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Technical Paper

Assessment of material removal capability with vibration-assisted wire electrical discharge machining

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ABSTRACT

Titanium alloys are prevalently used in automotive, aerospace and biomedical applications. It is identified as not easy to machine by conventional machining process because of fast tool wear. Hence, for machining of titanium alloy, non-conventional machining processes are generally recommended. In non-conventional machining, vibration assisted Wire Electrical Discharge Machining has shown promising results to improve the machining rate. The present work will focus on machining of titanium alloy workpiece by vibrating the wire in lateral direction with varied frequency of excitation to enhance the material removal rate and to obtain the required kerf width in Wire Electrical Discharge Machining. Experiments were performed on Ti-6Al-4V alloy material during a wire electrical discharging machine operation using zinc coated brass wire and brass wire electrode. Roughness with all those irregularities on machined surface, with varied vibration condition, are measured with contact stylus type surface roughness measuring instrument. Machined kerf size was measured using non-contact optical Co-ordinate Measuring Machine. White layer formed and surface integrity were examined through Scanning Electron Microscope with provision of Energy Dispersive Spectroscopy. The developed vibrating system worked effectively, improved material removal rate and their surface modification has been obtained and reported.

1. Introduction

In many engineering applications, titanium alloys are used due to its excellent corrosion resistance high strength and light weight. Titanium and titanium alloys are used in aircraft, aerospace, chemical and automotive industries where high safety is essential [1]. In addition, owing to their excellent corrosion resistance and biocompatibility they are used in medical application [2].

In mechanical industry, the demands for machining alloy steels, conductive ceramics, aerospace and biomedical parts are important aspects. Titanium is generally heat resistance compared to other metals due to which the heat induced while machining does not dissipate instantly. Hence, the heat generated is concentrated locally between the tool face and cutting edge thereby reducing the tool life. At the high cutting temperature, titanium alloys have the ability to react chemically with the surrounding environment and cutting tools [3].

Wire Electrical Discharge Machining (WEDM) is an important unconventional machining process to machine the material irrespective of their toughness, impact resistance and hardness. To machine a complex profile requiring dimensional accuracy and fine surface details, WEDM provide effective solution. After machining the parts it is essential to measure the dimension, surface roughness and surface modification due to the change from the mechanical and thermal process. In this work, the surface integrity of the TI6Al4V alloy after WEDM under various wire vibration frequency are studied for two wire material such as brass and zinc coated brass wire (ZCBW).

The WEDM process is based on the electro-thermal energy involving the wire electrode and workpiece, with a thin wire as an electrode applying high frequency pulsed current to the workpiece.The wire electrode and workpiece is separated by a minute spark gap of dielectric medium. De-ionized water and hydrocarbon oil are generally used as dielectric medium. Machining at high temperature of discharge energy, the hydrocarbon oil decomposes and pollute the air. High dielectric strength is required for the medium so that it is electrically non–conductive until the breakdown voltage is attained. After the discharge, the dielectric medium should de-ionize rapidly, should serve the purpose of a coolant by dissipating the generated heat-effectively, and also flush the metal sludge formed at the cutting gap.

In WEDM and EDM machining process have no direct contact between wire electrode and workpiece and hence it can eliminate chatter, vibration and mechanical stresses. For any wire cut surfaces, the surface integrity is vital for the geometric design features, mechanical and metallurgical properties of the product [4]. A

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Table 1
Chemical Composition of Ti6Al4V.

Chemical Elements	Al	V	Fe	C	N	O	Ti
Wt% (Actual)	6.2	4.04	0.4	0.06	0.02	0.1	Balance

narrow gap of 25–75 μm between electrode and workpiece is consistently controlled by a computer positioning system [5]. At high temperature a channel of plasma is generated between the electrode wire and workpiece, which melts the material enabling the cutting action [6].

It has been observed that the movement of longitudinal, low-frequency vibration of workpieces in EDM process has increased the rate of material removal, and decreased rate of tool wear and surface roughness [7]. The material removal rate has increased and less molten material was recast on the machined surfaces by cryogenically cooled tool electrode with ultrasonic assisted EDM [8]. Different frequency of vibration applied to wire electrode and workpiece coupled with PZT actuator increased the rate of cutting and improved the surface quality on machined surface [9]. The high frequency and ultrasonic vibration of the wire electrode revealed a shift of the discharge point and made the discharge distribution more uniform thus leading to better machining stability and better surface quality [10].

The above literature review reported that material removal rate and surface quality improved by applying vibration along longitudinal direction to the tool electrode and workpiece. The present work considered lateral vibration of the wire in WEDM in order to study its effect on performance parameters like material removal rate and dimensional accuracy. Its covers the machining of varied slot size which are required in industries for manufacture of micro channels and mould die insert.

2. Experimental procedures

The experiments were carried out on a four-axis CNC type WEDM. The CNC program generated using ELAPT software. Samples of dimensions 160 mm × 25 mm × 8.5 mm were prepared by cutting and grinding from a Ti6Al4V plate for the machining experiments. The bulk chemical composition of the Ti6Al4V plate material was verified by Optical Emission Spectroscopy (OES) method, the result of which is given in Table 1.

The electro-dynamical shaker responsible for the vibration it is fixed with the wire head of the machine and is connected to the vibration unit by an extension rod. The vibration unit has a pair of locating screws which are interconnected by a nylon frame for the purpose of electrical insulation; refer Fig. 1(a). The tip of the locating screws has fine groove to locate and guide the wire feed. The dielectric fluid flows around the upper and lower wire guides. A function generator capable of producing the required frequency and amplitude is connected to the shaker through an amplifier.

With the help of a capacitance sensor the amplitude was measured at different frequencies. Fig. 1(b) shows the method of measuring amplitude, the data collected in the form of voltage using an oscilloscope and converted in to micrometer. In Table 2, the various process parameters employed in the machining operation is tabulated. Increase in the spark gap between the wire electrode and the workpiece has led to better dielectric flushing leading to an improved cutting rate.

Machining was done by two methods: by inducing vibrations of different frequencies on the wire and the normal without vibration condition (WOV). In both the methods, two different wires were utilized viz. a brass wire and a ZCBW. Size of the cutting wire, i.e. the brass wire and the ZCBW at the diameter of 0.25 mm, and their average tensile strength was about 900 N/mm^2. Brass wire is widely used in WEDM for cutting material in various engineering application. The zinc coated wire had a zinc layer on the brass substrate wire. Zinc coating on brass wire improves the electrical conductivity during machining; the coated zinc disintegrates at the high temperature. Coated wire electrode gives higher machining speed and reasonable surface finish [11].

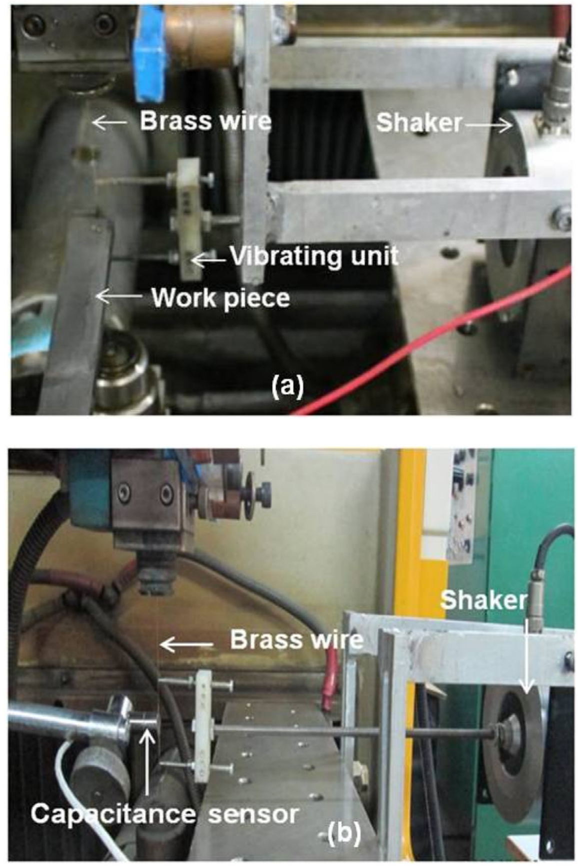

Fig. 1. Experimental setup (a) A view during Machining (b) Method of measuring amplitude.

Table 2
Parameters used in machining of Ti6Al4V with WEDM.

Process parameter	Condition
Electrodes	Brass wire, Zinc coated brass wire
Open Voltage (Volt)	100
Gap Voltage (Volt)	45–50
Current (Ampere)	1.2
Pulse-on time (μs)	1.05
Pulse-off time (μs)	190
Dielectric	De-ionized water
Frequency (Hz)	WOV, 225, 200,175,150,125,100

During machining by ZCBW, the zinc gets heated up and vaporized quickly and helped in cooling the core which reduced the wire breakage [12]. The gap voltage of 40 V–60 V and open voltage of 100 V is the proficient range of the machine employed for the experiment. Based on the prior work, the pulse-on and off time for the WEDM were selected [13,14]. The dielectric medium pressure, wire tension and wire speed were kept constant throughout the experiment as they have the least effect on surface roughness and rate of material removal [15]. The wire speed and flushing pressure of dielectric not have considerable effect on the microstructure of machined surface [16]. De-ionized water is the one of the dielectric used in WEDM for effective cooling result to increase the material removal rate and reduce the white layer thickness [17]. Above the 225 Hz there is no noticeable material removal rate and below the