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Research Article

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Experimental Investigations on Kerf width and Material Removal Rate in Wire Electric Discharge Machining of Titanium Alloy

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Abstract:

Titanium and its alloys are used in many different industries such as biomedical and medical applications, automobile, aerospace, chemical field, electronic, gas and food industry because of its extreme properties like high tensile strength, fatigue resistance, highest strength-to-weight ratio, corrosion resistance, toughness at elevated temperatures and able to withstand high temperatures. Wire electric discharge machining (WEDM) has become one of the most popular processes for producing precise geometries in hard materials like titanium alloy. Improper WEDM process parameters setting can affect the surface roughness, overcut, micro structural changes and totally affect the process performance and efficiency. This paper presents an experimental investigation of Wire Electric Discharge Machining (WEDM) of Titanium alloy. The objective is to investigate the effect of wire electric discharge machining process parameters including pulse on time, input power. servo reference voltage, wire feed rate, wire tension, dielectric fluid pressure and server feed rate on process performance parameters such as kerf width, cutting speed, material removal rate and overcut. Experimental results reveals that, as the pulse on time/ pulse duration, input power, server voltage, wire feed and wire tension increases, the kerf width also increases. Lower feed rate gives bigger kerf width and as the feed rate increases kerf width decreases. Experimental results reveal that as the pulse on time, input power, water pressure, server feed increases the cutting speed also increases. However for extended pulse on time, input power the cutting speed decreases. It is observed that pulse on time, input power, server voltage, server feed have more significant effect on cutting speed. The material removal rate increases as the pulse on time, input power, water pressure and server feed increases. However for extended pulse on time, input power the material removal rate decreases. Further reveals that the material removal rate decreases as the wire feed, wire tension increases. The overcut increases as the pulse on time, input power, server voltage and water pressure increases. At optimum and low level of wire feed and server feed the overcut is more and at moderate level of wire feed and server feed, the overcut is low.

Keywords: WEDM, titanium alloy, Kerf width, Material Removal Rate, Cutting Speed, overcut.

I. INTRODUCTION

Titanium alloys are hard metals which contain a mixture of titanium and other chemical elements. Ti6Al4V grade titanium alloy is the most popular titanium alloy and is used for a range of applications in the aerospace, marine, power generation and offshore industries. Titanium alloys have very high tensile strength, fatigue resistance, light in weight (highest strength-to-weight ratio), extraordinary corrosion resistance, toughness even at elevated temperatures and able to withstand high temperatures. However, the high cost of both raw materials and processing limit their use to military applications, aircraft, spacecraft, medical devices, connecting rods on expensive sports cars and some premium sports equipment and consumer electronics. Auto manufacturers Porsche and Ferrari also use titanium alloys in engine components due to its durable properties in these high stress engine environments. Although "commercially pure" titanium has acceptable mechanical properties and has been used for orthopedic and dental implants, for most applications titanium is alloyed with small amounts of aluminum and vanadium. This mixture has a solid solubility which varies dramatically with temperature, allowing it to undergo precipitation strengthening. This heat treatment process is carried out after the alloy has been worked into its final shape but before it is put to use, allowing much easier fabrication of a high-strength product. Yang, X, Liu, CR et al., studied the machining of titanium and its alloys (1), Kuriakose, Sh, Shanmugan MS et at., studied the characteristics of wire electro discharge machined Ti 6Al 4V surface (2) and Rahman.M.M et al., have done the modeling of machining parameters of Ti 6Al 4V for electric discharge machining using a neural network approach (3). Titanium and its alloys are attractive and important materials in modern industry due to their unique properties. Titanium is a very strong and light metal. This property causes that titanium has the highest strength-to-weight ratio in comparison the other metal that are studied to medical use. Titanium is also incredibly durable and long-lasting. When titanium cages, rods, plates and pins are inserted into the body, they can last for upwards of 20 years. Titanium non-ferromagnetic property is another benefit, which allows patients with titanium implants to be safely examined with MRIs and NMRIs (4, 5). Titanium and its alloys are used in many different industries such as biomedical applications, automobile, aerospace, chemical field, electronic, gas and food industry (6). In recent decades, titanium is applied widely in biomedical and medical field because it is absolutely a proper joint with bone and other body tissue, immune from corrosion, strong, flexible and compatible with bone growth. Titanium is used in different medical applications such as dental implants, hip and knee replacement surgeries, external prostheses and surgical instruments (4, 7). Elias C.N et al., studied the Bio Medical applications of Titanium and its alloy (8) and Kumar A et al., has done the investigations into machining characteristics commercially pure titanium using CNC electric discharge machining (9). On the other hand, there is some limitation for titanium use because of its initial high cost, availability, inherent properties and manufacturability (9). Machining titanium and its alloys by conventional machining methods has some difficulties such as high cutting temperature and high tool wear ratio. Thus, titanium and its alloys are difficult-to-machine through conventional machining process. Therefore, unconventional machining processes are introduced for machining titanium and its alloys (2, 6). Gu.L, Rajukar K.P et al., studied the electric discharge machining of Ti-6Al-4V with a bundled electrode.

Wire Electrical Discharge Machining (WEDM) technology has been widely used in tool and die-making industry, automotive, medical and practically any conductive materials. It is a non-traditional machining process which used the continuously circulating wire as electrode and cuts the work piece along a programmed path. Wire Electrical Discharge Machining known as wire-cut EDM, a thin single-strand metal wire is fed through the work piece submerged in a tank of dielectric fluid. WEDM is typically used to make punches, tools, and dies from hard metals that are difficult to machine with other methods. Wire EDM is commonly used when low residual stresses are desired, because it does not require high cutting forces for removal of material. If the energy per pulse is relatively low, little change in the mechanical properties of a material is expected due to these low residual stresses, although material that has not been stress-relieved can distort in the machining process. The work piece may undergo a significant thermal cycle, its severity depending on the technological parameters used. Such thermal cycles may cause formation of a recast layer on the part and residual tensile stresses on the work piece.

Titanium Ti-6Al-4V has become very popular materials and widely used as implants for dental, restorations and orthodontic wires, as well as orthopedic due to their low density, high corrosion resistance and excellent mechanical properties (10). However these alloys were very difficult to fabricate as they are not ductile and have low fracture toughness at room temperature (11). Furthermore, due to its excellent strength property, it is found that it is extremely difficult to machine by conventional method. Several researchers (12, 13) have been investigated the different aspects of machining but no comprehensive research work has been reported so far in the field of wire electrical discharge machining of this alloy. Hence, it is essential to introduce an alternative method in machining of this alloy. Wire electrical discharge machining (WEDM) becomes an important non-traditional machining process due to its competency in machining of work pieces with complex geometry and hard stiffness (14). The material is removed by a series of discrete electrical discharges between the wire electrode and the work piece in this process. The discharges, which are highly focused by the dielectric medium, cause rise in the local temperatures of the work piece near the point of introduction. The temperatures are high enough to melt and vaporize the material in the immediate vicinity of the electrical discharges. Since, there is no mechanical contact between the work piece and the electrode, material of any hardness can be machined as long as it is electrically conductive (15). Due to this reason, it has dramatically increased in high application of materials with high stiffness in the aerospace, nuclear, and automotive industries. WEDM was effective solutions for machining hard materials such as titanium, molybdenum, zirconium and tungsten carbide with complex shapes and profiles that are difficult to machine using conventional methods (16, 17). With improper of selecting parameters there are possibility of wire breakage imposes certain limits on the cutting speed, which in turn reduces productivity. The selection of optimum cutting parameters is solution in obtaining a higher cutting speed or good surface finish. However, even though with the up to- date computer numerical control (CNC) WEDM machines exist, the problem of selecting optimum cutting parameters for WEDM processes is not fully solved. Machine feed rate, discharge current, wire speed, wire tension and average working voltage are the machining parameters which affect WEDM performance measures (18, 19). This study aimed in achieving the appropriate conditions in machining Titanium Ti-6Al-4V resulted in term of kerf width, cutting speed, material removal rate (MRR) and over cut.

II. EXPERIMENTAL WORK

The experiments were conducted on ULTRACUT S1 Four Axis Wire Cut EDM machine from Electronica India Pvt. Ltd. The titanium alloy of Ti 6Al 4V was used as work piece material for the present Investigations. The chemical composition of Ti6Al4V titanium alloy by % weight is given in Table 1. A diffused brass wire of 0.3 mm diameter was used as the wire electrode due to its extreme properties like electric discharge performance, heat resistance, low calorification and heat release. The chemical composition of brass wire was 63% copper and 37% Zinc by weight and its tensile strength is 142000 PSI. The deionized water was used as dielectric because of its low viscosity and rapid cooling rate and its temperature was kept at 20ºC. The process parameters such as pulse on time, input power, server voltage, water pressure, wire feed rate, wire tension and server feed rate has taken at three different levels as shown in Table 2 and experiments were conducted on ULTRACUT S1 Four Axis Wire Cut EDM machine with brass electrode of diameter 0.3 mm. The selections of these factors were based on the suggestions from the handbook recommended by the machine manufacturer, preliminary research results and journals. The kerf width was measured with optical microscope with magnification of 100X. Ten readings at different ten spots were taken and their average has been considered as kerf width of the cutting slot. The cutting speed was directly noted from the parameters display of Wire Cut Electric Discharge Machine. The material removal rate was analyzed by taking cutting speed, kerf width and thickness of the test specimen into consideration. Over cut was also determined with the difference of kerf width and wire diameter. The influence of wire electric discharge machining process parameters such as pulse on time, input power, servo reference voltage, wire feed rate, wire tension, dielectric fluid pressure and server feed rate on response variables such as kerf width, cutting speed, material removal rate and overcut have been studies with reference to the experimental results.

TABLE I. CHEMICAL COMPOSITION OF TI-6AL-4V TITANIUM ALLOY

C	Fe	Al	O2	N2	V	H2	Ti
0-0.08	0- 0.25	5.5-6.76	0-0.2	0-0.05	3.5-4.5	0-0.15	Balance

TABLE II. TEST CONDITIONS

Process Parameter	L1	L2	L3
Pulse on Time (µs)	100	110	120
Input Power	10	11	12
Server Voltage (V)	40	50	60
Water Pressure (PSI)	5	10	15
Wire Feed Rate (m/min)	5	10	15
Wire Tension (N)	8	10	12
Server Feed Rate	50	1050	2050

III. RESULTS AND DISCUSSIONS

A. *Kerf Width*

The experimental results releave that as the pulse on time/ pulse duration, input power, server voltage, wire feed and wire tension increases, the kerf width also increases, as shown in Fig. 1. Pulse on time, input power and server voltage mostly influences the kerf width. The influence of water pressure, wire feed, wire tension and serer feed is very little on kerf width. Experiment with lower feed rate gives bigger kerf width and as the feed rate increases kerf width decreases. K.P Somasekhar et al., does not recommended the usage of high feed rate since it influences kerf width (20). Nihat Tosum et al., proved that open circuit voltage and pulse duration were highly affected parameters on both the kerf width and the material removal rate (21). Aniza Alias et al., also proved the same.

Fig 1 WEDM parameters vs. Kerf Width

B. *Cutting Speed*

Experimental results reveal that as the pulse on time, input power, water pressure, server feed increases the cutting speed increases. However for extended pulse on time, input power the cutting speed decreases. From these experimental results it is observed that pulse on time, input power, server voltage, server feed have more significant effect on cutting speed and machining voltage, wire feed rate and wire tension have no significant effect on cutting speed. Farnaz Nourbakhsh and K. P. Rajurkar et al., are also proved the same (24).

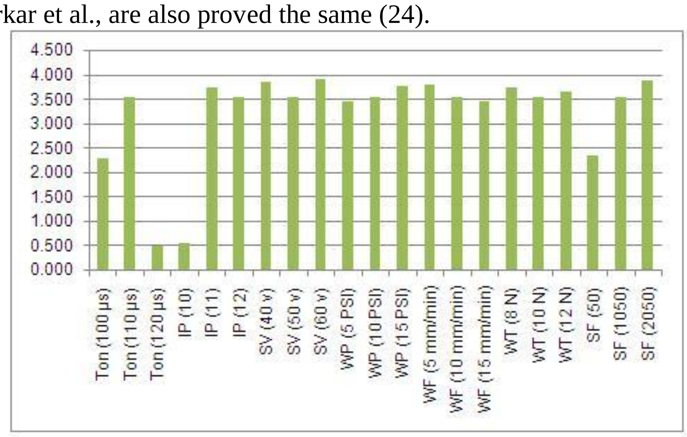

Fig 2 WEDM parameters vs. Cutting speed

C. Material Removal Rate

The experimental results revels that the material removal rate increases as the pulse on time, input power, water pressure, server feed increases. However for extended pulse on time, input power the material removal rate decreases. Further reveals that the material removal rate decreases as the wire feed, wire tension increases. Pujari Srinivasa Rao et al., has used the equation for calculation of material removal rate as; Material Removal Rate (mm^3/min) = $\mathbf{F \times D_w \times H}$,

Where 'F' is the machine feed rate in (mm/min), 'Dw, is the wire diameter in (mm) and 'H' is the work piece thickness in (mm) (22). By taking the over cut into consideration, the material removal rate will be calculated using the equation as; Material Removal Rate (mm^3/min) = $\mathbf{CS \times K_w \times t}$

Where 'CS' is the cutting speed in (mm/min), 'Kw' is the kerf width in (mm) and 't' is the work piece thickness in (mm).

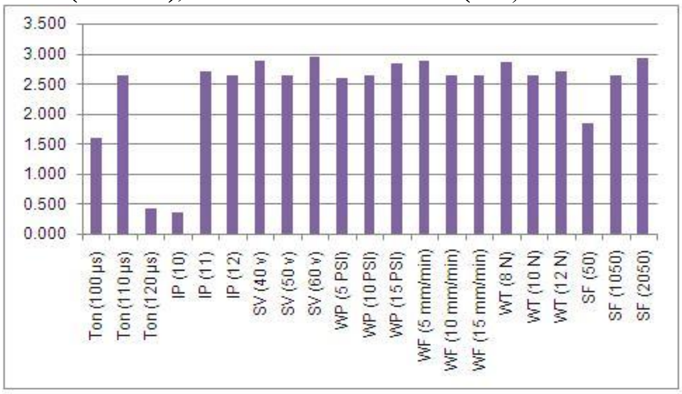

Fig 3 WEDM parameters vs. MRR

D. Over cut

The reason that the cutting width is greater than the width of the wire is because sparking occurs from the sides of the wire to the work piece, causing erosion. The difference between the kerf width and diameter of wire is termed as 'over cut'. The experimental results reveals that the overcut increases as the pulse on time, input power, server voltage and water pressure increases. At higher and lower wire feed, server feed the overcut is more and at moderate wire feed and server feed the overcut decreases.

Fig 4 WEDM parameters vs. Over cut

IV. CONCLUSIONS

In this study, the influence of wire electric discharge machining parameters such as pulse on time, input power, server voltage, water pressure, wire feed rate, wire tension and server feed rate on kerf width, cutting speed, material removal rate and over cut has been studied. Based on the experimental results the following conclusions were made:

- As the pulse on time/ pulse duration, input power, server voltage, wire feed and wire tension increases, the kerf width also increases. Lower feed rate gives bigger kerf width and as the feed rate increases kerf width decreases.
- Experimental results reveal that as the pulse on time, input power, water pressure, server feed increases the cutting speed also increases. However for extended pulse on time, input power the cutting speed decreases.
- The material removal rate increases as the pulse on time, input power, water pressure and server feed increases. However for extended pulse on time, input power the material removal rate decreases. Further reveals that the material removal rate decreases as the wire feed, wire tension increases.
- The overcut increases as the pulse on time, input power, server voltage and water pressure increases. At optimum and low level of wire feed and server feed the overcut is more and at moderate level of wire feed and server feed, the overcut is low.

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