Metallographic Analysis of Pure Titanium (Grade-2) Surface by Wire Electro Discharge Machining (WEDM)

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***Abstract*- WEDM process is most suitable for machining of pure titanium. Titanium is having excellent combination of properties such as high strength-to-weight ratio, low thermal conductivity, and high corrosion resistance. The WEDM is widely accepted for machining and shaping of pure titanium. The titanium was roughly machined with negatively polarized wire electrode having Ø0.25 mm. This research work is mainly focused on experimental investigation on metallographic analysis of pure titanium by WEDM. The metallograhic in terms of machining parameters such as pulse on time, pulse off time, peak current, spark gap voltage for pure titanium in WEDM process were explored. The selected machined samples were analyzed using energy dispersive X-ray analysis, scanning electron microscope. It was observed from the results that there occurred significant material transfer from the dielectric as well as tool electrode on the work surface either in free form and/or in compound form. It was observed that pulse on time and peak current significantly deteriorate the metallography of machined samples which produces the deeper, wider overlapping craters, pock marks, globules of debris and micro cracks.**

***Keywords*- WEDM; Titanium; Microstructure; Surface Topography; EDX; Material Transfer**

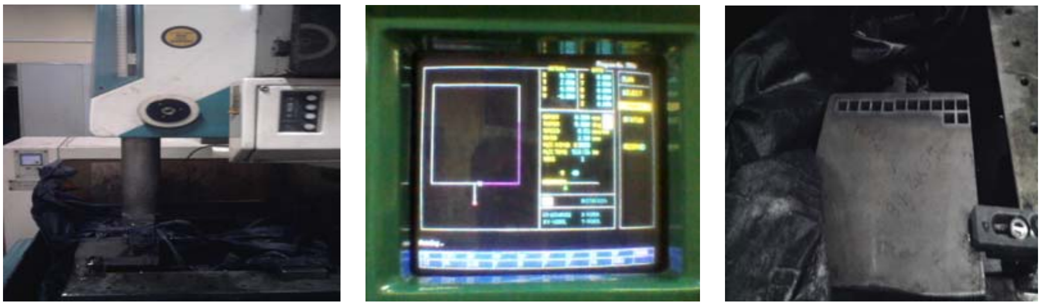
I. INTRODUCTION

With its low mass, high strength, and excellent resistance to corrosion, titanium solves many engineering challenges. Titanium is 30% stronger than steel but is nearly 50% lighter. Titanium is 60% heavier than aluminum but twice as strong [1]. The aerospace industry is the single largest market for titanium products. Titanium applications are most significant in jet engine and airframe components that are subject to temperatures up to 593°C and for other critical structural parts. 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's high corrosion resistance is also a valuable characteristic. When exposed to the atmosphere, titanium forms a tight, tenacious oxide film that resists many corrosive materials. Microstructure and mechanical properties in metals are intimately coupled. On a microscopic level, the interaction of crystalline structures in titanium and its alloys determines the mechanical properties of that alloy. On a macroscopic level, thermo-mechanical processing manipulates the formation of crystalline phases. The major application of the material is in the aerospace industry, both in airframes and engine components. Non aerospace applications take advantage mainly of their excellent strength properties, for example steam turbine blades, super-conductors, missiles, etc. or corrosion resistance, for example marine services, chemical, petrochemical, electronics industry, biomedical instruments etc [2]. Owing to high process capability it is widely used in manufacturing of cam wheels, special gears, bearing cage, various press tools, dies, and similar intricate parts. In this process, a slowly moving wire travels along a prescribed path and removes material from the workpiece. WEDM uses electro-thermal mechanisms to cut electrically conductive materials. The material is removed by a series of discrete discharges between the wire electrode and the workpiece in the presence of die-electric fluid, which creates a path for each discharge as the fluid becomes ionized in the gap. The area where discharge takes place is heated to extremely high temperature, so that the surface is melted and removed. The removed particles are flushed away by the flowing dielectric fluids.

The wires for WEDM are made of brass, copper, tungsten, molybdenum 0.05-0.3 mm in diameter which capable to achieve very small corner radii. Zinc or brass coated wires are also used extensively in this process [3]. The wire used in WEDM process should possess high tensile strength and good electrical conductivity. WEDM process is usually used in conjunction with CNC and will only work when a part is to be cut completely through. The melting temperature of the parts to be machined is an important parameter for this process rather than strength or hardness. In this research work the effects of WEDM process parameters on the surface texture of pure titanium were investigated. In further, the selected machined samples were analyzed using energy dispersive X-ray analysis (EDX), scanning electron microscope (SEM).

II. PLANNING FOR EXPERIMENTATION

The experiments were performed on a four-axis CNC type WEDM (Electronica Sprintcut, 734) as shown in Fig. 1a. During experiments, parameters such as pulse on time, pulse off time, peak current and spark gap voltage were varied to explore their effect on surface integrity of pure titanium. The parameters kept constant during machining are shown in Table I. The chemical composition of work material taken for experimentation was C: 0.10%, N: 0.03%, O_2: 0.25%, H_2:0.015%, Fe: 0.30% and Ti: 99.03%. Fig. 1b shows the work path profile during machining. In the present study, the job has been considered as a square punch as shown in Fig. 1c. The Table II presents the factors and their levels. The factors and levels of the present study have been selected on the basis of pilot experimentation using one factor at a time approach (OFTA) method [4]. In this study the surface integrity was analyzed by using SEM (Make JEOL, Tokyo, Japan model JSM-6610LV) which was integrated with an energy-dispersive X-ray spectrometer (EDX). Before SEM, the machined samples were etched with Krolls reagent (2 ml Hydrofluoric acid, 10 ml nitric acid and 88ml distilled water). The samples were also cleaned with acetone $(CH_3)_2CO$.



(a) (b) (c)

Fig. 1 Job profile and experimental setup of WEDM machine tool
(a) 4-Axis WEDM CNC type, Electronica Sprintcut-734 machine tool (b) Work-path profile (c) Square punch produced after WEDM

TABLE I WEDM FIXED OPERATING CONDITIONS

S.No.	Machining Parameters	Units	Fixed operating conditions
1.	Electrode material	-	Brass(0.25mmØ)
2.	Electrode polarity	-	Negative
3.	Work material	-	Pure titanium
4.	Work material size	mm	148 × 148 × 26
5.	Dielectric fluid	-	deionized water
6.	Dielectric pressure	Kg/cm^2	7
7.	Conductivity of dielectric	µs/m	±20-24
8.	Working temperature	°C	25

TABLE II FACTORS AND THEIR LEVELS

S.No.	Symbols	Input factors	Level			Units
			I	II	III	
1.	A	Pulse on time	0.7	0.9	1.1	μs
2.	B	Pulse off time	17	26	38	μs
3.	C	Peak current	120	160	200	Ampere
4.	D	Spark gap voltage	40	50	60	Volt
5.	E	Wire feed	4	7	10	m/min
6.	F	Wire tension	500	950	1400	grams

III. RESULTS AND DISCUSSION

During WEDM process, the discharged energy produces very high temperatures at the point of the spark, causing a minute part of the sample to melt and vaporize. With each discharge, a crater was formed on the machined surface. The surface topography was altered due to significant electrical parameters such as pulse on time, pulse off time, peak current and spark gap voltage. It was observed from Fig. 2a-d SEM micrographs that WEDM surface produces the more irregular topography and defects included globules of debris, spherical particles, varying size craters, pockmarks and micro-cracks. The pulse on time and peak current are the most significant parameters which lead to deteriorate the surface texture. When pulse on time was increased the surface texture of the machined surface is composed of varying size of deep craters. These deep and overlapping craters were formed due to successive electrical discharge, intense heat and local melting or evaporization of work material. The results of the present study are agreement with findings [5, 8]. Under shorter pulse on-time, electrical sparks generate smaller craters on the work surface. The high pulsed current caused frequent cracking of dielectric fluid, causing more melt expulsions and larger tensile stresses. These effects were turned in poor surface finish. At higher peak current, the impact of discharge energy on the surface of workpiece becomes greater, and thus, resulting erosion leads to the increase in deterioration of surface roughness. Some spherical shape particles were observed due to surface tension of molten material. Matt surface with many fine nodules were also observed in Fig. 3. These nodules were observed from the solidification of molten or vaporized titanium particles during machining. Spherical shape of the nodules revealed that the surface energy is minimized during solidification. When a smaller pulsed current and pulse-on duration was applied, the surface characteristics had minor hillocks and valleys as seen in Fig. 3. This phenomenon might be attributable to a higher peak current and a longer pulse on time causing more frequent cracking of the dielectric fluid, as there was more frequent melt expulsion leading to the formation of deeper and larger craters on the surface of the workpiece. It was observed from SEM micrographs Fig. 4 that less number of craters and no micro-cracks were formed due to lower peak current and pulse on time. Due to lower peak current and pulse on time the machined surface impinges with less electrical discharge and may result in improved surface roughness. High peak current and low pulse off time increased the debris in the spark gap, which leads to abnormal arcing. The abnormal arcing decreased discharge rate and the material removal rate [6]. Also abnormal arcing reduced the dielectric strength resulting in wire breakage. It was found that on decreasing the spark gap voltage, the wire speed increases which leads to increase the MRR. Servo voltage (SV) is used for controlling advances and retracts of the wire. During machining, the mean machining voltage varies depending on the state of the machining between the workpiece and the electrode. SV established the reference voltage for controlling advances and retracts of the wire. If the mean machining voltage is higher than the set voltage level, the wire advances, and if it is lower, the wire retracts (to be precise, the work table advances or retracts instead of wire). Therefore, a higher the value for SV, the wider the gap between the work piece and the electrode becomes. Higher values for SV also decrease the number of electric sparks, stabilizing electric discharge, although the machining rate is slowed down. When a smaller value is set for SV, the mean gap becomes narrower, which leads to an increase in number of electric sparks. It can speed up the machining rate; however, the state of machining at the gap may become unstable, resulting in wire breakage [9, 10]. The present study revealed that higher MRR can achieve at the lowest spark gap voltage, pulse off time and high peak current.

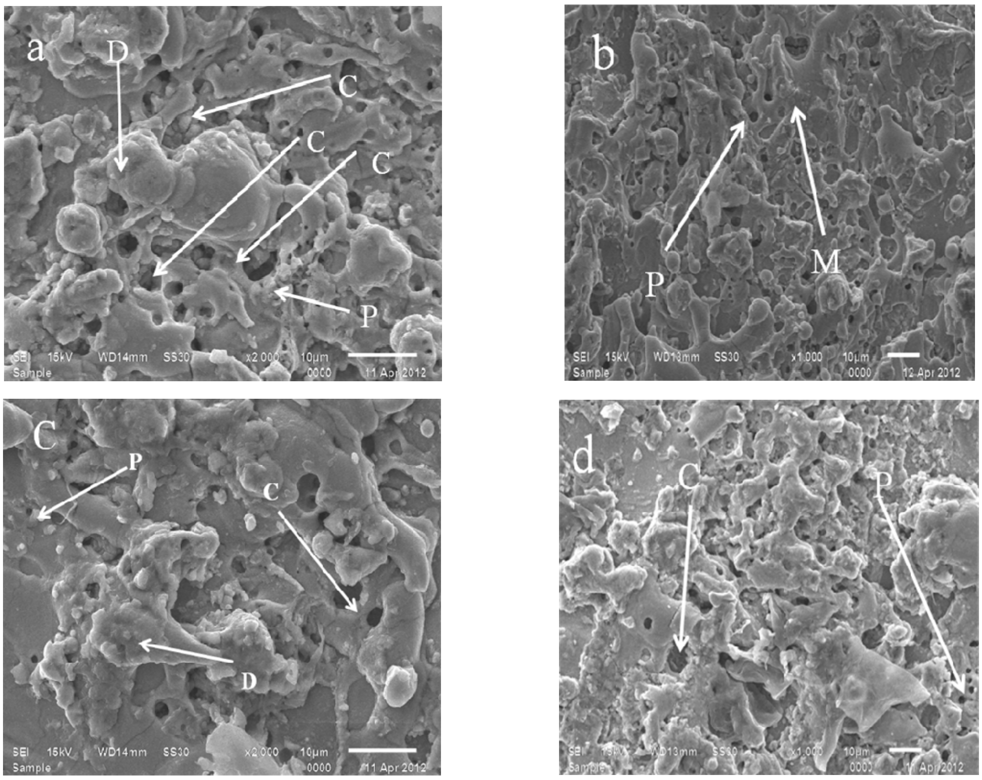


Fig. 2 SEM micrographs observed with C→Craters, P→Pockmarks, D→Debris, M→Matt Surface due to higher pulse on time and peak current

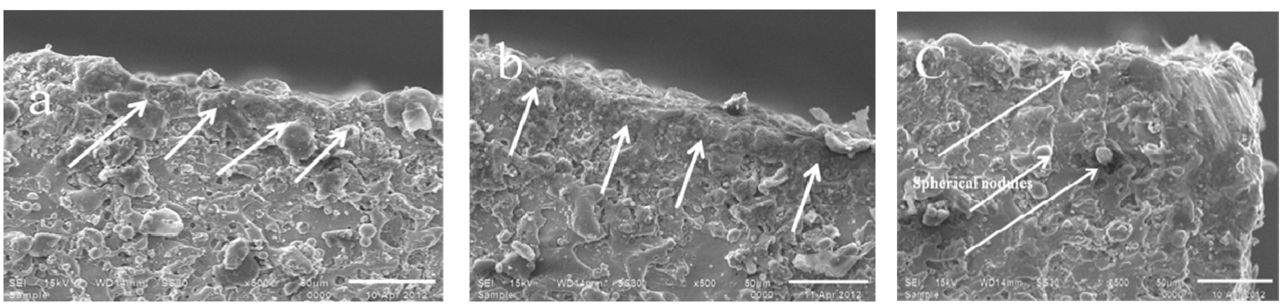


Fig. 3 Minor hillocks and valleys due to lower peak current and pulse duration

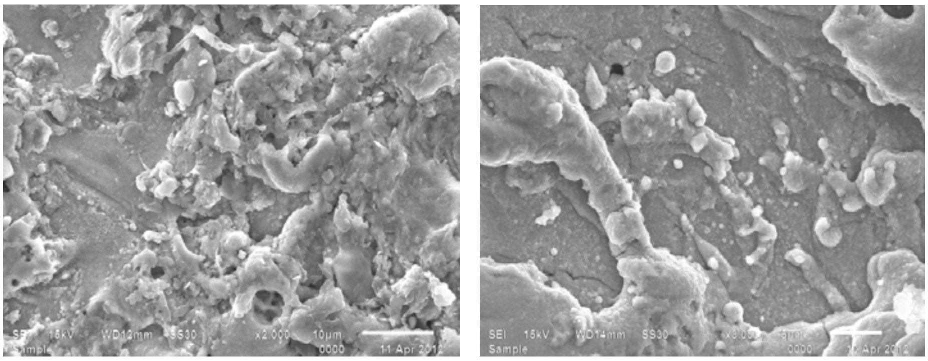


Fig. 4 SEM micrograps with less number of craters and no cracks were formed at lower peak current and pulse on time

IV. ENERGY DISPERSIVE X-RAY ANALYSIS (EDX)

The compositions of WEDM samples were detected through EDX. EDX is the technique which is used to identify the elemental composition of the machined samples. The output of an EDX analysis is a plot of how frequently an X-ray is received for each energy level. An EDX spectrum normally displays peaks corresponding to the energy levels for which the most X-rays had been received. Each of these peaks is unique to an atom, and therefore corresponds to a single element. The higher a peak in a spectrum, the more concentrated the element is in the specimen [7]. Fig. 5 showed the energy dispersive X-ray (EDX) of affected surfaces, which are obtained by accelerating voltage of 3 kv. Through EDX analysis, the residuals of copper and Zinc were also detected in the machined samples. This may be due to the melting, evaporation and re-solidification of the brass wire electrode and may results what they were transferred to the work material. The presence of oxygen in the titanium probably was due to oxidation as a result of high temperature involved in the process. Although EDX result showed that carbon and oxygen also existed in the titanium, these elements were observed due to the fact that dielectric fluid with debris normally contains carbon and oxygen.

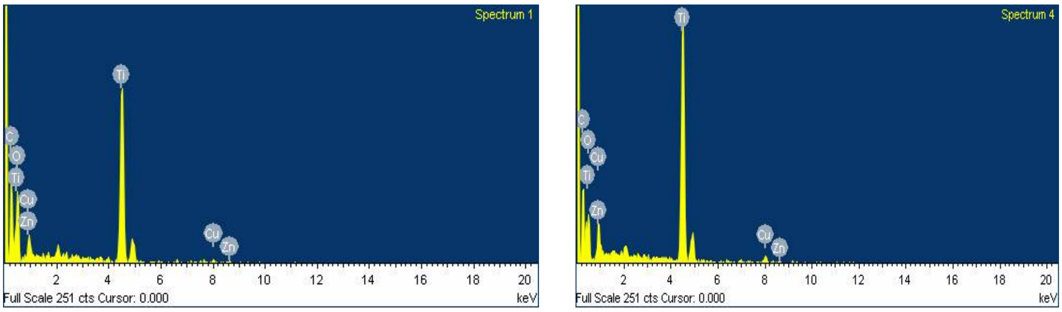


Fig. 5 EDX analysis of pure titanuim after WEDM

V. CONCLUSIONS

In the present research work, two significant parameters are identified i.e. peak current and pulse on time which effect the surface integrity of pure titanium. Finally it can be concluded that:

(1) The surface integrity was analyzed by using scanning electron microscope (SEM). It was observed that pulse on time and peak current deteriorate the integrity of machined samples which produces the deeper and wider overlapping craters, pock marks, globules of debris and micro cracks. The higher discharge energy caused more frequent melting expulsion, leading to the formation of a deeper and larger crater on the surface of the workpiece, and resulted in a poorer surface finish.

(2) The residuals of copper, carbon and zinc were detected in the machined samples using EDX analysis. This may be due to the melting, evaporation and re-solidification of the brass wire electrode and are transferred to the work material.

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