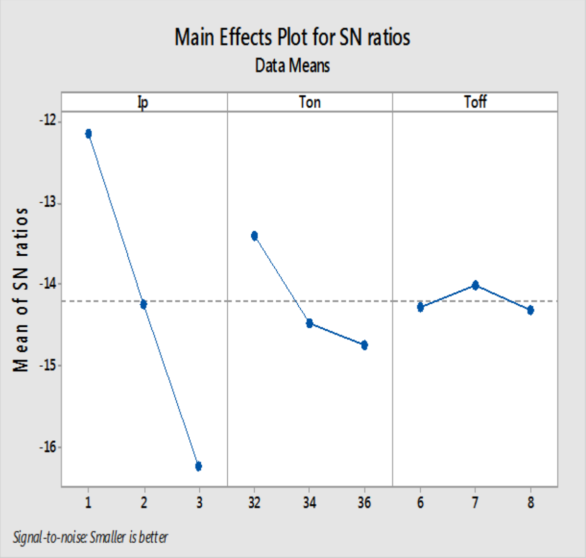


Figure 4.4: Effects of Significant Parameters on Surface Roughness (Molybdenum wire)

CONCLUSION

In this study, the influence of brass wire on the performance of wire electrical discharge machining is compared with molybdenum wire. Also, the effect of process parameters on the process performance was determined by performing experiments under different machining conditions. Based on the experimental results and analysis, the following conclusions can be drawn:

- Experiments results of wire electrical discharge machining of titanium indicate peak current and pulse on have significant effect on material removal rate and surface roughness.
- Analysis using Taguchi method shows that the optimized values of current, pulse on and pulse off for material removal rate is 3,36,6 respectively and for surface roughness is 1,34,7.
- Compared with brass wire, molybdenum wire results smoother surface finish but the material removal rate is less.

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